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Preface

You are reading the Proceedings of the 23rd EuroFM Research Symposium, organized in connection with the 29th EuroFM Conference, held 9-12 June 2024 in London. The theme of the 2024 conference, ´Transformation for future-proof FM', is reflected in the papers included in these proceedings. The paper topics fall under Digital Transformation, Green Transformation, Spatial Transformations, and Services in Transformation. The proceedings comprise 23 papers, a delightful record in recent Research Symposium history! We want to thank all Authors for their hard work, dedication, and good collaboration during the process which started already at the end of 2023. It is humbling that so many have chosen the EuroFM Research Symposium 2024 as an outlet for their research. Thank you for being a part of the FM research community.

All 23 papers have undergone a double-blind review process, with a minimum of two reviewers per paper. We are forever indebted to the members of the Scientific Committee for their commitment and expertise throughout the review process. We are proud to note that the Scientific Committee hails from 10 different European countries, as well as Hong Kong, Thailand, and Australia. Without your contribution there would be no proceedings, so thank you. We would also like to thank members of the Best Paper Committee for their efforts in selecting the recipient of the Best Paper Award 2024. Congratulations to the winner Ronald Beckers for his innovative paper 'Exploring the Home Office with Participatory Photography'!

We extend our thanks to all Session Chairs at the Research Symposium, Nipuni Sumanarathna, Oluwaseun Ajayi, Alenka Temeljotov-Salaj, Per Anker Jensen, Chiara Tagliaro, and Matthew Tucker. Thank you for good discussions and for making everything run smoothly and on schedule. We wish to further thank our local host, the London Metropolitan University. We would especially like to thank Nipuni Sumanarathna for local support and for introducing local students to the conference. We want to express our gratitude to Maria Morapeidi and her team for organizing the 29th EuroFM Conference, Gala Dinner, and fascinating tours in vibrant London.

Our thanks to Danica Widarta for once again creating the color-scheme, cover, and layout for the proceedings. The EuroFM Research Network wants to promote Open Access (OA) research. Consequently, the proceedings are available OA on Zenodo. Our hope is that readers will find their way to the proceedings, even beyond the academic community. We warmly invite the reader, whether researcher, educator, student, or practitioner, to engage in the most recent FM research from Europe.

Enjoy your reading!

Dr. Riikka Kyrö
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Exploring Digitalization in Facility Management: Towards a Research Agenda

Vigren, O.[1], Tagliaro, C.[2], Ghalandar, T.[3], & Phan, T.[4]

[1] KTH Royal Institute of Technology, Department of Real Estate and Construction Management
[2] Politecnico di Milano, Department of Architecture, Built Environment and Construction Engineering
[3] NTNU Norwegian University of Science and Technology, Department of Architecture and Planning
[4] NMBU Norwegian University of Life Sciences, Department of Property and Law
Contact: olliky@kth.se

ABSTRACT

Background and aim. Digitalization in facility management (FM) services is an emerging phenomenon. The sector tends to prioritize the adoption of technology to address immediate concerns rather than effectively framing fundamental problems, hindering the creation of a comprehensive strategy. There is a lack of reflection on the complex relationship between digital technologies and FM services, highlighting the necessity for new conceptualizations to address implementation challenges. Our paper aims to identify categories that facilitate research and knowledge exchange between academia and industry to enhance the understanding of digitalization and its strategies within FM.

Methods. We conducted workshops with academics and industry representatives focusing on (i) classification and conceptualization of digital technology applications in FM, (ii) the effects of digital technologies in FM, and (iii) standardization and scaling up digital solutions within organizations and the industry.

Results. The article advances understanding of digital technologies' potential for use in FM. (i) We classify digitalization based on business development, technology, and value chain perspectives. (ii) We identify technology considerations, such as incentives, return on investment, and efficiency, as well as barriers, including collaboration, contextual factors, and cultural challenges. Human-centric solutions are proposed to address these barriers. (iii) We discuss standardization challenges, including SME perspectives, ISO fragmentation, cybersecurity, data management, software integration, and path dependence.

Practical implications. Conceptualizations co-created by industry and academia contribute to the establishment of a relevant research agenda and the facilitation of digital technology implementation.

Type of paper. Research (short)

Keywords. building, digital technology, facility management, innovation, standardization

INTRODUCTION

Digitalization — defined as "a sociotechnical innovation process for the generation, development and implementation of new ideas focused on digital technologies" (Vigren, 2022: p. 2) — stands as a major trend that shapes the future of our built environment and society. Digitalization has gained momentum in the industry and academic debates, also due to the diffusion of buzzwords such as 'PropTech', 'RealEstateTech', and others. Nevertheless, Facility Management (FM) and the broader field of the built environment (BE) appear as contexts in which digitalization has been challenging, as evidenced by the slow adoption of digital tools (FMgoesDIGI, 2022). Yet, the use of digital technologies in FM presents unprecedented opportunities. Implementing these technologies within FM practices demands a new understanding of the technologies themselves, their potential applications, and the challenges associated with their implementation. Lack of such understanding has long slowed down innovation in the sector (Vigren et al., 2022). Furthermore, the need and demand for "knowledge coordination" between construction project teams and the delivery and operation phase (Whyte et al., 2016) requires adopting a building lifecycle perspective. In essence, digitalization of FM is seen as part of the digitalization of BE with consideration of the multiple viewpoints including projects, organizations and people integral to innovation within the field (Papadonikolak et al., 2022).

While research on digitalization in FM has been growing extensively, a comprehensive overview of the phenomenon is still missing. A recent article identifies more than 30 distinct digital technologies relevant to research and practice in FM (Brozovsky et al., 2024). A significant portion of the existing corpus of research focuses on one of these specific digital technologies in isolation from the others. For instance, a large part concentrates on the development, applications, and implementation of Building Information Modeling (BIM) (Won et al., 2013). Other, more recent papers address technologies like the Internet of Things (IoT), digital twins (DT), Artificial Intelligence (AI), unmanned aerial vehicles, augmented and virtual reality (AR/VR), blockchain, and many more. A typical characteristic of these studies is the notion that if 'technology x' is adopted, it can bring specific benefits. Still, the implementation of technologies, often initially developed outside the FM context and then expected to be applied in it, has not been straightforward. Nor is there clear evidence of the value for money of technology implementation in FM as a systemic strategy, more than as a ready-to-use solution for a specific problem. Available classification and conceptualization frameworks of digital technologies in FM are still insufficient; the effects of digital applications are poorly acknowledged, including positive and negative effects; and opportunities for scaling up across organizations in the construction and real estate industry are seldom identified. Furthermore, several authors have argued that research should further consider the social and organizational contexts of practice in which digital technologies are being introduced (e.g., Atkin & Bildsten, 2017; Bröchner et al., 2019; Johannes et al., 2024; Tagliaro et al., 2020).

Therefore, there is a need for a more organized approach to the research and management of digitalization within the field, which is currently scant and scattered and offers only sparse views and interpretations of the phenomenon. This emphasizes the necessity for new conceptualizations to address implementation opportunities and challenges. Our paper aims to identify categories to facilitate research and knowledge exchange between academia and the industry to enhance the understanding of digitalization and its strategies within the FM sector. In this scope, through knowledge exchange between researchers and industry practitioners, this paper elaborates on a research agenda for digitalization in FM.

METHODS

We follow a methodology similar to Ritala and Gustafsson (2018), who hosted an academic seminar titled "Fostering Rigor in Innovation and Entrepreneurial Ecosystem Research: Concepts, Methods and

Theory" at the 2017 Academy of Management Annual Conference. Their aim was to promote shared interpretation of the topic and appreciation and understanding of different perspectives. With a similar aim, we conducted two online workshops in 2022 and 2023 with academics, followed by a third in-person workshop with industry professionals in 2023. The academic workshops were EuroFM online meetups, involving leading academic participants in the FM field. Unlike Ritala and Gustafsson (2018), who focused on theory development, our third workshop targeted industry professionals as part of the EuroFM 2023 conference in Istanbul. Given that FM and its digitalization are practice-oriented fields, inclusion of industry experts is necessary for developing a relevant research agenda. Furthermore, the collaborative nature of these workshops enhances the relevance and validation of the conceptualizations. Overall, approximately 20 people participated in the workshops, all considered expert insiders in FM, reflecting both academic and industry perspectives. Each workshop lasted for one to one and a half hours. The workshops were prepared and led by the authors. We held multiple online meetings to coordinate the agenda of the workshops and analyze results. Through literature review and consensus among the authors of this paper, three emergent and central thematic areas were identified to structure discussions in the workshops: (1) classification and conceptualization of digital technology applications in FM; (2) effects of digital applications in FM; and (3) standardization and scaling up digital solutions in organizations and the industry. The workshops were documented through handwritten notes, which were then qualitatively analyzed for this paper. This analysis and the structure of the findings section followed the three aforementioned themes.

RESULTS

Classification and conceptualization of digital technology applications in FM

The workshops on potential approaches for classifying and conceptualizing technologies in FM brought up multiple complementary perspectives. Each of these perspectives highlights different aspects in assessing the value-added of digitalization in FM.

INFORMATION TECHNOLOGY PERSPECTIVES:

- IT Architecture Models: Highlights the increased value of technologies when used together, such as combining BIM with Artificial Intelligence.
- Technology Maturity: Referring to frameworks like the hype cycle or Technology Readiness Levels, in FM contexts. Similarly, in a recent article, Brozovsky et al. (2024) classified digital technologies into dominant, emerging, underdeveloped, and niche technologies.
- Data and Technology Supply Chains: Emphasizes data sources and requirements from client organizations, drawing inspiration from supply chain theories. A parallel 'technology supply chain' classification focusing on technologies was also discussed.

BUSINESS DEVELOPMENT PERSPECTIVES:

- Business Type: Categorizes technologies based on provider-client relationships, namely Business-to-Business, Business-to-Consumer, and Business-to-Administration criteria. It proves advantageous for identifying different markets, actor types, processes, and value-creation mechanisms.

- Scalability: Identifies different levels of scalability, e.g. mobile apps with cloud-based infrastructure (scalable across multiple use-cases) compared to standalone legacy software (non-scalable beyond individual machines).
- Risk: Delves into the associated risks of technologies. An example is the juxtaposition of a smart home security system, introducing digital complexities, with a traditional mechanical door lock, relying on simpler, more physical security mechanisms.
- Business Outcomes: Technologies provide different types of value, such as operational efficiency, customer experience, and competitive advantage. Furthermore, technologies provide different return on investment, both in terms of potential profits and costs.

VALUE CHAIN PERSPECTIVES:

- Actors: Focusing on actor types (e.g., technology provider, real estate owner, FM operator, end-user), opens discussions on actor roles and the demand and supply dynamics.
- FM Service Process: Considers the processes within FM services where technologies could be applied, facilitating practical performance comparisons between different digital technologies. For instance, evaluating whether blockchain or traditional hierarchical and relational databases perform better in providing the same service to FM professionals.
- Building Life Cycle: Provides a holistic perspective on the integration of technologies at different stages.

Positive and negative effects of digital technologies in FM

The discussions on the effects of digital technologies focused on their added value, stakeholders, practical applications, and associated challenges. Although digitalization is largely deemed positive for the FM industry, significant obstacles remain to its effective implementation.

MAIN POSITIVE EFFECTS: Participants recognize that return on investment can significantly influence the adoption of digital technologies in organizations, either facilitating or hindering the digitalization process. Without sufficient incentive, there may be little motivation to promote digital technologies in the FM business. Furthermore, digitalization and automation are viewed positively as responses to labor shortages, leading to increased efficiency and time savings in task performance. Additionally, participants acknowledged the positive impact of digitalization on sustainability.

RISKS AND MYTHS: Participants raised concerns about increased automation's impact on individuals in FM services and organizations. For example, participants acknowledged that technologies, such as translation technology, are useful, but not all technologies meet the actual needs of the employees in practice. Furthermore, technologies often outpace individuals' ability to adapt, creating tensions within organizations and work processes and increasing the need for skill development. Some employees fear technology replacing people, potentially eroding trust in technology over time.

BARRIERS AND ENABLERS OF TECH IMPLEMENTATION: The cultural context and social norms play important roles as either barriers or enablers of technology implementation. Developing organizational cultures is important for technology acceptance. Policy issues and decision-making obstacles at the management level require resolution to facilitate further digitalization. These tensions vary by location, as some regions are developing faster than others. Also, they are inter-organizational, as rapidly advancing organizations exert pressure on others to follow suit. Additionally, while new PropTech startups were seen as interesting, participants expressed challenges in developing new products into platforms at the firm level.

COPING STRATEGIES: Participants emphasized human-centric thinking and the relationship between humans and machines in FM to foster technology integration. Starting small with a step-by-step approach was suggested as important to successful digitalization. Furthermore, increasing understanding and capabilities of digitalization, along with efficient change management, were seen as integral for digitalization.

Standardization and scaling up digital solutions in organizations and the industry

OPPORTUNITIES FOR STANDARDIZATION: Participants identified high-priority FM issues for digitalization and emphasized the urgency of exchanging meaningful data. They highlighted a fundamental lack of interoperability and integration between software as a major issue, leading to knowledge fragmentation and duplicated efforts across different building types. For example, service providers within one building type or the same organization are using separate software systems for e.g., accounting, human resources, and back-office. Fragmented services and software hinder standardization and scaling efforts. Also, specific software exhibits high path dependency and ISO standards direct development in siloes. Participants proposed lean software solutions adapTable to changing needs and noted SME firms lagging in standardization. This complexity results in different interpretations of concepts and data, which technology could harmonize.

HINDERING FACTORS: Participants discussed unaddressed FM issues in digitalization, focusing on the practical field's intersection with its digital interface. They noted FM as a low-margin service business serving bigger industries, where their clients are not pushing digital innovations but rather opting for off-the-shelf solutions. FM is primarily focused on day-to-day business, lacking long-term business development. Moreover, FM's reliance on physical space makes digital solutions challenging. Additionally, they noted that the FM industry cannot drive innovations alone, as the efficiency of a building is closely interlinked with the construction stage. A holistic perspective on innovation in the built environment was seen as necessary. Furthermore, the participants noted challenges in defining the value of digital innovation in practice. They also highlighted issues with GDPR, which may hinder the use of sensors or tracking, and the existence of differences between countries in terms of legislation related to privacy. Also, development is constrained by a lack of datasets, compared to other industries. When asked about standardizing FM activities, participants noted challenges in identifying standardized activities and highlighted the absence of cross-professional definitions and standards, hindering information transfer. They also pointed out inconsistencies in definitions across service domains and property types. Finally, participants suggested learning from innovations in other industries and emphasized the importance of industry-research dialogue to address FM's slow adoption of digital innovations.

DISCUSSION AND CONCLUSION: TOWARDS A SHARED RESEARCH AGENDA

Our paper aimed to identify categories to facilitate research and knowledge exchange between academia and the industry to enhance understanding of digitalization and its strategies within the FM sector. In this scope, this paper identified key areas to be elaborated further into a research agenda (Table 1).

These findings point towards a new understanding of digitalization in FM. First, classifications are important as they help make sense of complex phenomena and view them through multiple and complementary perspectives. Second, there is a need for defining the effects of digitalization to highlight not only the positive ones but also risks, myths, barriers, enablers, and coping strategies. Third, while there are recognized opportunities for standardization and scaling-up, many hindering factors deserve attention.

Table 1 Key themes for a research agenda on digitalization in FM

Classification of technology applications	Effects of digitalization	Standardization and scale-up
Information technology perspectives	**Main positive effects**: return on investment; efficiency; time saving; sustainability.	**Opportunities for standardization**: exchanging meaningful data; reduce duplicate efforts; unify software systems; lean solutions that can adapt to changing needs; harmonized data.
Business development perspectives	**Risks and myths**: not all tech meets actual needs; too fast pace of implementation; need for skill development.	
Value chain perspectives	**Barriers and enablers**: cultural contexts and social norms; organizational cultures; management issues; location-specific limitations and industry pressure. **Coping strategies**: human-centric thinking; step-by-step approach; change management.	**Hindering factors**: FM is a low-margin, practice-oriented and location-bound business; interlinked with multiple industries over buildings' life cycle; the intangible value of digital innovation; lack of datasets; absence of cross-professional definitions and standards.

Future research should consider the financial effects of digitalization, workforce implications, cultural contexts and social norms, policy issues, management-level obstacles, regional disparities, as well as challenges and success factors faced by PropTech startups. Integrating long-term business development perspectives into the day-to-day focus of FM requires attention, along with fostering industry-research dialogue for collaboration and shared advancements.

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Aligning Academic Curriculum with the Needs of Facility Management Industry - An Analysis

Wills, N[1]. & Bartels, N.[2]

[1] Department of Business and Engineering, Real Estate, University of Applied Sciences Mittelhessen, Friedberg
[2] Faculty of Civil Engineering and Environmental Technology, University of Applied Sciences Cologne
Contact: nadine.wills@wi.thm.de

ABSTRACT

Background and aim. Due to a shortage of skilled labor, facility management (FM) is adopting new technologies such as sensor technologies, building information modeling, Virtual Reality, or Artificial Intelligence. Against the backdrop of a shortage of skilled labor in FM, the integration of new technologies creates new professional domains and presents fresh challenges for skilled personnel. Qualified personnel are essential to meet the expectations of future workforce demands. This contribution aims to investigate whether the curriculum contents of German universities align with the needs of the future job market.

Methods. This study is grounded in a 2023 examination of FM labor market requirements. German universities' curricula and teaching methods are scrutinized to align with the content and methods assessment. The labor market and curriculum analysis outcomes are then juxtaposed in a matrix. Based on this comparison, the final step involves formulating recommendations for adapting curricula and module handbooks to better align with the identified needs of the FM job market.

Results. The paper presents an overview of actual curricula and the alignment/gaps with FM industry demands. Recommendations concerning the adjustment of curricula are given on new technologies in education to integrate knowledge required in the future job market into teaching.

Practical or social implications. The dynamic development of using new technologies in FM emphasizes the need for academic curricula to adapt and align with the industry's evolving demands. This approach offers a holistic understanding of challenges and opportunities at the FM sector's intersection of technology, education, and workforce dynamics.

Type of paper. Educational

Keywords. curricula and teaching development, digital transformation, FM labor market, skilled worker shortage

INTRODUCTION

Facility Management (FM), functioning as a lifecycle-oriented management discipline, generates and requires diverse data throughout the building lifecycle (Bartels, 2020). Particularly within the area of Internet of Things (IoT), technology-based tools have emerged to strengthen FM service delivery (Atta, 2021). The integration of IoT sensors (e.g., humidity, temperature, or presence sensors), Building Automation Systems (BAS), and Building Information Modeling (BIM) provides data, enhancing the efficiency of FM service provision (Bartels & Weilandt,2020,).

Several researches in this domain focus on optimizing user comfort based on IoT data (Laftchiev & Nikovski, 2016; Tomat et al., 2020), improving service provisioning (e.g., cleaning services) through demand-oriented approaches (Dahanayake & Sumanarathna, 2022; Wills & Diaz, 2022), minimizing energy consumption, enhancing sustainable operation and maintenance (O&M) (Opoku & Lee, 2022; Serra et al., 2014; Shah et al., 2019), and enabling data-driven machine-based and deep learning for predictive maintenance (Cheng et al., 2020; Sanzana et al., 2022).

Particularly crucial for the development of FM, especially in the context of emerging concepts like smart buildings, is the enhancement of IT skills among FM staff. To meet future customer needs comprehensively, FM must become the stakeholder and principal user of building data, potentially giving rise to new job roles such as Facility Data Manager or Smart Building Manager (Bartels & Wills, 2023). Concurrently, facility managers providing FM services are obliged to navigate and control data, thereby elevating the importance of IT and IoT skills in their professional repertoire. The FM industry is undergoing a transformative phase, marked by the integration of cutting-edge technologies reshaping the landscape of service delivery and management practices (Lünendonk & Hossenfelder GmbH, 2022; Statistisches Bundesamt [Destatis], 2023). In response to a shortage of skilled labor, the FM sector is increasingly turning to innovative solutions, including sensor technologies, building information modeling (BIM), Virtual Reality (VR), and Artificial Intelligence (AI), to streamline operations and enhance overall efficiency (Wills & Bartels, 2023). Furthermore, discussions with students and employers revealed a palpable interest in leveraging IT tools to enhance sustainability and efficiency in building Operations and Maintenance (O&M). However, the transition from academic settings to the workforce brought a significant discrepancy to light: a perceived lack of essential IT skills in many students' first jobs, leading to disappointment.

As the FM industry transforms towards technologically driven future, the content and methodologies of academic programs become pivotal in shaping a workforce capable of meeting growing demands. This study aims to analyze whether the current curriculum contents of German universities align with these futuristic needs. The paper is rooted in an examination of German study programs, building upon a study conducted in 2023, with additional data incorporated for a holistic perspective, focusing on German universities' curricula and teaching methods and scrutinizing them against the backdrop of the labor market's content and methodological requirements. The outcomes of these analyses are then juxtaposed in an interface matrix, paving the way for the formulation of recommendations to align curricula and module handbooks with the identified needs of the FM job market.

In conclusion, this paper seeks to address the gap between academic curricula and industry demands within the FM sector's technological evolution. By investigating and proposing adjustments to curricula, the study aims to prepare a workforce equipped with the skills essential for the future of FM, aligning academic programs with the dynamic requirements of Smart Buildings and beyond.

RESEARCH METHODOLOGY

In this paper, a mixed review is employed, combining a scoping study (Arksey & O'Malley, 2005) in the form of a scientometric review and a critical review of the results, seeking to examine the extent and range of study programs in Germany that handle the requirements for the future labor market. The methodology consists of two stages: In stage one, a scientometric review of study programs occurs. Therefore, the following databases are used for research: "Hochschulkompass", "studieren.de", and the "overview of gefma-certified universities". Hochschulkompass provides information on current study programs at German educational institutions and offers further information on studying (Hochschulkompass, 2024). "Studieren.de" is a detailed directory of degree programs for study orientation in Germany (xStudy SE, 2024). The gefma working group "Education and Knowledge" develops guidelines for high-quality training and further education in FM for students and specialists. The working group publishes the education and training courses certified by Gefma in the overview "German-certified education and training courses" (German Facility Management Association [GEFMA], NN). After finishing the data collection, in stage two, a critical review of the results is conducted. Therefore, first, a quantitative analysis in the form of screening and a classification of the results identified takes place. Secondly, a qualitative analysis of the identified study programs is done.

The keywords used for the study course research are "digital real estate management", "real estate", "civil engineering", "construction management", "real estate management", and "facility management". The selection of keywords is based on the study by Bartels and Wills (2023), which examined the extent to which IT requirements will be needed by professionals in the labor market of the Architecture, Engineering, Construction, and Facility Management industries (AECO) industry. The choice of keywords aims to identify those academic programs that teach technical skills and knowledge in building operations (FM). The analysis is conducted separately for universities and universities of applied sciences. Next, the identified results and analysed study program names are listed to verify that the programs linked to keywords meet content requirements of FM, real estate, and building operations contexts.

The critical review is separated into two steps: in a first step, a quantitative analysis is conducted to examine how frequently the specified terms occur in the module handbooks. In the second step, a qualitative analysis of the study programs and courses that include the keywords in their curriculum is carried out. Qualitative aspects of this analysis include the scope of the topic in hours, the achievable European Credit Transfer and Accumulation System (ECTS) points, the examination format, the type of teaching method (seminar-based, lecture, or practical), and, finally, the subject-specific, social, methodological, and interdisciplinary competencies. The results are analyzed in an interface Table according to the requirements of the industry, based on the contribution by Bartels and Wills (2023).

RESULTS

Data collection

The analysis of existing study programs in Germany generated 673 results. Within the scope of data preprocessing, 140 duplications were identified. Duplications arose, for instance, due to the classification of programs in databases with multiple keywords. The results that do not align thematically with the programs under analysis, such as “Railway Engineering”, or those that exhibit a thematic distance from the domains of FM due to excessive specialization (e.g., building protection civil systems engineering, energy or wood engineering) were filtered out. The initial screening for relevance and removal of double occurrences, and exclusion of irrelevant study programs to the purpose of the study left a total sample of 439 study programs relevant for the analysis. The first results are shown in Figure 1.

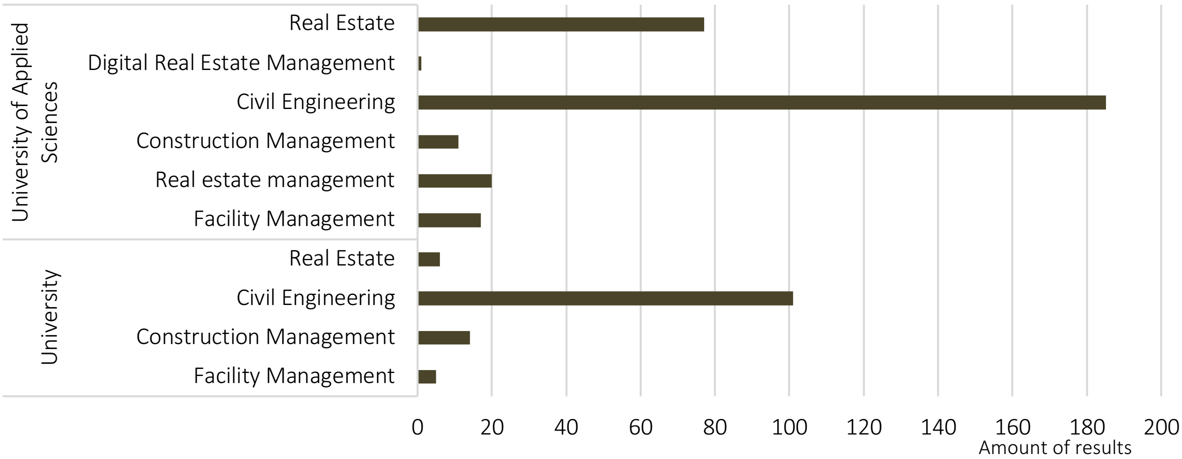

Figure 1 FM- and real estate-related study programs in Germany

The examination of academic programs at both universities and universities of applied sciences reveals distinct emphases on various disciplines within the built environment. Notably, “Civil Engineering” occurs as a predominant focus at universities, with a substantial count of 185 instances, compared to 101 instances at universities of applied sciences. On the other hand, “Real Estate” is a predominant subject at universities of applied sciences, appearing 77 times, while universities exhibit a relatively lower count of 6 instances. “Digital Real Estate Management” and “Construction Management” exhibit limited representation across both university types, with only one occurrence each in programs offered by universities of applied sciences. Regarding property management and facility-related disciplines, both “Real Estate Management” and “Facility Management” demonstrate a presence at universities and universities of applied sciences, though with varying frequencies. “Real Estate Management” is more widespread at universities of applied sciences (20 occurrences), while “Facility Management” is slightly more emphasized at universities (17 occurrences).

In the next step, the identified 439 results are listed, and the designations or names of the study programs are examined more closely. The goal is to determine whether the study programs associated with the keywords meet the content requirements or if the database linkage between programs and keywords also included study programs that are not contextually related to FM, Real Estate, and Building Operations. The final screening left a total sample of 115 relevant study programs for analysis.

Quantitative analysis

In the quantitative analysis, an examination of the frequency of keywords across the dataset, distinguishing between their total occurrences and their mentions specifically within modules (module handbooks) is conducted. Figure 2 summarizes the findings (where the y-axis is interrupted for the sake of readability).

The keyword "BIM" receives significant attention with a total frequency of 1,268 mentions. Furthermore, its occurrence extends across diverse contexts, featuring 72 instances within module handbooks, with 21 occurrences in universities and 55 in universities of applied sciences. Keywords such as "Robotics", "Blockchain", "IoT", and "AR" showcase a noTable presence, indicating a growing interest in these cutting-edge technologies. Their varied frequency both in the overall dataset and within module handbooks suggests their importance across different contexts. The keyword "Database" is frequently mentioned (184 occurrences) and has 35 occurrences within module handbooks, with a slightly higher presence in universities of applied sciences (29 occurrences) compared to universities (six occurrences). The keyword "predictive maintenance" is not mentioned.

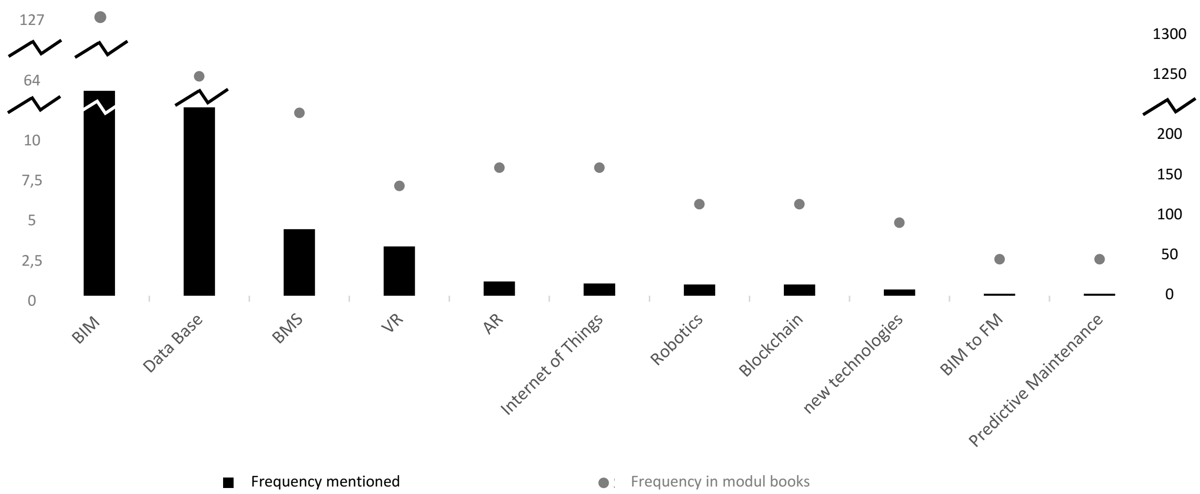

Figure 2 Frequency Analysis Across the Dataset: Total Occurrences vs. Module Mentions

While "Building Management System/Operation" is more often mentioned in module handbooks of universities of applied sciences, "AR" shows a balanced presence across both traditional universities and universities of applied sciences. "IoT" and "Database" underscore their significance, with frequencies of 12 and 184 mentions, respectively. "IoT" finds representation across traditional universities and universities of applied sciences, while "Database" displays a more nuanced distribution. In the subject of robotics, the findings showcase a total frequency of 11 mentions, with three occurrences within module handbooks of universities of applied sciences and an additional mention in traditional universities. Similarly, "Building Automation Systems" received 27 mentions with representation in both traditional universities and universities of applied sciences. The thematic cluster of "new technologies" is distinctly present with six mentions, all found within module books at universities of applied sciences. "Blockchain" and "VR" also exhibit frequencies, emphasizing their relevance primarily within module handbooks of universities of applied sciences. The keywords “Predictive Maintenance” and “BIM to FM” are uniform, totaling two mentions within module handbooks at universities of applied sciences. Figure 3 presents the results.

After completing the quantitative analysis, a qualitative investigation is conducted, which aims to examine the thematic areas relevant to the labor market contextually within the module handbooks. This closer look examines the extent to which the teaching format of the individual subject areas is considered. During the quantitative investigation, the term "BIM" was frequently mentioned in the academic programs of various subject areas, with a higher concentration in civil engineering and construction programs. To obtain a more precise statement, the investigation is narrowed down to only civil engineering programs that explicitly address FM and real estate in a broader sense based on their program names.

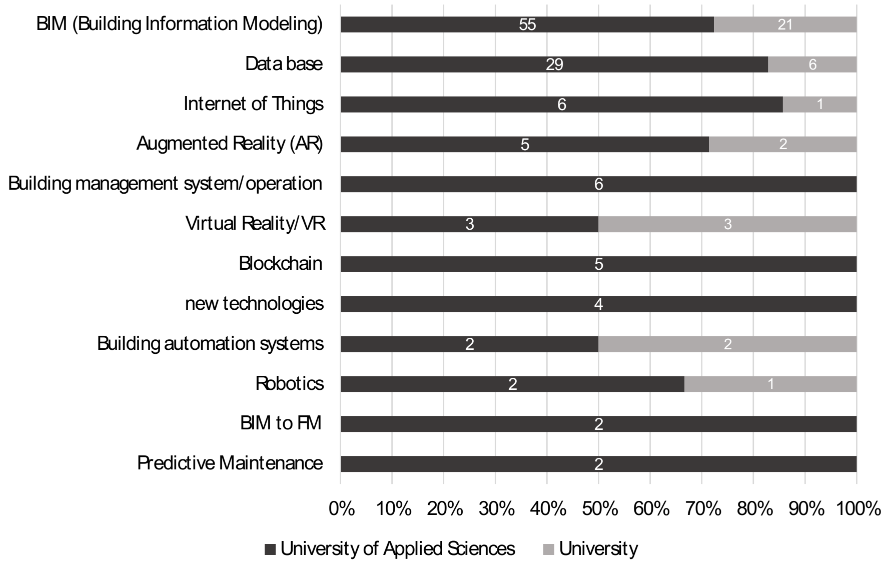

Figure 3 Comparative analysis of keyword occurrences in module books

Qualitative analysis

In line with Mayring's inductive categorization approach, categories were derived directly from the various program names (Mayring, 2022). This data-driven methodology allows an open investigation of the material without predefined structures, facilitating the identification of emerging themes and connections. Based on the names of the degree programs, the following categories shown in Table 1 are formed according to Mayring (2022).

The keyword BIM is prominently featured in the module handbooks of study courses within “Construction and Civil Engineering” programs and in “Real Estate and Facility Management” programs. 29 modules take the name BIM directly in their title, led by modules from the “Construction and Civil Engineering Program” (N=6). In Real Estate and FM programs, five modules are named BIM. In Figure 4, alongside the relative frequencies of the term BIM (darker bars), the frequency of the term BIM in module names (lighter bars) and the detailed designation of modules related to BIM are presented.

Table 1 Inductive categories derived from study course program names according to Mayring (2022)

Inductive categories	Study course programs
Technology-oriented programs	Business Administration; Technology and Management in Construction Operations; Smart Building Engineering; Construction Information Technology; Digital Engineering; IT-Construction; Sustainable Building Planning; Digital Technologies in Construction Operations; Technical Building Planning – Smart Building Engineering
Management and Economics programs	Business Administration; Industrial Management; Sustainable Real Estate Management; Real Estate Economics; Banking and Finance; Construction Business Administration; Management (Construction Real Estate Infrastructure).
Construction and Civil Engineering programs:	Civil Engineering-Planning, Building, Operating; Civil Engineering (dual); Civil Engineering - Construction in Existing Structures; Architecture; Construction Process Management and Real Estate Management, Construction Management and Construction Operations.
Real Estate and FM programs:	Real Estate Management; Facility Management; Real Estate and Facility Management; Building Maintenance and Construction in Existing Structures; Real Estate and Construction Management; Construction and Real Estate Management-Technical Real Estate Management; Facility Management and Real Estate Management; Real Estate, Industrial Engineering-Real Estate.
Digital and Information Technology programs:	Construction Information Technology; Digital Real Estate Management; Digitalization and Real Estate Management.
Smart Building and Engineering programs:	Smart Building Engineering; Smart Building Engineering and Management; Industrial engineering and management-Sustainability and Smart Building Technology".
Cross-Disciplinary programs:	Real Estate and Integral Building Technology; Real Estate Technology and Real Estate Economics; Technology and Management in Construction Operations.

The instructional format of modules directly bearing the name BIM consists of lectures and exercises (N=17), supplemented by courses featuring workshops (N=3) or seminars (N=4), as well as project work (N=3). For two modules, the instructional formats were not further specified. The extent of instruction in this domain varies between 180 hours (N=13), 150 hours (N=10), 90 hours (N=1), and 75 hours (N=1). Taking a closer look at the module handbooks of study courses within “Real Estate and Facility Management” programs, it becomes clear that students learn to articulate BIM definitions, outline associated requirements, and differentiate between Little BIM/Big BIM and Open BIM/Closed BIM, identifying interfaces between these concepts. Additionally, students learn competence in recognizing the utility of BIM across various phases of real estate projects, such as planning, construction, and operation. Students learn to weigh the advantages and disadvantages of BIM in each building lifecycle phase.

Furthermore, the analysis shows that students are expert at identifying and shaping BIM processes, including BIM-compliant contract allocation, defining roles in BIM, addressing client information needs as well as exchange information requirements, understanding the creation of BIM execution plans, and modelling subcomponents within BIM. The findings indicate that students can apply BIM elements, principles, and scenarios through practical projects, demonstrating their ability to independently create models, evaluate presented quality models, and utilize exchange formats to ensure consistency in information flow. Students exhibit the capacity to present and discuss the pros and cons of various solutions, collaboratively developing suitable proposals within a team setting. The analysis observes that students critically evaluate and compare these statements, acknowledging the complexity of the overall context.

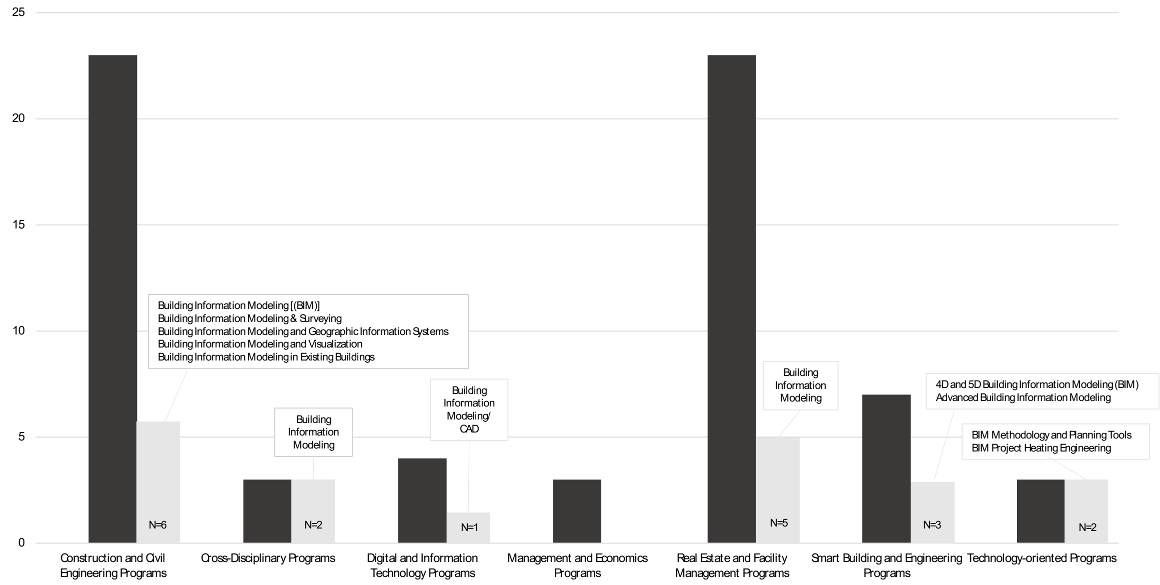

Figure 4 Distribution and characteristics of BIM modules in study programs

The keyword "IoT" is mostly mentioned in the module handbooks of Technology-oriented programs, Digital and Information Technology programs, Management and Economics programs, and Real Estate and Facility Management programs. None of the modules has the term “IoT” directly in its name. The lectures covering IoT-related topics include “Mobile Applications”, “Digitalization of the Energy Industry”, “Digital Construction Project and Building Management Operation 2”, “IT Systems in Facility Management”, “Operation”, “Digitalization in Facility and Real Estate Management”, and “Introduction to Digital Planning”. Figure 5 illustrates the frequency distribution of modules that explore IoT within their content. The extent of instruction in this domain varies between 210 hours (N=1), 180 hours (N=1), 150 hours (N=3), and 120 hours (N=1). Notably, the study programs falling under the inductive category of Real Estate and FM each encompass a comprehensive duration of 150 hours.

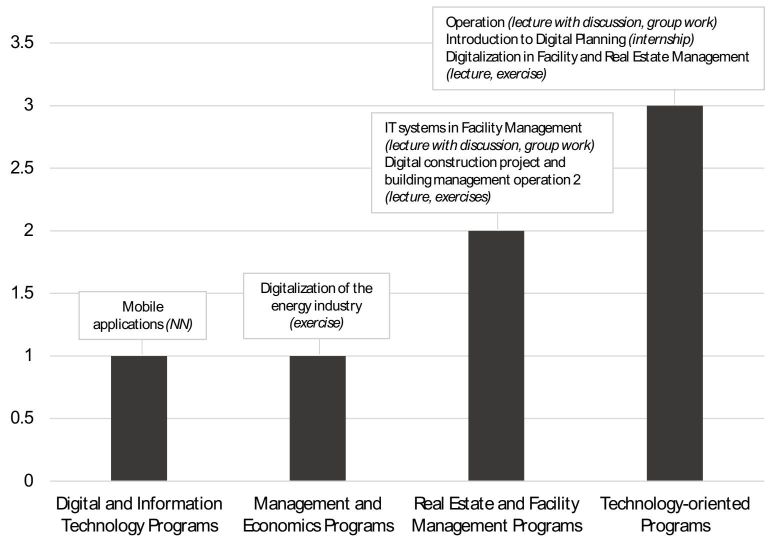

Figure 5 Frequency Distribution and Instructional Formats of IoT Modules

After searching the keyword "database" across various degree programs, it was discovered that several various options are available in the field of databases and information technology. One such option is the construction information technology curriculum, which offers a lecture series on databases. This program includes group discussions and activities to enhance the learning experience. The course, conducted in the second semester, extends over 150 hours and contributes 5 ECTS credits. Similarly, within the Management and Economics programs, Industrial Management introduces a lecture series coupled with exercises in the second semester, focusing on databases and Supervisory Control and Data Acquisition (SCADA) systems. This module spans 150 hours and carries 5 ECTS credits. Real Estate and FM programs integrate the study of data modeling and databases, delivered through lectures and exercises. This program lasts 150 hours, earning students 5 ECTS credits. Figure 6 shows the distribution and characteristics of database modules in study programs.

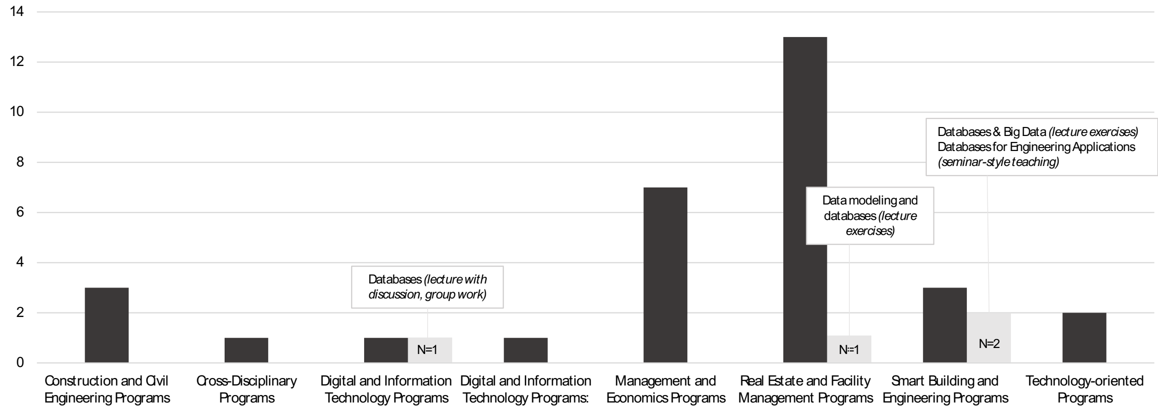

Figure 6 Distribution and characteristics of data base modules in study programs

The analysis of study programs incorporating VR and AR reveals diverse lectures across various academic categories, as can be seen from Figure 7.

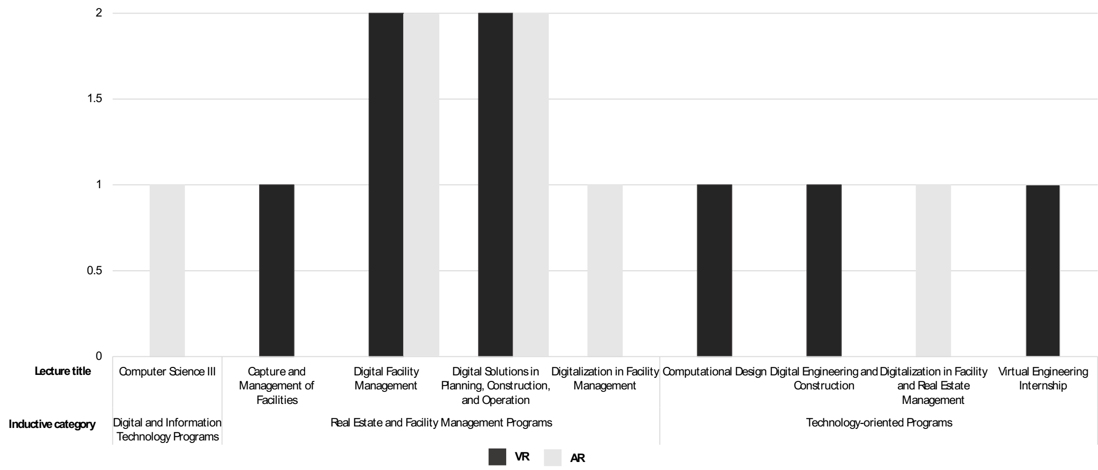

Figure 7 Distribution and characteristics of VR and AR modules in study programs

In VR-related courses, the programs encompass a range of lecture formats, including lectures, seminars, discussions, and group work. The extent of these programs varies, spanning two to three semesters, with total workloads ranging from 150 to 200 hours. AR elements are integrated into programs through lectures, discussions, and group work. The extent of AR programs varies, with total workloads ranging from 150 to 200 hours over two to three semesters. The courses equip students with diverse skills related to the evolving field of digitalization in facility management and planning. All modules encompass themes of digitalization in building operations, addressing areas such as VR and AR as data capture and visualization tools.

Moving to "Smart Building and Engineering" programs, the Smart Building Engineering and Management curriculum explores databases and big data through a lecture and exercises format in the first semester. This course spans 150 hours, with an ECTS credit allocation of 5. The curriculum emphasizes databases for engineering applications in the context of Smart Building and Engineering programs with a technical focus on civil engineering. The lecture series, exercises, and seminar-style teaching reveal more than 180 hours, earning students 6 ECTS credits.

DISCUSSION OF THE RESULTS

To answer the research question of whether academic curricula meet the demands of the FM labor market, an industry-academic alignment analysis is conducted. This analysis involves evaluating the skills, knowledge, and competencies expected by industry professionals and comparing them to the content and structure of the academic curriculum. The goal is to identify gaps or misalignments between what the industry seeks in graduates and what the academic program provides. The results are shown in Table 2. To better prepare students for future labor tasks related to BIM, the authors propose integrating more real-world case studies to module handbooks. This addition to the curriculum ensures that students gain practical depth in analyzing actual occupancy scenarios or facilitating a more practical application of BIM fundamentals in space optimization. Regarding BIM for energy consumption based on occupation, it is recommended that students' exposure to various BIM software tools is expanded. This broader familiarity will equip students with skills in industry standard tools, fostering adaptability in diverse professional environments. In the context of BIM for adaption of service provisioning, there is a suggestion to strengthen interdisciplinary collaboration within the curriculum. For BIM use cases within the design of new buildings, it is recommended to provide additional practical exposure to VR and AR technologies. This exposure will enable students to leverage these technologies more effectively in e.g. the design phase of new buildings.

Moreover, highlighting real-world case studies is essential for providing students with a comprehensive understanding of IoT applications. By training theoretical knowledge in practical scenarios, students can hold the complexities and challenges of real-world implementations. A balanced approach between traditional lectures and hands-on exercises is essential to enhance practical skills further and ensure that theoretical knowledge is coupled with practical experience, preparing students for the dynamic IoT landscape. An example for a real-world case study could be a corporate office building aiming to optimize energy consumption and enhance sustainability through IoT. Students can analyze how sensors are strategically placed to monitor lighting, heating, ventilation, and air conditioning (HVAC) systems. By collecting and analyzing data in real-time, the smart building system adjusts temperature, lighting, and energy usage to ensure optimal comfort for occupants while minimizing energy waste. Challenges to explore include data security, device interoperability, and user acceptance. Hands-on exercises involve designing a simplified IoT energy management solution for a smaller-scale facility.

In the area of VR/AR for using data in designing new buildings, recommendations focus on broadening the integration of VR/AR concepts across diverse study programs, as these technologies become integral to various industries, providing students from different disciplines exposure to VR/AR applications fosters interdisciplinary collaboration and prepares graduates for versatile roles. An example could be a case study where a FM team maintains complex facilities. VR/AR technologies can be applied to create immersive training simulations for technicians. Students can examine how virtual scenarios imitate equipment failures or maintenance challenges, allowing technicians to practice troubleshooting and repair procedures in a risk-free environment. The case study could explore the integration of VR/AR into existing training programs, emphasizing its impact on reducing downtime and improving overall maintenance efficiency.

Table 2 Industry-academic alignment analysis

Industry requirement	Academic Curriculum	Alignment /Gap	Strengths	Weaknesses
BIM for the use cases of space utilization ratio, energy consumption based on occupancy, adaption of service provisioning, and using data for the design of new buildings.	Students articulate BIM definitions, outline associated requirements, and differentiate between Little BIM/Big BIM and Open BIM/Closed BIM. Recognition of BIM's utility across planning, construction, and operation phases, weighing its advantages and disadvantages. Identification and shaping BIM processes within the context of different life cycle phases.	Alignment	Comprehensive coverage of BIM fundamentals. Practical application within relevant contexts; Clear understanding of BIM's role in service provisioning optimization; Application of BIM data for sustainable design considerations	Potential for enhanced emphasis on real-world case studies for practical depth; Limited exposure to a variety of BIM software tools; Potential for increased emphasis on interdisciplinary collaboration; opportunity for more practical exposure to VR/AR technologies
IoT (and sensor data) for the use cases of space utilization ratio, energy consumption based on occupancy, and adaption of service provisioning	Modules provide fundamental knowledge of sensor networks, building automation, and IoT application in FM and Real Estate Management. Students can critically evaluate digitalization technologies and implement simple sensor networks. The curricula include a module on Mobile Applications covering IoT data generation and its applications in the construction industry.	Alignment	Integration of fundamental IoT concepts into the curriculum. Practical experience in assessing optimization potential and implementing sensor networks. Experience to mobile application development aligning with IoT data generation.	Opportunity for deeper exposure to advanced IoT technologies and applications; Emphasis on real-world case studies for a more comprehensive understanding; Potential improvement in the balance between lectures and hands-on exercises for enhanced practical skills development.

Industry requirement	Academic Curriculum	Alignment /Gap	Strengths	Weaknesses
VR/AR for the using data for the design of new buildings	Relevant courses provide insight into VR fundamentals, including hardware, software, and applications. Hands-on experience in development environments like PolyVR and Blender, culminating in the creation of VR applications in small groups.	Alignment	Practical exposure to VR/AR technologies. Practical experience in developing VR applications.	Opportunities for broader integration of VR/AR concepts across different study programs; Potential for deeper exploration of VR/AR applications in building design. Workloads are substantial, reflecting a commitment to in-depth exploration of VR and AR.
Data(bases) for data analysis and therefore the use cases of space utilization ratio and the design of new buildings	Various modules across programs covering databases and data analysis.	Alignment	Practical application of data analysis techniques and SQL Overview of industrial control systems and their integration with SQL. Understanding of modern database systems and their applications. Comprehensive coverage of various database and Big Data concepts. Integration of computer-based solutions for engineering applications.	Limited detailed content information on space utilization and design. Limited information on specific SCADA-related topics. The information provided in the modules lacks detailed content specifically related to space utilization ratio and the design of new buildings. There is a gap in addressing these specific aspects within the context of database usage for data analysis.

Recommendations for databases and data analysis, particularly in space utilization ratio and building design, focus on enhancing the detailed content within relevant modules. The curriculum should comprehensively cover space utilization ratio and design considerations within the database context, e.g. exercises that focus on calculating space utilization ratio using SQL queries, considering factors such as floor area, occupancy data, and room functionalities. Due to date, module handbooks only provide general information on database but rarely specified to the real estate sector.

Furthermore, addressing the need for more information on SCADA-related topics is essential for preparing students to work with industrial control systems. Providing insights into SCADA systems and their integration with databases ensures that graduates can handle the complexities of data analysis in real-world scenarios. These recommendations aim to fortify the academic curriculum, ensuring students are well-prepared and adapTable to the intricacies of database applications in diverse industry contexts.

CONCLUSIONS

This paper investigates the alignment between academic curricula and the evolving demands of the FM labor market, particularly in the context of emerging technologies such as the IoT, BIM, VR, and AR. The study focuses on German universities and employs a mixed methodology involving a scientometric review and a critical review of the results. The industry-academic alignment analysis highlights areas of alignment and provides recommendations for improving the curriculum to meet industry requirements better. This paper identifies gaps between academic curricula and industry demands in the FM sector and provides actionable recommendations to bridge these gaps. By addressing these recommendations, academic institutions can ensure that their graduates are well-equipped with the skills and knowledge essential for the future of FM. Nevertheless, despite the analysis of module handbooks and the juxtaposition of these teaching contents with the requirements of the FM job market, the fundamental principle of "freedom in research and teaching" persists. The intensified teaching contents and formats outlined in the module handbooks need to conclusively indicate how the contents are carried through purely analytical examination. The extent to which the examined contents are taught covers only a minimal scope of the overall duration of the studies (both throughout the entire study program and within individual modules). Primarily, when modules occur in earlier semesters, it is crucial to investigate to what extent the teaching contents can be applied in practice. It is also important that teaching is implemented in accordance with the curriculum. This means, for example that VR or AR applications are taught in a way that meets the needs of the future job market. Further research and concepts are needed for this.

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Machine Learning Techniques for Building Predictive Maintenance: A Review

Adhikari, A.[1], Karunaratne, T.[2], & Sumanarathna, N.[3]

[1] School of Applied Management, University of Westminster
[2] School of Architecture, Technology and Engineering, University of Brighton
[3] School of the Built Environment, London Metropolitan University
Contact: a.adhikari2@westminster.ac.uk

ABSTRACT

Background and aim. Proper maintenance is crucial for ensuring the sustainable use of building systems and equipment throughout their life cycles. Predictive maintenance strategies aim to minimise unplanned downtime and improve equipment lifespan, but their implementation is complex. Machine learning (ML), on the other hand, offers a novel solution for making systematic predictions across various disciplines. This review analyses the interrelationships between predictive maintenance and ML techniques to identify current research trends and potential areas for further study.

Methodology. A bibliographic analysis was conducted on a sample of 102 journal articles with VOSViewer. Key topics generated by co-occurrence analysis were then discussed semi-systematically, focusing on the most popular predictive maintenance applications and ML techniques.

Results. The results show a distinct relationship between the two terms, yet co-author analysis reveals a lack of global collaboration among authors. Additionally, Support Vector Machines, Artificial Neural Networks, Deep Neural Networks, Decision Trees, Random Forests, Bayesian Networks, and K-nearest neighbours are found to be the most frequently used ML techniques.

Originality. The study recognises the current research trends and provides future research implications. This study highlights the importance of adopting ML for predictive maintenance to achieve sustainability and NetZero carbon policy goals, which have not been explicitly addressed before.

Practical or social implications. The recommendations of this research broaden the scope of predictive maintenance studies. Emphasising collaborations between authors, institutions, and countries could significantly enhance research output in Facilities Management and Building Life Cycle.

Type of paper. Research (full)

Keywords. Bibliometric analysis, Machine learning, Predictive maintenance

INTRODUCTION

Predictive maintenance has emerged as a key strategy in the sustainable management and operation of building systems and equipment, aiming to proactively identify maintenance needs before failures occur, leading to minimised unplanned downtime and extended equipment lifespan (Bouabdallaoui et al., 2021). This strategy is pivotal in the context of facilities management, where the impact of unexpected equipment failures is crucial (Valinejadshoubi et al., 2022). Recent advancements in machine learning (ML) have offered promising new tools which can be adapted to enhance predictive maintenance efforts, facilitating accurate, timely, and cost-effective solutions (Ma et al., 2020).

The application of ML in predictive maintenance represents a combination of data analytics and operational technology. This is a paradigm shift from traditional, periodic maintenance approaches to one that is data-driven and predictive in nature. ML algorithms can analyse large data sets from various sources, such as sensors and operation logs, to detect trends, predict potential failures, and propose maintenance activities proactively (Leukel et al., 2021). This shift enhances the reliability and safety of building systems while improving operational efficiency (Teoh et al., 2023).

However, the implementation of ML-based predictive maintenance in the building sector is not straightforward. The possible challenges include the complexity of integrating ML algorithms into existing maintenance frameworks, the accessibility to high-quality, relevant data, and the requirement for expertise in both domain-specific knowledge and ML technologies (Villa et al., 2022). Additionally, there are concerns about the funds for deploying such technologies, particularly regarding capital and the operational costs associated with data collection, processing, and analysis (Carvalho et al., 2019).
Recent studies have focused on addressing these challenges, proposing frameworks and methodologies for integrating ML techniques into predictive maintenance strategies (Arsiwala et al., 2023; Nunes et al., 2023). These studies emphasise the need for a systematic review of current research trends, methodologies, and results related to the application of ML in building predictive maintenance.

ML plays a crucial role in improving predictive maintenance by analysing large datasets to anticipate equipment failures and schedule preventive actions, reducing downtime and costs. Despite growing recognition of ML's advantages, its systematic integration across industries remains underexplored. Few systematic reviews, such as Carvalho et al. (2019) and Scaife (2024). However, there has been a lack of studies that have considered building facility systems. Moreover, existing literature highlights gaps in understanding the synergistic effects of ML integration with predictive maintenance protocols, including challenges and benefits. Limited research explores the collective impact on operational efficiency and reliability, with few detailed case studies or empirical evidence on implementation processes, scalability, and quantifiable benefits.

This paper aims to fill this gap by conducting a Bibliometric analysis of the literature followed by a semi-systematic review of ML techniques for predictive maintenance in the building sector. For this purpose, the analysis has been conducted by selecting articles from Scopus and Web of Science. The study identifies key trends, applications, and challenges in this emerging field. Moreover, it recommends potential future research areas for authors to consider.

PREDICTIVE MAINTENANCE IN BUILDINGS

Predictive maintenance in buildings is a strategic approach that focuses on predicting how and when building equipment could fail, allowing maintenance to be carried out at the optimum time to prevent failure. Predictive maintenance is distinct from preventive maintenance, which relies on routine or scheduled maintenance, regardless of the actual condition of the equipment (Madureira et al., 2017). Predictive maintenance techniques typically involve monitoring and evaluating the operational data of building systems to identify trends that signal impending equipment failure (Flores-Colen & Brito, 2010).

Vibration analysis, acoustic monitoring, oil analysis, and thermal imaging are some of the well-known predictive maintenance techniques (Civerchia et al., 2017). The applications of predictive maintenance are commonly used in various building systems. The advantages of adopting such a maintenance strategy are profound, resulting in greater reliability, improved safety, and extended asset life. Moreover, this approach contributes to energy savings, as optimally maintained equipment operates more efficiently and prevents the unnecessary costs of scheduled maintenance when it is not required (Cauchi et al., 2017). Implementing predictive maintenance in buildings requires an in-depth understanding of the operational characteristics of each building equipment.

MACHINE LEARNING TECHNIQUES

ML, a subset of artificial intelligence, involves training computers to learn from data, identify patterns, and make decisions with minimal human intervention. ML has made significant advances in various fields, and its application in building management is upgrading predictive maintenance strategies (Yang et al., 2018). ML's capacity to process substantial amounts of complex data and learn from it results in high accuracy predicted outcomes (Villa et al., 2022). ML techniques consist of various algorithms designed to extract patterns and insights from data. Among them, Support Vector Machines (SVM) are effective for classification and regression tasks, separating data points using hyperplanes to maximise margins, and Artificial Neural Networks (ANN), on the other hand, consist of interconnected nodes that process information through layers to make predictions (Carvalho et al. 2019). Deep Neural Networks (DNN) extend ANN's capabilities with multiple hidden layers, enabling them to learn intricate patterns and hierarchies in data (Bouabdallaoui et al., 2021). Decision Tree (DT) ML algorithm is used for prediction-based regression or classification. Each node of the tree represents a decision, and based on a feature, different branches are created until a prediction is made at the leaf nodes (Carvalho et al., 2019). Each of these techniques has unique strengths and weaknesses, making them suitable for different applications within the realm of ML.

MACHINE LEARNING AND PREDICTIVE MAINTENANCE IN BUILDINGS

In the context of predictive maintenance in buildings, ML techniques analyse operational data from various building systems to predict equipment failures (Cheng et al., 2020). By employing advanced algorithms, ML can recognise sophisticated patterns that correlate specific conditions or anomalies with impending equipment failures. This allows for a proactive approach to maintenance, where actions are taken based on predictions of what might happen rather than reacting to what has already occurred (Hong et al., 2020). These predictions allow facility managers to schedule maintenance proactively while minimising downtime and extending equipment life. Nevertheless, the benefits outweigh the requirements and drive the adoption of ML in smart building management, leading to a new era of efficiency and intelligence in building operations (Carvalho et al., 2019).

RESEARCH METHODOLOGY

This study adopts a mixed method of bibliographic analysis and a semi-systematic analysis of existing research as the research methodology. Bibliographic analysis allows researchers to extract the essence of a considered research domain by analysing a large amount of data (Oladinrin et al., 2023). Primarily, VOSviewer is utilised to analyse the data. VOSviewer is a scientific mapping system that utilises features such as Natural Language Processing (NLP) and clustering algorithms to perform bibliometric analysis tasks (Orduña-Malea & Costas, 2021). Following the co-authorship and co-occurrence analyses, predictive maintenance studies were reviewed under different ML algorithms.

Data Collection

This study focuses only on the research on building predictive maintenance that incorporates ML for improved accuracy and efficiency. Initially, Google Books Ngram Viewer was utilised to analyse the historical trend of both terms. Ngram Viewer is a corpus of over 5 billion digitalised books that allow users to analyse historical data on keyword frequency in a diachronic context (Zięba, 2018). The term ML had exponential growth after 2010, and the term 'predictive maintenance' maintained a consistent phase throughout. Hence, the literature search was conducted from 2010 to 2024. Sources for bibliographic analysis and systematic analysis were extracted from two major databases, Scopus and Web of Science. Then, a keyword search was conducted using the advanced search method of each database using keywords such as "Predictive maintenance" AND ("Machine Learning" OR "ML" OR "Deep Learning" OR "Artificial Intelligence" OR "AI") AND ("Building" OR "Construction"). The results are further refined by adopting the keywords to filter the journal articles and reviews. The filtration process resulted in 83 articles through Scopus and 75 articles in Web of Science journals. Subsequently, a manual duplication analysis was conducted to remove duplicate articles, which resulted in 102 articles for bibliographic analysis and systematic analysis. The articles were further analysed to extract the studies conducted on FM systems of buildings, which resulted in 16 articles. These articles were reviewed under different ML techniques.

RESULTS

Co-authorship analysis

The first step of the analysis using VOSviewer software was co-authorship analysis to identify the most influential authors who have published on Facilities Management and ML. A total of 351 authors and 102 published documents have been considered for the analysis. Based on the number of publications, Hosamo H.H., Nielsen H.K., Svennevig P.R., and Svidt K. ranked as the top four publishing authors. Based on the number of citations, Chen K., Chen W., Cheng J.C.P. and Wang Q. ranked top, scoring 235 citations for each. However, there is no common topper based on both indicators. Ashari A. from the Khalifa University of Science & Technology, Abu Dhabi, UAE, ranked among the top 10 from both indicators by publishing two documents and scoring 230 citations. The VOSviewer software facilitates the visual representation of author relationships. As Figure 1 indicates, only 11 authors out of 351 have strong collaborative relationships with each other.

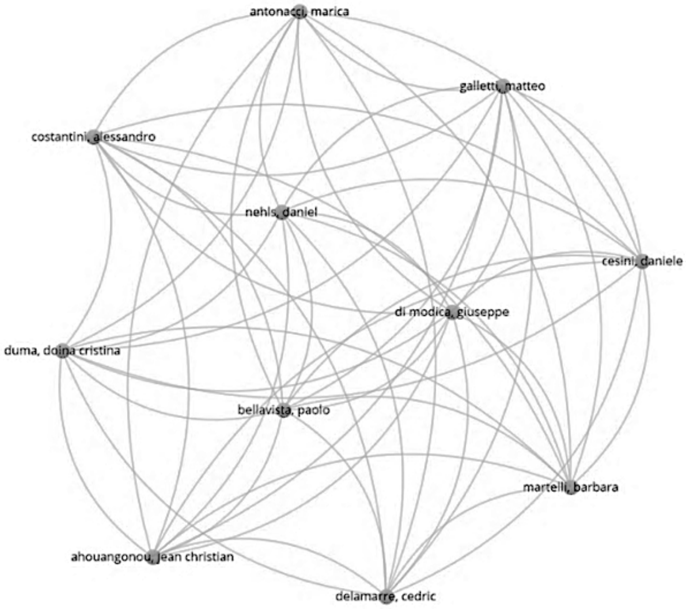
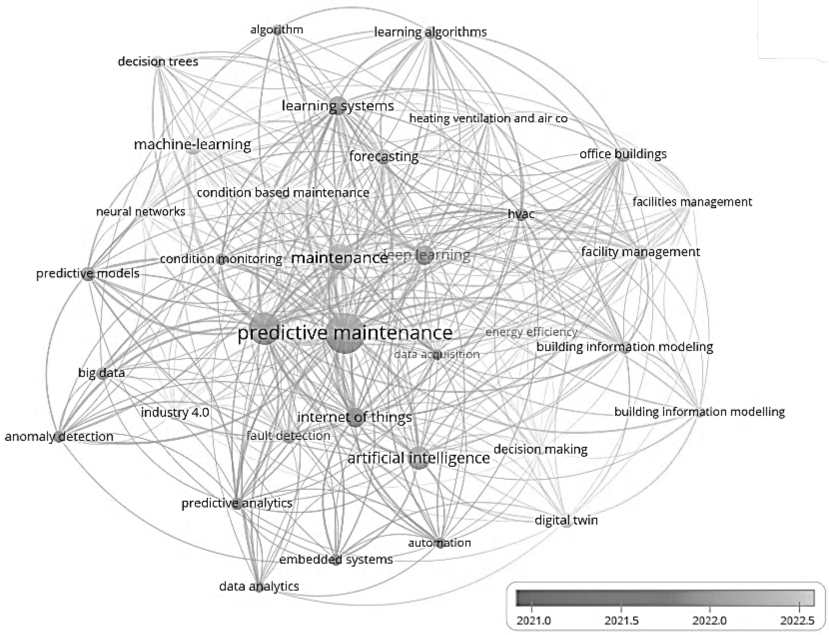


Figure 1 The network of cooperation, based on the co-authorship of the principal authors

Co-occurrence analysis

This section analyses the author's keyword distribution to identify the inter-relationships. The keywords included in the titles, abstracts and keyword sections are considered for this analysis. Keywords that



occurred in more than five instances were considered, which resulted in 35 keywords.

Figure 2 Cluster Visualization Map for co-occurring keywords

Among the top 10 keywords, 'Predictive Maintenance' occurred 64 times, while 'machine learning' occurred in 57 instances. Terms 'maintenance', 'internet-of-things' and 'learning systems' are also positioned among the top 10. Figure 2 visualises the keyword network and its weights. The weight of each keyword represents the size of the node, and the distance between the two nodes represents the strength of the relationship between the two keywords. Strongly related keywords are indicated with shorter distances. Moreover, the keywords are clustered and visualised in different colours. VOSviewer generated four main clusters for the given dataset, with the Red cluster being the most prominent. The Red cluster includes terms such as predictive maintenance, artificial intelligence, internet of things, and condition-based maintenance. Moreover, the second cluster is Blue (Machine learning, predictive models, forecasting), the third cluster is Yellow (maintenance, deep learning, predictive analytics), and the fourth is Green (Building information modelling, facilities management, digital twin, energy efficiency).

Since 2021, there has been an increase in these areas. The incorporation of terms such as 'Anomaly detection', 'Predictive analytics', 'Internet of things', and 'Embedded systems' are visible in early 2021. With the rapid growth of ML techniques and the substantial consideration of sustainability, by 2022, the research interests expanded to include concepts such as 'Digital twins', 'Neural networks', 'Industry 4.0', 'Energy efficiency' and 'Facilities management'. Components of ML and predictive maintenance can be seen throughout the considered period.

Application of machine learning techniques for predictive maintenance in buildings

Table 1 presents the description of each study, FM task(s)/functions(s) focused in each study, ML applications or techniques used and author details. The most frequently used ML techniques/algorithms for building predictive maintenance are discussed next.

ARTIFICIAL NEURAL NETWORK: Among the articles considered for this review, Cheng et al. (2020) employed ANN for predictive maintenance of MEP components in buildings using data obtained from IoT sensors, BIM models, and the FM system. Moreover, Hosamo et al. (2022) conducted a similar study, adapting ANN for fault detection in Air Handling Units. The results demonstrated high prediction accuracies; however, the authors concluded that prediction accuracy depends on the type of ML technique and the quality of input data. The following year, Hosamo et al. (2023) conducted another study for predictive maintenance in HVAC systems, utilising different ML techniques. The study integrated BIM, real-time sensor data, occupant feedback, and probabilistic models to create a digital twin and employed nine multiclass classification algorithms for predicting faults. The results suggested that ANN performs better compared to other models. Finally, Pałasz and Przysowa (2019) employed ANN and two other ML techniques to predict heat meter failures. The authors improved fault detection efficiency by using hyperparameter optimisation, reaching 95%. It is evident that ANN is frequently adopted for predictive maintenance in various FM systems.

Table 1 Empirical evidence on the application of ML for predictive maintenance in buildings

Description	Predictive maintenance Task(s)/ function(s)	ML techniques used	References
An ML-based framework to predict the future condition of MEP components for maintenance planning	Condition monitoring and fault alarming; condition assessment; condition prediction; maintenance planning.	ANN, SVM	Cheng et al. (2020)
A digital twin predictive maintenance framework for Fault detection and diagnosis (FDD) in air handling units	FDD of air handling units	ANN, SVM DT	Hosamo et al. (2022)
A combination of time-series modelling and ML techniques to develop an efficient fault detection for chillers	FDD of building management system	SVM	Yan et al. (2014)
A model-based fault diagnosis method for HVAC system	FDD of HVAC system	SVM	Mulumba et al. (2015);
ML-based anomaly detection methods to vertical plant wall systems to enhance predictive maintenance for the indoor climate	FDD for vertical plant wall systems / predictive maintenance for the indoor climate	NN	Liu et al. (2020)
Predictive Maintenance of the HVAC system	Prediction failures of HVAC	DNN	Bouabdallaoui et al. (2021)
Predict building occupants' complaints regarding thermal conditions	Predict building performance (Indoor cooling)	Multi-Layer Perception (MLP)	Assaf and Srour (2020)
To detect and predict HVAC issues	FDD of HVAC / predictions on comfort levels	Comfort analysis: Bayesian Networks (BN) Fault detection strategy: ANN, SVM, DT, KNN, RF, MLP, GB and XGBoost (XGB)	Hosamo et al. (2023)
To conduct fault diagnostics and predict remaining useful life estimation	Building performance	Similarity-based model	Schwartz et al. (2022)
Design of advanced heating systems for smart buildings and optimisation of stocks and maintenance processes in existing heat meter networks	Optimise heating systems; enhance the energy efficiency of buildings	SVM, ANN, and Bagging Decision Trees (BDT); Ensemble classifier	Pałasz and Przysowa (2019)
Maintenance scheduling for hospital buildings	Maintenance scheduling	Hierarchical and -means clustering algorithms	Ahmed et al. (2022)
To predict failures of smoke detectors	Prediction of potential failures of Fire alarm/smoke detectors	Autoencoder (AE) algorithm	Sousa Tomé et al. (2023)
To maintain the functionality and extend the lifetime of HVAC of hospital buildings/ operational effectiveness	Predictive maintenance of the HVAC system with a focus on the Air Handling Units	SVM, DT and KNN; Prephet forecasting and SARIMA	Al-Aomar et al. (2024)
Predictive maintenance of air conditioning systems using supervised machine learning	Fault detection (i.e., gas leakage and capacitor malfunction) of HVAC system	DT	Trivedi et al. (2019)
A new framework is introduced to optimise predictive maintenance of the HVAC system	Predictive maintenance for HVAC system	An autoencoder and a Neural Network (NN)	Tian et al. (2023)
A novel deep-learning-based method to conserve energy and mitigate emissions in building energy systems	Optimise building energy systems	DNN	Chen et al. (2024)

SUPPORT VECTOR MACHINE: Similar to ANN, SVM is a common ML algorithm used in predictive maintenance functions. Researchers such as Cheng et al. (2020), Hosamo et al. (2022), Hosamo et al. (2023), and Pałasz & Przysowa (2019) have employed SVM alongside ANN in their studies. Yan et al. (2014) also conducted a fault detection and diagnosis (FDD) study on chillers using SVM. They investigated five faults: 1. Reduced condenser water flow (F1), 2. Reduced evaporator water flow (F2), 3. Condenser fouling (F3), 4. Non-condensables in refrigerant (F4), and 5. Refrigerant leak (F5) by utilising existing FDD techniques and the proposed SVM approaches. The results indicate a significant improvement in accuracy and a reduction in false alarms. Another FDD study conducted by Mulumba et al. (2015) concluded that the SVM-based approach outperformed traditional methods in terms of performance evaluation metrics such as precision, recall, and F-measure.

DEEP NEURAL NETWORK: DNN is one of the most advanced ML algorithms used in predictive maintenance research in the recent past. Bouabdallaoui et al. (2021) proposed a five-step predictive maintenance framework, including data collection, processing, model development, fault notification and model improvement. The authors developed an LSTM (Long-short Term Memory) network to train the collected data and detect faults in HVAC systems. The authors have identified several challenges from the study, such as the scarcity of public datasets, long-term investments in building profiTable solutions and developing a tailor-made solution for different building types. Additionally, a recent study conducted by Chen et al. (2024) proposed a novel lifelong learning method with deep generative replay to conserve building energy and mitigate emissions. The results indicated a 53.4% increase in accuracy compared to the standard methods, which reached 0.89. A comparison study with other ML techniques, such as SVR, KNN, RF and XGBoost, suggested a 10% to 20% performance enhancement of the proposed method.

BAYESIAN NETWORK: Hosamo et al. (2023), in their study, developed a digital twin framework to predict comfort performance evaluation of building occupants and automated fault detection. The Bayesian Network model served the former purpose, predicting comfort performance based on a probabilistic approach. The model has been developed using Python box in Dynamo. Information such as building features, HVAC readings, occupancy density, etc., were considered data.

K-NEAREST NEIGHBOURS: Followed by an in-depth analysis based on the Bayesian Network model regarding building occupants’ comfort level in indoor environments, Hosamo et al. (2023) trained several ML models (as the digital twin framework) for automatic fault detection of the HVAC system; KNN is one of them. KNN is a supervised ML technique that classifies the types of faults in the HVAC system. However, the authors found that another ML technique, the Extreme Gradient Boosting (XGB) algorithm, provided the most accurate predictions. Furthermore, Random Forest delivered the fastest outcome in their study. Similarly, in their recent study, Al-Aomar et al. (2024) developed a KNN ML model, in addition to different ML models, to predict the maintenance of the HVAC system in a hospital building focusing on AHU units.

DECISION TREE AND RANDOM FOREST: As explained by Trivedi et al. (2019), in their study on predicting faults of the HVAC system, a simple DT model does not have a good predicting power. Hence, enhanced methods such as Random Forest should be adopted to improve the prediction accuracy. Pałasz and Przysowa's (2019) study on the optimisation of heater meters shows the empirical evidence on different ML models predicting failures of heater meters. A Bagging Decision Tree (BDT) is one of the ML techniques used to develop the ensemble classifier. BDT is derived by training multiple DTs on different subsets independently. The final prediction (classification) is obtained by considering the majority of predictions of all trees.

DISCUSSION

With the advancement of ML techniques over the years, predictive maintenance research has also shown rapid growth. By the year 2021, the study focused on utilising concepts such as 'Internet of Things' (Gordon, 2021), 'Transfer learning' (Gribbestad et al., 2021), and 'Deep Learning' (Berghout et al., 2021; Bouabdallaoui et al., 2021) for various predictive maintenance applications. More recent research focused on the latest applications such as 'AI-assisted Digital Twins' (De Donato et al., 2023; Hodavand et al., 2023), 'Industry 4.0' (Mohapatra et al., 2023) and 'Lifelong Learning' (Chen et al., 2024). A recent study by Scaife (2024) revealed that AI and ML generate opportunities to conduct remote monitoring, fully automated control of facility systems, immediate awareness of emergent conditions and accurate predictive maintenance operations with minimal labour.

Moreover, the analysis reveals a strong correlation between predictive maintenance and ML. Yet, there is a lack of collaboration among authors around the globe. The reason might be that influential authors fluent in predictive maintenance and ML areas have yet to emerge. Researchers have recognised that this research area is new and significantly impacts achieving sustainability goals (Cardoso et al., 2023).
From the semi-systematic review conducted on the empirical studies focused on predictive maintenance in buildings, ML techniques such as SVM, ANN, DNN, DT RF, BN, and KNN are found to be the most frequently used in the context of different FM services. Each ML technique has strengths and weaknesses in predictive maintenance tasks such as fault diagnostics, detection, and optimisation. DNN is commonly employed and demonstrates high prediction accuracies. DNN offers advanced capabilities but faces challenges such as data scarcity. BN provide probabilistic predictions, while DT-based methods like Random Forest and BDT enhance classification-based prediction accuracy. The choice of technique depends on factors such as the nature of the data, specific application requirements, and available resources. Based on the findings of this study, it is recommended that researchers need to focus on integrating Digital Twins and Generative ML algorithms to enhance the energy efficiency and automation of the predictive maintenance processes (van Dinte et al., 2022).

CONCLUSIONS

This study examines the research trends in predictive maintenance and ML through bibliographic analysis and semi-systematic literature review. Results from analysing 102 journal articles are categorised under Co-authorship and Co-occurrence analysis in the Results section. The findings highlight significant advancements and increasing research interest post-2021, emphasising ML's crucial role in enhancing predictive maintenance strategies. Beyond academic relevance, there is a need to evaluate the practical application of these technologies in the Facility Management (FM) industry. ML's predictive capabilities can optimise resource allocation, minimise downtime, and extend the lifespan of building systems. Future research should focus on practical implementation strategies to advance FM practices, including clear guidelines for integrating ML into FM workflows, case studies in diverse building environments, and cost-effective solutions for small to medium-sized enterprises. Additionally, integrating Digital Twins and Generative ML algorithms can enhance energy efficiency and automation, while research should align with sustainability goals and Net-zero carbon policies.

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Tools and Guidelines for More Sustainable Facilities Management: Operational Plans and Budgets

Jensen, P.A.[1], Nielsen, S.B.[2] & Rasmussen, H.L.[3]

[1] Department of Technology, Management and Economics, Technical University of Denmark
[2] Rambøll
[3] DFM, Danish Facilities Management Association
Contact: pank@dtu.dk

ABSTRACT

Background and aim. The Danish Facilities Management association (DFM) started a development program in 2022 to establish a stronger foundation for digital and sustainable Facilities Management (FM) through a series of best practice guidelines. This paper presents the results of a project on operational plans and budgets. The aim of the project was to develop tools to support practitioners to integrate sustainable considerations and activities.

Methods. The project was carried out in a project group with practitioners and researchers and included literature reviews, document studies, workshops, case studies, and external tests and assessments.

Results. The project resulted in two tools and guidelines for practitioners to support work with sustainable FM in operational plans and budgets. It also provides templates with a comprehensive overview of FM activities and a correlated budget and account structure.

Originality. The project shows how to work sustainably with FM, whereas previous guidelines did not address sustainability activities explicitly.

Practical implications. The project provides generic guidelines for FM best practice, which are of relevance for FM-organisations, building client organisations, software providers and other interested parties.

Type of paper. Technical

Keywords. budget, facilities management, guideline, operational plans, sustainability

INTRODUCTION

The Facilities Management (FM) profession and industry is, like society in general, facing the major challenge to become more sustainable and fight climate change. Digitalisation provides a wealth of opportunities with systems and tools to help us in this process, but it is also in itself a challenge to select, develop, adapt, implement, and use the appropriate and secure digital systems and tools. Together these two challenges require a major transformation of society and of FM. To support and speed up this transformation the Danish Facilities Management association (DFM) has started a development program to establish a foundation for digital and sustainable FM. The need for this programme and the specific project were raised by the members of DFM and its working committees. The program has financial support from the philanthropic foundation Realdania and runs from 2022 to 2024. It includes four projects and two of these were finalized in 2023, and the other two are ongoing. The overall aim of the program is to provide common guidelines and concepts to FM organisations etc. on selected and central areas within sustainable and digital FM. Information on the program and the projects is available

in Danish at DFM's website (DFM, n.d.). The guidelines and related templates (Nielsen et al., 2023a+b) can be downloaded freely.
The four projects were:

1. FM's use of digital sustainability information
2. FM specification for sustainable operational plans and budgets
3. Value creating implementation of FM systems
4. FM competences to receive sustainable building projects

DFM's secretariat has the overall responsibility for the program and an internal project coordinator for each project. There is a reference group for the whole program with representatives from industry associations and knowledge institutions. The projects are carried out in workgroups with practitioners and researchers and includes literature reviews, document studies, workshops, case studies, and external tests and assessments.

This paper will present the results of project 2 on sustainable operational plans and budgets. This project did not deal with digitalization, and the aim of the project was to develop tools to support practitioners to integrate sustainable considerations and activities with particular focus on environmental sustainability. The project group included a consultant with a research background as project manager, an experienced researcher with a practical background, and a self-employed consultant with an in-house FM-background. There was also an external control group with IT- and FM-expertise, who undertook quality assurance. The project resulted in a tool and guideline on operational plans and a tool and guideline on operational budgets and accounts. An Excel-file is available for each tool with a template showing the detailed structure etc. The guidelines are only available in Danish, while the Excel-files have sheets with Danish and English text.

The operational plans and budgets have a common overall structure, which consists of the following six main group, which each are divided in sub-groups:

1. Property operation
2. Support services
3. Property and tenancies
4. Changes and interior design
5. Management, planning and administration
6. Company specific activities

The last group is related to activities, which should be kept separate, when benchmarking with other FM-organisations, in accordance with European FM-standards.

As this is a technical paper, there is no literature review section, but the next section presents materials and methods. The operational plans and budgets are presented in the following two sections, including an example from a case of the Copenhagen University's Campus Service. The paper finishes with sections on discussion and conclusion. The discussion will mainly focus on how operational plans, budgets and accounts can support a more sustainable development with reflections and what we have done in the tools and guidelines particularly in this regard. In Appendix A an excerpt from the Excel sheet for operational plans in English is shown.

MATERIALS AND METHODS

The common structure and the tools are based on various existing structures, operational plans and account structures used in FM, including European standards, books, industry publications, public re-commendations, and the Danish benchmarking association and examples of plans and accounts from members of DFM-benchmarking. These were all in Danish, except for EN 15221-2 (2011), EN 15221-4 (2011), IPD (2006), and NS 3454 (2013). The list of references includes these and the two guidelines. Lists of other Danish publications can be found in the guidelines.

The project started with a webinar open for everybody interested on 24th August 2022 with presentation of the project and invitations to provide examples and cases to develop and test the tools, and to participate in workshops. Following there were two workshops with the first on 16th November 2022 and the second on 26th April 2023. In between, two case studies were conducted with a public and a private company in Copenhagen.

Each workshop lasted four hours and consisted of presentations by the project group and invited speakers and rounds of groupwork each finishing with presentations of the results. The participants were mainly FM-practitioners but also included IT-providers and consultants. The documentation included written minutes based on notes and posters produced by the groups. The first workshop had 40 participants, which beforehand had received a first proposal for structures of operational plans and budgets. There were three rounds of groupwork. The first focused on commenting on the proposed structures and the next two rounds focused on making suggestions for the further work on operational plans and on operational budgets, respectively. The second workshop had 27 participants, which beforehand had received a draft for the two guidelines for the tools. These were discussed and commented on in two rounds of groupwork.

The two case studies concerned the Copenhagen University Campus Service and a large Nordic developer and manager of rented out buildings. Each case study included two meetings concerning operational plans and operational budgets, respectively, as well as document studies. Both case organisations gave presentations at the first workshop, and both have managers with leading positions in DFM-benchmarking. All meetings were documented with minutes, which like the final case description were sent for acceptance by the case organizations.

The guidelines were sent for quality assessment by two consultants in a company with specialization in IT and in FM (the control group), and to representatives of an IT-provider of FM systems and the Danish Council for Sustainable Building (formerly Green Building Council Denmark) for testing and assessment. The council is responsible for the German building certification system DGNB in a Danish version: DGNB-

DK. The two consultants gave their preliminary assessments and the representatives from the IT company gave their assessment at the second workshop.

The preliminary results were presented at DFM's annual conference on 1st June 2023, and the final results were launched at an event on 11th October 2023 held at the main banquet hall of the Copenhagen University with approx. 70 participants. At the event the project group presented the guidelines, and the two consultants and the representative from the Danish Council for Sustainable Building presented their evaluation of the usefulness of them. In the discussion and conclusion sections of this paper the assessments are summarized. The final guidelines and templates provide a concept for operational plans and budgets, which can be adapted to specific company contexts.

OPERATIONAL PLANS

An operational plan is here understood as a plan for the coming year's activities in a FM organisation. Therefore, it is not operational in the narrow sense as ongoing routine activities, but it also includes for instance property investments, change and development projects, and covers activities on strategic, tactical, and operational levels. The content in an operational plan can vary dependent on the company and the responsibilities of the FM organisation. The template for operational plans attempts to make a gross list of all FM activities, but the plan can be adapted to suit individual organisations by adding, moving, and changing activities. Table 1 shows all the columns in the Excel sheet, while Appendix A shows an excerpt from the Excel sheet with many rows but only the first two columns.

Table 1 Columns in the Excel sheet for operational plans

Operational plan				
Main group/sub-group	**Activity**	**When/frequency**	**Responsible**	**Comment**
1. Property operation				
1.0 General	Property operation management	Ongoing	Head of operation	Management of activities concerning property operation

Activity is a brief description of a topic that can be the subject of an operational plan. When/frequency indicates a proposal for the time of the activity execution. This can be ongoing, at regular intervals or as needed, e.g. at special events. For multi-year, long-term plans, a frequency of 4 years is suggested. Responsible is a proposal for the function responsible for preparing and executing the operational plan for a given activity. Comment can be a more detailed description of the activity.

Example of FM plans

The case of Copenhagen University's Campus Service (CAS) included their FM plans on strategic, tactical and operational levels as shown in Figure 1. The plans are divided in Master plan and Campus plans on strategic level. Maintenance plans for larger projects (budget over 300.000 DKK) are at the tactical level and managed in collaboration between the central CAS organization and the decentral operational units called CSO. Operational plans undertaken solely by the CSOs are at both tactical and operational level, and the CSOs are also responsible for operational tasks at operational level, while maintenance tasks on operational level are managed jointly.

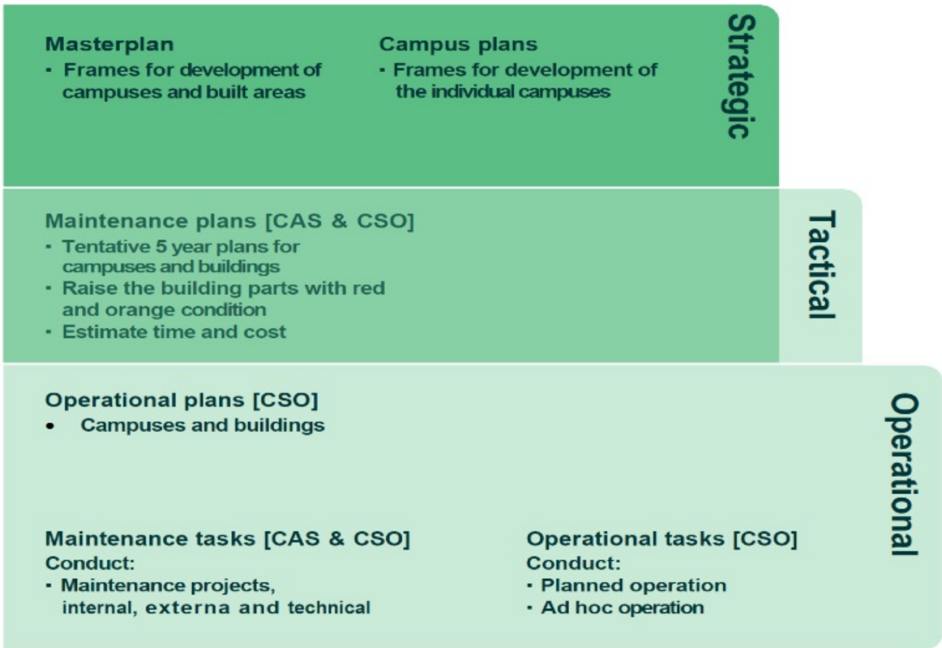

Figure 1 Plans on strategic, tactical, and operational level in Copenhagen University's Campus Service

Preparing an operational plan

For activities where detailed operational activities are needed, plans can be prepared by answering a series of questions:

1. Purpose of the activity: What is to be achieved? What are the requirements for the result? What are the success criteria?
2. Scope of the activity: Which activities and sub-activities are included?
3. The company's sustainability goals: What role does the activity have in relation to the company's sustainability profile, and its development? Are there concrete sustainability goals for the activity?
4. Stakeholders: Who will benefit from the activity and who are other stakeholders. Should some of these be included in the planning, informed/involved during implementation, and/or give feedback afterwards?
5. Location: At which locations and in which buildings will the activity take place? For which facilities and assets (building parts) must the activity be carried out.
6. Procedure: How should the activity be carried out?
7. Implementation: How should the activity be organized and staffed, and who is responsible for the various sub-activities?
8. Resources: Which physical and digital tools and which other resources should be used?
9. Time: What is the timeTable for the activity and the different sub-activities?

10. Finance: What is the budget for the activity and how should it be distributed among sub-activities?
11. Evaluation? Which methods must be used, who carries it out and who must be involved in evaluating the result and meeting success criteria?

Tips for using the template for operational plans

1. *The FM management should make a strategic announcement.* At the start of the preparation of an operational plan for the coming year, the FM management should announce the assumptions and framework on which the planning must be based. They should also define two to three Critical Success Factors, which must reflect the company's strategy, and can be measured by KPIs.
2. *Make a schedule for preparing the operational plan and budget.* Prior to the preparation of an operational plan and budget, a schedule for the process should be prepared, as these plans are mutually dependent. Attention must be paid to the fact that for some activities it is necessary to prepare a detailed operational plan to be able to draw up a budget The schedule must be coordinated with the company's annual wheel.
3. *Prepare the operating plan.*Prepare the operational plan by use of the template and answering the questions. It might be relevant to carry out a risk assessment and possibly allocate reserve funds in the budget.
4. *Ensure adequate management and follow-up of operational planning*. During planning, the FM management must ensure continuous monitoring and management of the process and ensure an appropriate decision-making process for the individual operational plans, including the involvement of relevant stakeholders.
5. *Prioritize.* When a preliminary operational plan and budget have been drawn up, a prioritization must be made between the various activities, so that the total budget remains within the established framework. Alternatively, negotiations must be made with the company's management as to whether changes can be made to the framework, and it might be necessary to involve other stakeholders.
6. *Register operating plans and operating budgets in the FM system*. The approved operational plan and associated budget are entered into the FM organization's IT system, and a plan is established for follow-up with relevant milestones etc.
7. *FM year wheel with reassessment and possibly updating the operational plan and budgets.* Deviations and reports are reviewed with appropriate frequencies. Is there documentation for proper and regular operation? Is there a basis for changing the frequency of various activities, or otherwise adjusting the plan and budget. Changes are communicated to relevant stakeholders.

OPERATIONAL BUDGETS AND ACCOUNTS

A budget is an overview of expected income and expenses for a period, e.g. the coming year or for a project. The core of a budget is an account plan, which is a list of accounts to be used for financial administration and management. Accounts have a name and a number. They are often made with a hierarchical structure, so that an overview can be created by aggregating amounts from underlying accounts. In the guideline, the term 'sub-groups' is used for the specific accounts, while main groups are used for aggregated accounts.

Budgeting is done for the individual accounts, and these are subsequently used for posting and accounting. This is typically part of a circular process, e.g. a year wheel for a company or for a project. When accounting, some characteristics (control dimensions) are specified for each posting, to be able to register the amounts as desired in the accounts. It will typically be in types (operating costs, wages, facilities, etc.) and place (organizationally on grant holders). For FM, location is essential (property, building, etc.) and for maintenance also building part (terrain, external building, internal building, building installation, fixtures/equipment) and method (remedial, preventive, corrective). Who can make postings is controlled by rights for employees in the financial system.

The legal and regulatory requirements for accounts are increasing, with requirements for, among other things, ESG reporting (environment, social, governance) in the EU. However, there are generally few requirements for organizations' annual accounts regarding FM. This leads to a common practice of using only few account numbers for posting FM operational expenses, possibly only for consumption such as electricity, heat, water, and waste as well as other FM expenses such as property management, maintenance, services, etc. Too few accounts hamper activity-based financial management, while too many accounts make accounting difficult and can lead to incorrect accounting.

Budgets are forward-looking estimates of expenses and income, while accounts are backward-looking and reflect the realized expenses and income. For making annual accounts the overall structure common with operational plans has been supplemented with two other main groups and sub-groups for assets and reliabilities (equity and debt items) for the balance sheet. This is typically drawn up at the company level and the FM organization contributes input on assets (property, equipment), and other values and liabilities.

The operational budget includes the annual expenses and any income in connection with property administration and building operation (OPEX – Operational expenses). However, it is also recommended to include investments (CAPEX - Capital expenses), so that the budget can be used for overall financial management and for Life Cycle Costing. Table 2 shows all the columns in the Excel sheet except the last for Comments.

Table 2 Columns in the Excel sheet for operational budget and account

Operational budget and account						
Main group/sub-group	**Sub-division (Optional)**	**Opex (DKK)**	**Opex (DKK/m²)**	**Capex (DKK)**	**Capex (DKK/m²)**	**CO_2 (ton)**
Property operation						

The accounts (sub-groups) in the Excel-sheets are intended as a checklist that can be adapted to the specific FM organisation by removing some and adding or changing others as needed. In addition, subaccounts can be added as needed in the second column. In the Excel-sheet there are columns for both OPEX and CAPEX in DKK and DKK/m^2, and there are also columns for CO_2 calculated as ton and kg/m^2. In the Copenhagen University's Campus Service case presented briefly in the former section maintenance projects with a budget over 300,000 DKK are seen as CAPEX, while maintenance activities with a lower budget are seen as OPEX.

Preparing an operational budget

The preparation of operational budgets in companies typically takes place as a combination of a top-down and a bottom-up process, possibly with several iterations as part of the company's financial year wheel. Initiation of the budgeting for the coming year typically begins with a top management announcement in the middle of the current year, where the framework for the coming year's budget is laid out. It can, for example, include announcements about which business areas are expected to expand and which are expected to be reduced, whether there are plans to establish new and/or liquidating existing business areas, in which areas there are opportunities for budget increases, and where savings are to be made. At the same time, expectation for the price development in the coming year is announced. Within this framework, the individual departments and business areas prepare their proposed budget, which is put up for consideration by the company's top management – possibly several times until an approved budget is reached.

For the individual departments, incl. the FM organisation, the budget proposal is prepared based on:

Current year's budget
Realized of the current year's budget, e.g. in the middle of the year
Expected price development for the coming year announced by the company's top management
Top Management announcement about budget expectations for the coming year
Collected budget proposals and input from various data sources
FM management's budget forecasts for the coming year

The relevant data sources can be:

Operational managers for the various parts of the FM organization
Suppliers and utility companies
Company management's plans for specific activities and intervention areas
FM management's plans for new initiatives/decisions
The financial function
Construction projects

Tips for using the template for operational budgets

1. *Clarify whether it is advantageous and possible to switch to the new operational budget?* Conduct an evaluation of the FM part of your existing financial system with a focus on structure, account plan and functionality for use in FM. What are the strengths and weaknesses, and in which areas is there a need for improvement?

2. *Can the new operational budget meet your needs?* Compare your budgeting system in the FM part of your existing financial system with the new proposal for operational budget. Investigate whether the new operational budget with adjustments can meet your needs for use in FM.
3. *Can the existing financial system be adapted to the new operational budget?* Investigate whether the FM part of your existing financial system and account plan can be changed so that the new operational budget with adjustments can be implemented. If this is not the case, then it should be considered whether a new FM part can be developed in the financial system. If the company is in the process of introducing a new financial system, consideration should be given to implementing the new operational budget.
4. *Adapt the new operational budget to your FM organization.* Conduct a thorough assessment of your needs and an adaptation of the new operational budget. Remove redundant accounts and add new ones. Examine whether the operational budget's account plan is appropriate in relation to your FM organization and flexible and robust in relation to organizational changes. Pay particular attention to overlapping entries for sustainability and adjust these to match your organization.
5. *Implement the new operational budget.* When implementing the new operational budget – regardless of whether it is in an existing or new FM part – you must ensure that there is the necessary flexibility, so that the account plan can be adjusted in relation to changing needs.
6. *Make a schedule for drawing up operational plan, budget, and accounting.* See tip 2 for Operational plan.
7. *Prepare the budget.* For the budgeting process see the former sub-section. In connection with budgeting, particularly of large items including new initiatives and investments, it may be relevant to carry out a risk assessment and possibly set aside reserve funds.
8. *Prioritize.* When a preliminary operational plan and a preliminary operational budget have been drawn up, a prioritization must be made between the various activities, so that the total budget stays within the established framework, or negotiations must be carried out with the company's management, whether changes can be made to the framework. The prioritization of major projects and initiatives must probably go through a decision-making process with other stakeholders as well.
9. *Enter operational plans and budget into FM system.* The approved operational plan and the associated budget are entered into the FM organization's IT system, and a plan is established for follow-up with relevant milestones etc.

DISCUSSION

The external assessments of the tools and guidelines by the two consultants were, that there is a great need for the tools and that they can help to improve the current challenges. There exists a lot of confusion about account plans and accounting, and the plans are seldom similar and often changed. The same type of expenses is often allocated by different people to different accounts. The quality is low because garbage in results in garbage out! Quality is more important than quantity. The tools and guidelines can lead to more relevant and streamlined accounts with more comparable data for benchmarking and more efficient reporting. The representatives from the IT provider and the Danish Council for Sustainability Building confirmed that the tools could be used in in their FM-system and in DGNB-DK, respectively.

Operational plans, budgets, and accounts cannot in themselves lead to more sustainability, but they are necessary prerequisites to work professionally with FM as part of a general administrative and managerial infrastructure. That is why this project is part of DFM's program "Foundation for digital and sustainable FM", and it should be seen and used together with the results from the other projects. A solid foundation does neither ensure sustainable FM, but it can be made, so it is suitable for use by digital systems and together they can make sustainability actions more efficient and effective. It requires an appropriate sustainability and digitalisation strategy for both the company and for FM, leadership from all management levels, competent employees, and manageable facilities.

It is not obvious how one should handle sustainability activities in operational plans, budgets, and accounts for FM. Ideally such activities should be integrated in all FM actions. However, it is also important to make sustainability activities visible, so they can be measured and managed. What we did in the common overall structure was to include several sub-groups specifically related to sustainability: *1.7 Maintenance, sustainability; 1.10 Utilities, energy savings; 1.11 Utilities, own energy production; 1.13 Utilities, water savings; 1.15 Utilities, waste reductions; 1.19 Cleaning, sustainability; 4.7 Sustainability improvements; 5.11 Sustainability/energy and environment.*

A short explanation for each is included in the Excel sheets. In budgets and accounts these are dedicated to specific sustainability activities. Most of these sub-groups are in the main group 1. Property operation. Sub-group 4.7 is in main group 4. Changes and interior design, and 5.11 is in main group 5. Management, planning, and administration. In the operational plan the last two sub-groups include several activities shown in Table 3.

Table 3 Operational plans in sub-group 4.7 and 5.11

4.7 Sustainability improvements	5.11 Sustainability/energy and environment
Renewable energy	Energy management
Energy saving	Environmental management
CO2-reduction	Certification
Climate adaptation	Sustainability reporting
Indoor climate improvement	

Renewable energy in sub-group 4.7 is meant for establishing renewable energy systems, while 1.11 Utilities, own energy production, is meant for operation of existing energy production systems, including renewable energy systems. We also considered, whether we in connection to sub-group 1.9 Utilities, electricity, could include savings from own renewable energy production, but that is not possible in a budget and accounting system, but it should be made visible in other ways, for instance in sustainability reporting included in sub-group 5.11, see Table 3.

Furthermore, in the operational plan there is for each main group a general activity called Sustainability initiatives, for instance under 1.1 General, see Appendix A. This is meant as a planning and coordination activity for initiatives to be implemented with integration in other activities in the main group in question. A comprehensive overview of activities and associated costs is an essential basis for a professional FM organisation striving to improve their practices in terms of sustainability and digitalisation. The two guidelines developed by researchers and practitioners are generic and can be adapted to specific contexts. A main challenge of using the checklists in the Excel sheets, see Appendix A, might be the required competences to translate the generic terminology to the local context, as each FM-organisation might be using different terminologies. With these measures, we have tried to make the operational plans, budgets, and accounts suitable to make sustainability activities visible and thereby more measurable and manageable. Whether we are successful in this endeavour only Danish FM practice and time can tell. We hope this paper can be of inspiration for FM-professionals in other countries in their sustainability efforts.

CONCLUSIONS

The operational plans and budgets presented in this paper aim to provide tools and guidelines to address a need among practitioners to improve their FM activities by creating better overview and be able to work in a more systematic way with environmental sustainability. The external assessments made of the tools confirm this need and that the tools and guidelines are useful to fulfil the need. The project is part of a program to create a foundation for digital and sustainable FM. This project only concerns sustainability and not digitalization, so the tools and guidelines should be used in combination with the results of the other projects. However, a foundation is only a prerequisite to support a digital and sustainable development of FM. It also requires an appropriate sustainability and digitalisation strategy for both the company and for FM, leadership from all management levels, competent employees, and manageable facilities. Although the tools and guidelines have been tested and assessed externally by specialised consultants, IT-providers, and a DGNB-DK certification agent, it still needs to be shown whether and how much the tools will be implemented in practice. The program for developing a foundation for digital and sustainable FM is still ongoing. We expect to present results of the whole program when it is finished in 2025.

ACKNOWLEDGEMENTS

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APPENDIX A Excerpt of template for Operational plan

Operational plan		Operational plan	
Main group /sub-group	**Activity**	**Main group /sub-group**	**Activity**
1. Property operation			Service contracts
1.0 General	Property operation management	1.17 Cleaning, external	Control and payment
	Operational policy and strategy		Quality assurance
	Sustainability initiatives		Adjust delivery
	Continuous/retro-commissioning		Reassess delivery
1.1 Maintenance, general	Condition assessment, thorough	1.18 Cleaning, internal	Control and payment
	Follow-up on condition assessment		Quality assurance
	Long-term maintenance plan		Adjust delivery
	Follow-up on maintenance plan		Reassess delivery
1.2 Maintenance, ground	Corrective	1.19 Cleaning, sustainability	Sustainability initiatives
	Plan preventive	1.20 Depreciations	Assess and decide
	Complete preventive projects	1.21 Submissions	Plan and decide
	Plan replacements	**2. Support services**	
	Complete replacement projects	2.0 General	Support service management
1.3 Maintenance, building, external	Corrective		Define and revise SLA's
	Plan preventive		Sustainability initiatives
	Complete preventive projects	2.1 Guarding and security	Guarding
	Plan replacements		Accces control/security monitoring
	Complete replacement projects		Gate control of vehicles and parking
1.4 Maintenance, building, internal	Corrective	2.2 Catering	Canteen
	Plan preventive		Coffee and the
	Complete preventive projects		Meeting and events
	Plan replacements		Food procurement
	Complete replacement projects		Food waste
1.5 Maintenance, installations	Corrective	2.3 Office support/ internal service	Reception
	Plan preventive		Call center
	Complete preventive projects		Office supplies
	Plan replacements		Post
	Complete replacement projects		Documents
1.6 Maintenance, furniture and equip	Adjust, repair, store and discard		Printing and copying
1.7 Maintenance, sustainability	Sustainability initiatives		Information Technology
1.8 Utilities, heating	Control and payment		Removal
	Reassess heating system		Handyman
	Adjust heating system	2.4 Other services	Administrative support
1.9 Utilities, electricity	Control and payment		Procurement and storage
	Reassess delivery		Transportation and vehicles
	Reassess electricity system		Staff support
	Adjust electricity system		Workwear

1.10 Utilities, energy savings	Sustainability initiatives		Plants
1.11 Utilities, own energy production	Operation		Recovery
1.12 Utilities, water and drainage	Control and payment	2.5 Depreciations	Assess and decide
	Reassess water and drain system	2.6 Submissions	Plan and decide
	Adjust water and drain system	**3. Property and tenancies**	
1.13 Utilities, water savings	Sustainability initiatives	3.0 General	Property management
1.14 Utilities, renovation/pest ctr.	Control and payment		Property policy and strategy
	Reassess delivery		Sustainability initiatives
	Reassess renovation and pest ctr.	3.1 Property investments	Portfolio plan
	Adjust renovation and pest control		Follow-up on portfolio plan
1.15 Utilities, waste reduction	Sustainability initiatives		Acquisition of property
1.16 Daily technical operation	Caretaking, control and monitoring		Control and payment of loans
	Operational assets/consumables		Assess financing
	Legally required tasks and other	3.2 Property taxes	Control and payment

Time-Benefit Analysis of Semiautomatic 3D Laser Scanning for BIM-based Facility Management

Barthel, T., Becker, P. J., & Wills, N.

University of Applied Sciences Mittelhessen, Department of Business and Engineering – Real Estate
Contact: Nadine.wills@wi.thm.de

ABSTRACT

Background and Aim. As-built data and knowledge of building structures are crucial for effective facility management (FM). Building Information Modeling (BIM) models offer the opportunity to integrate information from digital building models into FM systems, without information loss. Data acquisition methods include 3D modeling and point cloud-based 3D laser scanning. While modeling point clouds in BIM software manual can achieve precise results, the process is time-intensive. Semi-automated modeling that relies on AI-based software can contribute to as-built data acquisition and modeling with reduced time and personnel requirements, known as semi-automated. Therefore, this paper aims to investigate the efficiency and limitations of integrating AI with BIM for FM, comparing manual and semi-automatic modeling approaches.

Methodology. Manual modeling based on point clouds is conducted before a semi-automatic classification is performed. The generated data models are then quantitatively evaluated for the required time for each measurement size and qualitatively evaluated concerning the accuracy.

Results. The analysis illustrates that semi-automated modeling methods are particularly efficient for standardized and even historical buildings by a 65% faster data generation than manual building modeling. The results are proven by valid data.

Originality. The investigation compares manual and semi-automatic modeling approaches. Evaluating time requirements and qualitative criteria provides a practical framework for decision-makers.

Practical Implications. The study offers insights for decision-makers in FM and related fields to make informed decision-making about modeling methods, contributing to process optimization by integrating modern technologies. Based on the results obtained, stakeholders receive a neutral approach backed up by valid key figures, providing a solid basis for future decisions in connection with data collection.

Type of paper. Technical

Keywords. As-built data acquisition, AI-based building modeling FM, cost-benefit analysis, new technologies, 3D laser scanner

INTRODUCTION

Facility Management (FM) operates at the crossroads of several disciplines within the real estate sector, encompassing tasks in the infrastructural (such as catering, cleaning, or gardening), technical (such as repair and maintenance), and commercial sector (such as contract management or budgeting) (GEFMA e.V. Deutscher Verband für Facility Management, 2004). The execution of these tasks is referred to as facility services (FS). It requires various data to carry out and maintain the multidisciplinary activities of all building life cycle phases as part of its integrated processes (Gouda Mohamed et al., 2020; Wildenauer et al., 2022; Wills & Bartels, 2022). The demand for data in FM has become increasingly important in the era of digital transformation, where the real estate sector is undergoing a paradigm shift with essential roles played by the Internet of Things (IoT), Building Information Modeling (BIM), Building Automation Systems (BAS), and Artificial Intelligence (AI) (Atta & Talamo, 2020). Digitalization has become critical in enhancing operational efficiency and data-driven strategies, and BIM has become a crucial tool in the FM sector especially. By creating, storing, and exchanging data in a digital form, BIM represents buildings and elements, enabling a holistic view of their life cycle and a collaborative way of working (Boje et al., 2020). Moreover, building information models allow the transfer of semantic information from the model to selected building operation systems, such as Computer-Aided Facility Management (CAFM) systems, without information loss (Bender et al., 2018). Nevertheless, the use of BIM in FM is limited to less than 1 % of all new and existing buildings in the international context (GEFMA e.V. Deutscher Verband für Facility Management, 2019), whereby the advantages of BIM are most apparent during the planning and construction phases of new buildings.

In contrast, the existing built environment poses a challenge, with many as-built structures and data that are not yet available in digital form, requiring attention for effective FM processes. Even though a valid statement about non-digitalized existing areas in Germany (and consequently, lack of digitally available data) cannot be made due to a lack of data foundation, there are approximately 7.27 billion square meters of existing space (approximately 3.84 billion square meters of residential and 3.5 billion square meters of non-residential buildings) that are not (BIM-based) digitally planned and constructed, thus lacking a digital data basis (Hörner et al., 2022; Statistisches Bundesamt (Destatis), 2022). As mentioned, a digital representation of building geometry and characteristics not only forms the initial basis for the digitization of buildings but also serves as a data foundation for execution plans and FM (Bartels, 2020).

As Tezel and Giritli (2023) highlight, there has been a noTable emphasis on automatic methodologies of data generation such as two-dimensional (2D) imaging (Bhatla et al., 2012; Hong et al., 2020), photogrammetry (Braun & Borrmann, 2019; Xu & Stilla, 2021), or three-dimensional (3D) laser scanning (Hu et al., 2021). This trend departs from conventional approaches relying on visual inspection, and extensive manual data collection and document analysis. Among the various data types used in these advanced methods, 3D point clouds derived from laser scanning and multiview stereo vision have gained widespread acceptance and application across a variety of scenarios (Skrzypczak et al., 2022).
The manual process of converting raw data into usable data for FM is time-consuming and impractical, maily due to the subjectivity involved. Moreover, automated procedures can handle a substantial volume of data quickly, enhancing efficiency (Borisov et al., 2022). For instance, scan-to-BIM processes efficiently handle large volumes of data obtained from survey sources, including point clouds, by utilizing laser scanning or photogrammetry to capture data and then processing it through 3D modeling (Croce et al., 2023).

Various of software tools are available to support transforming point cloud data into BIM software, commonly known as semi-automatic modeling. While some software is independent of the manufacturer, others rely on the laser used for the scan process. Additionally, different software employs varying calculation methods, such as filtering, transformation, meshing, or classification (Gao et al., 2016). However, despite the advantages of semi-automatic processes in modeling point clouds in BIM, there is a lack of concrete evidence regarding time savings, and manufacturer specifications are often relied upon.

This study aims to investigate the efficiency and limitations of integrating an AI-supported model with BIM for facility management, comparing manual and semi-automatic modeling approaches. The paper is organized as follows: Section 2 provides information on different types of building modeling for facility management. Section 3 presents a case study illustrating the various steps involved in the reconstruction approach (methodology). Section 4 presents and discusses the results, while Section 5 concludes the study and identifies potential areas for future development.

BIM-BASED DATA GENERATION FOR FM IN EXISTING BUILDINGS

Traditional methods for acquiring (geometric) as-built data involve using tools like laser distance meters, digital cameras, and measuring tapes. In this approach, dimensions of building components such as walls, windows, and doors are manually measured and recorded. The process is labor-intensive, time-consuming, and error-prone field surveying work (Anil et al., 2011; Klein et al., 2012). Furthermore, as data sets are typically interpreted manually, they must be electronically integrated into the project design and schedule (Akinci et al., 2006). In addition to the mentioned instruments, trained personnel is required, capable of working with modeling software such as Autodesk Revit.

An industry-used method is the scan-to-BIM-procedure that concentrates on converting available survey data, such as point clouds, into BIM (Rocha et al., 2020; Volk et al., 2014). Scan-to-BIM processes exists of three steps as shown in Figure 1.

Figure 1 Process of scan-to-BIM (created by authors)

In a first step, data become captured through laser scanners using point clouds or photogrammetry (Croce et al., 2023). Point cloud generation using a LIDAR (Light Detection and Ranging) or LADAR (Laser Detection and Ranging) sensor describes a contactless Time of Flight (TOF) measurement technique. Fundamentally, a distinction is made between the direct and indirect TOF methods. In direct TOF sensor measurement, the elapsed time between sending a light pulse, its reflection, and its return to the sensor is measured. The elapsed time and the distance between the object and the sensor are proportional, allowing for mathematical determination of the distance. In the indirect TOF measurement technique, distance is determined through the phase shift of the reflected and transmitted light. In the next step, the generated data become processed, which means that semantic descriptions for the objects within the unstructured point clouds are added (Rocha et al., 2020). Point clouds are an aggregation of individual measurement points, each receiving X, Y, and Z coordinates. This multitude of points within a vector space collectively forms a spatial structure known as a point cloud (Che et al., 2019). Last, the 3D modeling takes place (Croce et al., 2023). Depending on the available resources, the scan-to-BIM modeling can occur either manually or semi-automatically.

Manual scan-to-BIM process

General approaches of scan-to-BIM primarily involve manual processes, requiring visual recognition and manual tracing (evaluation) of building components from a point cloud (Croce et al., 2023). The process of evaluating point clouds is done manually by visually aligning point clouds with the building components within CAD software. Individual points within point clouds can also be used as anchor points to fix the orientation line of building elements, ensuring that the point cloud and building component almost completely overlap in specific locations. The process is manual, as each anchor point of a building component is manually placed on the referenced point cloud. Distorted components in the existing structure must be accurately represented by the inserted 3D objects in the CAD software. The accuracy of the adaptation process of the 3D model to the referenced point cloud depends on the drafter and the predefined parameters that must be adhered to during modeling. As additional support for the alignment with the point cloud, the images captured by the 3D scanner can be used. The color and image data captured by the scanner can clarify any unclear technical relationships that cannot be derived from the point cloud. Several literature reviews, such as those by Volk et al. (2014), López et al. (2018), Logothetis et al. (2015), or Tang et al. (2010) prove that manual methods, while extensively established, result in time-consuming and labor-intensive processes. Responsible staff has to provide a manual identification, isolation, and reconstruction of each class of building elements, which requires time (Volk et al., 2014). Moreover, the process of manual modeling is subjective-oriented, as the result is based a) on the skills of the modeler and b) on the knowledge of the classification. Therefore, a risk of subjective decision-making within the classification exists (Xiong et al., 2013).

Semi-automatic scan-to-BIM process

In manual modeling, professionals typically remodel the individual points of a point cloud into components and classify them, which means that modeled building elements are assigned to a component class, such as walls, windows, or floors. The software partially classifies the point cloud imported into the CAD or BIM software in semi-automatic modeling. The term "semi" refers to the fact that the model is not entirely automatically created but that components must first be selected, and the software then provides a classification proposal. Core challenges in defining semi-automated methods lie in identifying and labeling data points on raw point clouds corresponding to specific building elements (e.g., windows, columns, walls, roofs) (Tang et al., 2010). Different strategies of semi-automatically scan-to-BIM process exist, such as primitive fitting methods, mesh-reconstruction methods, reconstruction by shape grammar and object libraries, or reconstruction by generative modeling (Croce et al., 2023). Primitive fitting methods use robust estimation of elementary parameters to fit basic geometries like planes, cylinders, and spheres to sets of points in the locations. Commercial solutions, such as “EdgeWise Building” by ClearEdge3D (clearedge3d.com) or “Scan-to-BIM Revit plug-in” by IMAGINiT Technologies (imaginit.com), utilize primitive fitting methods for semi-automatic recognition of walls, slabs, and pipes. Primarily applied in indoor environments (Jung et al., 2014; Previtali et al., 2014), these methods effectively detect building elements like floors and walls. However, shape extraction and BIM conversion are constrained to simple geometries with standardized dimensions, limiting their applicability to building structures with diverse forms and types (Macher et al., 2017).

Mesh-reconstruction methods involve reconstructing a mesh for each building component or group from the original point cloud using triangulation techniques. While 3D textured meshes can be converted into BIM objects, mesh manipulation, and geometric modification limitations exist, as the mesh models lack editability and parametric control (Yang et al., 2018). Reconstruction via shape grammar and object libraries involves creating 3D libraries of architectural elements (families) to handle the complexity of materials and components in historic architecture (Baik, 2017).

Last, reconstruction by generative modeling involves guiding reconstruction through formalizing architectural knowledge, using visual programming languages (VPLs) to program geometric manipulations interactively. Tools like Grasshopper (for Rhino3D) and Dynamo (a Revit plug-in) are standard for new buildings, whereas VPL is less used for as-built buildings (Croce et al., 2023). Automated (fully) modeling is not considered in this paper, as this method is still a challenge in the literature and has yet to be sufficiently scientifically tested (Jäkel et al., 2023). Reasons for this include the lack of publicly available training data sets of heterogeneous building elements and components that cover a variety of inventory scenarios (Schlenger et al., 2023).

RESEARCH METHODOLOGY

The integration of 3D laser scanners with AI-driven software in the real estate sector necessitates a thorough examination of their time-effectiveness. This evaluation is crucial for making informed decisions regarding optimal FM practices. The primary goal of this study is to assess the potential improvement in modeling efforts through the practical application of semi-automated classification in the modeling of as-built models using software. The methodological approach employed in this study is outlined in Figure 2.

Step 1: Generation of data

The initial preparatory step divided the data generation process into three sub-steps. The Faro Laser Scanner Focus 3D S was utilized to create point clouds. During an automated scanning step sequence, the scanner captures measurement points with a 300° vertical field of view and a 360° horizontal field of view. The scanner is equipped with a built-in optical emitter and a deflecting unit that can orient itself in any direction through a two-axis rotation. The scanner captures both black-and-white and color scans. Color scans capture exterior and facade scan points with an outer 4x recording profile. In contrast, black-and-white scans are used to conduct interior and confined space scans using the inner 4x profile. Scanning was conducted on 12 buildings in the Middle Hesse region of Germany, characterized as historical or existing structures built as half-timbered buildings. It is acknowledged that deformations in historical properties are inherent in the region of Middle Hesse, presenting novel challenges for surveying endeavors. This research extends beyond examining conventional warehouses or model homes typical of new construction. Instead, the focus lies on the assessment of urban properties currently vacant, which harbor considerable potential for conversion into valuable residential spaces.

In the next step, point clouds were developed by processing the scanned data using Autodesk ReCap® registration software. The software merges the individual scan positions to generate a structured point cloud with interconnected panoramic views. The point-to-point (P2P) distance of individual scans in Recap was set to 6mm by default. The scaling process involves automatic distance detection by the laser scanner, with a 1:1 scaling factor applied in Recap. Any ambiguity surrounding this process requires clarification. The data were consolidated and cleaned in the third substep to optimize the computational resources during processing and analysis. During the capture process, insignificant points and errors described as "ghosts" are identified alongside important distance points to the object and neighboring structures. Ghosts result from laser reflection off reflective surfaces, such as mirrors, glass, reflective coatings, and smooth surfaces, such as metals. Although ghosts can be reduced with matte sprays, they remain unavoidable in an efficient workflow. The Autodesk ReCap® functions select and remove specific point cloud areas in a three-dimensional space.

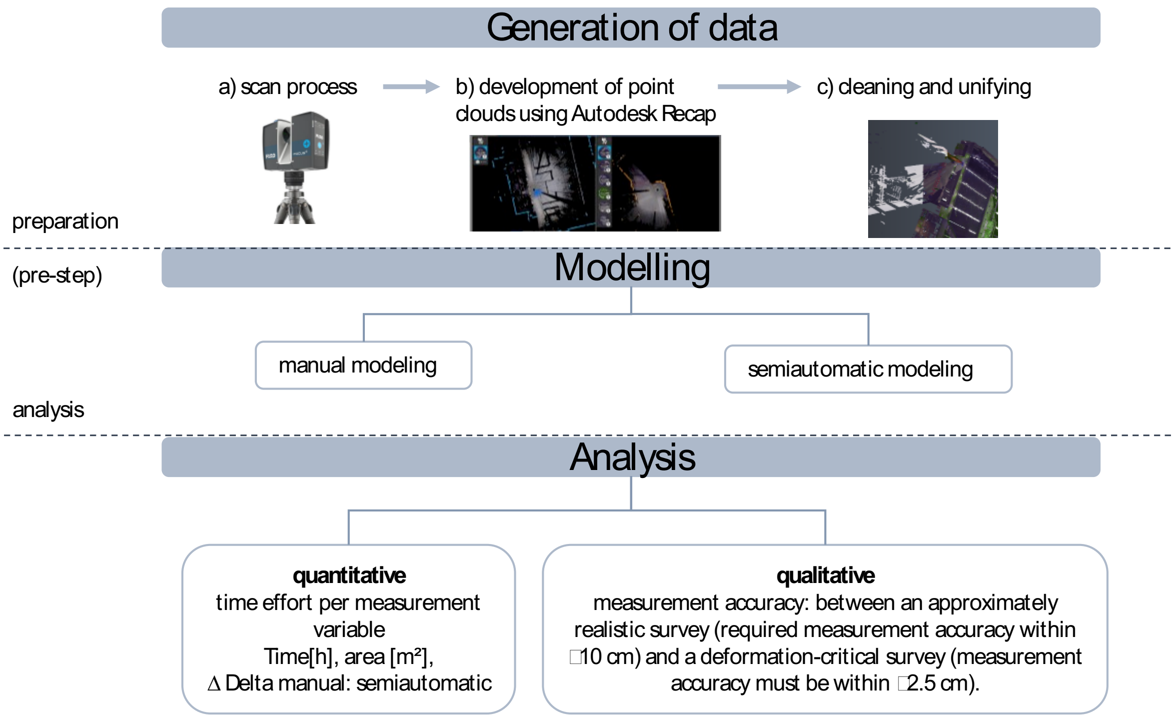

Figure 2 Methodical approach (created by authors)

Additionally, all points outside a small radius extending from the eaves of the buildings are removed, and mobile objects, such as people or cars, are excluded. The third step involves unifying. "Unifying" refers to the removal of point duplicates from the point cloud. This step reduces the data mass, points, and relative relationships between the individual scan positions. A single scan without duplicates was created from numerous individual scan positions connected through relative relationships and point or distance overlaps. It is important to note that this step is irreversible and occurs after processing.

Step 2: Modeling

The modeling process is divided into two sub-steps after generating the required data as a point cloud. In the first step, manual modeling is performed. Manual evaluation of point clouds is primarily conducted by visually aligning the point cloud imported into the CAD program with the utilized components. The individual points of the point cloud can also serve as anchor points to fix the orientation line of a component. This way, the point cloud and component coverage can be ensured at specific locations. Adapting a 3D model to a reference point cloud is performed manually. Each anchor point of a component is manually placed onto the point cloud, and the deformed components in the existing structure must be accurately represented by inserting 3D objects into CAD software. The images captured by the 3D scanner can further enhance alignment with the point cloud. The color and image data captured by the 3D scanner may clarify any unclear constructional relationships that cannot be deduced from the point cloud alone.

The generated point clouds were modeled in the second step using software to identify the efficiency of semi-automatic modeling compared to manual modeling, which involves the execution, compilation, and processing of the scan data, facilitated by software tools such as Recap. Subsequently, in Revit, the ability to filter point clouds by classes (layers) was utilized, and particular objects, such as walls, were automatically placed based on predefined criteria. According to the manufacturer, the software is an AI-based tool that accelerates scan-to-BIM by directly assigning BIM attributes to the point cloud of objects. The manufacturer promises time savings of 50%. The AI used in the software recognizes pipes and their fittings, trusses, stairways, furniture, walls, windows, doors, ceilings, and floors from point clouds. A specific manufacturer was deliberately not named to ensure a completely neutral and reliable database.

Step 3: Analysis

While conducting steps one and two, a quantitative and qualitative evaluation of the generated data models occurs. Therefore, the time taken for the scans and the manual and semi-automatic modeling processes were recorded, including all relevant time components, such as data preparation and modeling (quantitative analysis). The time hours are calculated per person; e.g., if five individuals work for one hour each, five hours are recorded. Two individuals were involved in these calculations. For qualitative analysis, the models generated in the semi-automated process were analyzed concerning the quality and usability for further use in FM by considering the measurement accuracy. Tolerances are defined between +-2.5 cm and +-10 cm, aligning with Level of Detail 100 and LOD 200. Finally, the data were compared.

RESULTS

The total gross floor area of the 12 scanned buildings was 3,495m², with the smallest building covering 140 m² and the largest building spanning 800m². The scanned data volume amounts to a total of 74.15 GB. Processing the data in Autodesk Recap into point clouds increased the data volume to 202.6 GB. The scanning effort for all buildings was 129.5 hours, with individual buildings requiring between seven and 28.5 hours, reflecting the heterogeneity of objects, construction states, and accessibility. Figure 3 shows two outward scan views of one of the buildings, with the left view yet to be classified and the right view already classified.

Point clouds were imported into Autodesk Revit for manual modeling and subsequently modeled iteratively, starting with different levels, walls, stairs, windows, doors, and furniture. The manual modeling efforts for scanned buildings varied across different constructions, reflecting the diversity of objects, construction states, and accessibility. The time spent on manual modeling ranged from 15 hours for a building with a construction area of 150 m² to 95 hours for a larger building covering 800 m². On average, the manual modeling effort was approximately 103.7 m²/h. All buildings' total manual modeling effort amounted to 413.5 hours, covering a gross floor area of 3,495 m².

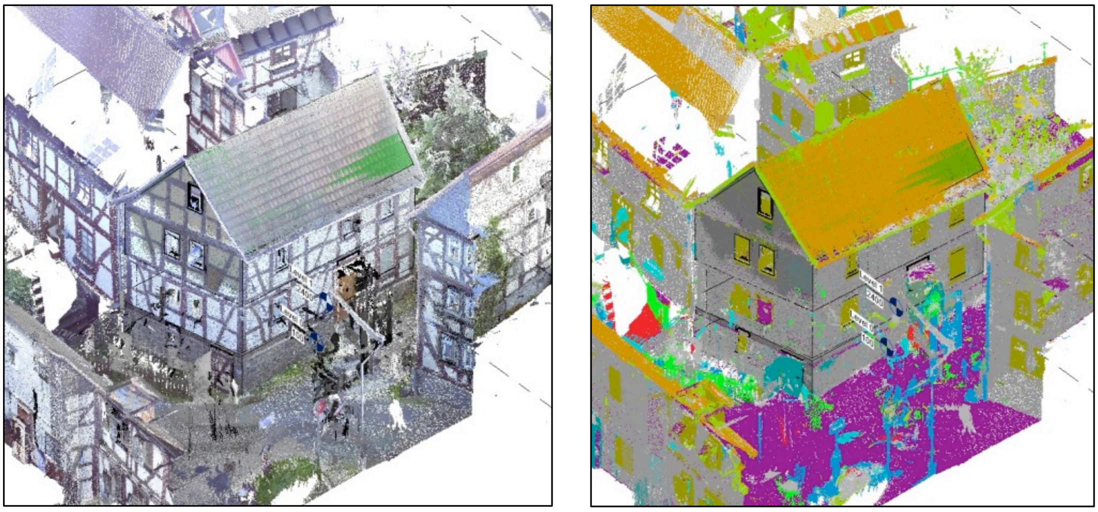

Figure 3 Exterior views – unclassified and classified scan views of building (created by authors)

The semi-automatic modeling process involved selecting different objects within the point clouds of the buildings, which were then classified by the software. The effort required for semi-automatic modeling varied, taking nine hours for a building with a construction area of 150 m² and approximately 61 hours for a building that covers 800m². The total semi-automatic modeling effort was approximately 252.85 hours. Despite the software's occasional incorrect suggestions, building components such as windows, walls, ceilings, furniture, and stairs were easily classified in the interior. Figure 4 provides a visual representation of the semi-automatic modeling process, illustrating the work within the software and an example of incorrect classification.

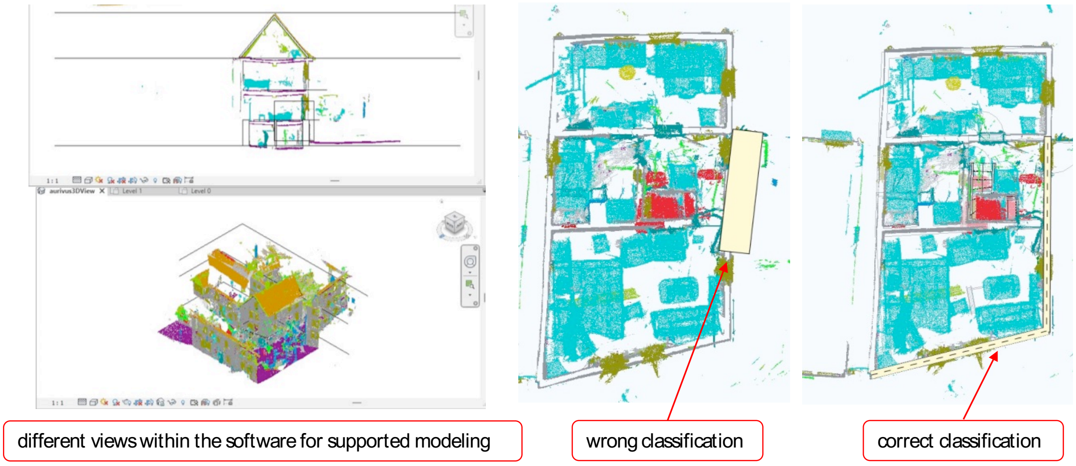

Figure 4 Semi-automatic modeling process and classification error example (created by authors)

Regarding the quality of semi-automatic modeling, it can be stated that the measurement data exhibits an accuracy of ± 3.8 cm, falling between an approximately realistic survey (required measurement accuracy within ±10 cm) and a deformation-critical survey (measurement and representation accuracy must be within ±2.5 cm).

The results of the comparison analysis are summarized in Table 1, which shows the key metrics for each scanning session. The data volume is presented in gigabytes (GB) for each relevant category, including scans and Recap project files. Additionally, the scan and manual efforts are provided in hours for a comprehensive overview of the resources invested in each scanning session.

Table 1 Data generation and time efforts comparison for Scan-to-BIM process

	Data generation					Time efforts						
	Object ID	Scans	Data Volumes		Time	manual			semiautomatic		comparison	
	Serial-ID	scan-positions	scans [GB]	Recap Project [GB]	scan effort [h]	manual effort [h]	gross floor area	m²/h manual	semi-automatic effort [h]	m²/h semi-automatic	∆ Delta manual:semi-automatic	semiautomatic /manual [%]
Project	P-9	80	6	15.1	15	45	370	8.22	26.625	13.897	-5.674	169.01%
	P-2	138	8.2	25.4	8	36	470	13.06	20.882	22.508	-9.452	172.40%
	P-5	68	7.7	21.2	17	54	350	6.48	32.841	10.658	-4.176	164.43%
	P-6	212	17.9	47.2	28.5	95	800	8.42	61.720	12.962	-4.541	153.92%
	P-7	82	5.1	13.2	9	22.5	186	8.27	13.313	13.972	-5.705	169.01%
	P-A	62	5	11.3	7	25	250	10.00	15.250	16.393	-6.393	163.93%
	P-B	56	3.3	9.2	8	30	200	6.67	17.750	11.268	-4.601	169.01%
	P-C	66	2.8	10.9	5	19.5	140	7.18	12.000	11.667	-4.487	162.50%
	P-D	96	3.8	15.3	6	18.5	197	10.65	11.250	17.511	-6.862	164.44%
	P-13	75	5.9	19	11	23	200	8.70	14.284	14.002	-5.306	161.02%
	P-E	36	2.45	5.8	7	15	150	10.00	9.000	16.667	-6.667	166.67%
	P-4	40	6	9	8	30	182	6.07	17.936	10.147	-4.080	167.26%
∑			74.15	202.6	130	413.5	3495		252.8502		-67.94595775	165.30%

As can be seen from the Table, the required times for semi-automatic modeling were lower than those for manual modeling. The time savings range between four hours (project P-4) and 9.5 hours (project P-2), depending on the size and complexity of the buildings. The average savings amount to approximately 65.3%.

DISCUSSION OF THE RESULTS

The productivity rates, calculated in terms of square meters processed per hour, reveal striking differences between manual and semi-automatic methodologies. For instance, project P-2 demonstrated a 172.40% efficiency increase when employing semi-automatic techniques, underlining the potential for significant time savings. Despite variations in project characteristics, the overall trend indicates a consistent advantage in favor of semi-automatic methods. The average efficiency rate for semi-automatic processes is 165.30%, showcasing the potential for streamlining scan-to-BIM workflows. The delta values underscore the difference between manual and semi-automatic efforts. The ratio between semi-automatic and manual efficiencies further accentuates performance disparities.

The software manufacturer mentioned that semi-automatic modeling makes 50% of the time savings possible. The study shows that semi-automatic classification modeling enables modeling of 60 % to 70% more square meters per unit of time. However, the nuanced interplay of project-specific factors may contribute to occasional instances in which manual methods exhibit comparable or superior performance. It is essential to understand that while AI saves time using semi-automatic modeling software, it is not the only factor. The time saved is also due to the simplified process for the modeler, who benefits from the automatic component classification. The subjective factors mentioned at the beginning of this paper, which influence modeling, remain present even in the case of semi-automatic modeling by executing personnel. Moreover, it should be noted that the buildings in this study did not involve sensitive data, so no special requirements were placed on the data security of the software used. However, protecting sensitive project data and intellectual property must be considered when using semi-automated modeling software from FM stakeholders, which includes compliance with data protection regulations and implementing robust security measures.

CONCLUSIONS

This study explores the intersection of FM and digital transformation by integrating AI with BIM for efficient scan-to-BIM processes. The study assesses the potential improvements and limitations of AI-driven BIM in FM by comparing manual and semi-automatic modeling approaches. Because there are extensive volumes of non-digitally documented as-built areas, artificial intelligence methods for data capture are viable solutions. While the literature often emphasizes the qualitative aspects of data generation techniques, the industry frequently mentions potential time savings that still need to be validated scientifically. This study implemented a three-stage potential savings process to provide a substantiated estimation of the actual time saved through semi-automatic modeling methods (incorporating AI in their software). The existing buildings were first scanned, followed by manual and semi-automatic modeling. Qualitative analysis revealed that applying semi-automatic modeling methods saves time, enabling the modeling of approximately 65% more square meters per hour. Furthermore, the semi-automatic approach meets the qualitative requirements of the FM. The semi-automatic modeling approach provides a simplified and time-resource-saving method for stakeholders in FM to capture existing data. However, semi-automatic modeling represents only an initial milestone. Future research should focus on enabling fully automated modeling using training datasets and machine learning. In the case of non-standardized structures and historical buildings, many training datasets may be necessary for this purpose. Furthermore, the modeled data consisted only of geometric information. In BIM models, details regarding building elements, known as Property Sets, must still be manually supplemented. This study has limitations in that it only examines purely geometric data capture without addressing the assignment of properties to individual building elements. The next step should investigate the amount of additional time required to assign properties to the modeled building elements. Moreover, this study aimed to examine the time components of manual and semi-automatic modeling. Monetary aspects, such as the costs of software or personnel, were not considered in this analysis, but this should be examined in detail in an additional case study.

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Big Data Analytics in Facilities Management Higher Education: A Way Forward

Sumanarathna, N.[1], Dahanayake, K. C.[2], & Adhikari, A.[3]

[1] School of the Built Environment, London Metropolitan University
[2] AGFS Consultancy LLC, Dubai
[3] School of Applied Management, University of Westminster
Contact: n.sumanarathna@londonmet.ac.uk

ABSTRACT

Background and aim. In this digital era, the facilities management (FM) industry tends to apply Big Data analytics (BDA), employing machine learning for functions such as predictive maintenance, energy management and workplace management. Therefore, it is essential to discuss the digital transformation of facilities management higher education (FMHE) and the requirements for FMHE to be future-proof. This paper aims to explore the extent to which BDA is applied in FM and how it is manifested within FMHE.

Methods. This viewpoint paper is developed based on the industry, academic and research experience of the authors. Prior literature findings are also incorporated to develop and support the views regarding the application of BDA in the industry and its representation in FMHE.

Results. Based on the experiential learning perspective, recommendations for BDA-related teaching and learning in FMHE are delivered.

Originality. This study addresses the potential gaps between the FM industry and higher education by discussing the advanced approaches which have not yet been extensively recognised in FMHE. Hence, this paper contributes to developing new FM capabilities among students within the context of digital transformation in FM.

Practical or social implications. The recommendations derived from the experiential learning perspective add depth to the discussion, offering suggestions for understanding and advancing FMHE. This study can also serve as a guide for conducting future research in this area.

Type of paper. Viewpoint

Keywords. big data analytics, digital transformation, facilities management, higher education

INTRODUCTION

Like every other industry, Facilities Management (FM) has also been affected by recent digital tendencies or digital transformation. Due to technological advancement, managing the building life cycle has become more efficient and straightforward. Facilities operate with enormous amounts of data throughout their life cycle. Thus, big data analytics (BDA) offers significant opportunities to enhance FM processes (Ahmed et al., 2017; Yang & Bayapu, 2020). FM tasks, such as predictive maintenance, energy management and workplace management has have been enhanced due to BDA techniques (Ahmed et al., 2017; Yang & Bayapu, 2020). For instance, Big Data gathered from sensors and Internet of things (IoT) devices, Building management Systems (BMS), computer Aided Facilities Management (CAFM) Systems and smart devices are taken to develop machine learning (ML) models and predictive analytics.

These ML models and algorithms can predict the maintenance regimes, spatial requirements, and energy requirements of the building, which enables reducing wastage and conforms to sustainable practices (Carvalho et al., 2019).

The term "Big Data" can be defined as a collection of large amounts of data (Volume), that contains various information (Variety) and are generated, processed and updated in high speeds (Velocity) (Dagan and Wilkins, 2023). These data can be generated through the sources such as social media (Wilkins et al., 2021) and mobile devices (Creany et al., 2021). Big Data are digitally generated, passively produced, automatically collected, location traceable and available in real life or in some time (Laux et al., 2017). Dahanayake and Sumanarathna (2021) elaborated on the FM functions such as Energy management, Operations and maintenance management, Space management, FM Project management, Emergency management and Quality management and how each function explains digital transformation in FM. Dahanayake and Sumanarathna (2021) have further explained the process of each FM function, which is carried out via tools such as Internet-of-Things (IoT) and Building Information Modeling (BIM). These IoT-BIM-based smart FM functions produce massive amounts of big data and are analysed for future reference.

The architecture, engineering and construction (AEC) sector is lethargic in adopting the Big Data concept in which the operation and maintenance (O&M) phase is barely researched (Yang and Bayapu, 2020). Although BDA is an emerging concept in FM, it is evident that minimal initial investments in BDA assure considerable savings in FM operations in the long term (Gingue, 2022). BDA ensures informed decision-making in FM service delivery (Demirdöğen et al., 2023). In recent years FM service providers have shown interest in moving towards BDA to improve strategic decision making (Gingue, 2022).

Facilities operate with structured and unstructured data (Konanahalli et al., 2020). FM information systems, including Computer Aided Facility Management (CAFM), Computerised Maintenance Management Systems (CMMS), and Integrated Workplace Management Systems (IWMS), provide access to a wide variety of facility data (Mawed et al., 2017). CAFM enables the capture of the majority of unstructured data such as photos, graphics, videos, and scanned documents (Konanahalli et al., 2020). On the other hand, BIM models provide structured facility data (Konanahalli et al., 2020) and Construction operations building information exchange (COBie) enables the transfer of data from the construction phase to the operations phase (Mawed et al., 2017). BIM models can provide a visual platform for data analytics (Ahmed et al., 2017). In addition, Building management systems (BMS) generate a massive volume of building operational data (Konanahalli et al., 2020). Traditionally, all data obtained through CAFM, BMS and COBie are handed over to facility managers as hard copies/ electronic documents (Mawed et al., 2017). Hence, an extensive amount of facility data was accumulated idle (Mawed et al., 2017). Thus, informed decision-making was challenging with SQL database or spreadsheet statistics due to the inefficiencies associated with data analytics (Konanahalli et al., 2020). Technological innovations, including the IoT, BIM, and Digital Twins, together with advancements in computational analytics and processing power, have transformed the ability of data-driven decision making, enabling smarter and innovative delivery of FM functions (Konanahalli et al., 2020; Dahanayake

& Sumanarathna, 2021). Konanahalli et al. (2020) highlighted that integrating IoT and BDA provides efficiency savings, sustainable growth, and key performance indicators (KPIs), adding value to building operations and maintenance, sustainability and energy management, and workplace design and optimisation. Although BDA in FM is still in the experimental phase (Mawed et al., 2017), it is noted that the efficiency of key FM functions, Operations management, maintenance management, and energy management, can be improved by incorporating suitable supporting technology (Ahmed et al., 2017). Under the umbrella of BDA, four major types can be discussed, namely, 1. Descriptive Analytics, 2. Diagnostic Analytics, 3. Predictive Analytics and 4. Prescriptive Analytics (Riahi & Riahi, 2018). Since FM deals with corrective, preventive and predictive maintenance functions, the utilisation of the full spectrum of BDA has become a necessity. Thus, to meet the requirements of today's FM industry, BDA has become one of the FM competencies (RICS, 2018; Konanahalli et al., 2018).

Even though the industry is transforming to digitalised practices, the status of higher education has not been thoroughly researched. Whether the applied degree education (i.e., FM higher education / FMHE) covers such content sufficiently and is updated promptly is questionable. While highlighting the importance of bridging this gap between HE and industry demand, this paper also argues that FMHE should be shaped in providing experiential learning to students. For instance, researchers and educators such as Memon et al. (2022) signify the importance of experiential learning to improve students' learning experience in applied degree education. If students are missing out on the knowledge received from the real world (i.e., the COVID-19 pandemic), Memon et al. (2022) have further discussed the potential of simulated environments as an alternative. This aligns with Kolb's (1984) experiential learning perspective, where knowledge through experience and reflection is recommended.

A little research has been conducted to explore the take on FM applied degree higher education regarding digital transformation, particularly on BDA to carry out FM functions. In order to address this gap, a brief literature study on how BDA is applied in FM and how it is manifested within FMHE is incorporated into the paper. Journal and conference papers were searched on several online platforms such as Google Scholar, Web of Science, ResearchGate, ScienceDirect, ProQuest and EBSCO using keywords such as "Facilities Management" AND ("Higher Education" OR Curriculum") AND ("Data Analytics" OR "Big Data" OR "Machine Learning" OR " Big Data Analytics". A total of 360 research articles were filtered after removal of duplicates. A larger portion of articles discusses the facilities management of universities or other Institutes to enhance Higher Education in General. There are only a handful of the most relevant research articles that could be extracted to discuss in this paper. The literature findings have been used to explore the use of BDA in the FM sector and how FMHE has incorporated BDA when the applied degree education is concerned. Due to limited papers published in this direction, publications on BDA in other higher education streams have also been considered in writing this paper (e.g., Idris et al., 2023).

Ultimately, this paper explores the extent to which BDA is applied in FM and how it is manifested within FMHE, incorporating literature findings and the authors' industry, academic, and research experience.

Furthermore, the paper emphasizes the need to explore future-proof FM by proposing comprehensive and innovative suggestions for understanding and advancing FMHE.

LITERATURE STUDY

Facilities Management

Big data applications have the potential to revolutionize various aspects of facilities management by providing valuable insights, optimizing operations, and enhancing decision-making processes. Dahanayake and Sumanarathna (2021) have considered FM functions to elaborate on their relevance regarding IoT-BIM-based digital transformation. The FM functions are as follows: Energy management; Operations and maintenance management; Space management; FM Project management; Emergency management, and; Quality management. Figure 1 illustrates some key FM functions and how BIM and IoT can be utilised to effectively implement these FM functions in buildings.

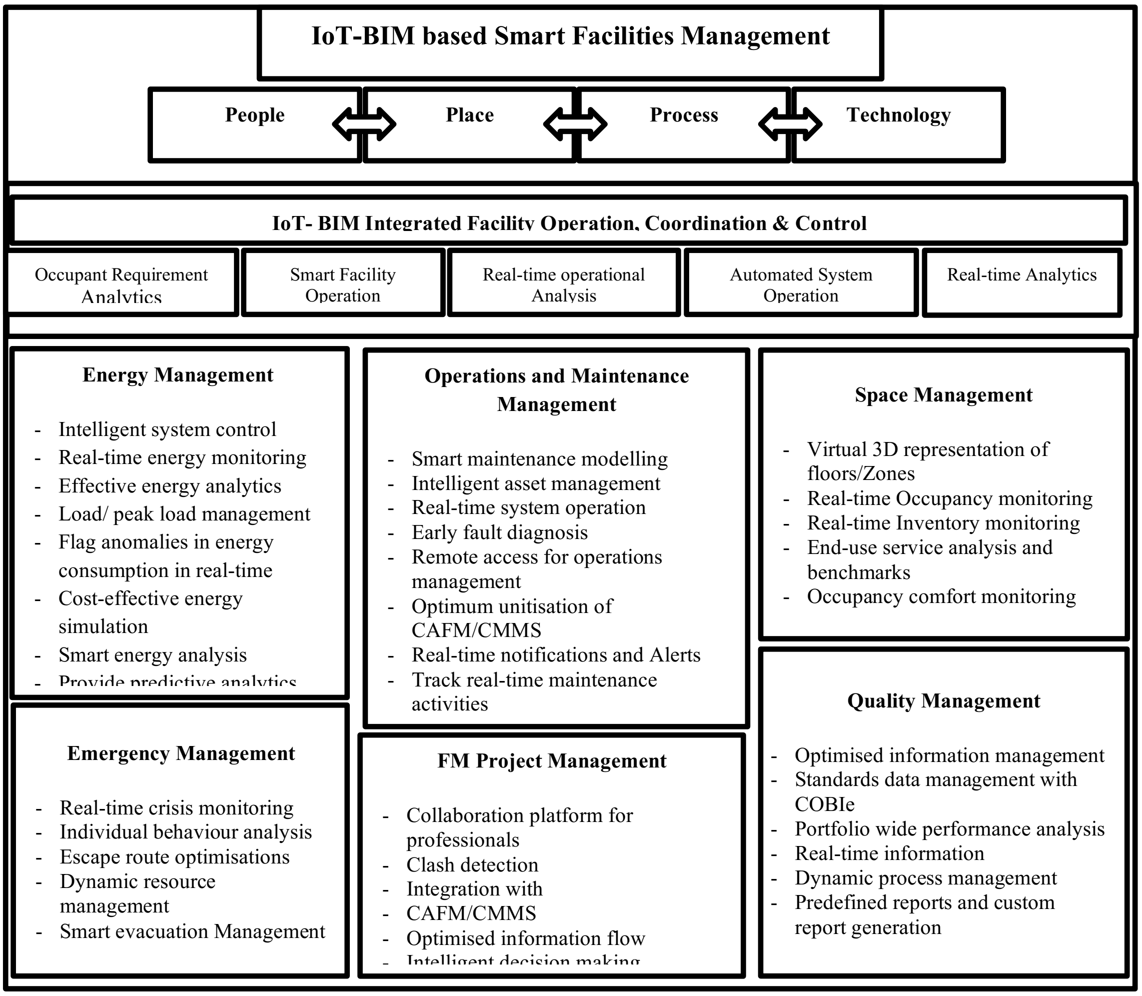

Figure 1 Proposed conceptual framework for smart FM in buildings.
Source: Dahanayake and Sumanarathna (2021, p. 11)

Junghans (2011) mentioned the ten most relevant FM research fields derived as research findings as follows: Sustainability; Knowledge; Added value; Workplace; Demand and Supply; Built Environment; Usability; Future; Health care, and; Work organisation. Among these, workplace, knowledge, health care, built environment and sustainability were found to have the highest number of scientific papers from a keyword-based advance search using Google Scholar. Lok et al. (2022) explained how facilities management is shifting towards sustainability (i.e., Strategic Sustainable FM) and adopting sustainable practices, which are various aspects of the seventeen Sustainable Development Goals (SDGs) at different organisational levels. For example, the recent ISO FM standards (i.e., (ISO/TC 267) are also aligning with SDGs by ensuring consistency of features of FM goods and services. Lok et al. (2022) further argue that the pursuit of Sustainable FM can enhance the effectiveness and efficiency of FM. The integration digitalisation in FM enables data-driven decision-making processes that optimise resource utilisation, enhance operational efficiency and ultimately facilitate sustainable FM. Big data plays a pivotal role in digitalised FM as BDA uncover patterns and insights in FM leading professionals to achieve sustainability through smart FM (McArthur, 2015).

Big Data analytics in facilities management

SUSTAINABILITY AND ENERGY MANAGEMENT: BDA enable real-time tracking and generation of ML models to predict energy consumption accurately. Gaining customised energy profiles assists in the introduction of controlled actions and tactics (Moreno et al., 2016). Smart energy meters and sensors enhance the BDA applications based on realistic data. Efficient data management using BDA algorithms can yield energy cost savings by implementing strategies such as load shifting and peak load reduction (Konanahalli et al., 2020). The emergence of IoT technology has enhanced real-time monitoring of significant energy-consuming assets in facilities, providing opportunities for big data analytics. These analytics provide insights into excessive energy consumption, abnormal consumption, and trends and patterns in energy usage. Thus, it helps facilities to run in energy-efficient terms. Mainly, BDA enable energy savings through building operational efficiencies (Dahanayake & Sumanarathna, 2021).

MAINTENANCE MANAGEMENT: BDA and machine learning have transformed traditional scheduled-based maintenance into more innovative strategies. Preventive and corrective maintenance strategies were commonly practised in facilities where maintenance is carried out on a schedule-based disregarding the actual maintenance requirement. However, IoT and real-time monitoring, along with BDA, enable smart monitoring of the performance of the assets and identifying exact maintenance requirements, promoting predictive and reliability-centred maintenance (Dahanayake & Sumanarathna, 2021). Big Data in FM enhances understanding of building, asset, and process performance through historical analysis and pattern recognition. By correlating issues and events in building subsystems, predictive technologies can identify potential maintenance issues, leading to extended equipment life, reduced operating costs, and minimized disruptions (Mawed *et al*, 2017).

OPERATIONAL MANAGEMENT: Sensor data is valuable for optimising cleaning schedules, restocking washroom supplies, and timely bin emptying. Predictive analytics can proactively identify potential issues before they lead to failure, maximizing asset utilization. Early warning notifications aid in prioritizing tasks and provide lead time for strategic planning of job activities (Konanahalli et al., 2020). BDA provides a clear understanding of the building occupancy, including peak occupancy hours, occupancy patterns, and floor heat maps, which enable the FM team to organise their staffing and provision of consumables to best match with the building operation (Gingue, 2022; Dahanayake & Sumanarathna, 2021). Continuous monitoring in real-time can enhance internal security, and dedicated weather sensors can offer early alerts for adverse weather conditions.

Facilities management higher education

Before the emergence of dedicated FM programs, the principles and practices of FM were often integrated into engineering or business-related disciplines. University of Strathclyde in the United Kingdom and Cornell University in the United States were among the pioneering universities to introduce dedicated FM programs in 1980's (Roper, 2017; Price, 2007). In recent decades, the number of universities around the globe offering education in FM has surpassed 50, with programs available at undergraduate, postgraduate, and even Ph.D. levels. This significant growth underscores the rapid advancement of the field.

In 1999, the journal 'Facilities' became the inaugural peer-reviewed publication exclusively dedicated to FM. A decade later, the 'Journal of Facilities Management' followed suit. Continuous research endeavours by the CIB W070-Facilities Management work group and professional associations like the European Facility Management Network (EuroFM), Institute of Workplace and Facilities Management (IWFM), International Facility Management Association (IFMA), and Royal Institution of Chartered Surveyors (RICS) have significantly enriched the body of knowledge in FM (Junghans & Olsson 2014; Roper, 2017). EuroFM currently has 22 universities and universities of applied sciences as members from ten countries (European Facility Management Network, 2024; Junghans & Olsson, 2014).

The number of institutions offering FM programs varies by region and is increasing due to the growing demand for FM professionals. Facility Planning and Design, Asset Management, Maintenance Management, Sustainability Management, Financial Management for Facilities, Workplace Management, Health and safety Management, Technology and Innovation in FM and Leadership and Strategic Management are a few of the key modules commonly included in the FM curriculumEuropean Union is collaborating with higher education institutes and supporting them in adapting to rapidly changing dynamic environments to thrive and ultimately contribute to Europe's resilience and recovery. The reason is that the HE plays a critical role "in shaping sustainable and resilient economies, and in making our society greener, more inclusive and more digital" (European Commission, 2021). Hence, HE institutions such as universities and technical institutions in Europe and globally are expected to design their education (curriculum) and research programs to meet such targets. Applied sciences disciplines such as facilities management should be perceived in HE by such expectations. Particularly with 'going digital' or 'digital transformation'. In their study, Junghans and Olsson (2014) explored and discussed facilities management as an academic discipline. Furthering their discussion, challenges faced in the academic world are discussed. In order to analyse the current FM curriculum offered in HE, a list of undergraduate and postgraduate FM/FM-related degrees offered by different universities around the UK is compiled. The following Table 1 summarises such degrees along with the core modules offered.

The information compiled in the Table is extracted from each university's website and is assumed to be accurate and up-to-date.

Table 1 FM courses/programs offered by the UK universities

No	University	Degree	Level	Core Modules
1	Brunel University	Building Services Engineering with Sustainable Energy	M.Sc.	Energy Conversion Technologies, Electrical Services and Lighting Design, Building Heat Transfer and Air Conditioning, Acoustics, Fire, Lifts and Drainage, Building Services Design and Management, Renewable Energy Technologies, Energy Efficient Ventilation for Buildings, Dissertation,
2	Brunel University	Building Services Engineering	M.Sc.	Energy Conversion Technologies, Electrical Services and Lighting Design, Building Heat Transfer and Air Conditioning, Acoustics, Fire, Lifts and Drainage, Building Management and Control Systems, Design of Fluid Services and Heat Transfer Equipment, Building Services Design and Management, Dissertation,
3	Leeds Becket University	Facilities Management	M.Sc.	Facilities Information and Operations Management, Commercial and Financial Management, Project Management, Managing the Property Asset, Facilities Management Strategy & Procurement, Environment, Services and Maintenance Management, Dissertation
4	Leeds Becket University	Facilities Management (Top-Up)	B.Sc.	Financial and Commercial Management, Facilities Management - Professional Practice, Work-based Learning, Facilities & Maintenance Management, Major Project
5	University of Central Lancashire	Facilities Management	M.Sc.	Project Planning, Control and Analysis, Risk and Value Management, Health and Safety Management, Project Team and Leadership Development, Facilities Management Practice, Asset and Property Management, Dissertation
6	University of Central Lancashire	Facilities Management	B.Sc.	Construction Technology, Sustainability and Science, Management and Economics, Introduction to Law and Procurement, Professional Practice, Interdisciplinary Project, Building Services, Production Economics, Contract Administration, Management and Project Planning, Health and Safety Management, Professional Practice - CPM, Maintenance Management, Facilities Management, Project Analysis and Appraisal, Business Practice and Law, Dissertation
7	University of Greenwich	Facilities Management	M.Sc.	Facilities Management, Management Principles, Critical Thinking, Delivering Sustainable Built Environments, Property Appraisal, Research Methods, Project Management, Dissertation (Built En't), Property Development & Finance
8	University of Wales Trinity Saint David	Property and Facilities Management	M.Sc.	Building Maintenance and Asset Managament, Building Services and Energy Performance in Buildings, Management of the Intergrated Working Environment, Strategic Property, Finance and Procurement, Energy and Resource Management, Research Methods and Professional Development, Master's Project
9	Edinburgh Napier University	Facilities Management	M.Sc.	Building Economics, Dissertation, Facilities Management, Health and Safety, Law and Administration: Property and Construction, Property Asset Management

As highlighted in Table 1, all the core modules offered in different degree programs have been focused on traditional FM competencies and there is a lack of incorporation of Big Data Analytics into their curriculum.

AUTHORS' VIEWPOINTS

Big Data analytics in FMHE: the experiential learning perspective

Experiential learning is defined as the learning as "*the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience*" (Kolb, 1984, p.41). Thus, the experiential learning perspective emphasises the significance of hands-on experiences and reflective learning. According to Kolb's (1984) experiential learning cycle, the learning process has four major stages: I) Concrete Experience, II) Reflective Observation, III) Abstract Conceptualisation and IV) Active Experimentation.

The first stage is the Concrete Experience, where a student encounters a new experience, situation, or even a new interpretation of an existing experience. The second stage, Reflective Observation, involves students reflecting on an experience and considering its significance and drawbacks. Subsequently, the third stage consists of deriving a new idea or modifying an existing one based on reflective observation. Finally, these new ideas, concepts, or modifications can be applied or tested as illustrated in the fourth stage, Active Experimentation.

According to Kolb and Kolb (2017), a classroom lecture might become an abstract conceptualisation or a concrete experience if students repeat what the lecturer says. Instead, facilitating students with site visits, internships, and virtual learning environments may provide them with a better opportunity to experience experiential learning. As the FM industry is adopting machine-learning-based data analysis (i.e., BDA) in several FM functions such as sustainability and energy management, maintenance management (i.e., preventive maintenance) and operational management, FMHE students need to engage with BDA platforms as part of their experiential learning journey.

Big Data in academia

With the digital transformation happening in many business organisations, in recent years, Big Data has also attracted the interest of academia. An argument placed by academia is that the facilities required for teaching BDA in HE, including the experts, are not sufficient. However, researchers claim that many academic institutions are moving to cloud architectures and creating ecosystems that facilitate BDA decision-making. Despite the growing interest, this may not be the same in developing countries (Murumba & Micheni, 2017). However, this paper argues that teaching BDA in the FM discipline would not be an issue if the curriculum were designed using the latest research outcomes and research-informed teaching was practised in HE.

Big Data Analytics in Facilities Management Higher Education: a way forward

There can be barriers for HE institutions when integrating BDA into the FM curriculum. For instance, Dewua and Barghath (2019) revealed that issues such as lack of resources (i.e., faculty expertise and technological infrastructure) and lack of awareness of the importance of BDA among students and educators are the major barriers. In Idris's et al. (2023) study, a blended approach has been mentioned to overcome such issues. Accordingly, a framework consisting of theoretical and practical components to teach BDA in FM effectively can be recommended. The involvement of industry experts in developing the curriculum has also been suggested by prior studies (Dewua & Barghath, 2019; Idris et al., 2023).
The following steps are suggested to include BDA in the FM applied degree curriculum;

- Conducting surveys in the industry to understand FM functions in which BDA is incorporated and identifying gaps in the FM curriculum
- Designing a common module as 'BDA in FM' and provide FM undergraduates with a basic knowledge of Big Data and machine learning-based data analytics
- Knowledge of Big Data Analytics also requires students to be knowledgeable about statistics and develop algorithms to construct predictive models; Knowledge of coding is also required (Picciano, 2012).
- Research-informed teaching in the area of BDA in FM
- Visits to FM organisations that use BDA to carry out FM functions
- Analysis of real-world case studies
- Classroom activities related to BDA
- Designing coursework that requires students to obtain Big Data and analyse them to make decisions (e.g., energy requirements based on BDA obtained from sensors and smart devices)
- Considering SDGs in curriculum development

Most importantly, some standardisation and consistency should be maintained to ensure the credibility and reliability of the FM curriculum.

CONCLUSIONS

This paper has delved into the incorporation of Big Data analytics (i.e., BDA) in Facilities Management Higher Education (FMHE), emphasising the importance for FMHE to evolve alongside the emerging digital transformation in the FM industry. The application of BDA in FM in various FM functions, such as energy management, maintenance management, and operational management in the building context, has been investigated through a brief literature study. Then, the status of FMHE, particularly the incorporation of BDA in the FM curriculums, has been explored. The paper reveals the lack of representation of BDA in FM curriculums even though it has become (or is becoming) an FM competency. Findings echo the necessity for FMHE to incorporate BDA into its curriculum to equip students with the skills and knowledge required to thrive in the digitalised FM landscape. Drawing from the experiential learning perspective, the paper advocates for a hands-on approach to teaching BDA in FMHE, emphasizing the importance of practical experiences, site visits, and real-world case studies to complement theoretical learning (i.e., blended approach). Moving forward, the following directions are suggested as future research to extend research in the area of BDA and FMHE. Firstly, an empirical study tracking the status and evolution of the FMHE curriculum and its alignment with industry trends in BDA adoption. Research can be further extended by exploring the required modifications to FMHE in providing future-proof FM higher education. Secondly, industry-academic research collaboration to co-develop FM curriculum for different undergraduate levels, designing curriculum with real-world data and case studies, and FM internships to bridge the gap between academia and industry. Thirdly, assessing students' FM learning outcomes related to BDA by introducing pedagogical innovations such as gamification and simulated learning environments. Finally, comparing, and contrasting FM curriculum in the UK with curricula of different countries against learning outcomes, educational policies, industry practices and digital transformation.

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How Do Customers Respond to a Digital Human at the Facility Management Service Desk?

Sissingh, K.

HAN University of Applied Sciences, School for Facility Management
Contact: karlijn.sissingh@han.nl

ABSTRACT

Background and aim. This research examines how customers respond to a digital human at the facility management service desks. A digital human, in this context, refers to an AI-powered entity capable of life-like conversations and forming emotional connections. The research aims to identify and understand the factors that influence the behavioural intention of facility management service desk users to accept a digital human.

Methodology. This study uses a framework based on the United Theory of Acceptance and Use of Technology (UTAUT) model, alongside with personal innovativeness, trust, and perceived immersion. Data was gathered through a video observing participant responses to a digital human and a questionnaire. A total of 125 respondents from Facility Management, Human Resource Management and Business Administration at HAN University participated.

Results. The findings show that performance expectancy, social influence, and personal innovativeness are significant predictors of users' intentions to adopt digital humans, with performance expectancy being the strongest predictor. Additionally, the study identifies that the study programme variable moderates the relationship between social influence, personal innovativeness, and behavioural intention.

Originality. Limited academic literature exists on digital human adoption. This research highlights the underexplored application in facility management departments, emphasising its potential to improve reception services and customer experiences while offering valuable implementation insights for managers.

Practical implications. By understanding the factors influencing users' intentions to use digital humans, facility managers can customise technology to meet expectations, enhance experiences, and remain competitive in the evolving digital landscape.

Type of paper. Research (full).

Keywords. Artificial Intelligence, Digital Human, Facility Management, Technology, UTAUT

INTRODUCTION

Significant global changes are fundamentally reshaping economies and various aspects of human life, compelling companies to adapt to maintain their competitive advantages (Dymitrowski & Mielcarek, 2021). This is only possible if companies are able to respond to changing customer demands, which necessitates responding to a wide range of developments, notably technology developments (Szabó-Szentgróti, Végvári & Varga, 2021). According to Schumpeter (2013), technology development is the overall process of invention, innovation and diffusion of a technology. Today's technological development shows many similarities to previous industrial revolutions. However, the fourth industrial revolution involved the most significant technological and labour market changes due to computer-controlled automation being replaced by the digital transformation, in which devices communicate autonomously along the value chain (Frey & Osborne, 2017; Da Silva et al., 2020). Recent technological breakthroughs have ushered in a new era of business (Ayres & Williams, 2004; Sheng, Amankwah-Amoah & Wang, 2019). The COVID-19 pandemic has enhanced the impact of digitalisation as a driver of transformation and progress in nearly every aspect of human life. The journey of human digitalisation has begun, with the majority actively embracing smart technologies and their benefits (Hassani, Huang & Silva, 2021).

Research has repeatedly shown that adapting to technology developments is critical to maintaining competitive advantages and provides various benefits to businesses. Studies highlight significant benefits such as elimination of human errors, enhancing creativity, faster decision-making, increasing efficiency and cost reduction (Ghobakhloo & Fathi, 2019; Grewal, Hulland, Kopalle & Karahanna, 2020; Pedota & Piscitello, 2022). One of these technological developments that can offer companies many advantages are digital humans. In recent years, there has been significant growth in the use of digital humans (Seymour, Yuan, Dennis & Riemer, 2020). A digital human is a life-like being powered by artificial intelligence (AI) that can converse, communicate, and form emotional connections just like any other human being (Silva & Bonetti, 2021). Through portals like video or phone screens, customers interact with digital humans, primarily for customer care purposes.

While the development and use of these digital humans have been the interest of multiple disciplines and industries (Fan et al., 2017; Hetherington & McRae, 2017; Seymour et al., 2020), the adoption within facility management appears to be limited, likely due to the limited representation in existing literature. This is remarkable since digital humans have great potential in facility management. Utilising digital humans, particularly in reception services, could notably benefit companies by minimising waiting times and facilitating more efficient customer interactions and support (Grewal et al., 2020).
Although digital humans have already proven to be valuable in several industries, it is unclear why this technology has received so limited attention in facility management. Therefore, to increase the adoption of digital humans and to realise the potential benefits for facility management departments, it is vital to obtain a better understanding of the acceptance factors of digital humans among facility management service desk users.

Research shows that user acceptance is very essential to the successful implementation of any new technology (Taherdoost, 2019; Venkatesh et al., 2003). The benefits of digital humans can only take place when the technology is actually accepted by the users. Therefore, the research aim of this study is to investigate the factors influencing users' behavioural intention to accept digital humans at facility management service desks. By understanding these acceptance factors, this research ultimately seeks to contribute to the goal of enhancing the adoption of digital human technology within the field of facility management.

LITERATURE STUDY

Venkatesh et al. (2003), conducted a comprehensive examination of eight former technology acceptance models and created a more comprehensive Unified Theory of Acceptance and Use of Technology (UTAUT). Researchers have increasingly relied on the UTAUT model to explain technology acceptance since its introduction in 2003. The UTAUT framework has been widely adopted in various studies, especially in understanding consumer mobile payment adoption and e-government services (Patil et al., 2017; Rodrigues et al., 2016; Slade et al., 2015). However, a study of Williams et al. (2011) revealed that although numerous studies have referenced the original article since its publication, only 43 have fully utilised the UTAUT model, with all its constructs in their research. Consequently, significant effort has been made to selectively include only relevant factors in the new developed model in assessing users' intentions to accept the digital humans at facility management service desks in this study.

Firstly, a modification has been made to the adopted UTAUT model by excluding the construct of use behaviour. Use behaviour typically refers to the actual frequency of using a specific technology (Venkatesh et al., 2003). Since digital humans did not exist at the time of this study and no facility management service desk was actively using the technology, it is impossible to quantify use behaviour. Furthermore, in the original UTAUT model, facilitating conditions are considered predictors of use behaviour. However, due to the inability to quantify use behaviour, as utilising a real digital human was not feasible in this study, a decision had to be made regarding the treatment of facilitating conditions. Ultimately, the decision has been made to repurpose this variable as a predictor of behavioural intention instead of use behaviour.

In terms of moderating effects, the study does not address voluntariness of usage due to absence of mandatory usage. Also, consumers often resist behavioural changes due to cognitive lock-in with familiar technology (Murray & Haubl, 2007). However, with digital humans being a novelty, prior experience is not available, making the experience moderator irrelevant for this study. Instead, literature suggests that individuals with diverse educational programmes hold differing views on knowledge and beliefs (Alexander & Dochy, 1995). Therefore, study programme will be included as a moderator in the model. Moreover, gender and age are assumed to influence the acceptance of using digital native technology (Gu, Zhu, & Guo, 2013), so both moderators will be considered in this study. In conclusion, there will be three moderators: gender, age and study programme.

Additionally, the UTAUT model overlooked a factor related to users' intentions with technology. Research, including studies by Xu and Gupta (2009), Thakur and Srivastava (2014) and Alkawsi et al. (2021), revealed that personal innovativeness influenced the behavioural intention of using technologies. According to Rogers (2003), author of the Innovation Diffusion Theory (IDT), innovativeness is defined as the degree to which an individual is relatively early in adopting innovation compared to other member of a social system. Given the novelty of digital humans, it is possible that individuals who are relatively early adopters of innovation may be more inclined to accept digital humans. Another important aspect that is not included in the original UTAUT model is the variable of trust. Numerous studies have highlighted the significance of trust in technology adoption (Alshehri, Drew, Alhussain & Alghamdi, 2012; Yu, 2012; Gao & Bai, 2014). The design of technology plays a crucial role in establishing trust, particularly in the case of smart AI technology that aims to replace human intelligence while maintaining a human-like interface (Waytz et al., 2014).

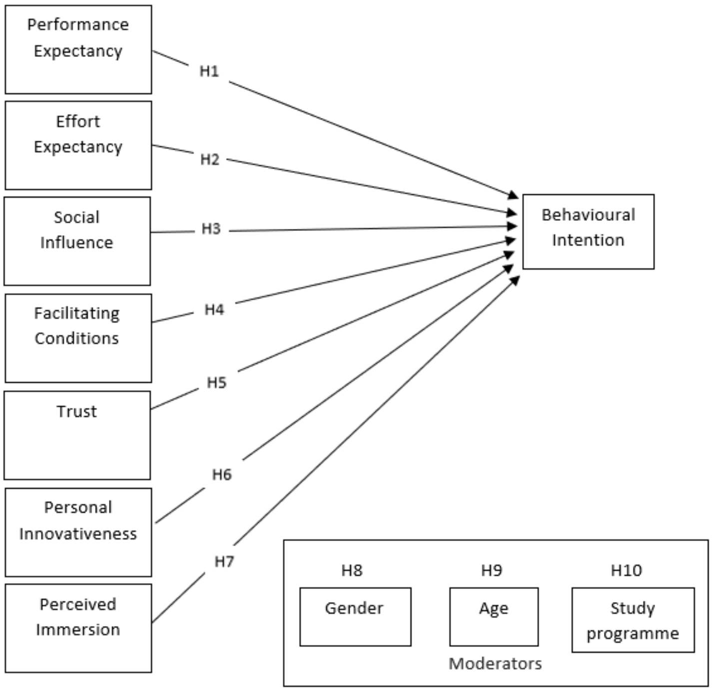

Figure 1 Conceptual model (Sissingh, 2022).

Moreover, another aspect overlooked in the original UTAUT model is the variable of perceived immersion. Perceived immersion refers to the extent to which a technology can provide users with a sense of reality (Slater & Wilburg, 2015; Rasimah et al., 2015). Studies of Seymour et al. (2020) and Xu et al. (2022) found a positive relationship between perceived immersion and the behavioural intention. Given that this study involves a video featuring a digital human, it is important to understand the influence of perceived immersion on behavioural intention. Therefore, the constructs of personal innovativeness, trust and perceived immersions are included in the theoretical framework of this study. Figure 1 presents the proposed research model along with the corresponding hypotheses.

RESEARCH METHODOLOGY

To validate the proposed framework, a combination of methodologies was employed. Firstly, an experiment was conducted to observe participant reactions to a video featuring a digital human. Utilising a real digital human was deemed impractical, hence the use of a video. It was essential to ensure that all respondents had a clear understanding of the concept of digital humans. To facilitate this, an existing video was used as a visual aid to demonstrate a real-life scenario in which a digital human effectively guides a visitor to the correct meeting room. This video was chosen for its ability to provide a visual representation of interaction between a real human and a digital human at a facility management service desk.

Following the video presentation, an explanation of the definition of the digital human concept was provided to the respondents. Subsequently, a brief discussion was held with the respondents to gather their perspectives on the potential use of digital humans. This allowed for a deeper exploration of their thoughts and insights regarding the application of this technology in facility management. Afterwards, participants were instructed to complete a questionnaire, created in Qualtrics, on their devices. The questionnaire consisted of two main sections. The first section focused on capturing participant's demographic information, including their ages, genders and study programmes. The second section of the questionnaire aimed to assess participants' perceptions of each construct in the theoretical framework. Participants were asked to indicate the extent to which they agreed with a series of statements on a 7-point Likert scale, ranging from 1 "strong disagree" to 7 "strongly agree".

All measurement scales utilised in this study were adapted from prior research. Constructs such as performance expectancy, effort expectancy, social influence, facilitating conditions, and behavioural intention, which are part of the UTAUT model, were measured using scales adapted from Venkatesh et al. (2003). The trust scale was adapted from Gao and Bai (2014), while the scale for personal innovativeness came from Alkawsi et al. (2021). The perceived immersion scale was adapted from Cheng and Tsai (2020) and Jennett et al. (2008).

This research was carried out at the HAN University, involving employees and students within Facility Management (FM), Human Resource Management (HRM), and Business Administration (BA) study programmes. Each respondent was kindly asked to participate in the research individually, completing their questionnaire one by one. The sample was obtained using quota sampling, ensuring an approximately equal representation of the different respondent characteristics. The following quotas were set: 50% male and 50% female, 33% from FM, 33% from HRM, and 33% from BA. Additionally, the sample aimed for an equal distribution between employees and students, with 50% of each category.
The collected data was analysed using SPSS, following a series of systematic steps outlined in the following. Measuring of internal consistency for content validity: To ensure the reliability of the measurement instrument, Cronbach's alpha analysis was employed.

IDENTIFYING MODERATORS: One-way ANOVA assessed differences by study programmes and gender, while correlation analysis was conducted to examine the relationship between age and constructs.
Assessment of correlation coefficients: Pearson correlation analysis was employed to determine the strength of the linear relationship between constructs.

CONDUCTING A MULTIPLE REGRESSION ANALYSIS: Consistent with previous studies on UTAUT (Rodrigues et al., 2016; Slade et al., 2015), a multiple linear regression analysis was conducted. This study applied a stepwise multiple regression analysis for hypothesis testing.

RESULTS

Demographic details

Due to quota sampling, the sample included nearly the desired balance across the three demographic factors (Table 1). Among the 125 respondents, 51% were male and 49% were female, resulting in a balanced gender distribution. Across the academies, the sample consisted of 33% respondents each from HRM and FM, and BA had 34% respondents. Additionally, the results indicated that 49% of the respondents were students, while 51% were employees. The age distribution of the respondents in this study is summarised in Table 2.

Table 1 Respondents Demographic Table (N=125)

	Business Administration	**Human Resource Management**	**Facility Management**	**Total**
Gender				
Male	24	18	22	64 (51%)
Female	19	23	19	61 (49%)
Total	43 (34%)	41 (33%)	41 (33%)	125 (100%)
Role				
Students	19	22	20	61 (49%)
Employees	24	19	21	64 (51%)
Total	43 (34%)	41 (33%)	41 (33%)	125 (100%)

Table 2 Age of respondents (N=125)

	N	**Mean age in years**	**Standard Deviation in years**
Academy			
Business Administration	43	34	15
Human Resource Management	41	32	14
Facility Management	41	32	14
Gender			
Male	64	34	15
Female	61	31	13

Internal consistency

All constructs, except for perceived immersion (α = 0.432), demonstrated accepTable (0.70-0.80), good (0.80-0.90), or excellent (≥0.90) levels of internal consistency, as indicated by their Cronbach's alpha values (Table 3). However, the construct of perceived immersion showed unaccepTable internal consistency (α = 0.432) and could not be improved by deleting items, indicating limitations in the reliability of this measure. As a result, the decision has been made to analyse the two items, PIM1 (8. Attention to the video) and PIM2 (9. Continuously awareness), of the perceived immersion construct separately in this study, due to its low internal consistency.

Table 3 Reliability Analysis

Construct	**Items**	**Cronbach's Alpha**	**Internal consistency**

1. Effort Expectancy	EE1, EE2, EE3, EE4	α = .860	Good
2. Performance Expectancy	PE1, PE2, PE3, PE4	α = .853	Good
3. Social Influence	SI1, SI2, SI3, SI4	α = .727	AccepTable
4. Facilitating Conditions	FC1, FC2, FC3, FC4	α = .742	AccepTable
5. Trust	TR1, TR2	α = .784	AccepTable
6. Personal Innovativeness	PI1, PI2, PI3, PI4	α = .902	Excellent
7. Behavioural Intention	BI1, BI2, BI3	α = .912	Excellent
8. Perceived Immersion	PIM1, PIM2	α = .432*	UnaccepTable

α *could not be improved by deleting items

Moderators

A one-way ANOVA was conducted to examine potential differences between male and female in the sample across the variables of interest. The analyses revealed that there are no statistically significant differences between the two groups. Furthermore, a correlation analysis explored relationships between age and the constructs. Findings revealed three negative and one positive correlation. The negative correlation implied that as age increased, respondents' effort expectancy, performance expectancy and trust decreased, with performance expectancy being the most affected. Regarding study programme, one-way ANOVA highlighted significant differences among respondents from different academies in '6. Personal Innovativeness' and '8. Attention to the video'. In forthcoming multiple regression, more attention will be directed towards age and study programme as moderators to ascertain their relationship with behavioural intention.

Correlation coefficient

A Pearson correlation was run to determine the strength of the linear relationship between the constructs and two variables (Table 4). The average mean across the 9 constructs is 4.94, with an average standard deviation of 1.15.

Table 4 Pearson's Correlation Coefficients

	1	2	3	4	5	6	7	8	9
1. Effort Expectancy	**5.43 (1.04)**								
2. Performance Expectancy	0.555**	**4.54 (1.15)**							
3. Social Influence	0.319**	0.489**	**3.36 (1.10)**						
4. Facilitating conditions	0.687**	0.497**	0.309**	**4.89 (1.01)**					
5. Trust	0.578**	0.477**	0.242**	0.461**	**4.91 (1.17)**				
6. Personal Innovativeness	0.557**	0.442**	0.185*	0.434**	0.316**	**4.67 (1.36)**			
7. Behavioural Intention	0.589**	0.626**	0.472**	0.541**	0.414**	0.514**	**4.76 (1.31)**		
8. Attention to the video	NS	0.210*	NS	NS	NS	NS	0.189*	**5.82 (1.05)**	
9. Continuously awareness	NS	NS	NS	NS	NS	NS	NS	0.277**	**6.06 (1.17)**

**Correlation is significant at the 0.01 level (2-tailed) *Correlation is significant at the 0.05 level (2-tailed).

Notably, performance expectancy showed the strongest positive correlation with a coefficient of r=0.626**. Furthermore, constructs trust and personal innovativeness, which are not part of the original UTAUT model, displayed moderate positive correlations with behavioural intention. Overall, the results suggest that all constructs, except for variable 8 en 9, have a positive and significant effect on behavioural intention, indicating their potential significance as predictors of behavioural intention.

Multiple regression analysis

To determine the influence of UTAUT predictors and moderators on behavioural intention, a multiple linear regression was conducted (Table 5). Model 1, consisting only of the two moderators[1] of gender and age, was found to be not statistically significant (F=0.725, P>0.05). Model 2, which incorporated the constructs of the original UTAUT, was found to have a significant relationship with behavioural intention (F=21.591, p<0.001) Model 3, in the adopted UTAUT model, including trust, personal innovativeness and the two items of perceived immersion, also exhibited a significant relationship with behavioural intention (F=13.939, p<0.001). As a result, the inclusion of these additional predictors slightly enhanced the model's predictive power. Model 3, which included study programmes, also exhibited significant relationships: Model 3 – BA (F=6.838, p<0.001), Model 3 – HRM (F=3.113, p<0.001), Model 3 – FM (F=8.944, p<0.001). These findings suggest that the relationship between the UTAUT predictors remain significant within each study programme, providing further support for the significance of the regression models.

Table 5 Multiple regression analysis. Dependent variable = Behavioural intention

	Model 1		Model 2		Model 3		Model 3 - BA		Model 3 - HRM		Model 3 - FM	
	Beta	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**
Constant		<.001		0.301		0.557		0.953		0.752		0.597
Age	-0.061	0.502	0.077	0.251	0.029	0.679	-0.083	0.515	-0.026	0.861	0.153	0.189
Gender	-0.84	0.357	-0.016	0.801	-0.051	0.444	0.043	0.693	-0.063	0.664	-0.174	0.151
Performance Expectancy			0.344	<.001	0.275	0.003	0.265	0.138	0.029	0.889	0.255	0.103
Effort Expectancy			0.253	0.008	0.15	0.155	0.323	0.107	-0.191	0.319	0.37	0.072
Social influence			0.173	0.023	0.191	0.012	0.335	0.043	0.394	0.016	0.005	0.966
Facilitating Conditions			0.151	0.096	0.13	0.151	-0.042	0.794	0.135	0.458	0.201	0.171
Trust					0.022	0.78	-0.028	0.846	0.208	0.226	-0.054	0.677

[1] The effect of the study programme has only been assessed in model three due to the categorical nature of this predictor, which consists of three distinct values. Linear regression analysis cannot directly incorporate nominal variables with multiple categories.

Personal Innovativeness			0.21	0.012	0.142	0.302	0.531	0.006	0.283	0.064
Attention to the video			0.039	0.575	0.084	0.473	-0.043	0.791	-0.024	0.822
Continuously aware			-0.026	0.702	-0.06	0.585	-0.026	0.875	0.009	0.924
ΔR^2	**-0.004**	**0.499**	**0.511**		**0.582**		**0.346**		**0.665**	
Sig.	**.487**	**.001**	**.001**		**.001**		**0.008**		**.001**	

One important finding is that gender and age were not found to have a significant influence of behavioural intention in any of the models. This suggests that these moderators do not have a significant role in the behavioural intentions of individuals within the context of the study. The adjusted R2 = 0.499 indicated that the original UTAUT constructs accounted for 49.9% of the variance in behavioural intention. However, when additional predictors such as trust, personal innovativeness and perceived immersion were included in the model, the adjusted R2 increased to 0.511, suggesting that the model accounted for 51.1% of the variance in behavioural intention. Thus, after adding more variables, the R2 slightly increased. This demonstrates that the inclusion of these additional variables slightly enhanced the predictive power of the model.

In Model 2, which includes the integrated UTAUT constructs, it is evident that performance expectancy has the strongest influence on behavioural intention, followed by effort expectancy and social influence. These predictors were found to be statistically significant suggesting that they play a crucial role in the behavioural intention of the individual. However, it is worth noting that facilitating conditions do not predict behavioural intention. This observation aligns with the original UTAUT model, where facilitating conditions are associated with use intention rather than behavioural intention.

In Model 3, an extended version of UTAUT, it was found that performance expectancy and social influence remained significant predictors of behavioural intention. Additionally, the newly introduced construct of personal innovativeness emerged as a significant predictor. Notably, the addition of personal innovativeness made the previously significant construct of effort expectancy insignificant. This implies that personal innovativeness moderates the relationship between effort expectancy and behavioural intention.

Additionally, the regression Models 3 for BA, HRM and FM, revealed interesting findings. In HRM and BA, social influence was found to be a strong predictor of behavioural intention, whereas in FM it lacked predictive power. Moreover, personal innovativeness emerged as a very strong predictor of behavioural intention in HRM but not in FM and BA. Therefore, study programme has a substantial influence on behavioural intention in certain contexts, highlighting its importance as a variable in this study.

DISCUSSION AND CONCLUSIONS

The study findings indicate that performance expectancy is the strongest predictor of behavioural intention towards digital human technology, which is consistent with prior research by Venkatesh et al. (2003), and other studies such as Al-Saedi et al. (2020) and Williams et al. (2015). Notably, Mejía’s (2015) UTAUT study in facility management also identified performance expectancy as a strong predictor. This suggests that performance expectancy is a critical factor within this context. In facility management, where efficient and effective service delivery is crucial, perceived performance and benefits associated with digital human technology significantly influence users' usage intentions.

The findings are also consistent with prior research (Lu et al., 2003; Yang & Forney, 2013), highlighting the significant impact of social influence on technology adoption. Lu et al. (2003), noted that especially young people are often sensitive to social influences. As 49% of respondents in this study were young, their technology adoption decision is likely to be influenced by opinions and roles of family members, friends and colleagues. Therefore, recognising the role of social influence is important for encouraging the intention to use digital humans. Further analysis focusing on the younger subgroup could offer valuable insights into their perceptions and behaviours regarding digital human adoption.

Furthermore, the study reveals that personal innovativeness has a significant effect on behavioural intention. This finding is in line with the literature review, including studies by Alkawsi et al. (2021), Tan et al. (2014), and Xu and Gupta (2009), which have consistently shown that personal innovativeness influences individuals’ intentions to adopt new technologies. Given that most respondents in this study were highly educated and young, they are likely to exhibit higher confidence and willingness to try new technology, enabling them to overcome uncertainties associated with adoption. This explains their positive intention towards adopting digital humans.

Trust and perceived immersion were not significant predictors of behavioural intention. Previous studies have emphasised the significance of trust in technology adoption (Alshehri et al., 2012; Yu, 2012; Gao & Bai, 2014). However, in the case of digital humans, their novelty and users' limited familiarity with them may explain why trust did not significantly influence behavioural intention in this study. Similarly, the absence of a significant relationship between perceived immersion and behavioural intention may be due to using a video to present digital humans, which may not fully convey their immersive qualities. Also, the lack of direct interaction with real digital humans may have influenced respondents’ perceptions of immersion and trust. Further research is necessary to explore these factors more extensively, potential using more immersive and interactive approaches to better capture users' experiences with digital humans.

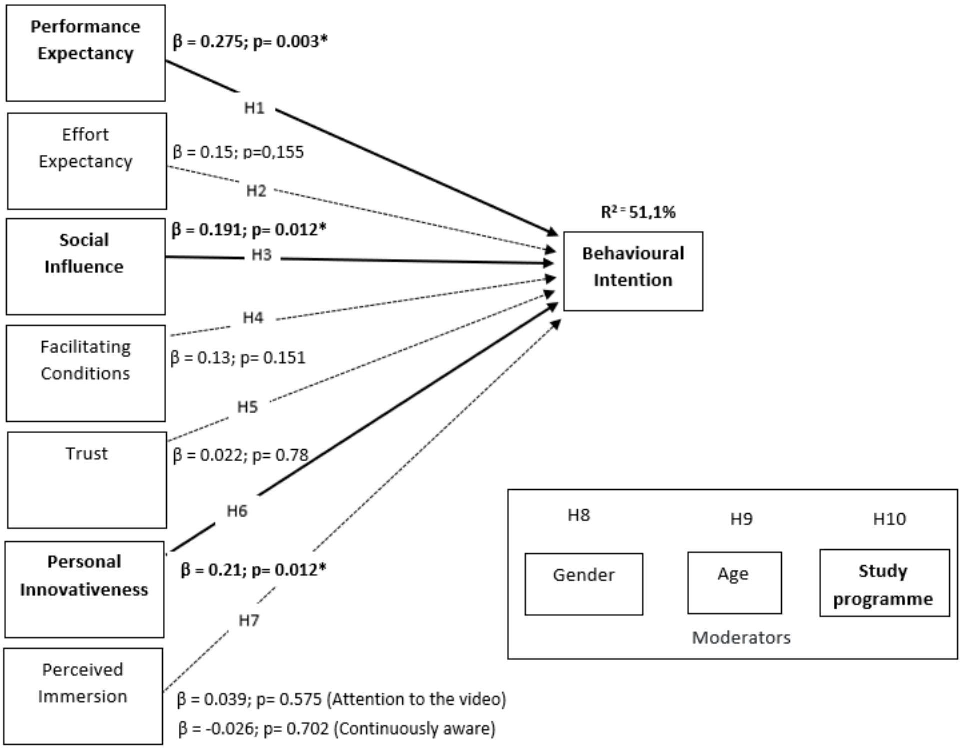

Figure 2 Conceptual model with regression coefficients. *= P<0.05. Dependent variable = Behavioural intention

To conclude, the findings indicate that performance expectancy, a construct of the original UTAUT model, is the strongest predictor of behavioural intention, followed by social influence and personal innovativeness. It explains the largest portion of the variance in behaviour intention. The result suggests that individuals' expectations of the performance and benefits they anticipate from using a digital human strongly influence the intention to use it. Additionally, among the respondents in HRM, personal innovativeness emerged as a very strong predictor of behavioural intention, implying the unique influence of the moderator study programme within this particular context. Figure 2 presents the highlighted constructs and moderators that impact the behavioural intention to utilise a digital human.

Practical implications

The significant predictors identified in this study can support facility managers in adopting a profiling strategy to facilitate consumer adoption of digital humans. This strategy involves creating user profiles based on individual characteristics, such as high personal innovativeness or personas from different study programmes. By segmenting users based on their unique needs and preferences, facility managers can customise their digital human offerings and communication strategies to better engage and attract different user segments. Furthermore, given the strong predictive power of performance expectancy, facility managers could consider promoting the features and benefits of digital humans that increase the likelihood of achieving tasks more quickly and improving productivity. If empirical evidence can demonstrate the efficiency gains and increased productivity associated with using digital humans, it can serve as a powerful selling point for their adoption.

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The Role of Digital Twins to Optimise Hospital Resilience Strategies to Heatwaves: A Review

Bawuah, D.[1], Pascale, F. [1], & Achour, N.[2]

[1] School of Engineering and the Built Environment, Science and Engineering, Anglia Ruskin University, Chelmsford
[2] School of Allied Health, Faculty of Health, Education, Medicine and Social Care, Anglia Ruskin University, Cambridge
Contact: db1034@pgr.aru.ac.uk

ABSTRACT

Background and aim. Resilience to natural hazards is central to the survival of all healthcare services, and the detrimental effect of heatwaves on hospital systems has been noted in research. While it has halted hospital functions and infrastructures, the thermal discomfort adds to the pressure on hospitals to deliver good health services. Hospitals are finding it difficult to deal with heatwaves and most resilient strategies adopted are often reactive. The aim of this paper is to explore how digital twins can be utilised in heatwave resilience within the hospital environment.

Methods. To explore the current resilience strategies for hospital heatwave hazards, this research uses scoping and semi-systematic literature review to build and analyse available articles, map out existing resilience strategies. The criteria for choosing articles are based on digital twins use in hospital resilience.

Results. The study reveal how digital twins enhance hospital resilience through its means of detecting, monitoring, and predicting hazards.

Originality. This paper emphasises the re-examination of immediate solutions provided by researchers in hospital resilience strategies in the face of heatwaves using digital twin technology.

Practical or social implications. The paper add to existing knowledge of enhancing hospital resilience using digital twins conceptualise themes to address the non-built asset issues relating to heatwaves.

Type of paper. Research (full)

Keywords. digital twin, heatwave, hospital, resilience, technology

INTRODUCTION

Resilience to natural hazards is vital to healthcare services, and to effectively detect, monitor and manage these natural events provides a robust system. The International Emergency Database (EM-DAT, 2022) reveals that the global community has witnessed numerous types of natural hazards such as climatological, hydrological, and meteorological causing 676,166 deaths and over 2 billion affected people, as well as nearly £2 trillion damages since 2010. The recent biological hazard, COVID-19 pandemic alone, has caused almost 7 million deaths worldwide, with an estimated infection of 770 million (WHO, 2023), exposed the fragilities of hospital systems (Marmo, et al., 2022), while forcing some hospitals in the United Kingdom (UK) to cancel elective operations, raising the concerns of compromising quality of care for patients with chronic diseases Achour, et al., (2022). An emerging healthcare services threat, climate change, which is deemed to have the potential to reverse health development and disrupt hospital management due to the direct effects of heatwaves, floods, and other extreme weather events. It may damage buildings, disrupt the IT, and transport infrastructure, and indirectly, generate air pollution or vector-borne disease, and the possible detrimental effects on people's health and wellbeing, creating increase demand on hospital and healthcare services (Kovats, et al., 2021). Research in hospital facility management (FM) acknowledge the impact of extreme heat incidents like the Guy and St Thomas hospital IT equipment overheating, interrupting services, and threatening the safety of patients and staff. The scale of heatwaves threat if not managed is large and costly, shedding light on the negative effect climate change has on healthcare systems. With the Met Office predicting rise in extreme heat events frequency, duration, and intensity due to climate change means, hospital FM teams need to be equipped to overcome future challenges.

This paper aims to explore and analyse innovative approaches to hospital resilience using digital technology to handle heatwaves. It explores research in digital twin (DT) as a technology medium for a proactive approach to hospital resilience towards heatwaves.

RESEARCH METHODOLOGY AND METHODS

The review of the literature in this study is organised in two stages. First, a grey and scoping literature review is conducted to understand hospital resilience in the face of heatwaves and the impact digital technology like digital twin can have on resilience. This review will grasp the threats of heatwaves to hospitals, mitigation strategies utilised, and the constraints associated with its implementation. Secondly, a semi-systematic literature review, is conducted to outline the importance and architecture of digital twin to enhance hospital resilience towards heatwaves, and to indicate resilient components being utilised in hospital resilience projects. Limitation to the methodology is, using a single database source where the intended keywords produce no data within the semi-systematic review. But because of time frame, the keywords are adjusted to produce results.

GREY/SCOPING REVIEW - HOSPITAL RESILIENCE TO HEATWAVES

Resilience can be defined as *"the ability of a system, community or society exposed to hazards to detect, resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management"* (WHO, 2020; NHS England, 2022; Khalil et al., 2022). According to the two definitions, resilience has three main themes: 'readiness' before an event occurs; 'response' when it occurs; and 'ability to function' in its previous capacity or a better state of operations (hence to adapt and transform) after an event. These elements will need to be incorporated in the resilience strategies against heatwaves to empower hospitals. See Figure 1 for an elaborated diagram of resilience concerns. Though, adopting the definition will improve hospital resilience towards natural threats, the persistence of heatwaves events causing problems to hospital functionality and thermal discomfort to patients and staff (Carmichael et al., 2013) shows, this is yet to be achieved.

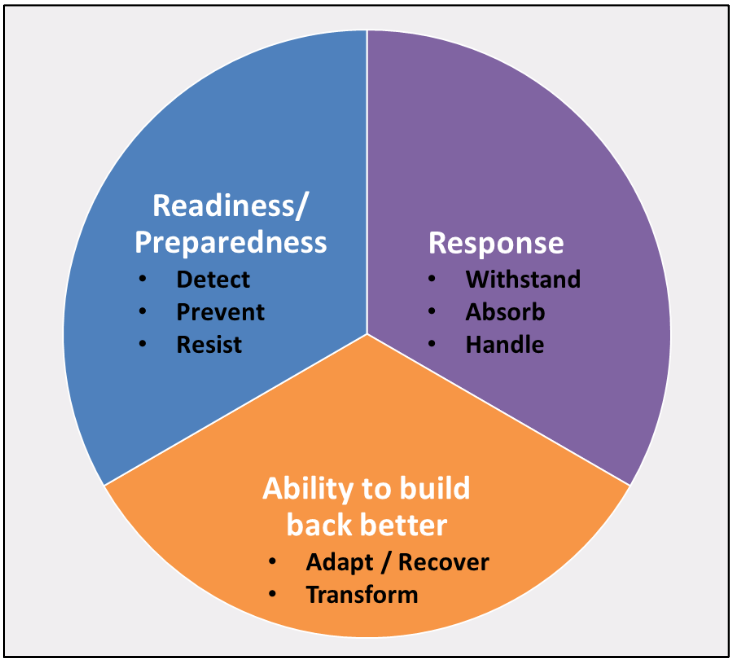


Figure 1 Resilience concerns diagram

Examined effect of heatwaves include distress of patients, visitors, and staff; equipment failure (refrigeration systems including morgue facilities); disruption or failure of IT and laboratory services; and degradation or loss of medicines (Kovats, et al., 2021). In 2019/20, 3,600 instances of overheating above 26°C in hospital buildings was recorded (Brooks, et al., 2023), and a report on Scotland found anecdotal evidence of overheating issues in four out of the five healthcare sites (BRE, 2018). Managing these instances of high temperatures cannot be undermined because of the link to mortality rate, which has doubled between 2016/17 to 2021/22 among the elderly and chronically ill. This is particularly concerning, because of the increasing ageing population numbers in the UK (Office for National Statistics, 2021; Gupta, et al., 2016). The impact of high temperatures on acute mortality (daily death) of all ages is also rising (Kovats, et al., 2021) and acute services will need to address and plan towards heatwaves challenges. Enhancing FM teams across the NHS to handle heatwaves hazards cannot be undermined, because a report by Jeffery (2023) indicates, 90% of UK hospitals are at risk from overheating due to predicted recurring and intense heatwaves as climates get warmer, resulting in increased pressures on NHS systems. Thereby making it disruptive and risking UK hospitals to poor thermal conditions if measures are not put in place.

Reflecting on the 2021/22 heatwave that hit England, some NHS Trusts adopted these approaches to handle the high temperatures: staff delaying discharge of high-risk patients, restricting surgical activity to day cases, and taking longer breaks and giving extra fluids (Stokel-Walker, 2022); shading patients and turning off unnecessary lights and equipment, and distributing porTable fans to patients and staff (Brooks et al., 2023). Whilst these responsive approaches seem to be accepTable, if no active or proactive measures are sought for, and a prolonged heatwaves incident occurs, will the NHS hospitals and facility management team be able to cope, who are narrowly coping with intermittent occurrences.

The impact of heatwaves on NHS hospitals can be significant, as evidenced by the IT problems experienced by Guy and St Thomas Trust Hospital. The heatwave caused unprecedented disruption to clinical services, resulting in staff working without full access to patient information and local GPs being unable to access test results. This had a direct and indirect impact on patient care. The question remains: are NHS hospitals and facility management team adequately prepared for prolonged heatwaves? Researchers have argued that NHS hospital FM are not ready to deal with disasters due to dated and inappropriate hospital design, inadequately maintained infrastructure and weak resilience strategies including business continuity plans (Achour, 2020; Achour and Price, 2010). This demonstrate the extent to which UK hospitals are affected by heatwaves, primarily the inability of infrastructure to combat heatwaves (Short et al. 2015). Although some hospitals have implemented responsive approaches for the year 2021/22, it is not possible for FM teams to implement them in all NHS hospitals due to infection prevention and control measures. Figure 1, details limitations in the approach carried by some hospitals.

Table 1 Strategies used by some hospitals to handle the 2021/22 heatwaves in England

Heatwave strategies	Limitations to the strategies
Distributing PorTable AC & Fans (Brooks et al., 2023)	Not all wards can adopt because of infection control and health and safety concerns.
Restricting surgical activities to day cases (Stokel-Walker, 2022)	The restriction creates a backlog of surgical activities.
Delaying discharge of high-risk patients (Stokel-Walker, 2022)	Creates an increasing demand for beds for new patients.
Shading Patients (Brooks et al., 2023)	Depends on the size of the hospital estates to dedicate extra space as cooling space and facility to create the shade.
Giving longer staff breaks (Stokel-Walker, 2022)	Will increase patient waiting time and decrease quality of service.
Adaptation and retrofitting (Lomas, et al., 2018; Short, et al., 2015)	Cost of retrofitting with NHS hospital financially struggling and the adverse effect on the day to day running of the hospital when adaption is taking place.

Considering this, NHS England's Emergency Preparedness Resilience and Response (EPRR) Framework recommends that the NHS needs to be able to plan for and respond to a wide range of incidents and emergencies including extreme weather conditions (e.g., heatwave and storms), that can affect health or patient care (NHS England, 2022). Now, if improved measures are not put in place, how will FM function to support the thermal needs of hospitals when faced with prolong heatwaves. This will be a substantial challenge for FM and hospital internal systems cope, with its current heatwave strategies. Researchers has expressed the urgent need for Hospitals to review their resilience strategies, foster appropriate general guidance, develop overheating mitigation principles, designs, and system. (Marmo, et al., 2022; Achour and Price, 2010; Anderson et al., 2020; BRE, 2018). Researchers have identified models to address the challenges. Marmo, et al., (2022) clarify that the adaptation process model linked with behavioural and infrastructural preparedness will likely make hospitals resilient in the future. Achour, et al., (2022) suggest that hospital plans need to be revised to include monitoring models that enhance hospital business continuity plans. When examining adaptions, retrofitting has been proposed as the means to enhance hospital infrastructure (Short et, al. 2015; Jeffery, 2023; Lomas, et, al. 2018). Additionally, Brooks et al. (2023), propose a strategic, long-term planning and investment to address the drivers for overheating risk and the barriers to action before and during a heatwave event to ensure a climate resilient health system. Meanwhile, others have suggested technological models through digitalisation and automation to speed up resilience (Chen, et. al, 2020). Behr, et, al. (2022) discuss how Artificial Intelligence (AI) has been used to develop adaptive equipment to cope with hospital demand. British Medical Association report (2020) calls for better collaboration between primary and secondary care, expansion of workforce and training capacity, and extensively calls on NHS Digital to increase investment to modernise, innovate and automate NHS IT infrastructure. The report states that addressing information technology demands is urgent for the NHS to capitalize on hazard-induced changes. Accordingly, in our modern era, with advance technology, can't digital technology be used to improve the resilience of hospitals to minimise the impacts of climatological incidents like heatwave.

DIGITAL TECHNOLOGY AS A HOSPITAL RESILIENCE STRATEGY

Hospitals as an organisation, is a "*combination of physical and non-physical factors working collaboratively and in harmony to provide diagnostic, treatment and rehabilitation of individuals*" (Achour, 2024). Hospitals experience three main challenges nationally: a reduction in public investments, surge in demand, and pressure to improve the performance of core processes. To understand and handle these challenges, hospital services must balance efficiency and resilient performance, which are generally seen as conflicting states (Rosso and Saurin, 2018). Digital technology and its subsequent automation have the potential to transform healthcare systems and become an enabler for managing such trade-off (Marques da Rosa, et al., 2021).

Technology in healthcare has advance it's focused on simple health solutions to the emergence of sophisticated tools like computed tomography (CT) scanners. Innovative ideas in information technology and the emergence of smart machines, Big Data, AI, Internet of Things (IOT), machine learning has given rise to the converging of the physical, biological and the technological world for a better health decision making and predictive tools (Kocheva, 2021; Mbunge, et, al., 2021; Tortorella, et, al., 2021; Marques da Rosa, et al., 2021). Digital technology systems and tools can be used to monitor resilience, predict operation, provide real-time information, and change the way NHS hospitals operate. It can guide hospitals to make decisions towards growth; improve quality, foster new medical technology, make the hospitals safer and more efficient and improve opportunities for staff (MSE FT, 2022) and provide better evidence for a robust resilience strategy. The fact that most hospitals still rely on simplistic methods like distributing fans and cold drinks to deal with heatwaves is concerning (Stokel-Walker, 2022). The core element of NHS England's *"Heatwave plan for England"*, elaborates that, a heatwave plan depends on having a well-co-ordinated plan to deal with severe hot weather before it strikes through organisation's experience and expert advice. The report acknowledges the use of the MET Office automated digital technology to predict heatwaves and alert healthcare providers, communities, and the public, and recommends NHS providers use available means to help and assist vulnerable people and assets.

Accordingly, this recommendation should be adopted and enhanced by NHS hospitals to detect and forecast a possible overheating incident within their domain, allowing time for mitigation measures to be put in place. A DT technology can be used to produce this desired predictive procedure and forecast measures for mitigation. Though this is the case, when it comes to climate change hazard like heatwaves, there is less research in the domain. Whilst no other research has been found yet on the use of digital twin technology to improve hospital resilience to heatwaves, digital twins have been utilized in hospitals for various purposes such as detection, prediction, and forecasting (Jensen and Deng, 2023), analysing and assisting clinical decision-making (Kaul, et al., 2023), diagnosis, treatment, and preventive care, electronic medicine (Kaul, et al., 2023). Research have been done on how facility management can use DT in structural health management (Khallaf, et al., 2022), disaster planning and management. During the COVID-19 pandemic, DT was used to simulate transmission rate, hospital accessibility and drug trials. DT tool is a relevant means to engage hospital resilience needs and enhance efficiency (Karakra, et al., 2020). Hence, conceptualising digital twin to achieve automation of hospital resilience strategies towards heatwave can transform hospital.

SEMI-SYSTEMATIC REVIEW

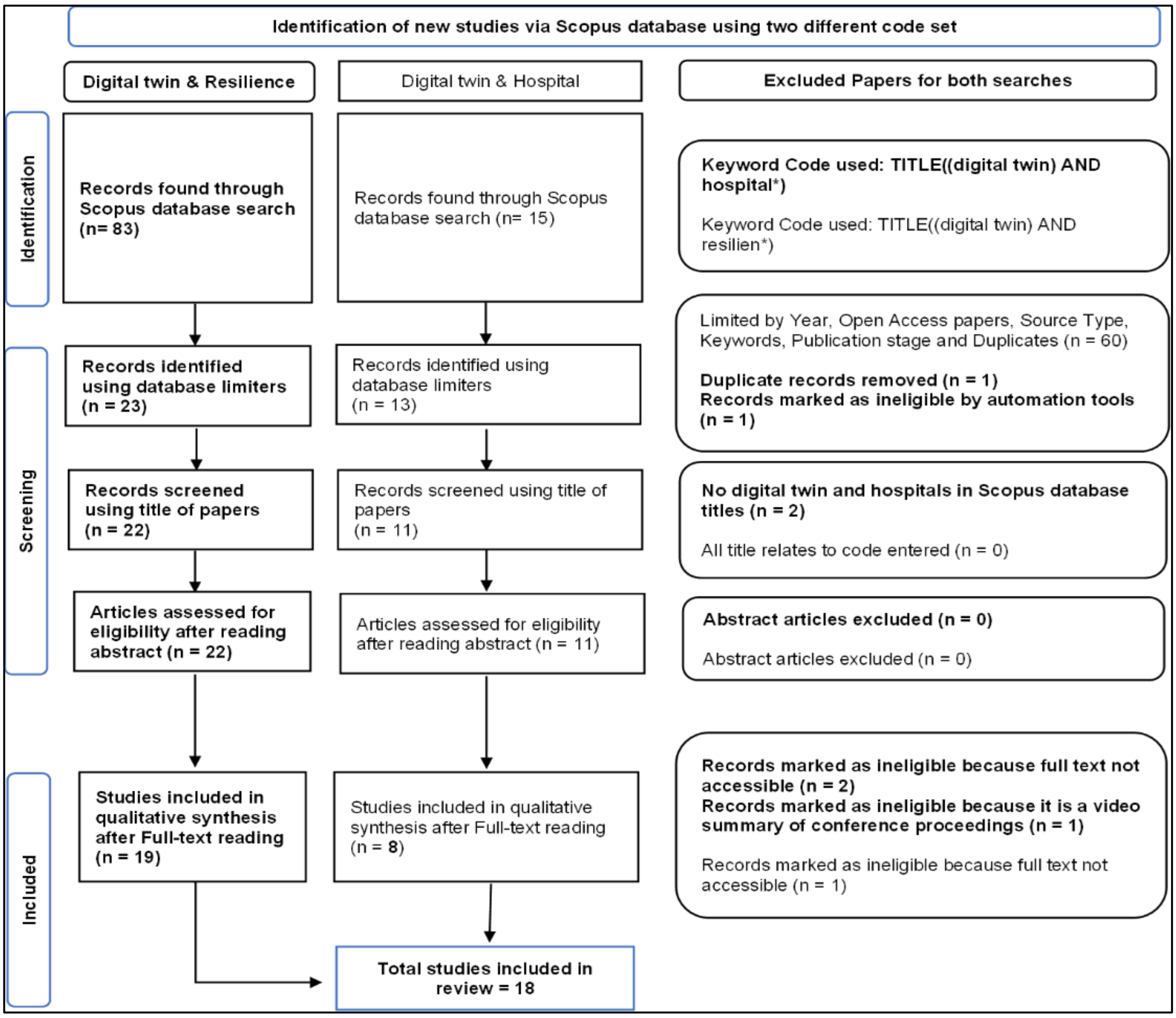
This research uses a semi-systematic literature review (Omazic and Zunk, 2021) to build and analyse secondary data on hospital digital twin frameworks in the Scopus database. Keywords (digital twin, heatwave, hospital, and resilience) initially input into Scopus database produce no relevant data. The authors spilt the keywords into groups, given in Table 2. The final keywords (i) digital twin and hospital and (ii) digital twin and resilience were used to generate data. The premise for the keywords is, in other to analyse existing research on digital twin use in hospitals against heatwaves, the research needed data that consisted of (if not all the keyword) at least three of them should be appropriate to conceptualise digital twin functions towards heatwaves. From Table 2, the highest articles per search with heatwave included, is five hence heatwave was dropped from the search. Also, these keywords (digital twin, hospital, and resilience) were not considered because of the low volume of articles generated. This prompted the researchers to split the keywords and pair each with digital twin since it is the mode of the study. In other, to remove random articles from the results, the search was re-done within Article Titles only, see Table 1.

Table 2 Keywords tried In Scopus and the number of papers retrieved

Number of papers generated in Scopus database		
Keyword Codes	**Search within Article Titles, Keyword and Abstract**	**Search within Article Titles ONLY**
Digital twin, hospital, heatwave and resilience	0	Not available
Digital twin, hospital* and resilien*	2	Not available
Digital twin, hospital and heatwave*	0	Not available
Digital twin, heatwave and resilien*	1	Not available
Digital twin and heatwave*	5	Not available
Digital twin and resilien*	544	**83**
Digital twin and hospital*	158	**15**

* Indicates searches for all different forms of the word

To analyse the digital twin application in hospitals resilience, a collected literature was retrieved from the Scopus database with these code "TITLE((digital AND twin) AND hospital*)" and "TITLE((digital AND twin) AND resilien*)." Together, a total of 98 papers were found, and the review of the documents is illustrated in Figure 2.



*n – indicates the number of papers

Figure 2 Prisma diagram of the research method review

The researchers initially excluded non-English language publications and duplications and utilised the database limiters (62 papers excluded). At the final stage, only 18 papers were included in the study. The papers have been used as primary data to better understand the digital twin application within hospitals.

RESULTS AND DISCUSSION

The intended code search yielded no results, so an amalgamation of codes was access with suitable keywords towards this study, indicated in Table 2, and the results is shown in Table 3 and 4. The review was conducted in three stages; i) papers which indicated or suggested digital twin as a resilient tool, indicating the resilient elements it proposes: ii) papers that produce or design a digital twin model, framework, or architecture, indicating methods followed: iii) papers which the digital twin aspect can be utilised in NHS Core standards for heatwave EPRR. The authors reviewed 18 papers according to themes. Within the resilience themes, only two papers model aligned with all the components (preparedness, response and ability to function after event). Individually, ten papers discussed Preparedness and 5 discussed Ability to function after event, while the least examined, Response is 4. This indicates, there is a growing number of research within the context of digital twin that can be applied to enhance hospital resilience strategies but more needs to be done in the context of climate change as none addressed heatwaves.

	Resilience						Developping Digital Twin													
	Preparedness/Readiness		Response		Ability to function After Event		Type of Digital Twin	Model (Structural, Behaviour al)	Arquire Input Data					Twinning Stage			Monitoring Stage		DT Output	
Authors / Year	Detect	Prevent / Resist	Withstand	Absorb / Accommodate / Handle	Adapt / Recover	Transform			How is Data Collected	Type of data	How is data stored	How is Data Transmitted	How is data Connected to DT	Analysis / Evaluate Data	Coding Language	Test & Validate the DT Parameters	Simulation and optimisation	Monitor and Refine	Transmit Output	Impact
Nasiri and Kavousi-Fard (2023)		√					√		√		√	√	√	√	√	√				√
Lektauers, et al., (202√)	√						√				√			√	√					√
Vrabic, et al., (202√)	√			√	√	√	√		√					√	√					
Park et al., (2023)				√			√		√	√					√			√		
Therias and Rafiee, (2023)							√		√	√										
Eirinakis, et al., (2022)	√						√													
Lu et al., (202√)						√														
Hu, et al., (202√)							√						√							
Brucherseifer, et al., (202√)	√					√	√													
Peng, et al., (2020)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√
Sun, et al., (2023)							√	√						√						
Flamini, (202√)	√			√			√	√	√					√						
Kaewunruen, ETAL., (2023							√	√						√						√
Karakra, et al., (2020)	√						√	√	√	√	√	√	√	√		√	√			√
Feng, Lv and Lv, (2023)	√									√				√		√	√			√
Zhang and Tai, (202√)						√				√			√	√						√
Lehmann, et al., (2023)									√		√	√	√	√	√		√			
Ahmad, et al., (2023)	√									√				√		√	√	√		

Figure 3 Papers reviewed against resilience elements with digital twin design or development

In the developing digital twin theme (Figure 3), there are four stages namely, Acquire input data, Twining stage, Monitoring stage and Output stage. About 13 papers researching how to acquire input data considered sensors as the best means for developing digital twin. In comparison, the twinning stage, comprising analysis and evaluating data, 12 papers, with half suggesting statistical analysis as their best choice. But all papers that used coding language suggested Python. The monitoring stage was discussed by six papers, primarily based on the digital twin simulation.

About half of the papers examined against the NHS Core Standard (Figure 4) has utilised DT to support overheating measures but mostly sits with ICT and equipment. For example, the DT designed by Nasiri and Kavousi-Fard (2023), can be used to decrease ICT & Equipment vulnerability and failure to overheating, which is a major issue for most NHS hospitals to keep some equipment cool during heatwaves and Peng, et al., (2020) DT can detect, monitor, and resist overheating/heatwaves by instigating prepared measures to reduce effect. For access, service provision and discharge of patient in the hospital five papers present DT ideas that can assist in that respective heatwave or other hazard. Lektauers, et al., implemented a digital twin methodology to assist remote working staff, while Peng, et al., (2020) paper, completely monitors all access routes including but not limiting to lifts, corridors, staff and predict weather conditions to enhance accessibility. During and after event, being able to assess impact is key in EPRR, but unfortunately only one paper (Peng, et al., 2020) dealt with it but it was extensively done to include using sensors and video to monitor to inform responders of any impact, while calculating best course for action. Two of the paper's models can be adapted to resilience exercise module, to forecast upcoming exercises, and identify, regulate and predict required lessons to revise exercising plans.

In all, only one paper (Peng, et al., 2020) extensively designed a DT that can function in the three themes, and this is because, the project was done to assist all aspect of hospital components (building, lifeline, staff, equipment, suppliers, and management & governance), also accumulated data from different aspect of the hospital, and the immense resource available to the team. This means, for a DT system to become a method of resilience strategy in hospitals, the different systems and sub-systems of the hospital must be considered in other to gain a comprehensive understanding and data to build the twin, and extensive financial support for a whole hospital twin entailing most functions if not all.

	NHS Core Standard for EPRR - Standards to Severe Weather Response										
	Overheating			Access		Service Provision	Discharge	Assessment		External Partners	Exercising
Authors / Year	Heatwave plan to Monitor Patient & Staff areas	Contingency arrangements to reduce temperatures	ICT & Equipment (cooling systems provided)	Plans to ensure staff can attend work	Plans to ensure site access is maintain	Arrangements to allow for caseloads to be clinically prioritised	Process in place to ensure vulnerable patients are discharged to safe home or referred	Plans to assess impact of severe Weather warnings	Warning and informing multiagency partners before & during event	Supply Chain	heatwaves exercise arranged and lessons identified and revise into plans
Nasiri and Kavousi-Fard (2023)			√								
Lektauers, et al., (202√)				√							
Vrabic, et al., (202√)	√		√								
Park et al., (2023)											
Therias and Rafiee, (2023)											
Eirinakis, et al., (2022)	√		√								
Lu et al., (202√)						√					
Hu, et al., (202√)			√								
Brucherseifer, et al., (202√)	√		√								
Peng, et al., (2020)	√	√	√	√	√	√	√	√	√	√	√
Sun, et al., (2023)											
Flamini, (202√)			√								
Kaewunruen, ETAL., (2023			√								
Karakra, et al., (2020)	√									√	
Feng, Lv and Lv, (2023)				√							
Zhang and Tai, (202√)											√
Lehmann, et al., (2023)											
Ahmad, et al., (2023)						√					

Figure 4 NHS core standard for EPRR towards severe weather response (like heatwaves)

The authors have aligned the discussed problems faced (see Figure 3) in some heatwave strategies used by some hospital in Figure 5. It depicts the digital twin models within the papers that can be used to solve the issue surrounding the strategies.

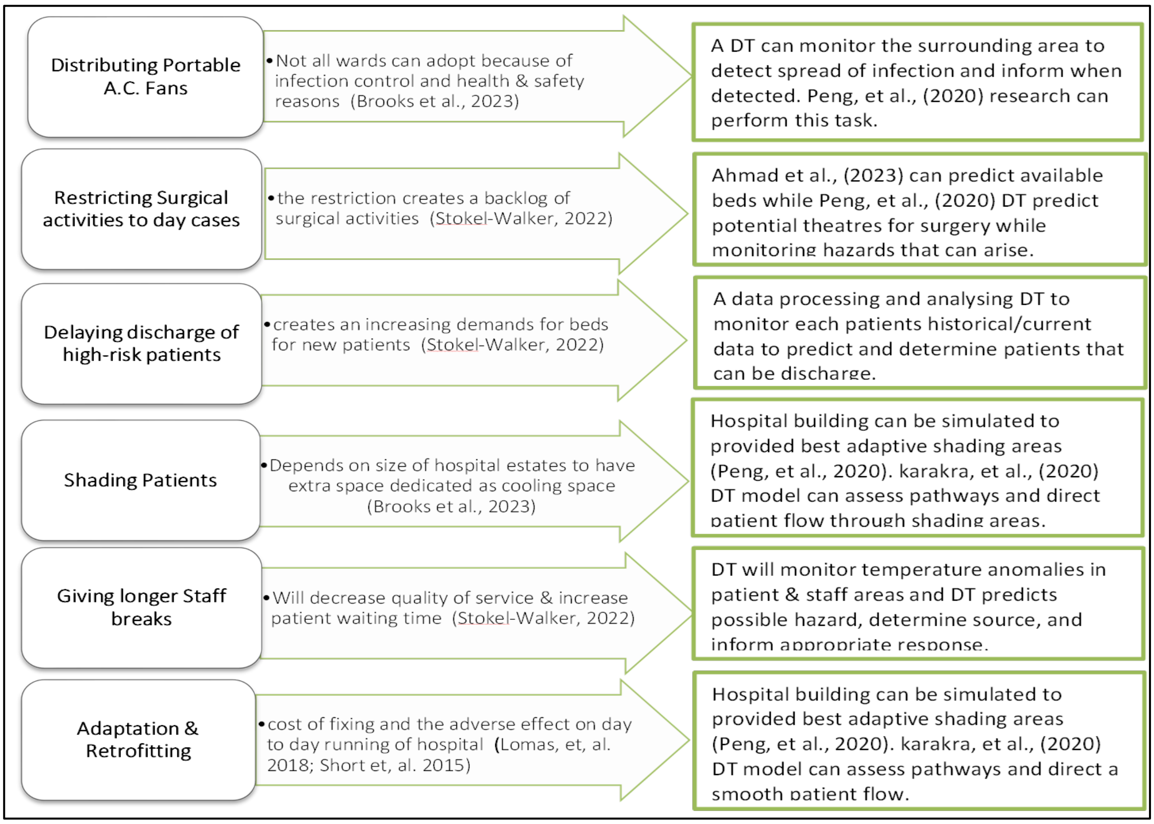


Figure 5 Using digital twin to answer some challenges experienced by hospitals during heatwave.

CONCLUSIONS

This study analysed the existing literature in the effective way of using digital twin to enhance hospital resilience against heatwaves under the framework of digital twin and the NHS Core Standard for EPRR. The findings reveal that more work needs to be done in DT towards hospital heatwaves resilience. But to extensively benefit from this technology, facility managers need to examine what benefit they need, in other to collect the best input data needed. The recommended use of sensors from the results indicates the move towards the detection of a threat before it occurs, and critical or simulated analysis to formulate a meted strategy to respond. The review has shown that DT have the capability to this effect, maximise hospital services, predict hazards, support effective decision makings, and simulate managerial activities to achieve desire goals towards resilience. However, its adoption in the real world is slow and FM team and the whole hospital systems needs to investigate and implement the technology into their functions because this paper brings to light the limited real-world testing and adoption even though its eminent importance has been discussed. The next step for this paper is to progress the research to produce a DT framework model that focuses on all the resilient elements and NHS Core Standard for EPRR against heatwave, which will be tested against real-world case study.

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Rehabilitation of an Existing Building: Structural Information Requirements

Scott, J. & Sumanarathna, N.

School of the Built Environment, London Metropolitan University
Contact: j.scott1@londonmet.ac.uk

ABSTRACT

Background and aim. The rehabilitation of existing buildings is an important response to the sustainability challenge by the built environment sector. Advice from the structural engineer on the ability of an existing structure to facilitate rehabilitation is often hindered by a lack of key information. Guidance is required on the collection of key structural information to inform design and investment decisions, allowing a better understanding of the opportunities for and risks to, sustainable project outcomes. This paper explores the structural information needed for rehabilitation and the role of structural engineer in collecting this.

Methods. This is a viewpoint paper, prepared at the earliest stages of a research project, drawing upon an amalgamation of industry experience and an initial exploration of the literature. A systematic, limited, literature study was undertaken to further develop the viewpoints offered. Utilising the practice and academic experience of the authors, we report upon current industry practice with regard to the rehabilitation of existing buildings, including reasons for obsolescence, interventions available, information requirements and barriers to adaptation.

Results. The paper provides suggestions for the collection and presentation of key structural information. Barriers faced by structural engineers in implementing such procedures are discussed, and options to overcome these offered. The paper concludes with recommendations for next steps to be taken within this research project.

Practical or social implications. The paper provides an outline for closer collaboration between structural engineers and facilities managers to promote more effective sustainable practices.

Type of paper. Viewpoint

Keywords. building rehabilitation, facilities management, retrofitting, structural design information, sustainability

INTRODUCTION

Researchers have recently brought forward the discussion on rehabilitation vs demolition and new construction. The rehabilitation of an existing building or structure via its re-use, refurbishment and retrofitting is becoming an increasingly important response to the ongoing climate challenge by the built environment sector (Built Environment Declares, 2023; Derwent London, 2022). From a sustainability perspective, retention and rehabilitation are often recommended, in preference to demolition and new construction, largely due to the greater environmental impact of carbon emissions from the latter. Case studies including Alba-Rodríguez et al. (2017), have proven that even a severely damaged building can be rehabilitated with repair and retrofit work, with lower cost and environmental impact compared to its demolition and new construction. However, such projects are frequently frustrated by a lack of adequate information on the existing structure (Hamida et al., 2023), on which key investment decisions can be made.

Some studies have been undertaken with a focus on the role of the architect, engineers and other designers within rehabilitation works. For example, Segonds et al. (2012) have developed a framework to carry out rehabilitation and re-design (i.e., architectural rehabilitation) projects that were re-designed to facilitate disable access. The authors suggest that the formation of closer collaborations among stakeholders such as designers, main contractor, client and end-users of projects can overcome complexities by paying better attention to end-user requirements. Nevertheless, further guidance is required on the reasons for, and current practices in, the collection and presentation of key structural information at the early design stages of a rehabilitation project. This will then allow a better understanding of the opportunities in terms of rehabilitation and the achievement of sustainable project outcomes.

This paper explores the type of structural information needed for the successful rehabilitation of an existing building or structure via re-use, refurbishment and retrofit, and the role of structural engineer at the design stage in collecting such data. The viewpoint paper is ultimately aimed at exploring how building owners and facilities managers can better collaborate with structural engineers to facilitate the collection of structural information, especially during the early stages of a rehabilitation project.

This is a viewpoint paper, where findings and research implications are an amalgamation of an initial exploration of the literature and industry experience (Vandenbogaerde et al., 2023). The paper introduces the background and aims of our contribution, and then reports on an initial literature study based on topics identified in the industry. We summarise our viewpoints based on these, including recommendations for future research activities, and draw some initial conclusions from the work undertaken to prepare the paper. This is an ongoing research project and this paper presents our preliminary findings and viewpoints.

The first author had worked as a structural engineer in the UK construction industry for more than thirty-five years and the views presented are derived from the practice and academic experience of the authors. The first author has provided design and advisory services on several significant heritage buildings and structures including; Chatham Dockyard Slipways, Norwich RC Cathedral, several Cambridge colleges (e.g. St Johns, Trinity), projects for the National Trust (e.g. Wimpole Hall, Ickworth House) and the Houses of Parliament, Westminster.

INITIAL LITERATURE STUDY

Managing the risk of obsolescence

All assets need to have relevance, without which a building or structure can swiftly become obsolete. Several authors have offered commentary on the reasons for obsolescence and the subsequent risks to existing buildings and structures when this is realised (Askar et al., 2021). A relevant building or structure needs to have value, a loss which can be due to one or more changes in the physical, technological,

functional, economic, social, legal or political demands on the asset (Rockow et al., 2019). Askar et al. (2021) have also noted that loss of value can also be caused by changes in operational conditions, emerging needs and uses not met by the asset and varying environmental and external factors.
When the risk of obsolescence is high or is realised, it is necessary for stakeholders to address this by improving the building or structure, in terms of physical, functional, or economic performance (Bullen and Love, 2011). As Askar et al. (2021) have noted, "most buildings become obsolete before their technical life comes to an end and is the dominant factor in the need for the building to be adapted or demolished" (p.11), requiring some form of adaptation or intervention to maintain relevance and, therefore, value.

When a building becomes obsolete, owners and managers of the asset are faced with a choice of actions to take; (a) to do nothing and wait for the market to change, (b) to sell the building, (c) to adapt the building, or (d) to demolish the building and redevelop the site (Baker et al., 2017). The choice is often based on the financial aspect, yet the sustainable aspects should also be considered in making such decisions.

Sustainability considerations

The sustainability case for retention of a building in lieu of demolition has been made by several authors (e.g. Baker et al.,2017) and is the subject of ongoing intense debate within current practice, as illustrated by the case of the proposed demolition and redevelopment of the flagship Marks and Spencer store in Oxford Street, London (Butler, 2023). A proposal for giving all potentially re-useable buildings and structures within the UK statutory protection from demolition, unless this is proven to be essential, has recently been mooted by structural engineer, Arnold (2022), who suggests that all such buildings should be given a grade 3 listing, beyond those current listed with grades 1, 2* and 2 (Creigh-Tyte and Gallimore, 1998). As a key response to the climate challenge, it is likely that opportunities for the re-use of existing buildings and structures will need to be fully explored by building owners and facilities managers during any project to deal with the potential obsolescence of their asset, before demolition would be permitted. This suggests that sustainable project outcomes (Bullen and Love, 2011) should be sought in all cases, which will require careful consideration of any proposed interventions, by all primary stakeholders - to maintain the relevance and value of the asset but within accepTable social, environmental and economic limits.

Sustainable project outcomes are those where the impact of the project on social, environmental and economic factors is minimised, with focus on the environmental impact. The RIBA (2019) has listed these as; *Net zero operational carbon, Net zero embodied carbon, Sustainable water cycle, Sustainable connectivity and transport, Sustainable land use and bio-diversity, Good health and wellbeing, Sustainable communities and social value and Sustainable life cycle cost*

When considering the potential re-use of an existing building or structure, the key outcomes required from any interventions to be made are likely to be net zero embodied and operational carbon. In order of preference UKGBC (2023, 2021), the following should be carefully explored; *Re-use the existing* *building or structure in lieu of demolition and redevelopment of the site, Minimise the additional embodied carbon within any physical interventions made, Minimising 'operational' carbon emissions (due to heating, lighting etc.), Minimising 'in-use' embodied carbon (due to regular maintenance, renewal of finishes etc.) and Maximise opportunities for minimising 'end of life' embodied carbon (dismantling, recycling etc.)*

In lieu of demolition

Once a decision has been made for retention of the existing building or structure in lieu of demolition, several intervention options are available to the project team (Baker et al., 2017). Options for rehabilitation include preservation, conservation, refurbishment, renovation and remodelling - each of which will enable the project team to add value to the asset and promote a return to relevance. The choice of intervention to be made will need to be assessed against the following criteria (Douglas (2006)): viability (economic feasibility), practicality (physical feasibility) and utility (functional feasibility). This will require the project team to consider the technical, legislative functional, economic, environmental, political, technological and social aspects of an evolving design proposal during the design and planning phases of the project (Hamida and Hassanain, 2022), decisions on which will require multi-stakeholder consideration (Sedhom et al., (2023). The concept of 'adaptive re-use' is well represented within the literature (e.g., Hamida and Hassanain,2022) and responds directly to the issues raised earlier, regarding decisions on interventions to be made to maintain the value of an existing building or structure.

Each of the forms of interventions, require a range of adaptations of the existing building or structure – for example, preservation requires only limited adaptation whereas remodelling often requires extensive adaptation. Many authors suggest that any interventions made should be considered as part of the whole life cycle of the building or structure, note that future adaptations are likely to be required, and that potential needs for these should be addressed. This concept has been described within the literature as 'circular building adaptability', where the intervention under consideration is seen as part of a continuum of interventions that will be required to maintain the value of the asset, within a wider circular economy. As Hamida et al. (2023) note "circular building adaptability in adaptive re-use is crucial to enable the built environment to withstand future changes, respond to cultural dynamics, eliminate waste generation, embody the regenerative capacity and create value out of the assets" (p.2)

Hamida et al. (2023) have suggested ten factors of an existing building or structure that will contribute to the successful application of circular building adaptability approach. These are: configuration flexibility, product dismountability, asset multi-usability, design regularity, functional convertability, material reverseability, building maintainability, resource recovery, volume scalability and asset refitability. These factors should be considered during the development of any design proposals for intervention works, to allow future interventions to again maintain the value of the asset, and to further promote, or maximise, sustainable outcomes for the current project. Hamida et al. (2023) also suggest that innovative design and construction is needed to reactively or proactively operationalise adaptability and circularity in buildings.

The literature offers descriptions of barriers that prevent effective adaptation of a building or structure, most commonly, the lack of records or information on the existing building (Fernandez, 2020). Others have reported that there are often errors, or inconsistencies, within documentation that may be available (e.g., Hamida and Hassanain, 2022). Without reliable and verified information on the existing building, an assessment of the quality of materials used in the construction of the asset, including their structural capabilities, cannot be undertaken. The condition of the existing structure is also cited as a barrier to effective adaptation; precisely "lack of physical flexibility due to the layout of the structural system" (Hamida and Hassanain, 2022, p.642). An inability to assess the ability of the existing structure to accommodate newly imposed, or increased loads is also a significant constraint on available options (Hamida and Hassanain, 2022).

Beyond the direct structural constraints offered by the building, difficulty in complying with legislation, the need to maintain cultural or heritage value of the asset, and financial constraints are also noted as barriers to effective adaptation (Hamida and Hassanain, 2022). These barriers are also indirectly influenced by the structural capabilities of the building.

Decisions on options for adaption require input from multiple stakeholders and specialist advisers. A key enabler of effective adaptation is the integration of knowledge and practices among primary stakeholders - in particular, during the early design phase, the promotion of client engagement with the design process, frequent budget reviews and early indication of the proposed architectural program and enabling a response by all primary stakeholders. During implementation of the works on site, they recommend competent supervision of site activities and adherence to QA/WQC procedures (Hamida and Hassanain, 2022).

Structural Information needs and requirements

Decisions on interventions to be made are often complex and multi-faceted (Oliviera et al., 2021), but most are either directly, or indirectly, influenced by the capability, or otherwise, of the existing structure to facilitate change. For example, changes of the use of the building may require changes in loadings applied to the structure, and changes in space planning within the building may require additional partitions or new building services to be installed, each with a significant influence on the existing structure. The need for adequate information on the existing building structure is key, therefore, to enable an effective contribution by the structural engineer to early discussions on the opportunities for, and risks to, sustainable project outcomes, and decisions on the viability, practicality and utility of the project.

At this stage of a project, critical, value based, investment decisions are often being made, but which are frequently informed by, or need to rely on, incomplete, or potentially inaccurate, structural information (Hamida et al., 2023). Several authors have reported on the impact of such errors within information used within early stage design and project decisions, how these become apparent in the later stages of the project, and the adverse influence they can have on project outcomes (Hamida et al., 2023).

An idealised listing of, and commentary on, information sources that should be consulted by the structural engineer during the appraisal of an existing structure has been made available (IStructE Appendix A, 2010). Table 1 presents a summary of the listing.

Table 1 Information to be consulted by the structural engineer (Source: IStructE Appendix A (2010)

Sources	Information
Primary Sources	building owners, building occupier(s), owners' and occupiers' professional advisers (solicitors, managing/estate agents/facilities managers, consulting architects, engineers, surveyors, insurers), original structural designers, other original design team members (architects, services consultants, quantity surveyors, building or party wall surveyors), adjoining owners (party wall agreements), contractors, maintenance and;
	defects data, including – with appropriate caution – anecdotal accounts, designers and contractors for refurbishment(s) or major alteration(s), Building control authority (or other warranty providers, etc.), public utilities and statutory undertakers, record offices and archives in which original drawings and other documents have been deposited and other specialist sources
Secondary Sources	topographical information, insurance plans, site and building history, geological data, constructional information (held in public or private databases)

A further paper by Fernandez (2020) illustrates a structural engineering-based approach for determining the opportunities offered by an existing structure at the early feasibility stage of a project. Fernandez notes that " it can be easy to simply focus on the risks and problems associated with keeping it, rather than the potential rewards" (p.15). Efforts should be made to explore, with the client and others, the reasons for the proposed project – questions such as 'What are the client's drivers? Why are they unhappy with their existing building?' are good starting points for discussions. Fernandez notes that "Drilling down into the detail of a client's specific issues can often inform a solution that doesn't necessarily involve demolishing and building a new" and that, following a desk study, "Carrying out a thorough early assessment can reveal exciting opportunities which can add significant value and might have been missed if reuse was not considered". This inquisitive approach to the background to the project and exploration of opportunities that the existing structure may offer is an essential means of achieving the most sustainable outcomes for the project. Whilst gathering desk-based data is of significant benefit to decision-making at the earliest stages of a project involving the rehabilitation of an existing building, validation of assumptions made is necessary, via intrusive investigations, or other on site testing (e.g., load capacity testing). Investigations are also required to determine the condition of the existing structure, especially where this is concealed behind finishes or otherwise inaccessible. Investigations also help to de-risk a rehabilitation project, which may be beneficial in resolving any procurement or contractual issues that could arise.

AUTHORS VIEWPOINTS

Opportunities for improvement: Through the lens of a structural engineer

We have identified a few key themes on the nature of rehabilitation projects and the current practice contribution to these by the structural engineer. At the earliest stages of a project, barriers to enabling effective adaptation and to achieving the most sustainable project outcomes are largely due to;

- Difficulties in obtaining adequate data on the existing building or structure
- The requirement for multi-stakeholder understanding of the nature and form of the existing building or structure, alongside risks to the values held by the asset and support with multi-dimensional decision making to mitigate against these

We suggest that there are several key areas for which further understanding is likely to be of significant benefit to enabling the retention and effective adaptation of an existing building or structure;

- The involvement of all primary stakeholders, including the structural engineer, in determining and understanding the current values held by the asset and potential risks to these.
- Allowing the form and nature of existing building or structure, and feedback on its current use, to inform opportunities for increasing the value of the asset, &/or to mitigate against risk of obsolescence.
- Beyond gaining an initial base understanding of the form and nature of the existing structure, building owners and facilities managers could consider the collection of further data to be an ongoing process and to record information in an easily accessible manner – both tasks in close collaboration with the structural engineer. This would allow frequent reviews of the potential risk of obsolescence offered by the asset, and corrective interventions made.

Research Implications and further research directions

Our initial review indicates that decisions on the potential interventions within, or adaptations of, an existing building or structure are informed by a number of key factors. These include:

- the reasons for the need for adaptation or intervention (why the value of the asset has changed)
- the extent of the intervention needed to maintain or increase the value of the asset, (and which value is driving the intervention (i.e. societal, economic, cultural, use or functional))
- the opportunities available for adaptation of, and intervention within, an existing building or structure
- risks to achieving sustainable outcomes
- the requirement for the adaptation or intervention to be based on a whole life view of the asset, or a much shorter timescale

The availability of adequate information on the existing building or structure on which to base key early investment decisions is frequently problematic and can often lead to significant adverse issues that need to be dealt with during the later stages of the project. Inaccurate or incomplete structural information is frequently cited as being a significant barrier to effective adaptation of an existing building or structure and, consequently, to the sustainable outcomes of a project.

Our review of the literature has not, so far, enabled us to explore the methods used to present or represent available structural information, to the wider project team, at the earliest stages of a project and, therefore, the potential influence of this on decisions made by multi-stakeholder teams. The perception, by the wider team, of risks due to incomplete or inaccurate structural information may be a factor causing adverse issues in the later stages of a project.

Our initial review, and the industry experience of the first author, indicates that improvements within the collection of information on the existing building or structure could be made by promoting closer collaboration between structural engineers and facilities managers. This could then allow;

- Access to all information made available to the building owner and facilities managers at purchase or handover of the asset
- Access to all data collected during routine maintenance and performance of the asset in use
- Access to information collected from, or reported by, users or occupants, on the performance of the asset
- Advanced notice of the potential for a reduction in the value of the asset and early exploration of options available to maintain this and a review of information required to enable early decisions on potential investments in adaptations or interventions.

To further progress our research, we are intending to undertake the further reviews of the literature, including case studies of refurbishment and rehabilitation projects. In particular, we will examine: project team roles, reasons for interventions or adaptations, collection of information on the existing building or structure, (re)presentations of structural information, dealing with information gaps, risk management, multi-stakeholder decision making etc. We are also intending to undertake longitudinal studies of projects involving the adaptation of buildings or structures to establish what (and how) additional structural (and other) information can be collected during and following adaptation works, in collaboration with facilities managers. We would like to determine the benefit of this additional information for future investment decision making by building owners and facilities managers to maintain the value and relevance of the asset, in the medium and longer term.

CONCLUSIONS

This viewpoint paper has aimed at exploring the type of structural information needed for the rehabilitation of buildings and the role of structural engineer at the design stage in collecting such data. Firstly, an understanding of current industry practice with regard to the rehabilitation of an existing building or structure, including the reasons for obsolescence, interventions available, information requirements and barriers to effective adaptation has been obtained. In general, the reasons for the implementation of a rehabilitation project are to maintain the value of a building or structure and thereby avoid obsolescence. From a sustainability perspective, adaptation is preferred to demolition and redevelopment, which may be given further statutory emphasis, due to the urgent need for the built environment sector to better respond to the climate emergency. Project teams will need to ensure that any interventions made to maintain the relevance and value of a built asset can be effectively undertaken with accepTable social and environmental limits. Interventions available are several, yet, beyond sustainability demands, all will need to assessed against a range of criteria including physical, functional and economic criteria. Consideration should also be given to the growing need for any intervention to be part of the circular economy, i.e. as part of the 'circular building adaptation' agenda. This suggests that an intervention not only deals with the current loss of value to the asset but also prepares the building or structure for the ineviTable next intervention, to again respond to a value challenge. Secondly, barriers to effective adaptation are several, and which tend to focus on two key areas: (1) availability of adequate information on the existing building or structure, and (2) the need for multi-stakeholder engagement with key decisions, especially early in the project cycle, have been suggested. The implications, from the structural engineers perspective, are that more effective, sustainable and efficient adaptations to existing buildings and structures - and early warning of potential reductions in value of the asset - could be achieved via the following;

- Earlier engagement, by the building owner or facility manager, with the structural engineer to enable access to all relevant information on the existing building or structure, both archival and that collected during routine maintenance, or ongoing performance monitoring etc.
- More formally enabling the form and nature of the existing building or structure, to inform opportunities for improvements in, and mitigate against risks to, the value of the asset.
- Considering the information gathering phase of a project to be part of a continuum of data collection on the asset - collecting such information prior to, throughout and beyond the immediate project lifespan.
- Undertaking frequent reviews of the risk of obsolescence of the asset and potentially mitigating against these via ongoing adaptations.

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Show Me the Backlog! Opportunities to Improve UK Public Sector Maintenance Investment Planning

O'Hara, R., Jones, K., & Wanigarathna, N.

Anglia Ruskin University
Contact: rpo113@aru.ac.uk

ABSTRACT

Background and Aim. The study considers why UK public sector property/FM managers do not invest adequately in their existing portfolios. The public sector routinely constructs built assets and then struggles to maintain them, resulting in investment backlogs and long-term liabilities. Underinvestment in existing assets drives financial inefficiencies and premature obsolescence, with late investment costing more. This study presents insights into the practice of growing investment backlogs and how current practices can be improved.

Methods. Study 1 employs content analysis to examine the extent to which UK public bodies recognise maintenance backlogs through their published estate strategies and other documents. Study 2 examines the experience of six senior public sector property professionals involved in property maintenance and facilities management, drawing on semi-structured interviews, to provide practice-based insights.

Results. Study 1 demonstrates the absence of publicly available cost plans for addressing maintenance backlogs and long-term liabilities. Study 2 identifies a series of deficiencies associated with current practices, including but not limited to short-termism, difficulty in delivering change, lack of leadership and prioritising wants over needs. With each deficiency ultimately representing an opportunity to improve current practices.

Originality. The paper suggests current property/FM outcomes can be improved through greater transparency of backlogs and long-term liabilities, and a greater emphasis on evidence-based decision-making.

Practical or social implications. Underinvestment increases maintenance costs for future generations and creates risk for public service delivery in the shorter term.

Keywords. backlogs, built asset management, facilities management, just transition, public estate
Type of Paper. Technical

INTRODUCTION

This technical paper originates from a perplexing and persistent problem, best articulated through one simple question, why do public bodies in the UK construct assets and then fail to maintain them? This perplexing practice appears increasingly at odds with contemporary concepts such as circularity within the built environment, the requirement to transition to net-zero, just transition theory and sustainable development (KPMG Economics, 2017., Climate Change Committee, 2019., Sneddon, 1988., Meadows, 1972., Kirkpatrick & Smith, 2011., Grub & Wentworth, 2023).

The relationship between the built environment and the climate crisis is explained by the World Green Buildings Council (2019). Buildings are responsible for 39% of global carbon emissions, decarbonising the sector is one of the most cost-effective ways to mitigate the worst effects of climate breakdown. Carbon emissions are released not only during operational life but also during the manufacturing, transportation, construction, and end of life phases of all built assets. These emissions, commonly referred to as embodied carbon, have to date largely been overlooked but contribute around 11% of all global carbon emissions. Until such time as new ways of constructing buildings are identified that generate significantly reduced carbon, or carbon sequestration is deployed at scale, construction activity must be considered as a challenge to the UK 2050 net zero target.

The World Conference in Rio de Janeiro (1992) recognised that existing production and consumption systems will lead to a global catastrophe. The current approach to producing and consuming built assets in the UK, and the associated underinvestment in maintenance, is inconsistent with sustainability theory (Our Common Future, 1987). An argument exists to suggest the public sector should not build more assets than it can afford to maintain and maintain fully the assets for which it is currently responsible, thereby delivering "…development that meets the needs of the present without compromising the ability of future generations to meet their needs" (Our Common Future, 1987).

The UK Public Sector appears to have developed a custom and practice of underinvesting in existing assets. By way of example, in 1996, the repairs backlog for English Registered Social Landlords was estimated at £19 billion (DCLG, 2008). The 2021 Department of Education Condition of School Buildings Survey in England estimated remedial works valued at £11.4bn. Similarly, in 2021-22 the NHS Estates Returns Information Collection (ERIC) estimated the total cost to eradicate maintenance backlogs was £10.2bn, representing an 11.0 per cent increase since 2020-21. It appears the public sector routinely provides built assets and then fails to maintain them, resulting in significant investment backlogs, potentially creating the conditions for any number of unintended consequences linked to the under investment in existing assets, including premature asset replacement which fuels carbon emissions. Current practices manifest in the premature deterioration of existing asset inventories (Shahin and Walther, 1990., HM Treasury, 2020) and a weakening of the wider economy (Percoco, 2012) as well as increased carbon emissions (World Green Buildings Council, 2019). Such practices are both bad for the environment and bad for the economy.

Existing building and infrastructure stocks are an important source of social, physical, economic and cultural capital for any country or region (Kohler & Yang, 2007). The maintenance and repair of buildings is a significant contributor to the wealth and wellbeing of the UK. New estimates from the 'Economic significance of maintenance report', compiled by the BCIS in 2022, shows the value of the building maintenance market in 2020 was circa. £64bn, more than £1.23bn a week. This would value the UK FM market at around 7.15% of UK GDP.

Two pilot studies were conducted to explore why public sector asset owners in the UK do not invest adequately in their existing assets and why they do not prioritise investment in the decarbonisation of existing assets.

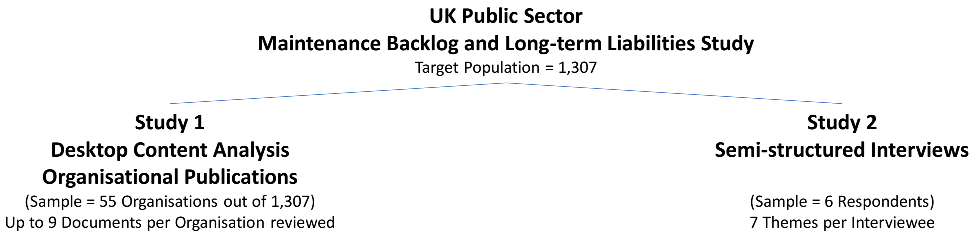

Figure 1 Summary of Study 1 and Study 2

In summary, this study considers the extent to which public sector organisations are planning to address current maintenance backlogs and long-term investment liabilities associated with issues such as decarbonisation, and the various factors that feed into resource allocation decision-making. It seeks to understand better the way public sector organisations plan and prioritise resources across the UK public sector estate, and specifically why public sector organisations build assets and then fail to allocate adequate resources to maintain them.

LITERATURE STUDY

Built assets appears to have been repurposed as a machine for economic growth (a.k.a GDP) rather than a machine for servicing human need (Kirkpatrick & Smith, 2011). Simultaneously, as a species, we appear to be living beyond the capacity of the biosphere (Milo et al, 2020). Annually the world reportedly invests circa \$2.5 trillion in critical infrastructure. Yet this level of investment falls short of our ever-expanding requirements by at least £350bn per annum (McKinsey Global Institute, 2016). The interplay between an unsustainable demand for assets and a compromised biosphere manifests as compromised built asset systems, which if replaced or renewed based on current construction practices will exacerbate climate change further. Rehan et al (2020) therefore argue that new “sustainable infrastructure” is required, triangulating new knowledge, innovation and transformational change dynamics to achieve and support a sustainable future. The 2013 McKinsey Global Institute report entitled ‘Infrastructure Productivity’, highlights three prevailing paradigms of the time, which in part explain why unsustainable practices may have taken hold:

1. future investment need is forecast based on historic spend rather than validated ‘bottom up’ estimates,
2. the methodologies employed to forecast future investment need exclude maintenance backlogs, indicating a disregard for the existing assets and their investment requirements, favouring new infrastructure, and
3. a political and public discourse exists focused on the adequacy of available financing to meet the rapidly growing infrastructure needs without consideration to matters such as the climate crisis and the transition to net-zero.

These insights portray outdated perspectives, biased towards the pursuit of unsustainable growth, and indeed potentially support the deployment of capital finance to build new assets rather than maintaining existing assets. Failing to give consideration for what is already built, and how to protect the inherent value(s) within existing asset inventories (Coyle, 2017).

Saeed and Shafqat (2017) propose an alternative in the form of sustainable infrastructure, which "involves conceiving, designing, constructing, operating, maintaining, and when needed, repairing and rehabilitating the existing infrastructure facilities to maintain or upgrade the existing social, economic and environmental conditions in any community to ensure human equity, and sustainable functioning of the community, resulting in an improved quality of life for all citizens". To achieve such an ideal a paradigm shift is potentially required, moving from the current practice of "design, build and forget", to a more sustainable approach based on design, build and maintain over the entire service life. The imperative for a new paradigm was recently endorsed by the World Bank, in June 2023, which stated "climate change has amplified the call for a new perspective on public asset management".

KPMG Economics (2017) indicate that public sector capital stock is 'consumed at a rate of about 2.5% p.a.' and that, ignoring inflation, 2.5% p.a. is required just to maintain and operate the public sector asset base. However, capital spend just equivalent to depreciation does not maintain the 'status quo'. New and emerging demand for built assets, fuelled by factors such as population growth, innovation, environmental degradation, and economic growth create a 'capital formation gap'. In conclusion, KPMG recommends that public sector capital investment should average between 5.5% and 6.0% p.a. of capital value. This insight is helpful in suggesting a potential minimum level of capital investment.

In the aggregate, the grey and academic literature reviewed indicates that shifting to a new paradigm requires the acknowledgement of natural limits and the active minimisation of waste and inefficiency. Henderson (2015) suggests that leaders will be required to find a way of managing the tension between 'exploitation' and 'exploration' i.e. the discontinuities between the status quo and the new alternative future. Bresnahan (2012), Christensen (1997) and Tushman & Romanelli (1985) explain that one of the reasons we fail to address such discontinuities is that investments in the future are rarely immediately profiTable and convention requires immediate short-term returns. Transformative investment, by way of contrast, requires a sophisticated understanding of the risks entailed in doing nothing. Malekpour et al (2017) explore why strategic planning for built assets represents a major challenge and why it frequently returns unsustainable outcomes and that little is known about how investment planning processes are undertaken in practice. Importantly this work acknowledges that investment in built assets continues to have adverse social and environmental impacts resulting in a divergence between vision and practice. Malekpour et al (2017) conclude that decision-making for investment in built assets always entails trade-off relating to conflicting objectives, multiple uncertainties, and irreducible uncertainties. Pantzartzis et al (2016) identifies capital and revenue availability as critical to achieving long-term interventions for backlog maintenance and that capital availability remains the main constraint.

METHODS

Study 1: Content analysis and thematic analysis

Study 1 adopted content analysis to acquire insights into the commitments UK public sector organisations have made in relation to investment backlogs and long-term decarbonisation costs. Content analysis is a popular and rapidly expanding technique for quantitative research (Neuendorf, 2017). This was achieved through the desktop analysis of publicly available documentation to examine the frequency distribution of phrases (Dicle & Dicle, 2018). Word (phrase) frequencies detail how often specified words (phrases) are found in the text documents. The omission or infrequent use of expected words (phrases) may also be meaningful for some research purposes (Drisko & Maschi, 2015). A problem-driven analysis approach was adopted, based on a desire to know something currently inaccessible and the belief that analysis of potentially available texts and other data could provide answers (Krippendorff, 2019).

A long list of local and central government public bodies was compiled estimating 1,307 public organisations across the UK, excluding Health Trusts and other Health related organisations because of the implications for the Anglia Ruskin University Stage 1 Ethics application. Probability (systematic) sampling was adopted (Gray, 2022) to select subject organisations. Given that the subject matter is 'UK public bodies' the target population was felt to be broadly homogeneous. To avoid oversampling a systematic sampling approach was adopted, targeting every 24th organisation. In terms of sample size statistical significance was not sought, so a sample of 55 public sector organisations in total was considered sufficient to allow for external statistical generalisations (Leech & Onwuegbuzie, 2007).

Table 1 Estimated number of Central and Local Government Organisations which formed the Target Population (Health related organisations removed for ethical reasons)

Jurisdiction	Nr. Central Gov Organisations	Nr. Local Gov Organisations	Target Population
England & Wales	646	377	1023
Northern Ireland	151	11	162
Scotland	90	32	122
Total	887	420	1307

Once the subject organisations were identified their websites were searched using the search criteria (words / phrases) in Table2. Each document identified was then reviewed in detail using a document analysis framework.

Table 2 Criteria for website document search

Maintenance Plan	Condition Survey
Capital Investment Plan	Decarbonisation Plan
Business Plan	Climate Action Plan
Estate Strategy	Accounts
Asset Strategy	

Study 2: Semi-structured interviews with senior public sector staff

Study 2 adopted semi-structured interviews combined with thematic analysis. A semi-structured interview framework was developed to support the interview process, drawing from the reflective analysis of the researchers and the literature review. Unlike structured interviews, the semi-structured interview methodology is more flexible and fluid in nature. Thematic analysis was employed to draw inferences by systematically and objectively identifying characteristics (classes and/or categories) within the transcribed interviews (Priyadarshini, 2020).

The recruitment process for subjects involved drawing up a list of senior professionals (Appendix A) know to the researcher that work in the UK public sector, representing a purposeful sampling methodology, which is consistent with the fact both studies are pilots, and do not seek to generalise to population level, but instead aim to develop an examination of the phenomenon observed, delivering practice-based insights. Therefore, a purposeful sampling strategy and method was felt to be appropriate (Gray, 2022). All participants had a minimum 5+ years' experience of working as a senior UK public sector property professional, with 'senior' defined as Head of Division, Assistant Director, or Director. To minimize costs, 'Voice over IP' (VoIP) technologies (specifically Microsoft Teams) were adopted as the Interview platform to facilitate and record the interviews. This approach maximised auditory and non-auditory communication and negated the risks, costs and challenges associated with face-to-face interviews.

RESULTS

Table 3 demonstrates that only one out of 55 organisations sampled had a condition survey available to the public, based on searching the organisations extranet (public website). Overall, the availability of documentation, based on the search criteria, was patchy and inconsistent, with no single organisation making available a full suite of documents covering estate strategies, investment plans and climate action plans. Less than 10% of organisations examined had an Investment Strategy, Condition Survey, Decarbonisation Plan, Estate Strategy or Maintenance Plan publicly available.

Table 3 Summary of Local Government and Central Government documents publicly available on the corporate website (Sample Nr. = 55 organisations). See Appendix B for graphical interpretation

Document (Criteria of Selection)	Document Located "Yes"	Document Located "No"	Total
Asset Strategy	15	40	55
Business Plan	12	43	55
Capital Investment Plan / Strategy	5	50	55
Climate Action Plan / Strategy	12	43	55
Condition Survey	1	54	55
Decarbonisation Plan	1	54	55
Estate Strategy	5	50	55
Maintenance Plan	2	53	55
Statement of Accounts	31	24	55
Total	**84**	**411**	**495**

Table 4 illustrates that of the 84 documents examined, although 16 organisations mentioned backlogs, only one provided any quantification and it was presented in a way that meant the full financial liability was not clear. Similarly, 30 organisations referred to investing in decarbonisation over the long-term, yet none of the documents analysed provided any quantification of the long-term costs of decarbonisation.

Table 4 Questions asked of each Local Government and Central Government document and the corresponding result (Sample Nr. = 55 organisations). See Appendix C for graphical interpretation

Document Analysis Framework Question asked of the Document	Number of Documents (from a sample of 84) that addressed the question	Number of Organisations (from a sample of 55) that addressed the question
Q1. Reference investment backlogs?	19	16
Q2. Quantify investment backlogs?	13	12
Q3. Commit to reduce investment backlogs?	15	14
Q4. What is the quantified backlog?	1 org. / 300k p.a.	1 org. / 300k p.a.
Q5. Reference investment in decarbonisation?	50	30
Q6. Quantify investment needed to decarbonise?	1	1
Q7. Commit to decarbonise existing assets	17	16

Six study subjects were asked to consider seven themes through a semi-structured interview protocol (Appendix D), specifically, (a) understanding investment need, (b) structuring of budgets, (c) strategic priorities, (d) culture, (e) choices (decision-making), (f) professional practice, and (g) leadership. Appendix E summarises the detailed insights and findings arising from the interview process. Key findings are described next.

VALIDATION OF UNDERINVESTMENT: All six interviewees confirmed that they are either aware of a public sector asset portfolio that is suffering from a significant under investment, or they themselves are currently operating a public sector portfolio suffering from under investment. The responses from interviewees suggest this practice is in part attribuTable to organisations failing to follow their asset strategies, budgets dictating spend rather than asset condition, insufficient asset information, evidence not being acted upon, and portfolios being too large relative to the funding available. In the round the behaviours, decisions and practices described could be considered unsustainable, with asset inventories requiring greater levels of investment than budgets can support, perhaps acting as a prompt for asset inventories to be reduced in size to fit the budgets available.

ENABLERS: The provision of dedicated budgets and staff resources along with condition-based maintenance planning were identified as key enablers. One interviewee described a situation where one organisation changed its approach dramatically, improving the viability and sustainability of the asset portfolio through the introduction of (1) senior sponsorship/leadership within the organisation, (2) making maintenance and decarbonisation a strategic priority, and (3) changing budgeting processes by providing dedicated funding for backlogs and decarbonisation.

BLOCKERS: The range of blockers recorded were significant, with most being mentioned by at least a couple of the interviewees:

- Skills and competence: decision-making that prioritises short-term cost efficiency because economists and accountants are not comforTable paying the premium that must be paid for green outcomes at this point in time. As a result, short-term costs are prioritised. In addition, property functions frequently sit under senior staff that do not have a professional background in property negatively influencing decision-making.
- Politics and lack of public understanding: politics was cited as a blocker along with the fact that society does not always prioritise what is good for it, or indeed appreciate the risks of not doing the right thing.
- Appetite for risk and change: the stakeholders that control and allocate budgets are risk adverse and have a predisposition towards tried and tested solutions.
- Unsustainable practices: conditions that allow political preferences to override evidence and fact. Conditions that create an internal market for funds leaves the property function competing for money against other more gratifying ways of spending funds.
- System based approach: The failure to take a system-based perspective also creates problems, interviewees recognised the failure to manage asset supply, demand, utilisation and funding at a broader level.

UNSUSTAINABLE PRACTICES: A few interviewees suggest that acknowledged wisdom does not appear to be finding its way into day-to-day practices. For example, the pursuit of revenue savings is destroying capital value, there are no long-term sinking funds for the operational phase of assets although business cases assume the monies will be available. Whole life costing (WLC) is not embedded into the business case process the way it should be. Other insights include the failure for capital plans to embrace the sustainability agenda instead working to minimum statutory standards. Rents or budget allocations fail to keep pace with inflation and as a result assets are underinvested in.

SUSTAINABLE PRACTICES: Interviewee responses contained limited insights into sustainable practices, suggesting that current approaches are generally not sustainable. There was a recognition among interviewees that organisations need to do more to protect the capital value of assets and to start to decarbonise the public estate, scale back on new build channelling more resource into existing assets (not reducing spend but simply redirecting monies), use evidence for decision-making and use evidence more rigorously to inform resource allocation generally.

LEADERSHIP: Opinions tended to relate to championing change, confronting the tensions that exist between the status quo and a new paradigm, as well as making tough decisions.

CULTURE: A series of systemic cultural failings are captured in the detailed transcripts which could be summed up as a system wide failure to act in the long-term public interest, which in part links to short-termism and a deficit in leadership, as well as an aversion to risk and change.

PROFESSIONAL PRACTICE: A series of damaging practices were identified including budget cuts, investing to minimum standards, opportunities to rationalise holdings not progressed, the dominance of short-termism, a propensity to demolish, continuing to allocate monies to activities such as road building, finance and accounting standards, and financial regulations and practices that are not conducive with the sustainable provision of assets.

GOVERNMENT & POLITICS: Views and opinions relating to this consideration potentially suggest that the machinery of government is more oriented towards addressing short-term issues or localised issues, and the processes and nature of government and approach to funding is not best suited to dealing with a challenge that stretches out over decades (such as backlogs and long-term liabilities linked to decarbonisation), because decision-making and budgeting in practice has a short-term bias, operating on an annualised basis.

OTHER POINTS RAISED: Inflation is exacerbating the problem, there are delivery issues, and the planning horizon of 2050 is too far away for many stakeholders to engage with.

DISCUSSION

Study 1 suggests the challenges associated with existing backlogs and long-term asset liabilities are perhaps not as central to asset management and facilities management plans, strategies, and practices in the UK public sector as they should be, at least within the documents examined. Similarly, although there are clearly good intentions relating to decarbonising the public estate, there does not appear to be any tangible or visible dedicated funding allocated to this activity, at least within the organisational documents examined.

Study 2 presents a broad suite of views from practitioners which generally validate the 'design, build and forget' phenomena postulated by Saeed and Shafqat (2017), confirming underinvestment in existing assets is regrettably common practice.

Returning to the question of why public sector organisations in the UK build assets and then fail to maintain them accumulating long-term liabilities. Based on the research conducted, multiple factors appear to feed into this phenomenon including custom and practice, lack of understanding of the risk of underinvestment, absence of quantification of the problem, the negative impacts of political influence, short-termism, difficulty in delivering change, lack of leadership, aversion to risk, lack of transparency, prioritising wants over needs, too many assets and not enough budget, and individuals with the wrong skills making the decisions.

If we consider what investment backlogs UK public sector asset portfolios typically carry and what commitments asset owners are making to address investment backlogs and long-term asset liabilities. This research suggests the scale and extent of the backlog issue across the UK public estate is not fully understood, as there is no single source that provides an overarching assessment of the situation, unlike the dataset in the USA that quantifies the issue at a national level, the 'USA Infrastructure Score Card'. That said, there are examples of good practice at portfolio level, as evidenced the 2021 Department of Education Condition of School Buildings Survey in England and the NHS Estates Returns Information

Collection (ERIC). Although there is no doubt that backlogs and long-term asset liabilities exist, a fact validated by all six interviewees, to what extent they are being actively managed and reduced is not clear. For this reason, maintenance backlogs and long-term investment liabilities associated with challenges such as delivering net zero should increasingly be considered a risk to the provision of public services.

Study 2 interviewees suggest that asset/facilities management outcomes can potentially be improved through greater transparency of investment backlogs and decarbonisation costs combined with a greater emphasis on evidence-based decision-making.

In combination, Study 1 and Study 2 suggest there may be a disconnect between, what organisations describe in terms of their outcomes and ambitions, as articulated in their published asset plans and strategies, and what is being delivered in practice. As a result, current practices appear to facilitate unintended consequences including premature asset obsolescence (or asset failure) linked to underinvestment and over provision.

CONCLUSIONS

In combination Study 1 and Study 2 point to a gap in knowledge (why does under investment happen?) and a deficiency in current professional practice (why do we let it happen?). The phenomena of underinvestment in existing assets is validated through this study, and a series of behaviours and practices that allow good intentions to flounder have also been identified. It is apparent that current asset management practices are not sufficiently transparent to make the risks and issues associated with under investment visible to all stakeholders. Equally, activities and behaviours that support sustainable outcomes have been recognised to represent an opportunity for improving professional practice. The research conducted ultimately supports the view that professional practice and guidance could be evolved to respond to the issues associated with backlogs and long-term asset liabilities, and in doing so, support the effective, efficient and sustainable delivery of public services in the longer-term. Both studies support the view of the World Bank (2023) that a paradigm shift is required moving forward in relation to public sector asset management. Opportunities for further research include studies that increase transparency of investment need at a portfolio, national or international level, the relationship between underinvestment in asset portfolios and carbon emissions, balancing asset supply and affordability, the processes and policies that underpin capital allocations and the risks associated with underinvestment in the public estate.

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Appendix A Study 2 Interviewee relationship to Study 1 organisations

Study 2 Interviewee	Local or Central Government	Jurisdiction	Was the Interviewee's employer sampled as part of Study 1
Interviewee 1	Central Government	England	No
Interviewee 2	Local Government	England	No
Interviewee 3	Local Government	England	No
Interviewee 4	Central Government	Northern Ireland	No
Interviewee 5	Central Government	Northern Ireland	No
Interviewee 6	Central Government	Northern Ireland	No

Appendix B Graphical presentation Study 1 results (Data sourced from Table 3)

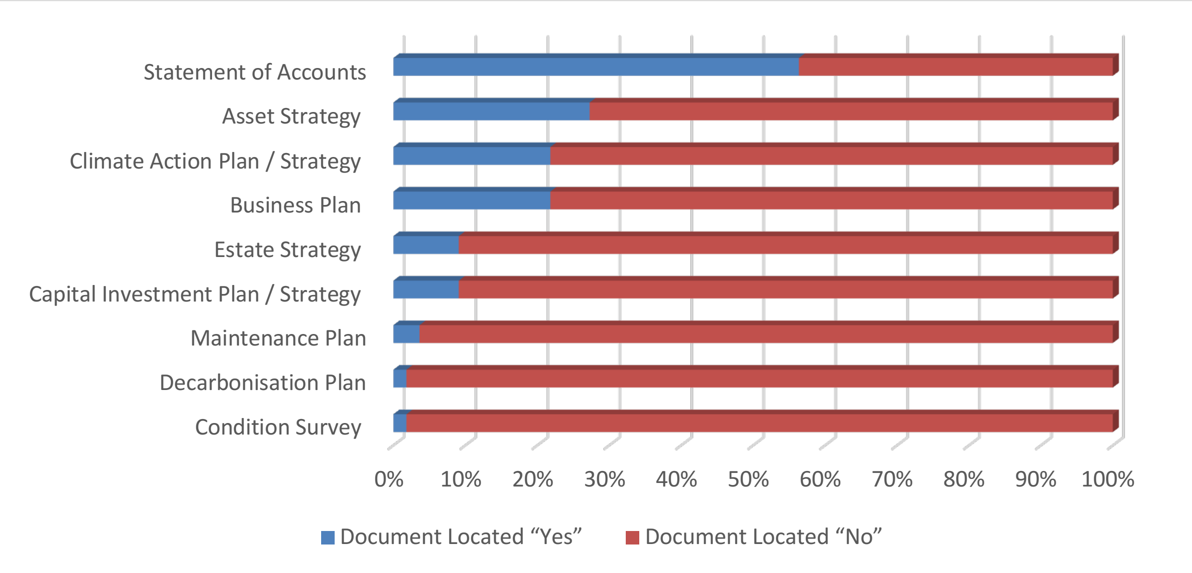

Figure 1 Percentage of documents publicly available on UK Local Government and Central Government corporate website (Sample Nr. = 55 organisations)

Appendix C Graphical presentation Study 2 results (Data sourced from Table 4).

Based on reviewing the publicly available documents (Condition Survey, Decarbonisation Plan, Maintenance Plan, Capital Investment Plan / Strategy, Estate Strategy, Business Plan, Climate Action, Plan / Strategy, Asset Strategy, Statement of Accounts) from the websites of 55 Local and Central Government organisations located in England, Wales, Scotland and Northern Ireland.

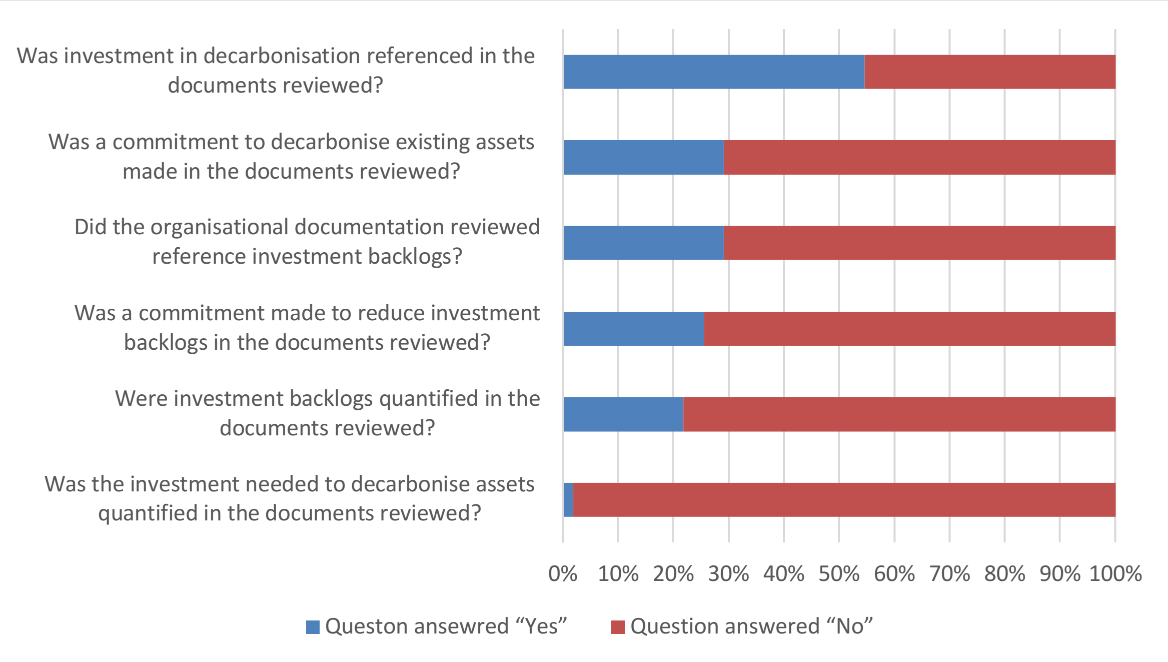

Figure 2 Percentage of UK Local Government and Central Government organisations (Sample Nr. = 55 organisations) that answered the following questions positively in the 84 documents examined

Appendix D Study 2 Semi-Structured Interview Framework

Theme	Example Questions
Context	• Portfolio managed i.e. size, nature, composition? • Annual budget: capital and revenue? • Priority given to backlog versus the new build programme? • Quantum of spend given to existing assets versus new build versus decarbonisation? • Decarbonisation plan?
1. Understanding Investment Need	• How is your organisation determining investment need across the assets that you own or manage?
2. Structuring of Budgets	• Are capital budgets clearly split into different buckets ie. (1) new build (2) maintaining existing assets and (3) decarbonisation?
3. Strategic Priorities for the investment planning process	• Are a set of 'investment principles' used to prioritise investment decisions? • Are some areas of investment being stopped to ensure that investment in decarbonisation can proceed? • Are existing assets being prioritised over and above new assets? • Is there alignment between organisational purpose, strategy, business models and asset provision?
4. Culture	• Does the organisation set evidence-based targets and is it transparent on how and where monies are invested? • Is sustainability embedded in budget planning decision-making?
5. Choices (decision-making)	• Are the risks of under investing in existing assets fully understood and quantified and publicised?
6. Professional Practices	• Do capital investment planning practices deliver better more sustainable outcomes? • Does your organisation ensure capital acts for the long term? • Is Whole Life Costing / WLCC influencing capital investment planning?
7. Leadership	• How does leadership manage the tension between providing new assets versus investing in existing assets? • Does leadership champion sustainability? • Does leadership prioritise or acknowledge future generations in decision-making?

Appendix E Study 2: Summary of themes and insights arising from the interviews

Theme 1. Validate Phenomenon No proactive asset management or maintenance plans. No thinking around (1) how we maintain assets, or (2) how we will replace them in the long-term. Many properties now need serious investment to bring them up to the right standard. We are not investing faithfully to the strategies that we set out. Not enough money to maintain the number of assets provided. Work is dictated by budget rather than investment need. Not enough money put into existing assets versus new build. We don't have the resources to decarbonise existing assets as well as maintaining them. Maintenance backlog of hundreds and hundreds of millions of pounds is commonplace. Income (or budget) is not sufficient to maintain the portfolio.
Theme 2. Enablers Retrofit can be cheaper (avoiding below ground risk and cost). Maintenance plans which incorporate zero carbon as the rationale for investment increasingly common. Multifaceted condition survey to assess 'where we are now' in terms of the asset base and the assets condition and functional suitability amongst other things and environmental performance costs, etc. Condition based maintenance planning looking ahead by 5 to 10 years. Separate protected and ringfenced budgets. Establishing a dedicated sustainability team. Investment projections looking forward 30 yrs. Securing high-level sponsorship and support from within the organisation. Making the maintenance of assets and decarbonisation a strategic priority. Making maintenance and decarbonisation a key decision-making criterion.
Theme 3. Blockers Make decisions based on cost which deliver a less sustainable outcome. Need to pay a premium of c. 20% for greener outcomes at the minute. Economists and the accountants struggle with the idea of paying more for a greener outcome. Historic schemes that haven't worked well make organisations risk adverse. Government / public sector is not good with risk and change. Public sector is struggling financially and our ability to borrow is tightening. Local and central government budgeting cycles force a short-term perspective. Good innovative ideas rejected because considered novel and contentious by government. Parish pump politics where everyone wants investment in their own geographic area regardless of the wider needs of society. An internal market where departments and functions have to compete for funds. The primary stakeholders, the citizen, do not prioritise investments in existing assets. People don't understand the risks associated with underinvestment. Decisions taken by leaders who may not have the appropriate background i.e. property sitting under corporate services directors. Budgets allocated with an operational bias rather than strategic. Priorities are set by organisations that do not actually look after the assets (department set NDPB and ALB priorities). Interventions made 20-30 years ago actually detrimental to the building fabric.
Theme 4. Unsustainable Practices Reactive spend has to be prioritised rather than preventative spend because of the extent of deterioration in the portfolio. Shrinking asset portfolio to deliver revenue savings rather than protecting the capital value. Evolving demand and therefore constantly shifting views on supply. WLC not adopted across the board in terms of business cases. The Green Book approach is a really good approach in terms of thinking about the whole life cycle but then actually once that property's built, there is no budget put aside to meet life cycle costs. Lots of asset management activity now managed by treasury and budget control and there is a real drive to bring down the level of investment for cost efficiencies (creating long-term liabilities). In terms of invest to save, spending now to prevent more significant failure costs at a later date, there is definitely an awareness of the principle, but it is not supported in practice. There is a tendency to 'kick the can down the road' leaving it for others to fix. Only when something gets to a level of failure does it become something that is invested in, rather than at the appropriate time, when indicated by a preventative maintenance plan. We have a fix on fail model. Budgets are fixed and the programme is built around the budget rather than investment need or customer need. We are storing up investment liabilities and creating a 'bow wave' which only becomes apparent when the actual investment need is calculated based on condition. Different properties sit in different portfolios with different budgets (creating silos rather than systems-based approach).

Budgets are in practice prioritised against operational need rather than strategic priorities.
Capital plans fail to accommodate the sustainability agenda - paying it lip service.
We don't prioritise ongoing maintenance.
Budget/rent rises failing to keep pace with inflation.

Theme 5. Sustainable Practices
We need to protect the capital value of our assets.
Get a better reinvestment into the buildings that we keep.
Start to decarbonize the estate.
Scale back on new build.
Use of evidence for decision-making and resource allocation.

Theme 6. Leadership
Need help to move past historic schemes that haven't worked well.
Prioritizing and championing decarbonization and maintenance of existing assets over new build.
There is no advantage to anyone to take a 30-year perspective (why face into the problems leave it for others).
Actively managing the tension between investing in existing infrastructure versus investing in new and different infrastructure.
Priorities are driven by 'what will the *demand* look like going forwards' rather than what is *needed.*
Making decisions that prioritise or consider future generations.
Ensuring a strategic approach to investment.
Gather the evidence and create and promote the case for change.

Theme 7. Choices
To decarbonise the estate requires difficult choices.
Zero carbon it is changing the debate.
We are still not taking the tough decisions and stopping some types of spend / investment.
The easiest thing is not to make a decision.
Some buildings like swimming pools are complicated and these are more suited for a new build programme.
Too many assets and not receiving enough money to care for them and leadership is not prepared to take the tough decisions.
Growing glut of town centre assets.
People seem blind to the fact that there only are so many pounds to go around (budgets finite).
If we used the business case process properly for new builds in many cases we would "never get beyond the assessment of need".
Organisations don't learn, they like having the money in the bank, not spending it on maintenance.

Theme 8. Culture
Government is not good with risk and change.
Accountable Officers have subjective views and exercise them.
Ministers influence outcomes with local priorities rather than strategic priorities.
Cultural and political reasons stop us doing the right thing.
We could affect the cultural change and the decision-making changes that need to happen quicker if we had greater transparency.
We need a rigorous and open-source monitoring system that shows exactly where and how money is spent.
In practice the political perspective does not support prioritising monies on sustainability and retrofit projects - nice new purpose-built facilities attract headlines and good publicity.
Public value associated with invested in mundane matters like new M&E is not explained and communicated.
Short-termism can't or won't see the big picture.
Nobody wants to innovate or take risks.
The assets flounder, they wither on the vine, because nobody wants to be criticised.
Gravitational pull of day-to-day operations too strong.
Inability to plan for the longer term.
Defer problems - deal with it another day.
Decisionmakers do not want to hear the truth,

Theme 9. Practices
Maintenance monies is always the first budget to be cut.
Rarely invest beyond minimum requirements.
Projects are not always faithful to the objectives they are meant to address.
Forecasting data is incorrect.
We are not changing where and when we deploy monies.
Opportunities to rationalize property holdings are not realised.
Business cases processed without considering to reusing space.
Decisions being made are short-term in their outlook.
Ensuring funding reflects the outcomes we want.
We are not investing for the long term.

Too quick to demolish. Monies not ring fenced for maintenance or decarbonisation. Monies flowing to the wrong type of capital formation i.e. roads Disconnect between those responsible for finance and accounting standards and the financial regulations that apply in a public body and the delivery of construction works. Works can't be delivered in a year. Accountants are “totally detached from reality”.
Theme 9. Government / Politics Still do political vanity projects. We do not prioritize anything over politics. If politicians are involved they will have a preferences based on political interest. Permanent Secretaries (Accounting Officers) will have preferences. Decision making occurs on a department by department basis - it should be centralized. Ring fencing budgets for strategic outcomes is not in the nature of the civil service and the political culture. Decentralisation is not necessarily supporting strategic outcomes. Why are we still designing new road schemes (where is the underlying growth and need). Parish pump politics surround the estate.
Theme 10. Other Net zero carbon target by 2050 - is too far away as a planning horizon. Our assets are withering on the vine because nobody wants to be criticised for taking tough decisions. If we did have the money how would we retrofit occupied buildings. There are problems with delivery. Budgets not keeping pace with inflation.

Resilience of Existing Buildings to Norwegian Climate Stressors

Øvstebø, Å.L., Temeljotov Salaj, A., Almås, A.J., & Bjørberg, S.

Norwegian University of Science and Technology
Contact: aadnelo@stud.ntnu.no

ABSTRACT

Background and aim. The scope of climate change with implications for the environment, health, and economy, makes it one of the most significant societal challenges today. Rapid climate changes can have dramatic consequences for existing buildings that are exposed to climates they were not originally designed for. A functional and reliable built environment is a prerequisite for societal economic growth and development. The aim of the study is to develop an assessment matrix for the building stock and its resilience to climatic conditions. The climate adaptation measures can also contribute to the NS-EN 17680:2023 standard.

Methods. A literature review has been conducted, aiming to identify literature addressing climate adaptation measures and characteristics of a resilient building, where the climate in Norway, and its challenges on buildings, have been central. The matrix is formulated based on key findings from the literature review.

Results. Key findings from the literature encompass various measures that can be implemented on existing buildings and areas that require attention to enhance resilience to climate change. Most measures are directed toward managing water-related events, such as heavy rain, water infiltration, rise of sea level and occasional flooding.

Originality. The novelty lies in identification of the assessment elements for climate resilience.

Practical or social implications. By conducting such a condition assessment, FM can classify the building's robustness and suitability to future climate stresses, which makes it easier to implement effective measures on vulnerable building elements.

Type of paper. Research (full).

Keywords. Climate change adaptation, condition analysis, existing buildings, FM, KPI, resilience.

INTRODUCTION

The first report from the United Nations Intergovernmental Panel on Climate Change (IPCC), highlighting the importance and consequences of climate change, was issued in 1990. Since that time, climate change has evolved into a global concern, and with each passing year, the imperative to implement measures against climate change becomes more pronounced. The scope of climate change with implications for the environment, health, and economy, makes it one of the most significant challenges humanity faces today. Climate change extends beyond just extreme weather events; it also encompasses gradual changes, such as rising temperatures and increasing sea levels.

In Norway, the anticipated impacts of climate change include warmer and wetter winters, fluctuations between plus and minus degrees during winter season, hotter and drier summers, and a heightened occurrence of intense rainfall and wind. The consequences of climate change can be profound for existing buildings, emphasizing the critical importance of a functional and reliable built environment for societal economic growth and development (Flyen et al., 2010). Buildings are now exposed to climates which they were not originally designed for (Phillipson et al., 2016). Future buildings in specific regions of the country are expected to face even greater challenges from changing climatic conditions. Particular attention is given to challenges associated with moisture due to the expected increase in precipitation and temperature (Grynning et al., 2017). A weather report from the Meteorological Institute in Norway notes that there was a 45% increase in rainfall nationwide in August 2023 compared to normal levels. The extreme weather event "Hans", contributed to over 100 rainfall records (Grinde et al., 2023), causing devastating flooding and landslides covering large size of areas. A study on sea-level rise in Norway shows that around 110.000 buildings are situated less than 1 meter from current sea level, being under risk of submergence due to rising sea level (Almås & Hygen, 2012). Based on the temperature and precipitation changes, in year 2100, 2.4 million of today's existing buildings in Norway will be situated in a climate zone with a high risk of rot decay (Almås et al, 2011). This is a significant increase compared to the 615.000 buildings located in this climate zone today. Extensive measures on existing buildings and strict regulations on new buildings/infrastructure are essential to prevent large economic losses in the future (ibid). Ingvaldsen (2008) indicated that the cost of repairing process-induced building defects in Norway amounts to 5 % of the annual capital invested in new buildings. Further, defects related to the building envelope constitute 66 % of the process-induced building defects. As much as 71 % of all the defect cases, are caused by moisture (Bunkholt et al, 2021).

Increased attention on climate adaptation in the building sector could therefore also have a significant economic contribution to society (Almås, 2013). The anticipated lifespan of the built environment ranges from 60 to over 100 years. To sustain it and ensure the sustainability of the new built environment, it is imperative to consider the heightened and altered climate stresses that buildings will face in the coming decades. With an estimated 80% of existing buildings still in use after 2050 (SINTEF, 2019), the resilience of existing buildings to climate change is therefore of high importance. In a study from 2018, 84 user guides and web portals dealing with climate adaptation were mapped and analysed. The study indicates that a large share of the guidance material communicates climate adaptation at a general level; the abundance of user guides does not automatically lead to better climate adaptation, and; there is a lack of user guides focusing on practical measures (Hauge et al, 2018). Due to climate variations in Norway, there is a significant difference in the stresses that buildings must endure, depending on their location.

Jones et al. (2021) developed a framework to provide a business decision tool to support pro-active mitigation planning to lower built asset vulnerability and increase resilience to earthquake disaster events. Based on the existing standards, Bjørberg & Salaj (2023) and Salaj et al. (2023) prepared guidelines leading facility managers through sustainable refurbishment standards and rules to make a clear decision about their concrete investments. The tools enable decisions about all three sustainability pillars and better decisions for health, well-being and quality of life. There is a need for a tool that will enable better decisions about resilience of the buildings in extreme situations, which could be connected to the standardized methodology. By evaluating different scenarios, facility managers can get a better understanding of the environmental hazards, risks and possible or needed maintenance improvements. Designing KPIs from the user perspective can become understandable enough for non-professional users and informative for professionals (Bjørberg &Salaj, 2023).

It is important to develop new and improved methods for assessing the risk associated with the potential consequences of changes in local climatic conditions. This will help identify vulnerabilities in existing buildings and find effective climate adaptation measures to increase resilience.

The aim of this paper is therefore to develop a matrix for assessing existing building stock and its resilience to future climatic conditions in Norway, where the key conditions involve increased precipitation combined with rising temperatures, which can lead to new moisture challenges for buildings. The matrix will primarily focus on exterior roofs, exterior walls, foundations, and adjacent building site. The resilience of these building elements is therefore central in this paper. To evaluate the resilience of existing building, it is crucial to establish a standardized analysis method. Furthermore, it is necessary to classify the buildings to facilitate the implementation of effective measures. This matrix will therefore positively contribute to facility management, as property owners, facility managers, maintenance managers, and larger organizations can use it to improve their building stock.

METHODS

This project is primarily based on findings from a literature search method known as a scoping review. The method aims to examine the literature within a specific theme with the purpose of creating a comprehensive overview of available knowledge. This includes the identification of key concepts and definitions, an evaluation of research methods that have been applied, and an assessment of any knowledge gaps within the chosen theme (Munn et al., 2018). The focus has been particularly directed towards identifying literature that evaluates and discusses specific measures and features of buildings that make them resilient to climatic stressors. This encompasses aspects such as the selection of materials, retrofitting techniques, design solutions, and other key areas related to climate adaptation. Emphasis has also been on finding information about climate conditions in Norway, building adaptation and protection against the most relevant climate stressors in the country.

Exclusion criteria

The purpose of this project is to develop a matrix that can be used to evaluate and classify a building's resilience to climate change, with a focus on building physics. Primarily, the project addresses vulnerabilities and measures associated with a warmer and wetter climate, where one can anticipate increased surface water, as well as moisture and rot damages to buildings. To achieve this scope, articles and topics related to climate adaptation in urban and spatial planning, infrastructure, governance, management, and energy efficiency in buildings were excluded from the project. Only articles published in the last ten years were included. The literature selection was adjusted in line with the aim to focus on the climate adaptation of Norwegian buildings, so publications addressing climate stressors on buildings in regions with different climatic conditions than Norway were therefore excluded.

Identification and selection of literature

To explore a broad spectrum of existing literature, it was decided to conduct comprehensive searches across multiple search engines and databases, so the following search engines were considered: Google Scholar, Oria, Scopus, Web of Science, and Elicit. Through systematic searches using various search strings with keywords, titles were reviewed to find articles related to resilience, measures, climate adaptation, and climate change. The flowchart in Figure 1 provides a visual representation of the search strings, associated keywords, and the results of searches in the search engines.

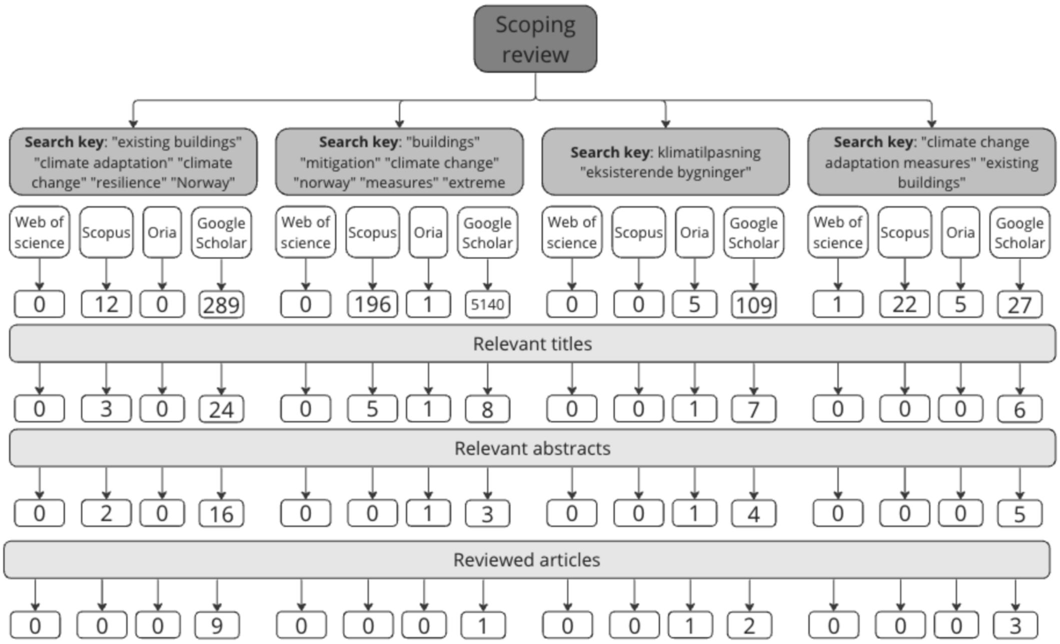

Figure 1 Flowchart of search engine results and literature selection (authors).

The results from Elicit are based on the research questions formulated for the project: i/ How to increase the resilience of existing buildings against climate change?; ii/ What specific measures need to be implemented to make and existing building resilient to natural disasters resulting from climate change?; iii/ How can the resilience of existing buildings be classified concerning climate change, based on the technical qualities of the building and the location of the site. Elicit is unique in its ability to generate an unlimited number of results; hence, specific figures for the total number of results or relevant titles are not provided. Searches in Elicit were conducted in both English and Norwegian to ensure broad coverage of relevant literature and to include potentially unique contributions from both language areas. 9 papers relevant abstracts were identified.

To further refine the search results, the authors conducted a manual selection process in three consecutive stages: i/ selecting the relevant titles; ii/ reviewing the abstracts, and; iii/ an in-depth analysis of the articles, with a comprehensive review and study of the content. If the article contained relevant material in line with the project's research questions, the content was used in the results section of this study. This manual selection process was implemented to ensure that only the most relevant and insightful material was included.

Matrix for assessing resilience to climate change

Weaknesses and vulnerabilities, which should be classified by the matrix, are defined for the building elements, which are exposed to climate change: roof, facades including windows and doors, basement, foundation, and the site where the building are situated. As a basic concept, the matrix from the standard EN-17680:2023 "Sustainable Construction - Evaluation of Sustainable Refurbishment potential" is used. It is established as a support tool to decide if an existing building can be sustainable refurbished (Bjørberg and Salaj, 2023). The standard consists of a methodology for assessing level of condition (an example in Figure 2). The classification is divided in classes of nonconformity: 0, None, 1, Minor or moderate, 2: Essential, and 3: Major or serious.

Table A.2 — Example of criteria for technical performance and performance classes based on technical inspection

Indicator	Class 0	Class 1	Class 2	Class 3
Foundation-load bearing system (Indicator 1)	Stable foundation founded on / to rock (piles). No risk or sign of settling damages. No sign of weakening of the structural system.	Small signs of settlement cracks, but stable	Stable foundation, a few signs of increasing structural damages. Small signs of weakening (spalling, cracks)	Unstable foundation. Signs of structural cracks or high risk of settlements damages. Signs of deflection or corrosion on reinforcement

Figure 2 Example of classification matrix. Ref.: EN 17680:2023

As a part of the study, for the climate resilience matrix, a decision is to examine the 6 indicators (Building envelope; Foundation; Internal Measures; Ground; Surface and External Measures; Layout; and Documentation), which are the most exposed for the climate change:

- Building: Extreme weather conditions (wind load, rain…), Materials and details of the envelope
- Site: Increase of sea level, Flooding, Landslide, Avalanche

RESULTS

This chapter will present the results of the literature review, and the findings addressing the aim of the study will be presented. These findings will be applied and utilized to develop a matrix that can be employed to assess the resilience of existing buildings to climate change.

Findings from the literature

As climate adaptation measures and the resilience of buildings to climate change are dependent on both the building's climate envelope and the surrounding area, they are presented separately. First, the main findings related to the building's envelope, and subsequently, the ones regarding the site, surface area, and solutions beyond the building envelope are presented. The descriptions present challenges and conditions facility managers are coping with in extreme situations.

Increased resilience of the building's envelope

Barrelas et al. (2021) indicate that solar radiation and wind-driven rain directly impact the degradation processes of facade materials. Facades are directly exposed to environmental stresses such as climate and pollution, making them vulnerable to defects that can result in reduced durability. Facade degradation affects quality, user comfort, and maintenance costs. However, it is essential to note the complexity of this context, as certain climate parameters are more relevant for some types of facade materials than others. For instance, extreme wind conditions are more relevant than average wind conditions in designing a facade. The intensity of driving rain may be more critical than the duration of precipitation events for facades with timber. Total ultraviolet radiation may also be more crucial for the lifespan of polymer materials than average annual temperatures.

External roof

Roof covering plays a central role in protecting the roof structure from water ingress and other external influences. The choice of roof covering significantly impacts the resistance of the roof, as the material affects both lifespan and durability. According to Building Acts and Regulations (DIBK, 2023b), roof tiles have a longer lifespan compared to roofing felt. Based on the research on damage cases, comparing cases in the last four years with those from the period 1993-2002, damage to the building's envelope constitutes 70% of the examined cases from the last four years (SINTEF). Over 30% of the damage cases are associated with flat compact roofs, and 40% are related to roof terraces (Rambæk, 2023). The importance of flashings, and roof overhangs in maintaining resistance to water ingress has been emphasized (Alfraidi and Boussabaine, 2015; Philipson et al., 2016; Barrelas et al., 2021).

At openings in the roof structure, flashings must be implemented to effectively prevent water ingress. To protect transitions from roof to wall, overhangs must be appropriate, helping prevent water infiltration at joints. Since a building generally constitutes a composite structure, transitions between different components are important. Undersized or poorly maintained gutters and downspouts pose a critical vulnerability (Flyen et al., 2014; Curtis and Snow, 2016), so to better manage intense rainfall, the adequate sizing is needed, regular maintenance, or even over-sizing elements with future climate stresses in mind. Flat roofs require special attention, with the need for a moderate slope and an effective drainage system to prevent water accumulation, especially in winter months when snow and ice can often block existing drainage systems. Integrated green roofs can enhance the building's resilience by acting as a measure for water delay and also contribute to a cooling effect (Stagrum et al., 2020).

Outer wall

The ability of materials to resist wind-driven rain and moisture varies, and for existing buildings, maintenance and rehabilitation measures are often crucial to improving their resilience (Barrelas et al., 2021). Alfraidi and Boussabaine (2015) emphasize adaptability of the buildings to meet future regulations and safety requirements, so the design should allow adjustment of building elements. Implementing moisture management system is an appropriate measure to regulate moisture level.
Windows and doors represent a critical point as they break the continuity of the facade. The use of flashings and overhangs are effective measures, helping to prevent water and moisture ingress. Placing a window deep into the insulation layer results in reduced cold bridge values, contributing to improved energy efficiency and indoor climate. Simultaneously, the window is better protected from precipitation as it is more sheltered by the facade. This solution introduces challenges related to moisture protection and protection against driving rain, as the installation becomes more complex. It requires careful design of rain and air sealing around the window. Alternatively, if a window is placed further out in the outer

wall, the risk of moisture damage to the wall below the window is reduced, and it may be considered more resistant to moisture damage. In flood-prone areas, the use of flood-resistant doors (Scott et al., 2022), preferably positioned above ground level, is an important measure to prevent water ingress. Alternatively, the door frame can be raised (Barrelas et al., 2021).

For buildings exposed to flooding and storm surges, it may be appropriate to use materials such as concrete, vinyl, ceramic tiles, and pressure-treated wood (Alfraidi and Boussabaine, 2015). Constructions with concrete outer walls, load-bearing walls, and floors prove to be more robust against moisture and water ingress compared to timber constructions (Flyen et al., 2014). For timber facades, it is advisable to use treated wood, such as pressure impregnation. Painting or other surface treatments to increase water resistance are also recommended (Barrelas et al., 2021; Scott et al., 2022). In general, The importance of implementing more durable materials is highlighted (Athauda et al., 2023), upgraded weather protection and insulation methods, as well as the development of advanced coatings and other safety measures aimed at minimizing the effects of moisture, UV radiation, and other environmental influences; and use of materials that are more tolerant to moisture and temperature fluctuations (composite materials, highly specialized coatings) or two-step sealing (Byggforsk, 2013).

Foundation

Like outer walls, concrete constructions show greater resistance to moisture and water ingress compared to timber constructions. To prevent water ingress into the foundation, a corrective measure may be to implement drainage sheet or a moisture barrier (Flyen et al., 2014). However, it is essential to note that concrete constructions are significantly heavier than timber, increasing the risk of settlements. Changes in the saturation level of the ground, influenced by significant amounts of water infiltration, can lead to an unsTable bearing capacity (Barrelas et al., 2021). A heavier construction will, therefore, be more susceptible to such events. Timber constructions, on the other hand, often have a lower likelihood of experiencing settlements. Nevertheless, it is important to note that through research on the adaptation of wood and existing wooden buildings to climate change, it was found that wooden building materials show a noticeable response to climate change (Stagrum et al., 2020). Alfraidi and Boussabaine (2015), Scott et al (2021)., and Scott et al (2022) mention in their articles that the height and depth of the foundation play a crucial role in the building's resistance to water ingress. A foundation exceeding the predicted flood height will effectively prevent floodwater from penetrating the building. In cases where the foundation is low, and the building is prone to external water ingress, a measure may be to raise the building. Increased resilience can also be achieved through deeper foundations.

Lykartsis (2019) has investigated the resilience of buildings to flooding and points out that complete prevention of water ingress or a "watertight construction" is challenging to achieve.

Two main strategies are recommended to improve the resilience of buildings to flooding, and the choice of strategy depends on the predicted flood height the property is exposed: i/ Water Exclusion Strategy for the predicted flood height below 0.3 m. The goal is to minimize water ingress, so effective building materials include engineering bricks, cement-based materials including water retaining concrete, and dense stones. ii/ Water Ingress Strategy for the predicted flood height over 0.6 m. The goal is to allow water into the building, promote drainage, and then drying. In that situation, the drying characteristics become crucial. It is essential to implement effective ventilation and drainage solutions to enable efficient water drainage without causing damage to the construction. This may involve facilitating drainage by having "holes" in the climate envelope, allowing water to exit easily (Alfraidi and Boussabaine, 2015). This strategy is like the water ingress strategy described by Lykartsis. Alternatively, the use of pumps may also be considered as another solution (Almås, 2013).

Increased resilience of the building's site

One of the most crucial measures to prevent water damage caused by external water ingress is to ensure that nearby surfaces have a slope away from the building, allowing for effective drainage away from the structure (DIBK, 2023a; Flyen et al., 2014). According to TEK17 (DIBK, 2023c), it is specified as an accepted performance standard that ideally, the slope away from the building should be 1:50 over a distance of at least 3 meters, if practically feasible. Implementing permeable surfaces, which increase water infiltration into the ground, constitutes a strategy to minimize the risk of water accumulation. Therefore, it is recommended to plan site areas with good infiltration capacity as a preventive measure against surface water (Alfraidi and Boussabaine, 2015). Observing natural drainage paths on the site is advisable, as water always seeks the lowest point. Subsequently, water-delaying measures can be implemented in these locations (DIBK, 2023a). The use of water-delaying solutions, such as rain beds, also contributes to regulating surface water (Curtis and Snow, 2016). Rising temperature variations, more frequent freeze-thaw cycles in the ground, and increased winter precipitation make it necessary to enhance the resilience of buildings against climate change (Grynning et al., 2020). Surface areas with impermeable materials, such as asphalt and paving stones, prevent water infiltration into the soil. This may temporarily lead to surface water issues during heavy rainfall. Therefore, careful consideration of drainage systems becomes crucial when large areas with such materials are present around the building (Flyen et al., 2014). Curtis and Snow (2016) have also examined the use of impermeable materials around the building, noting that an increase in moisture levels in the ground, coupled with the use of impermeable materials near buildings, raises the likelihood of moisture-related problems. Furthermore, a rising groundwater level and inadequate drainage can adversely affect foundations and basements. Strategic placement of trees and vegetation around buildings provides several benefits, including improved natural ventilation, protection from wind, and reduced exposure to sunlight (Alfraidi and Boussabaine, 2015; Scott et al., 2022). Additionally, trees and vegetation act as natural preventive measures against erosion during heavy rainfall and floods.

Matrix for assessing resilience to climate change

Utilizing the matrix in Figure 2, a new one is prepared to provide a comprehensive understanding of whether the building is robust against the expected climatic conditions in Norway, characterized by increased precipitation and unpredicTable weather patterns.

The matrix is built on assessment parameters derived from literature studies on climate adaptation measures and potential issues related to increased humidity and precipitation. Through an evaluation of these parameters, one can analyse the most critical aspects and elements in a building related to climate stressors. This provides insight of key parameters for assessing the building's resilience (Figure

3). The Table contains the descriptions only for the roof element. After conducting a comprehensive assessment of resilience using the matrix, the building will be assigned an overall condition grade based on assessment parameters. This condition grade reflects the building's general ability to handle future climate changes. Simultaneously, it provides valuable insights into specific vulnerabilities, simplifying the implementation of targeted measures to reduce these vulnerabilities.

ASSESSMENT OF RESILIENCE TO CLIMATE IMPACTS ON EXISTING BUILDINGS				
The assessment will address the key evaluation parameters regarding resilience to current and future climate stressors. The stresses on Norwegian buildings are primarily related to water and moisture damage resulting from heavy rainfall, increased temperatures, and water infiltration. This assessment will focus on the building's technical qualities, its envelope, and solutions adjacent to the building.				
Evaluation parameters	State of condition 0	State of condition 1	State of condition 2	State of condition 3
BUILDING ENVELOPE				
EXTERIOR ROOF				
Roofing Includes roofing materials, fasteners, overhangs, flashing and orientation.	The roofing is additionally secured in wind-exposed areas, and there are no indications of degradation. Overhangs and flashings are appropriately dimensioned to protect vulnerable areas. The orientation of the roof is gentle to prevailing wind conditions, heavy rainfall, and solar exposure. Roof is well-maintained.	The overhangs and flashings are intact but not oversized. The construction is somewhat vulnerable to heavy rainfall.	Lack of maintenance makes the construction highly vulnerable to water infiltration. Overhangs and flashings have undergone significant wear or dents and do not provide optimal protection.	Overhangs and flashings are absent, and the construction is extremely vulnerable to weather exposure. This level requires extensive upgrades.
Drainage Includes gutters, downspouts, drains, biological growth, flat roofs, and winter precipitation.	Gutters and downspouts are oversized, ensuring good drainage. No signs of blockage, and downspouts effectively divert water away from the building. Good maintenance routines are upheld. For flat roofs, slight slopes are implemented to aid in efficient drainage and prevent water accumulation. An adequate number of drains are installed.	The gutters and downspouts function effectively but may have potentially low capacity during intense rainfall events. There are minor signs of damage to gutters and downspouts, and minor biological growth, but the drainage is still sufficient. The number of drains may not be sufficient.	The gutters and downspouts exhibit evident damages and leaks, resulting unnecessary water exposure on the building facade. There is extensive biological growth and blockage, and maintenance is lacking. Replacement is necessary in certain areas.	The gutters and downspouts are not functionin, resulting in poor drainage and significant damage. There is a need for comprehensive replacement, clear signs and observations of water accumulation on the roof.
Technical Details Include insulation, moisture protection, ventilation.	No damages are visible, and the building is well-designed and executed. Moisture protection is effective. There are adequate ventilation options for the roofing.	There are some signs of wear and degradation of the roofing. The air circulation is maintained, but attention is needed on moisture protection details.	Some damages to the moisture protection are visible, and there are signs of moisture defects. Lack of ventilation.	Clear damages to the roof structure and severe moisture damage are visible. There is a significant need for replacements.

Figure 3 Presentation of the Matrix for assessment of resilience to climate impacts on existing buildings, for the Roof indicator (authors).

Definition of state of condition

A deliberate choice has been made to develop a scale with four condition grades, ranging from 0 to 3. This scale corresponds to the existing matrices, contributing to clarity and reducing the possibility of misunderstandings. A harmonized approach also makes it easier to transfer the condition grade to other mapping areas. The importance of having clear differences between condition states is emphasized. Clear and distinct differences between 0 and 1, as well as 1 and 2, are desirable. Introducing too many states could make the boundaries between each state less clear. The concept behind the condition grades is simple: 0 represents an ideal condition where everything functions optimally, and the building exhibits high resilience to climate change. Level 1 symbolizes somewhat natural wear and tear, but the building still performs well and does not require extensive repairs. It has partial resilience. Levels 0 and

1 can be considered as a green light. Level 2 can be seen as a yellow, indicating the need for attention directed towards rehabilitation and prevention. Damages become more visible, and the building starts to show vulnerability to external climate stressors. Level 3 represents a red light, and immediate action. The building has very low resilience and is extremely vulnerable to external climate stressors.

From findings to the development of criteria

The development of the criteria and condition grades is based on findings from the literature, where measures and aspects of resilient and resistant buildings have been carefully examined. Condition grade 0 therefore represents a synthesis of all the solutions and measures that should be implemented to achieve a building with high resilience. The subsequent condition grades involve a gradually reduced implementation of these measures and solutions. These also include other factors and observations identified as less favourable against climate change. The definition of the different condition grades has also been shaped with inspiration from existing assessment matrices.

DISCUSSION

The aim of the study has been to investigate how to enhance the resilience of existing buildings to climate change and identify specific measures necessary to achieve improved resilience. It has also been desirable to classify the resilience of existing buildings using a matrix. The goal is to contribute to reducing potential damages to existing structures due to weather-related stresses, which are expected to be different in the future than they are today. Matrix is designed, based on the NS-EN 17680:2023 matrix template, using the results from the literature review. That kind of assessment enables facility managers to provide level of better understanding and planning the resilience strategy.

The research strategy involved identifying literature addressing specific measures to improve resilience. This provides insight into the distinct aspects and features of buildings that make them resilient. By understanding which parts of a building are most vulnerable, it becomes clear which areas require extra attention regarding increased climate stresses due to climate change. The results from the conducted literature search, which involved extensive searches in various databases using multiple keywords and reviewing both academic and non-academic sources, reveal a noTable lack of specific climate adaptation measures for existing buildings. This indicates an area that requires further research and attention in the coming years. Among the analysed articles and literature, there is a common theme where many share the same motivation: awareness of climate change and the necessity to adapt current building stock to future climatic stresses. Despite this shared motivation, there are few that delve into specific measures for building construction. Several literatures explore theoretical frameworks and methods related to climate adaptation, evaluate knowledge gaps, conduct literature reviews based on existing research, and analyse barriers and driving forces for climate adaptation. Only a few articles address the aim of the study and present concrete suggestions and methods for specific climate adaptation measures relevant to existing buildings. Although, all findings are included in the results section, it would ideally be desirable to have more research on this topic to support the findings on climate adaptation measures. There have also been findings in the literature that address climate adaptation measures and improvements to consider in the planning of new buildings. Unfortunately, several are not relevant or feasible for existing building stock. It is natural for existing buildings to have certain limitations regarding how intrusive these measures can be.

Implications of Limitations

By restricting literature searches primarily to Norway and its conditions, there is a potential risk of overlooking other relevant literature. Building styles vary significantly globally, and regions beyond Norway and North Scandinavia are likely to experience increased precipitation and temperatures, leading to a rise in humidity and rot damage in buildings. Expanding the search area allows for the inclusion of literature from other parts of the world facing similar climatic conditions as Norway.

CONCLUSIONS

Climate change encompasses not only extreme weather events but also gradual changes such as temperature rise and increased sea levels. In Norway, climate change is expected to bring warmer and wetter winters, hotter and drier summers, along with more frequent and intense rainfall and wind. These changes can have dramatic consequences for existing buildings, exposing them to a climate they were not originally designed for. A functional and reliable built environment is crucial for the economic growth and development of society. To ensure buildings have sufficient resilience against future climate stressors, it is generally crucial to implement more sustainable materials and upgraded methods for weather protection and insulation, minimizing the effects of moisture and other environmental impacts. The importance of building design and construction work must be emphasized. The objective of this study is to develop a method for assessing existing building stock and its resilience to future climatic conditions in Norway. This assessment will be carried out through a developed matrix. The purpose of this matrix is to highlight climate adaptation measures for vulnerable building elements and identify preventive or reactive measures that can be implemented. The matrix could also serve as a valuable contribution to the recently established standard NS-EN 17680:2023. The assessment tool focused on climate stressors could be used by facility managers to focus and other stakeholders as end-users, policy makers, investors, financial and insurance companies. It is essential to focus on future climate predictions in the development of building codes and standards that contribute to determining building resilience. The resilience of a building can be mapped based on various assessment parameters. Assessment parameters for outer roofs include roofing, flashing, overhang, and drainage systems. Adaptability and material choices are crucial to enhance the building's resilience to climate change. For outer walls, the resistance of materials to moisture and maintenance, as well as the cladding's ability to allow air circulation, are considered. Openings such as windows and doors are also vulnerable as they break the facade, requiring attention to these elements. Aspects such as foundation height, foundation depth, permeability, and drying characteristics are also important to strengthen the building's resilience. The choice of vegetation and surfaces on the site is critical for managing surface water, and effective measures include proper slope away from the building, permeable surfaces, and appropriate placement of vegetation.

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Exploring Circular Facilities Management: A Case of Portfolio, Building, and Workplace Transformation

Jensen, P.A.[1] & Nielsen, H.J.[2]

[1] Department of Technology, Management and Economics,Technical University of Denmark
[2] Niras
Contact: pank@dtu.dk

ABSTRACT

Background and aim. The focus on circular economy has become increasingly stronger as part of sustainable development in recent years. However, the focus on circularity in Facilities Management (FM) has until now been very limited. The purpose of this paper is to develop the concept of Circular FM (C-FM) and to show, how FM can support an organization in optimizing workplaces, buildings, and portfolios in a holistic sustainable way.

Methods. Based on a literature study on circular economy, buildings, and FM, and on a case study of facilities transformation, the paper identifies essential elements and enablers in C-FM and use a value tree to show the potential benefits of C-FM.

Results. The paper shows how property portfolios, existing buildings and workplaces can be developed, transformed, managed, and operated from principles of circularity with the aim to contribute to a building stock, which is more holistic sustainable covering not only environmental and economic aspects but social aspects as well. This is illustrated by value trees to show the value of C-FM. The paper also shows how circular actions can prolong buildings' lifespan and intensify building use, and it adds basic space optimization to actions described in literature.

Originality. This is one of the first research papers on C-FM and points out its possible value.

Practical or social implications. The paper can help researchers and practitioners to advance C-FM and thereby contribute to future-proof FM to be holistically sustainable.

Type of paper. Research (full)

Keywords. Circular economy, Facilities Management, sustainability, transformation, value tree.

INTRODUCTION

The purpose of this paper is to introduce the concept of Circular Facilities Management (C-FM) and to identify the possible value of C-FM by showing how FM can support an organization to optimize both environmental, social, and economic sustainability. The focus is particularly on transformation of portfolios, buildings, and workspaces, and not on recycling building materials, property operation, and facilities services. To identify the possible value of C-FM, the papers will present a case study and analyse the value of a transformation of facilities by use of a value tree concept from a management decision support tool called the FM Value Guide, which is presented in a technical paper at this conference (Jensen et al., 2024). The research question for this paper is: *How can Circular Facilities Management contribute to holistic sustainability?* A definition of C-FM is presented in the second section.

The starting point is the Circular Economy (CE), which in recent years has received increasing interest in industry and research communities (Kyrö, 2020; Lundgren et al., 2023). It has likewise received increasing political interest globally, which the recent COP28 in 2023 clearly indicates. The proposal for decision by the President: "Notes the importance …. to address climate change, including through circular economy approaches …" (COP28, 2023, paragraph 36). CE is seen as a panacea to solve the major global problem that economic growth results is an overuse of limited resources by decoupling economic growth and use of natural resources by applying CE principles.

The European Commission has for some years focused on CE. Since 2015 the EU has implemented action plans for CE as part of the Green Deal (EU, 2023). EU has also initiated ESG-reporting of non-financial activities, which from 2024 is compulsory starting with large companies, and in 2023 the first ESRS (European Sustainable Reporting Standards) were adopted, including standard E5 on Resource use and Circular Economy (EFRAG, 2023). CE challenges the linear economy model of make-use-dispose, focusing instead on retaining value that is already created in the system and make a transition to a circular economy (Larsen et al., 2022; Lundgren et al., 2023). There has for a long time been a focus on life cycle thinking and life cycle management (UNEP, 2023). There has also been an increased focus on CE in relation to the Built Environment (BE). This has mainly been related to the environmental life cycle in the design of new buildings, but recently there has been an increasing focus on renovation of existing buildings and on FM.

The paper is structured with definitions and literature in the next section followed by methodology. The fourth section presents and analyses the case study. The paper finishes with discussion and conclusion.

DEFINITIONS AND LITERATURE

This section starts with definitions and use of CE. Based on this we introduce and define C-FM. We then give an overview of the research on CE and the BE in general and FM in particular.

CE is used as a concept in many contexts and defined in different ways. It has mainly been used in relation to the production and lifecycle of products. Kirschherr et al. (2017) analysed 114 definitions and found among other things: "that the definitions show few explicit linkages of the circular economy concept to sustainable development. The main aim of the circular economy is considered to be economic prosperity, followed by environmental quality; its impact on social equity and future generations is barely mentioned. Furthermore, neither business models nor consumers are frequently outlined as enablers of the circular economy."

This picture is very different from how CE is defined by the EU. ESRS E5 Resource use and Circular Economy defines CE as: "An economic system whereby the value of products, materials and other resources in the economy is maintained for as long as possible, enhancing their efficient use in production and consumption, thereby reducing the environmental impact of their use, minimising waste and the release of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy." (EFRAG, 2023). The EU has developed a circular economy measuring framework

with five themes: production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability and resilience. Except for competitiveness and innovation, which e.g. includes investments and patents, they all concern environmental aspects. Data are collected annually by Eurostat for each of the 27 member countries (EU, 2024). The independent Circle Economy foundation produces Circular Gap Reports focusing also on environmental aspects on both global and national levels, including a recent report on Denmark (Circle Economy, 2023).
An example of a more holistic sustainability view on CE is presented by Issac (2023) who writes: "If implemented right, the Circular Economy holds the potential to preserve the endangered environment, boost social equity, and foster sustainable economic progress." This view is in line with what we pursue concerning FM in this paper. Issac (2023) with references to OECD states, that only niche markets like Product-Service Systems (PSS) in automotive coatings and resource recovery in the steel sector so far have been able to successfully adopt CE to a significant extent.

In contrary to the finding by Kirschherr et al. (2017), the literature on CE and the BE often refers to business models (Baniya, 2023; Kyrö, 2020; Lundgren et al., 2023; Murano et al., 2020). However, the term business model indicates that it is for making a profit. Public organisations and in-house FM-organisations will not necessarily look for an economical gain but implement circular processes, because it is beneficial for environmental reasons, part of a sustainability strategy, or for compliancy with certifications or public regulations. Sustainable business models have been developed, but they are often also for profit and focus on helping other companies to become more sustainable.

CE in the BE mostly concerns environmental sustainability. A common framework is to work in the order: Reduce, reuse, recycle. This so-called 3R framework is one of several R frameworks and waste hierarchies, which many see as the 'how- to' of CE (Kirchherr et al., 2017). Another topic of increasing interest is embodied carbon, and a research-based handbook in relation to the BE has just been published (Ariza & Moncaster, 2024). The book, like Kyrö (2020) distinguishes between *urban* level, *building* level and *material* level. This paper focuses on the building level, including property portfolios and workspaces.

One of the conclusions from The European Energy Agency (EEA, 2022) is that "The most effective circular renovation actions to reducing embedded emissions are extending the lifespan of existing buildings and increasing the intensity of building use." The actual lifespan or lifetime of buildings is also called service life or useful life. The literature often distinguishes between technical life, the functional, and the economic life of buildings (e.g. Remøy, 2014). Which of these determines the actual lifespan varies and depends partly on developments in building technology, business processes, user preferences and real estate markets. Different circular actions can be used to prolong the actual life as we show in the following.

From the general definitions of CE and the use of CE in the BE it becomes clear, that CE mainly focuses on economic and/or environmental sustainability without considering social sustainability. However, both BE generally, and FM particularly, can have considerable social impact. When we talk about C-FM, we therefore do not see it as circular economy implemented to FM but as implementing life cycle thinking and circular principles in FM. Thus, we see C-FM as a sub-discipline of FM and define: *Circular FM integrates lifecycle thinking and circular principles to contribute to holistic sustainability.* By "holistic" we mean that it covers environmental, social, and economic aspects in contrast to most of the literature on CE, which only focus on environmental and/or economic and not social sustainability.

Methods for quantitative calculations of Life Cycle Costing (LCC) and environmental Life Cycle Assessment (LCA) for buildings have been developed and are formalized in ISO standards and implemented in building regulations in some countries using the uniform measurements: Net Present Value for LCC and CO_{2e} for LCA. A literature review of the use of LCA for CE in the BE is presented in Andersen et al. (2022). Attempts have been made to develop a common measurement method for Social Life Cycle Assessment (S-LCA), e.g. by Malmgren et al. (2015) on sustainability assessment of building renovation and Lundgren (2023) on adaptive reuse. Larsen et al. (2023) presents a literature review on integrating LCA, LCC and S-LCA into Life Cycle Sustainability Assessment (LCSA) in relation to buildings in general for use mainly at the design stage. However, there is no standardised methodology for S-LCA.

We have only found the research paper by Baniya (2023), that explicitly has CE and FM in the title and even use the term Circular Facilities Management. It is a literature review and focuses on environmental sustainability for facility service providers on the three scopes: Procurement, building use, and end of life. The paper finds that subtle changes in the core facility function, such as in products' purchase approach, delivery of ongoing maintenance and refurbishment of building assets, and end-of-life management, possess the potential to enable circularity. The paper primarily has an operational environmental focus, while we in this paper will have a more strategic focus on buildings and space use from the perspective of an in-house FM-organisation and impacts on holistic sustainability.

A Swedish research group has published several research papers on CE in the BE, and we will review the three mostly related to FM. The first by Kyrö (2020) used a literature-based framework called SPAR (Share, Preserve, Adapt, Rething) and the two paradigm shifts 'access over ownership' and 'service-based business' to analyse cases. The author concluded in line with the SPAR framework that CE in the BE includes preserving and adapting existing buildings, shared use of space, and new circular business models.

The second by Lundgren et al. (2023) concerns building renovation. They aimed to contribute to the assessment of circular business models, and they assessed and compared two adaptation scopes of a former textile factory to offices in Sweden both from an environmental, social, and economic perspective. They defined two different scopes of the renovation. The minor scope included basic measures to bring the building up to standard, and the major scope in addition included space efficiency measures, extended building services, on-site energy production and various circular activities. The project sounds more like adaptive reuse with repurposing and transforming a building to a new use than renovation/refurbishment. They found that the major scope consequently captured more of the identified value propositions of the organization than the minor scope. They concluded that more circular activities do not necessarily lead to better environmental performance, however, may lead to higher profit and social gain (Lundgren et al., 2023). This shows the importance of taking a holistic and not just an environmental view on sustainability.

The third paper by Kyrö & Lundgren (2023) developed a concept called "The Value Building". It is based on integration of two models, see Figure 1. One is the 6S-model from the seminal book "How Buildings Learn – What Happens after they are Built" by Brand (1994), who divided a building into six layers with different lifetime expectancy: Site, Skin, Structure, Services, Space plan, and Stuff (IT-equipment, furniture etc.). The site may last forever, while the others have limited expected lifetimes, for instance 50-75 years for structure and 15-20 years for services. Layers with short lifetime should be possible to replace without interfering much with layers with longer lifetime. The other model is "The Value Hill" by Achterberg et al. (2016), which is developed for the life cycle of products and divided in a pre-use, a use, and a post-use phase. At pre-use value is added increasingly as one moves up the hill from extraction over manufacturing and assembly, use is the flat top of the hill with repair and maintenance, and in post-use value is retained decreasingly as one moves down from reuse/redistribution over refurbishing and remanufacturing to recycling.

The paper identified 12 so-called "Circular business model categories", and these are shown in Figure 1 with colour codes according to how much value they are assumed to create. Only environmental value is considered. The categories could also be called strategies or means of action. In the remaining part of this paper, we will for simplicity use the term actions. Five of the actions concern the use phase and they are assumed to create most value (major or moderate). However, it is not clear from the paper, what the value assumptions are based on. The description of these will briefly be summarised:

- *Transactions:* Rental models, which besides traditional leases, can include more flexible lease agreements, and even pay-per-use access. The value retention potential is major (Kyrö & Lundgren, 2023). Green leases could be mentioned as well (Collins, 2019). Transactions is an example of the CE principle of 'access over ownership' (Brinkø et al., 2015; Petrulaitiene et al., 2018).
- *Maintenance and minor repair:* Value in the system is best retained through optimal use throughout buildings' useful life by maintenance and repairs. The value retention potential is major.
- *Sharing:* In the building context mainly takes the form of shared space, which can improve space efficiency and possibly provide cost reduction, synergies, sustainability, and flexibility. The value retention potential is major (Kyrö & Lundgren, 2023). This is another example of the CE principle of access over ownership. It is also part of the sharing or collaborative economy (Brinkø et al., 2015).
- *Refurbishment:* Renovation with low intervention, e.g. energy retrofits or replacing building systems at end-of-life. Renovation is typically more beneficial to the environment than new construction due to the embodied impact of new construction. The value retention potential is moderate.
- *Adaptive reuse.* Repurposing and transforming buildings to a new use. More intervention is required, and more value is lost in the process compared to a minor renovation. The value retention potential is moderate (Kyrö & Lundgren, 2023). However, adaptive reuse can – besides environmental value – create more social and economic value as shown by Lundgren et al. (2023).

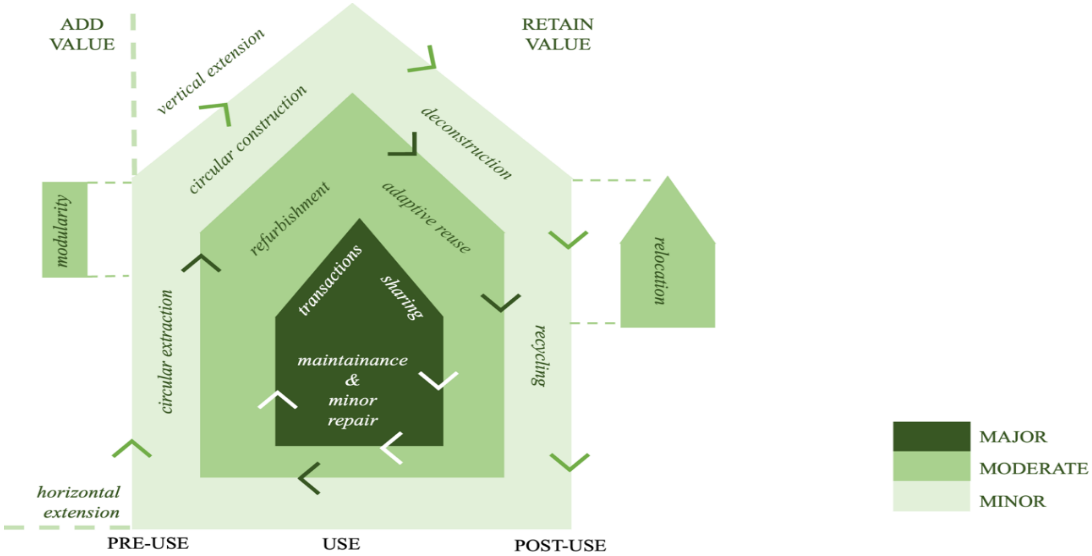

Figure 1 The Value Building (Kyrö & Lundgren, 2023)

All these actions can be part of C-FM in varying degree in relation to the three pillars of sustainability and the three types of lifespans of buildings as demonstrated in our analysis of C-FM in the case study. The Value Building does not include ‘service-based business’, which is mentioned by Kyrö (2020), see also discussion.

RESEARCH METHODOLOGY

The research included a review of definitions and literature summarized in the former section, and a case study of Danske Bank (DB), which is the largest financial institution in Denmark, concerning the transformation of its property portfolio, buildings, and workplaces in the Copenhagen area. The case was studied retrospectively based on document studies. Retrospective studies use data recorded for other purposes than research (Hess, 2004). Furthermore, the second author was involved as external project manager of the transformation process, which can be regarded as active participation observation (Atkinson & Hammersley, 1994). The project partners were awarded a sustainability prize by the Danish Facility Management association (DFM) in 2022. A central document for the case study was their description in the application for this award. It included calculations of space and CO_2 reductions, which were made by a method defined together with a university professor specialized in quantitative sustainability assessments, who also validated the results (Danske Bank & ISS, 2022). However, there is no generally agreed method to assess the dynamic effects of hybrid work.

The case was analysed holistically from the perspective of C-FM and sustainability. To show the value of C-FM, value trees (Mustajoki, & Hämäläinen, 2000) were developed. The value tree concept used is part of the FM Value Guide, which was developed by DFM with participation of the first author. A first version from 2021 is freely available in Danish. It includes guidelines for six value parameters and two new guidelines are under development, including one on C-FM. The FM Value Guide includes as an essential element value trees for five different scopes of FM: Portfolio management, Project Management (buildings and change projects), Space/workplace Management, Property Management, and Service Management. This paper focuses on transformation within the scopes of portfolios, buildings and change projects, and workspaces, and scaling property footprint to activity needs, which is the dominating feature of the case.

CASE STUDY

Danske Bank (DB) has branches and finance centres distributed in all parts of Denmark, and representation in Scandinavia and the Baltics. This case distinguishes between banking branches, that are costumer oriented, and finance centres that are support functions and non-customer oriented. The case describes portfolio, building and workspace transformation within the banks finance centres in the greater Copenhagen area. During the Covid-19 pandemic and the subsequent lockdown, like the rest of the Danish society, DB was forced to ask their employees to work from home. That also included their approx. 8,500 FTE´s (Full Time Equivalents) working out of their finance centres. The finance centres consisted of 6 main sites of various sizes in and around Copenhagen, and some smaller office spaces in downtown Copenhagen, amounting to a total of approx. 230,000 m^2.

With the lockdown DB started a strategic initiative to qualify what type of workplace strategy to assume once the lockdown was eventually lifted – the Cornerstone project. At the time of the lockdown most of their employees had dedicated workspaces, and the idea of using the lockdown to define and plan the implementation of a new workplace strategy emerged. The bank conducted various questionnaires to investigate their employees' attitude towards working from home and looked at their data describing productivity and turnover for their various business units. The data showed that DB's core business was largely not impacted by the fact that their employees worked from home. In fact, some data suggested that sick leave frequency was smaller than prior to the lockdown, and the questionaries showed a positive response to working from home.

DB then investigated what impact the implementation of a hybrid workplace strategy (Orel et al., 2024) would have on their FM services and portfolio strategy. They realized that setting an estimated frequency of approx. 2 days of working from home per week could be translated into a significant reduction in property m^2 footprint. So, DB did another questionnaire among their employees and suggested to offer the opportunity to work from home 2 days per week in average. The trade-off suggested in the questionary was to receive an allowance to establish a workstation at home, and then in return give up the dedicated workspaces in the offices, and instead implement a desk sharing policy. The employees returned with an overwhelming positivity towards that trade-off and hence the bank decided that a hybrid workplace strategy should be implemented.

Since the banks employees would now in average be working 3 out of 5 workdays at the corporate offices, with only very specific functionalities having dedicated workstations, the work from home frequency could be translated into a raise in employees assigned to an office. Thus, an office with a capacity of 500 FTEs could now have 700 FTEs assigned to it, because the excess 200 FTE´s would at any given workday in average be working from home. DB started planning a workplace design with desk sharing and zones for different workstyles, so that it could be ready when the lockdown in Denmark was lifted.

Parallel to this process the bank evaluated their property portfolio strategy and estimated that 2/5 of their total property footprint of approx. 230.000 m^2 could be terminated. After evaluating their lease obligations and considering numerous other parameters, DB decided to terminate the lease contracts for one of the main sites and several smaller offices, amounting to a reduction of approx. 60.000 m^2 equivalent to 27.3% reduction of space. DB had a total goal for CO_2 reduction of 40% in 2023 compared with 2019. The portfolio consolidation contributed with 471 tons annually (21%) and reduced commuting with 788 tons (34%). The emissions from the employees working at home was not included.

Upon evaluation of the project, and after having monitored the employees' behaviour with this new workplace strategy, DB could see that the actual occupancy rate suggested that their employees worked at home around 3 days a week in average rather than the expected 2 days a week. Despite the deviation from the expected ratio, the employee satisfaction with the new strategy remained positive according to DB's satisfaction surveys and so did the data on productivity and turnaround. This indicated that the potential for m^2 and CO_2 savings was even bigger than anticipated.

Analysis of the case

The change of workplace strategy from traditional open plan offices with personal workplaces to a non-territorial office with shared workplaces for activity-based working (ABW) (Orel et al., 2024) can be seen as an example of *shared space*. Where the normal approach to generate savings on energy and costs in the BE is to look at the facilities and optimize on their technical performance, the experience in the DB case was that significantly greater savings could be generated by changing the processes and activities and adapt the facilities accordingly.

A counter argument to the statement that less space being spend as a resource on the activity of conducting financial business is, that part of this activity was simply being moved to the employees' homes. But the reason that this was possible is that the "working from home" principle, that became a prerequisite for many people and businesses with knowledge work in periods, when the lockdown was partly lifted, turned the home of the employee into a multifunctional space. In this way the home became a *shared space* used for other purposes than private dwelling. One could argue that employers of knowledge work started occupying and utilizing space rent free in the homes of the employees by introducing hybrid work principles during and after the Covid-19 pandemic (Serrano, 2022). Thus, DB like many other corporations took advantage of the newfound potential of the home as a multifunctional space to reduce the footprint of the corporate office space, utilizing the CE principle of access over ownership (Brinkø et al., 2015; Petrulaitiene et al., 2018). Due to the footprint reduction DB could terminate lease contracts on the excess space, which then became part of the Greater Copenhagen's commercial property rental market to be used by other organizations.

In the BE the most prominent form of the CE-principle *sharing* takes the form of *shared space* as mentioned by Kyrö & Lundgren (2023) and included in Figure 1. Among the other actions in the use phase in Figure 1, the case can be seen as an example of the action *adaptive reuse* and has also to a certain degree involved the actions *refurbishment* of the interior of the buildings, which DB decided to keep in operation. However, this was kept to a minimum, because DB in the next phase is planning to move many of their functions in the Copenhagen area to a new headquarters. By having a policy of renting space, DB can terminate the leases for the buildings they no longer need. These buildings can by use of the action of *transaction* be rented out for other companies or transformed for other types of use. The action *maintenance and minor repair* were not part of the transformation, but the pandemic was a good time to do all kinds of building work, because building activities were not included in the lockdown in Denmark and work could be done with minimum disturbance of the users in office buildings.

A value tree for the DB case is shown in Figure 2. It is simplified and meant to show the principles and the most essential elements divided in environmental, social, and economic sustainability for each of the three scopes. The main circular action is *shared space* with introduction of ABW and work from home. This reduces space in the portfolio and reduce the company' energy and material use in abandoned buildings by *transactions* and provides opportunity for *adaptive reuse* and *refurbishment* to optimize staff interactions and improve indoor environment and workspace quality with reduced number of workstations and less space per FTE at the company's facilities.

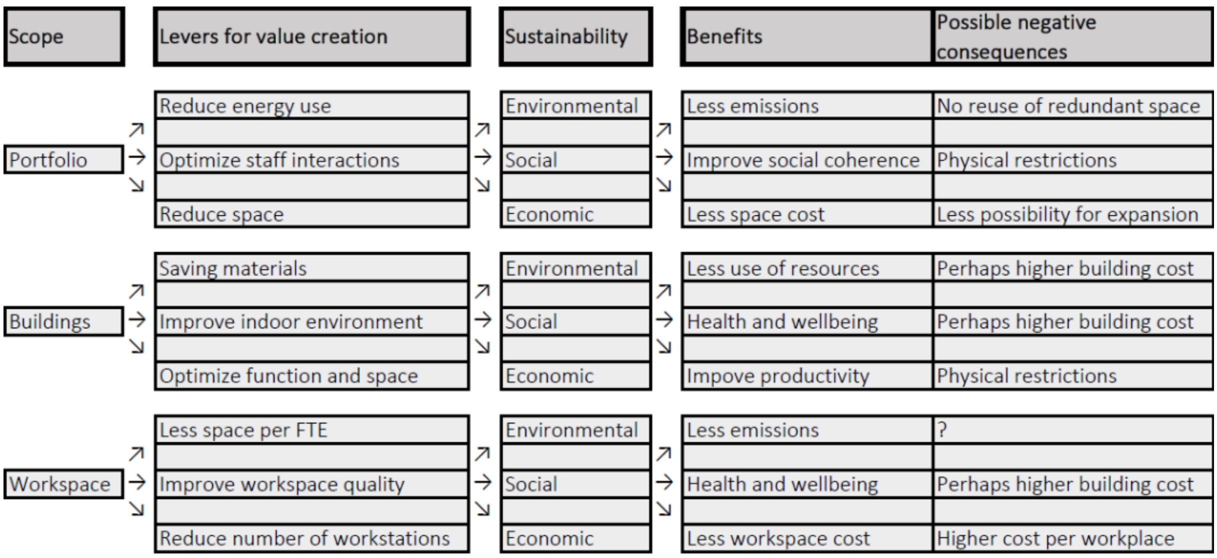

Figure 2 Value tree for the DB case

DISCUSSION

In FM and workplace management, buildings are viewed in the same way as a product that functions as a resource, which supports an activity. This is best translated into the relation between an activity and the space required to conduct that activity (McGregor & Then, 1999). A purpose of and a value driver for C-FM is to lower the consumption of space in relation to the activity the space facilitates, and thereby lower the CO_{2e} footprint of that activity. By doing this, space can be freed up for potential retrofitting to facilitate more of the same activity or for other activities. This will lower the demand for the construction of new buildings and potentially add to the life cycle span and circularity of existing buildings. This can be done by *shared space*, but it can also be done by *basic space optimization*, which is what the FM sub-discipline Space Management is all about, by improving the functional layout and distribution of space to match supply with demand. A typical example of this is going from cellular offices to open plan offices.

Another important way is to reduce the number of support spaces, which can be done on a large scale, when a company consolidate its space in fewer building. Many small support spaces can be reduced to fewer bigger with a more rational layout and economies of scale. This will typically involve organizational changes. Thus, *basic space optimization* is a sixth circular action. In the DB case the potential for C-FM evolved, because DB realized that by changing the process in their core activity to hybrid work, they could significantly reduce their need for support services due to the reduced property footprint and the reduced FTE presence at the workplace. Due to that change the need for cleaning services was obviously reduced equal to the property footprint reduction, and all other support services related to building footprint, such as hard FM maintenance service. In relation to the reduced FTE occupancy, demand for catering services, on-site security, and on-site technical support, was reduced in accordance with the reduced occupancy and m^2 property footprint.

To reduce embedded energy the most effective circular renovation actions are extending the lifespan of existing buildings and increasing the intensity of building use (EEA, 2022) as referred in the literature review. The actual lifespan of building depends as also mentioned on the technical, functional, and economic lifespans. The possible impact of the six circular actions on the different types of lifespans is assessed in Table 1.

Table 1 Circular actions and impact on lifespans of buildings (XX = direct impact, X = indirect impact)

Lifespans Circular actions	Technical	Functional	Economic
Shared space		X	XX
Transactions		X	XX
Basic space optimization		X	XX
Adaptive reuse	X	XX	X
Maintenance and minor repair	XX		X
Refurbishment	XX	X	X

Three of the six actions have a direct impact, and all have an impact, on economic lifespan, which is good because economic sustainability is a precondition for having long technical and functional lifespan with social use being the fundamental purpose of the BE. Only *adaptive reuse* has a direct impact on the functional lifespan, which is also good, because a long functional lifespan likewise is a precondition for willingness to invest in a long technical lifespan. *Maintenance* and *refurbishment* are mainly related to the technical lifespan.

Only *shared space* and *basic space optimization* are directly aimed at intensifying building use, but *transactions* and *adaptive reuse* can be used to optimize space use as well. With hybrid work the employees' private residences also become *shared space* – not by sharing with other employees but with making the home into a multifunctional space.

Circularity is not the only way to improve sustainability. Circularity is basically about optimizing the way we use resources, but it does not influence the demand for products and services. Optimizing and reducing demand is just as important as optimizing supply. In a market-based economy, demand is only vaguely related to need but particularly among the richer part of society more related to economic opportunities. Therefore, it is difficult to reduce demand except by public regulation or influencing user behaviour for instance by creating incentives and nudging.

FM is usually seen as a profession on the supply side, and it is clearly the case for facility services (FS) providers. However, FM as an in-house function has as its most important role to mediate between demand and supply of facilities and services, including managing the supply of FS independent of it being delivered internally or externally. Where FS providers have an economical interest in maximizing their turnover, in-house FM has a main role to adapt the supply to the needs of the company, so the demand for facilities and FS is aligned with the needs and strategy of the core business and delivered in the most sustainable way. Thus, FM must engage in a dialogue with the representatives of the core business at all levels and with the users, to reduce demand to the actual need and optimize the way supply is provided by influencing the client and customers, and the user behaviour.

A CE principle not mentioned by Kyrö & Lundgren (2023) and not relevant to our case is Product-Service Systems (PSS), which concerns the integration of business processes and models for companies. Kyrö (2020) mentions PSS but choose to use the rather misleading name 'service-based business'. An example of PSS from the BE is Public-Private Partnership (PPP), where a private consortium Build, Own, Operate (BOO) and possible transfer (BOOT) a building to a public organization for instance after 30 years (Akintoye et al., 2003). This is an example of the CE principle of access over ownership and can for instance secure funds for proper maintenance over the contract period. PSS is according to Issac (2023) one of the few markets with a high uptake of CE and particularly used in the manufacturing industry.

CONCLUSIONS

The paper shows that FM has much to offer in relation to circular and holistic sustainable management in the BE. As Kyrö & Lundgren (2023) have indicated, the actions in the use phase of buildings have the highest potential for creating environmental value. This is in line with EEA, who concludes that prolonging life span and more intensive use of space have the highest environmental effect. The paper adds to the existing theory by adapting CE and circularity to FM and adding *basic space optimization* as a circular action of particular importance for C-FM and thereby to CE in the BE in general. The DB case, and the value trees based on it, clearly shows that C-FM is about much more than environmental sustainability even though most activity on CE in the BE only concerns this. CE includes the name economy but should be more than this. In fact, C-FM is more about life cycle thinking and circularity than about CE. Therefore, it is recommended that decisions on C-FM and CE in the BE is based a holistic and conscious balance between environmental, social, and economic sustainability. Environmental sustainability in the BE is much about prolonging the lifespan of buildings to sustain embodied energy and to increase the intensity of use to avoid using more materials for buildings than necessary. To achieve this, it is important that the technical, functional, and economic lifespan has as similar lengths as possible. Therefore, it is also recommended that decisions on C-FM and CE in the BE is based on a holistic and conscious balance between the technical, functional, and economic lifespans. In-house FM has a crucial role as a mediator in balancing the demand and supply for space and related services. Demand should as far as possible be equivalent to need and defined, so it can be met with a supply that can be provided in the most sustainable way. The Covid-19 pandemic has stressed the importance of this role and helped to raise the general understanding of FM's strategic relevance. C-FM is an important new sub-discipline, which facilities managers need to master to sustain this relevance.

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Enabling Circular Futures of Workspaces through Facility Management: A Backcasting Approach

Lundgren, R.[1], Kyrö, R.[1], Toivonen, S.[2] & Tähtinen, L.[2]

[1] Faculty of Engineering at Lund University (LTH)
[2] School of Engineering, Aalto University
Contact: rebecka.lundgren@lth.lu.se

ABSTRACT

Background and aim. Circularity plays a key role in future-proofing workspaces. Sharing and digitalisation are efficient circular strategies which allow for flexibility, multifunctionality, and maximising the use of existing assets. We aim to provide insights on future facilities management (FM) practices which would promote the green and digital twin transition in the workspace context.

Method. We employ the futures studies method of backcasting and engage 14 topic experts in three workshops. Each workshop centres around one preferable circular future. The first focuses on shared and collaborative use of corporate offices, the second on rural hubs as the most popular physical workspaces outside homes, and the final on hybrid and virtual spaces as the most popular workspaces overall. The experts are facilitated to devise actions needed for the respective circular future to realise by 2035.

Results. Findings reinforce the notion that collaborative spaces are dependent on hybrid and virtual spaces, and that the two are complimentary of one another. To increase uptake of both, creative content and social activities should be provided both at the workspace and in the local community, delivered through e.g., a community manager. The future workspaces will resemble traditional town marketplaces, where the community gathers to meet and do business.

Practical or social implications. The results emphasise the importance of a skilled service provider, engaged in both the technical management of the physical and virtual space, and community management. Through transformative practices, FM has the potential to ensure a functioning and engaging physical and digital workspace.

Type of paper. Research (full)

Keywords. circular economy, futures studies, hybrid spaces, sharing, workspaces

INTRODUCTION

Circularity has gained foothold as a potential solution to the pressing sustainability crises, and a way forward in the green and digital twin transition. The green transition refers to measures to decrease environmental impact, whilst the digital twin transition are digital counterparts of the real world. These transitions can both reinforce each other, but also clash. Sharing and digitalisation are considered key circular strategies as they maximise the use of existing assets (Ellen MacArthur Foundation, 2015). In the workspace context, shared physical spaces (hereafter referred to only as shared spaces) and virtual spaces are efficient circular measures as they allow for flexibility and multifunctional use. Shared spaces and virtual space solutions even hold potential for reducing the overall need for workspace. Francart et al. (2018) suggest space sharing is a key enabler for reducing the overall need for floor area, and meeting climate targets. Hybrid and virtual spaces decrease demand as some activities take place online and can therefore decrease the demand for physical space (Ness & Xing, 2017). Furthermore, Lundgren et al. (2022) observed a combination of physical and virtual presence allowed organisations providing shared spaces to be more flexible to future demands.

New business models are developing in asset provision and management through servitization of space and a social push towards circular economy (Estarrona et al., 2019). Facilities management (FM) is a critical factor in managing and improving space utilisation due to its link with the organisations and the space itself (Nik Lah et al., 2015). Digitalisation and sustainability are currently the main driving forces for change in FM practices (Bröchner et al., 2019). Digitalisation allows for more efficient, flexible, and higher quality FM, whilst sustainability forces a focus beyond individual facilities (Bröchner et al., 2019).

Yet, barriers exist to implementation at scale of shared spaces and digitalisation. For example, current energy metrics do not incentivise sharing of space, as energy use based on floor area does not take space utilisation into consideration (Francart et al., 2020; Lundgren et al., 2023b). Employees may also be unwilling to share space (Brinkø & Nielsen, 2018). Despite technological innovation allowing for new work practices and places (Bröchner et al., 2019) health related issues persist (e.g., Guna et al., 2020; Roy, 2022). Further, as a downside of urbanisation, many cities are shrinking and as a result, an increasing number of spaces are left vacant or underused (Kiviaho & Toivonen, 2023). Many living permanently or temporarily in shrinking areas appreciate the possibility to work remotely, but they still suffer from the lack of social connectedness. Therefore, shrinking areas hold a great potential to offer collaborative spaces that could tackle negative environmental impacts caused by shrinking and promote socialisation and foster peer support.

Previous research has had a strong focus on the characteristics, benefits, and challenges of shared and virtual space solutions (e.g., Brinkø & Nielsen, 2018; Lundgren et al., 2022; Mariotti & Di Matteo, 2022). In the realm of FM, studies have focused on the role of FM in the delivery, for instance community mangers (Kyrö & Lundgren, 2022; Lundgren et al., 2022). There is however still a need for futures-oriented approaches that would not only concentrate on the past development and current status, but to open up new avenues for imaginative, yet possible, solutions. We therefore aim to provide insights on future FM practices which would promote the green and digital twin transition in the workspace context. To achieve this aim, we employ the method of backcasting, known from the field of futures studies, to elicit actions needed to reach circular futures of hybrid and virtual spaces, shared and collaborative use of space, and rural hubs. Opposed to traditional predictive forecasting, which relies on extrapolation of current trends, backcasting aims to generate preferred futures and look backwards from the future to the present and identify the steps how to reach those futures (Robinson, 2003). This allows more imaginative and possibilistic approach to design strategies and pathways towards desired future conditions (Vergragt & Quist, 2011). For the purpose of this paper, the data from the backcasting workshops was analysed through template analysis to elicit common themes important for the FM practice to be able to reach the described futures.

The remainder of this paper is structured as follows. Section 2 presents the theoretical background on circularity in the built environment. The following Section 3 describes the research design. Section 4 introduces the key findings. Section 5 discusses the findings further, and Section 6 concludes the paper with some final remarks and suggestions for future research.

CIRCULAR WORKSPACES

This section provides an overview of existing research within the three explored circular strategies, namely, shared, rural, and virtual workspaces. Focus is on the known benefits, barriers, and existing FM considerations.

Shared and collaborative spaces

Shared spaces and virtual spaces are both examples of efficient circular business models (Lundgren et al., 2023a). Shared spaces which have received increasing attention in research and industry over the past years are coworking spaces (e.g., Brown, 2017; Durante & Turvani, 2018; Jakonen et al., 2017; Orel & Alonso Almeida, 2019; Spinuzzi, 2012; Waters-Lynch & Potts, 2017). Coworking is a type of serviced space. A serviced space is a furnished physical space ready for use, providing facilities and an operator who manages the space. Coworking is a concept where offices are shared between workers and the aim is often to facilitate collaborative work (Spinuzzi, 2012). The concept is mainly aimed at knowledge workers (Kojo & Nenonen, 2016). The mediation mechanism usually found in coworking spaces provide the opportunity for flexible workers to exchange knowledge with other users, as well as emotional support and increased productivity (Orel, 2020). In serviced spaces a community manager is often present to facilitate such mediation (Lundgren et al., 2022). Creating a sense of community is one way in which collaborative spaces tackles challenges of flexible working (Orel & Dvouletý, 2019).

Serviced shared spaces which has a facilitator often has a large content focus (Lundgren et al., 2022). Yet, Lundgren et al. (2022) found no difference between spaces with a facilitator and without a facilitator in terms of the feeling of commitment to a space. However, Bardhi & Eckhardt (2012) found that self-sufficiency increases the feeling of commitment with the shared object. Similarly, Kyrö & Artto (2015) has comparable findings when studying an on campus coworking space. Furthermore, collaborative spaces have been found to increase innovation and efficiency (Orel & Dvouletý, 2019). Accessibility and contract options are important aspects when users choose coworking locations, however, preference of concepts may vary depending on country and thus a blanket business model may not be successful across borders (Appel-Meulenbroek et al., 2021).

Rural hubs

Following the increased attention of coworking, a special interest in rural coworking has developed since the year 2020 (Sánchez-Vergara et al., 2023). Rural coworking enables people to live rural, potentially reducing the need for new construction in urban areas. Rural revitalization has been studied increasingly over the past few years, with publications peaking from 2017 onwards (Liu et al., 2023). Telecommuting, multi-local living, and emerging industries has been highlighted as new opportunities for areas outside of major urban centres (Kiviaho & Toivonen, 2023). Additionally, digital nomadism has removed geographical boundaries for where people live and work (Orel, 2023).

New business strategies can be created through space regeneration and revitalisation by the creation of rural coworking (Sánchez-Vergara et al., 2023). Rural coworking spaces may need public investment in order to adequately serve its users, such as freelancers (Sánchez-Vergara et al., 2023). However, Mariotti and di Matteo (2022) found coworking in peripheral areas may be enabling higher revenues for the users than those in urban centres. Further, Rex and Westlund (2024) suggest rural coworking spaces may be contributing to developing local economies through agglomeration.

Virtual and hybrid spaces

Creativity and collaboration are possible in both physical and virtual workspaces (Amigoni, 2021). Technological innovation allows for new work practices and places (Bröchner et al., 2019). The uptake of virtual workspaces accelerated due to the COVID-19 pandemic (Roy, 2022), however, issues such as stress relating to digital and hybrid work (Roy, 2022) and virtual reality sickness (Guna et al., 2020) prevails despite the feeling of community existing in online spaces (Belk, 2014). Often workers tend to carry out concentration work at home and collaborative work in the office, however this is also dependent on the type of space available in each setting (Appel-Meulenbroek et al., 2022).

The real estate industries are increasing their digital offerings (Vigren et al., 2022) and coworking facilities are becoming increasingly hybrid in nature as it enables them to be more flexible for unknown future changes (Migliore et al., 2021). Orel and Dvouletý (2019) suggest hybrid spaces will increase focus on co-locating all services to one place to cater not only for the work life, but also living and social life of users. Furthermore, Petrulaitiene et al. (2018) consider the physical space only to be a component of the service offering, adding that the highest value comes from the experience of the workplace.

RESEARCH DESIGN

We employ a qualitative, futures studies-based research approach. The multidisciplinary nature of futures studies aligns well with addressing complex issues and is designed to be employed to explore how preferable futures can be reached (Glenn, 2009; Masini, 2006). The preferable futures are those which align with social values and researchers within futures studies often discuss present crises in relation to these futures (Masini, 1993). In view of the current climate crisis and action required to keep within the planetary boundaries, we present three preferable futures images based on circularity principles. The preferable circular futures are: 1) corporate offices are all in shared, collaborative use, and 2) rural hubs have become the most popular physical workspaces outside homes, and 3) hybrid and virtual spaces are the most popular workspaces overall. The future images are based on the general circular economy concepts and established circularity hierarchies, as presented e.g. by Reike et al. (2018) and Ellen MacArthur Foundation (2015). Furthermore, the Authors' previous research within the spatial context on access-based consumption (Lundgren et al., 2022), and circular hierarchies (Kyrö & Lundgren, 2023), through the research project Share, Optimize, Reimagine (SHORE) – reframing circular economy for the real estate and construction industry, has guided the future images.

The main technique used is backcasting. Backcasting can assist in seeking new solutions to reach a preferable future, as opposed to forecasting which tends to only result in small steps based on current perspectives (Phdungsilp, 2011). Backcasting is noted particularly well-suited for complex and generally normative sustainability issues, allowing departure from extrapolating existing and unsustainable business-as-usual pathways (Holmberg & Robert, 2000; Vergragt & Quist, 2011). This study employs backcasting with the aim of finding actions and actors required to reach the presented preferable futures. The backcasting was performed in three separate workshops, one for each preferable future, during the Spring and Summer 2023. Two of the workshops were organised via Zoom, while one was organised face-to-face (F2F). All workshops were conducted in two-hour sessions. Each hosted 4-5 topic experts from different disciplines to broaden the discussion (see Table 1 for details). Each participant was informed of the purpose of the workshop and was asked for consent to record the session. The lead author for this paper facilitated the workshops, while the co-authors were invited as experts in one workshop each (marked with * in Table 1).

Table 1 List of workshop participants

Workshop	Country	Expertise	Organisation type	Mode	Date	Code
Collaborative spaces	Sweden	Workplaces	Industry	Zoom	27 September 2023	N1
	Sweden	Workplaces	Industry	Zoom	27 September 2023	N2
	Denmark	Sustainability	Research	Zoom	27 September 2023	N3
	Finland	Real Estate*	Research	Zoom	27 September 2023	N4
	Finland	Workplaces	Research	Zoom	27 September 2023	N5
Rural Hubs	Sweden	Urban Studies	Research	F2F	5 May 2023	N6
	Sweden	Real Estate	Research	F2F	5 May 2023	N7
	France	Real Estate	Research	F2F	5 May 2023	N8
	Sweden	Real Estate*	Research	F2F	5 May 2023	N9
	Finland	Real Estate*	Research	F2F	5 May 2023	N10
Virtual & hybrid spaces	Italy	Workplaces	Research	Zoom	13 June 2023	N11
	Sweden	Real Estate	Research	Zoom	13 June 2023	N12
	Sweden	Artificial Intelligence	Research	Zoom	13 June 2023	N13
	Finland	Workspaces	Industry	Zoom	13 June 2023	N14

All workshops were structured as follows. First, the experts were presented with the desirable future, the so-called Future Scenario 2035. The experts then had time to self-reflect on the actions and actors which needed to be in place by 2030 for to the Future Scenario 2035 to realise. The strategic management tool PESTLE (Political, Economic, Social, Technological, Legal, Environmental) was utilised as an aid to organise thoughts and to structure the actions and actors. As such, the participants were told not to worry about the correct categorisation and that themes outside of the PESTLE would be developed through the analysis of the data. The participants were asked to consider which actions need to be taken, and by which actors, for the predetermined circular futures to realise. The PESTLE framework was chosen to structure thoughts as it is easy to understand, and supports inclusion of various societal perspectives, thus building a more holistic multi-sectoral view of the complex topic, as described by Perera (2020). Whilst internal factors are also of importance, this study focuses on external macro-environmental factors which impact on the way which FM organisations may deliver their services to enable circularity. The workshop participants did however go into internal factors at times, especially in the social factors, and this has been included in the results. All ideas were posted on a shared digital or physical whiteboard with sticky notes, depending on if the workshop was on Zoom or F2F. The experts then discussed the sticky notes, creating a deeper understanding and consensus. The same process was repeated for 2025, only two years after the date of the workshop. The output of each of the workshops were a digital or physical whiteboard and a transcript of the discussion.

Data was collected from sticky notes and recordings from the workshops. For the purpose of this paper, the data was analysed through template analysis to elicit common themes important for the FM practice to be able to reach the described futures. Template analysis is commonly used to discover themes and patterns across a data set using pre-defined themes and themes emerging from the data (Saunders et al., 2009). Pre-defined themes, based on the PESTLE framework were used to begin the analysis. As the PESTLE framework was only used to structure thoughts these themes were not considered in the final emerging themes. From the data structured around the PESTLE, themes which were inter-connected emerged, namely, Interdependence of physical and virtual spaces, and services and community. It is worth noting that the backcasting method and PESTLE tool were employed to structure the data, and the specific years and categorisations are not included in the data analysis. This differs from the typical aim of backcasting, which is to imagine pathways that would help to reach the aimed futures. However, in this paper, our aim is to identify the joint themes describing the role of FM along the entire given timespan and not to focus on particular years as such. This approach was chosen because it enables us to reveal the thematical relevance of FM's role of tackling the aforementioned challenges.

RESULTS

With a focus on FM to deliver the circular futures, two main themes emerged from the PESTLE data, namely, interdependence of physical and virtual spaces, and services and community. These are described in further detail in the following.

Interdependence of physical and virtual spaces

In the workshops on hybrid and virtual spaces the importance of social interaction and physical and mental health was lifted; *"soulful communications, whether it's the mindset or whether it's the perceived value that you get from interpersonal communication" (N14)*. These interactions were believed to work better in a physical setting enabling the community aspect. Effectiveness through technology was brought forward as an enabler to free up time to do other things in person.

Users of collaborative spaces are thought to have a strong online presence outside of the physical space. Collaborative spaces were suggested as physical spaces for hybrid communities; *"we go to these kinds of places to charge our social energy batteries" (N5)*. Additionally, collaborative spaces with mixed uses were though to create social synergies in spaces such as rural hubs. An example of elderly homes co-located with coworking hubs was brought forward, as well as provision of services and meeting places, as well as hybrid solutions.

Services and community

The idea of rural hubs being used to combat loneliness and build community was similarly lifted for collaborative spaces. For this to be enhanced the space could function as an old marketplace, creating interaction between individuals and organisations in a physical space, like a rural hub. Changes to how people live, and work will also require changes to the services around homes, workplaces, and third places such as hubs. Service provisions in hubs would create a flow of people and spaces will need to be designed to allow for community building; *"designing these spaces, buildings, et cetera, in a way that* *they are actually meaningful places" (N4)*. The notion of the space as a service and not just a physical space was considered significant for future business models in collaborative environments; *"there are so many possibilities to have add on services with these collaborative spaces. I think that it's a new kind of market area" (N5)*. In rural hubs it was considered especially important to provide more functions than just workspace. Social and cultural events can be provided, with rural hubs likening little villages, including a marketplace.

In the case of rural hubs, emphasis was put on accessibility. Particularly in terms of the space being accessible to a wide range of users creating inclusiveness and synergies. To do this the threshold of joining a shared space needs to be lowered; *"I think that's it's a daunting prospect to move your entire business into a co-working setting all of a sudden, from having your own office to all of a sudden being out in the open. We found that for us what works is that we have a lot of members who are part of bigger organisations, foundations, for example, or bigger NGOs. But we give them a foot in the door by providing single memberships or a couple of memberships per organisation so that they can get into the mood and the mindset of our kind of shared hub. But they don't all come at the same time. So, as they've moved from traditional offices to working more from home or from libraries or cafés or third places, they also have the option to come here X amount of days per week and still have that sense of community, but without all the extra baggage of joining a co-working space." (N14)*. Collective care was brought forward in both the rural hubs and the collaborative spaces workshops as a way to care for, and better maintain buildings; "*if you have the right community around it, you can get both social sustainability in a way, and you can get a be a better maintenance of the building. So possibly more long-lived buildings as well" (N3)*. Providing content within a space, whether physical or virtual, was seen as an enabler to get people into a space and to build a community; *"it's been really interesting to see that when you provide a kind of framework and you provide something for people to latch on to then that's the kind of shared ethos of the community" (N14).*

New management practices of how to build a community, including new roles, were believed to be needed for rural hubs and collaborative spaces, as well as for virtual and hybrid spaces. A range of roles were suggested, such as enhancement janitors, facilitators, community managers, collaboration operator, and relationship facilities manager. However, the essence of the roles was all the same, to nurture the cooperation, collaboration, and interface between space users; "*having a skilled facilitator for the community might be super important and that there might be types of jobs that don't exist yet, there might be a different job entirely. And I'm thinking the social aspect, the community aspect is probably very important" (N3)*. This is considered especially problematic when you have both physical and virtual communities; *"we might end up with this kind of chaos that we have internal people who are in one place and then there is another circle with the people who are online, and I think that that is a really big exercise in organisations around the topic of trust in how we can build these new communities" (N5).* Creating and maintaining common goals between organisations using a shared space was considered an important aspect of the role in order to increase the uptake of organisations which chose to share space; *"if we see what we have in common and what we're striving towards, maybe then it's easier to share space" (N2)*. Further, the role needs to be able to support technical aspects for hybrid spaces. The role will also be required to successfully mix working with leisure for spaces which service provision spans both activities.

DISCUSSION

This paper aims to elicit themes of importance to the future FM practice to reach circular futures of hybrid and virtual spaces, shared and collaborative use of space, and rural hubs. The interrelatedness of collaborative and virtual spaces is highlighted throughout the workshops. The physical space relies on the existence of virtual spaces and needs to cater to hybrid work, as well as hybrid solutions making the spaces more flexible to future changes as found by Migliore et al. (2021). The physical space was seen as complimentary to the virtual space as a place for social interaction. Belk (2014) has previously found that the feeling of community exist online, however was here not considered as strong as in the physical space. The physical space was suggested as a place where one can charge their social batteries, and thus possibly alleviating some of the mental health issues related to virtual workspaces, such as those found by Roy (2022) and Guna et al. (2020). Hybrid spaces could however provide a social space both in the physical space as found in the workshops, or virtually, as previously found by (Belk, 2014). Rural hubs and collaborative spaces were both lifted as spaces with the possibility to combat loneliness and build community. The sense of community, and the creation of social synergies, could be further enhanced through mixed uses and co-location. Orel and Dvouletý (2019) suggest focus for hybrid spaces to provide services for social life and living will increase, which also emerged from the results in this study. Service provisions were presented as an opportunity to create a flow of people, allowing for community building. Co-location of a wide variety of organisations and facilities was also suggested, e.g., elderly homes and coworking hubs, together with services and meeting places, to create the feeling similar to a marketplace where individuals and organisations interact. The space as part of the overall service provision was seen as important for future business models, similar to the findings of Petrulaitiene et al. (2018).

Further, the mediation mechanism suggested by Orel (2020) can be harnessed to provide increased knowledge exchange, emotional support, and increased productivity through an FM role such as a facilitator. Lundgren et al. (2022) found that a community facilitator role was the most prominent service provided in shared spaces and that the role enabled other services, such as events. New roles emerged in the workshops as required in order to meet the demands of community building in collaborative spaces, physical and virtual, through nurturing cooperation, collaboration, and interface between users. The role could also be required to support technical aspects for hybrid spaces and be able to create a mix between the working and leisure spaces if there are mixed activities and co-location. This highlights the social aspects as a service offering and the need to have a dedicated and trained person in the role in order to deliver such a service efficiently. Further, Lundgren et al. (2022) found that there was a large content focus in the shared spaces which had a facilitator. Findings from the workshops underline the possibility of content provision to get more people into the space and part of the community. For rural hubs social and cultural events were suggested, which could be organised by the community facilitator.

Collective care of the spaces as a way to better care for buildings was highlighted for the physical spaces. Both Bardhi and Eckhardt (2012) and Kyrö & Artto (2015) found that self-sufficiency increases the feeling of commitment with the shared object. However, Lundgren et al. (2022) found no evidence of differences in that regard between serviced and non-serviced spaces. The findings from the workshops emphasised the role of community in the collective care in order to achieve both a better maintained building and social gains. In line with findings from Appel-Meulenbroek et al. (2021), accessibility emerged as an important factor in the workshops which included collaborative spaces and hubs. Lowering the barriers to entry through the provision of memberships at different scales was brought forward as an approach. However, it is important to keep in mind that there might not be a blanket approach and each facility needs to be considered in its own context, as suggested by Appel-Meulenbroek et al. (2021) which may be contradictory to the wide focus beyond individual facilities forced by sustainability considerations as presented by Bröchner et al. (2019).

Charef et al. (2021) reviewed 41 journal papers which study the barriers to implementation of CE in the built environment. Interestingly, as opposed to many previous studies on implementation of CE in the built environment, the focus in the workshops for the role of FM was predominantly on enhancing opportunities rather than overcoming barriers. Perhaps a shift in focus from barriers to opportunities will create more solutions to increasing the uptake of circular business models for the FM sector.

Limitations of study

As the study is of a qualitative nature, research limitations: sample is limited, and the results are not generalizable, sample is limited, they apply to certain group of people and to certain geographical area. The workshop participants' expertise was transdisciplinary, and the focus was broader than this paper's FM scope. This may have led to the omission of actions which FM can provide. However, without the limitation of FM the participants could freely consider possibilities which lead to the emergence of several actions relating to FM, which may not have been uncovered if the focus was too narrow. Further, the study has a small number of participants in each workshop and despite several countries being represented the geographical area is still limited, which may limit the findings to apply only to certain groups and locations. The participants are however experts in their field, with the participants having a wide range of knowledge to contribute to the workshop, creating interesting and dynamic discussions from different points of view. Given the small number of workshop participants, statistical generalisation was not the aim of the study. Instead, the intent was analytic generalisation. Analytic generalisation is described by Yin (2009) as theories being expanded and generalised without probabilities, and characteristics are identified which may be transferable. Further research is however called for to verify the results of this study. The experts, although appreciating the intention with the backcasting technique, did find it difficult to move backwards from the future. One issue was the urgency of the transition that many felt, which caused them to think of everything that needs to be done right now. Even a future which was just over a decade away seemed too far for many. Moreover, the experts had difficulty in pinpointing whether the actions and actors they had come up with would be relevant by 2030 or already 2025. However, some experts expressed specifically that they experienced the technique to allow them to think freer about possible actions and actors. Which, for the purpose of this paper identifying the actions relevant to the FM practice was sufficient.

CONCLUSIONS

Findings reinforce the notion that collaborative spaces are dependent on hybrid and virtual spaces, and that shared spaces and virtual spaces are complimentary of one another. To increase uptake of both, different activities should be provided within and surrounding the space, creating something similar to the traditional marketplace with its related community, emphasising the importance of a skilled community manager. These service provisions can be new business opportunities for FM to deliver. Findings provide insights on FM services which can accelerate the uptake of circular initiatives. Through transformative FM practices, FM has the potential to provide both a social and a technical service to ensure the space is functioning both from the perspective of the community and the space itself, whether digital or physical. Future research could focus on FM organisations' readiness to adopt these, and other, transformative practices. Future research could also investigate the practices found in this study further, to expand the knowledge on how these could be implemented.

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The Smart Buildings Paradox!
How to Combine Smart Building and Novel IT-Technologies?

Kuijlenburg, R. [1], Houtveen S.,[2] & Joosstens, F.G.L.[3]

[1] Logius, Ministry of the Interior and Kingdom Relations & Facility Management, Hanze University of Applied Sciences
[2] Center for People and Buildings, Delft
[3] School of Facility Management, The Hague University of Applied Sciences
Contact: rachel.kuijlenburg@logius.nl.

ABSTRACT

Background and aim. Novel IT-technologies in buildings aim to enrich facility managers with valuable data to achieve strategic goals, including sustainability targets such as energy reduction and efficient space utilization. However, facility managers face various challenges, such as growing digital infrastructure complexity, expensive data service fees, and privacy concerns hindering sustainable development promises. This research delves into the viewable and hidden costs of smart building technology, focusing on a fully digitized educational floor at The Hague University of Applied Sciences (THUAS).

Methods. 'The cycle for practice-oriented research and innovation' by van der Donk and van Lanen (2016) has been the starting point for this applied practice request. This methodology promotes applied learning in the context of the workplace environment and leads to natural forms of knowledge exchange between professionals. This has resulted in the use of a mixed methods approach.

Results. Findings highlight the challenges faced by facility managers in meeting energy reduction goals, emphasizing the importance of stakeholder management and sustainable facility management practices.

Originality. This research contributes to the field by offering insights into the practical implications of managing smart educational buildings, addressing gaps in the literature, and informing stakeholders for optimized resource allocation and sustainable learning environments.

Practical or social implications. The outcomes of this research have direct implications for facility managers, educational institutions, and policymakers. By understanding the challenges and advantages associated with smart educational buildings and true pricing, stakeholders can make informed decisions, optimize resource allocation, and create learning environments that foster innovation and sustainability.

Type of paper. Viewpoint

Keywords. facility management (FM), IT-technologies, smart educational buildings, sustainability, total cost of ownership

INTRODUCTION

As is known buildings contribute hugely to the energy consumption and have an impact on the carbon footprint of organizations. The commercial/institutional and the residential sector accounts for about 12% of the European Union's (EU) greenhouse gas emissions (GHG) (European Environment Agency, 2021), and buildings account for approximately 41% of the EU's energy use (The European Green Deal, 2019; Carlander & Thollander, 2022). Energy saving in buildings is a subject of paramount importance in the global quest for sustainable development and environmental conservation (Papadakis & Katsaprakakis, 2023). Digital technologies are one of the key tools for addressing pressing global issues, such as climate change.

The general concept of viewing digital technologies as novel technology lies in the idea that data enables better decision-making. The premise of novel technology is to help facility managers achieve and control their strategic sustainability objectives. Facility managers face numerous external and internal challenges, including the increasing complexity of digital infrastructure, high service fees for accessing dashboards and data, evolving regulations concerning privacy and ethical considerations, which sometimes hinder the realization of promised sustainable development. For many, these challenges resemble a Gordian knot.

In 2020 the school of Facility Management of the Hague University of Applied Sciences (THUAS) foretold the need to acquire more knowledge about smart buildings and digitalization. Future facility professionals need to be well prepared before entering the facility field. To adequately prepare future facility professionals for their field, a fully digitized educational floor was established within the School of Facility Management at THUAS in 2021. This initiative, known as the FM living lab, aimed to achieve two objectives: first, to enhance understanding of smart building technology among both students and lecturers, and secondly, to address the challenges associated with implementing smart technologies to create a built environment that optimally balances sustainability benefits for both individuals and organizations. The challenges were not solely initial implementation costs. A smart building encompasses more than just the installation of sensor technology, such as data security concerns, digital footprint, and the need for staff training. The experience of four years has yielded many lessons. With this viewpoint paper we aim to share the knowledge we have acquired.

Smart & circular FM living lab

The FM Living Lab is currently located at THUAS. A digital network, consisting of over 300 sensors on a surface of 1100 m^2, provides data analytics on temperature, humidity, CO2-levels, energy consumption and occupancy. The network is perpetually connected to an IT- platform, and this platform is narrowly followed by users, such as students. Although the change for interval of measurement varies per sensor, such as every minute, hour, or every time a door opens or closes, its dashboard can be accessed at any time by authorized users such as students, lecturers, and the facility management staff of THUAS. The rapidly accumulating data serves as a valuable repository of information for users, enabling them to gain insights, visualize resource utilization, predict patterns, and save time in data analysis. The desired outcome is a built environment that uses technology to become more operationally efficient, protect occupant health, safety, and wellbeing, improve employee productivity, and reduce environmental impact. In daily practise the FM living lab measures the occupancy of classrooms, the indoor air quality, energy use of classrooms, the filling rate of waste bins and the usage of toilets.

However, these are merely the basic functions, the FM living lab has a much broader function. In the interplay of technology, data and facility management, the FM living lab is a digital and physical playground for all kinds of research. It offers students the opportunity, and challenges lecturers/researchers to become acquainted with the usefulness of innovative technologies, such as smart buildings and data-driven management. Our experiences of recent years have led to new teaching methods and applied research. A data-led approach sustainable cleaning services and waste management is one of the pilots that have been deported among students and others. The living lab has yielded a set of new competencies for the future facility manager; proficient in augmented analytics (AA) and artificial intelligence (AI). This ensures that the facility manager can perform high-quality data management that were previously only done by specialized data scientists.

LITERATURE OVERVIEW

The use of digitalization, data and technology in the built environment can optimize the performance of HVAC systems, facilities and assets in the building and thus reduce the CO_2 emissions and the need for energy resources. FM and CREM together play a crucial role to achieve the organization climate goals. To clarify the role of FM and CREM in relation to greening and digitizing of the built environment the FM value map of Jensen & Van der Voordt (2016), as shown in Figure 1, has been applied on the FM living lab.

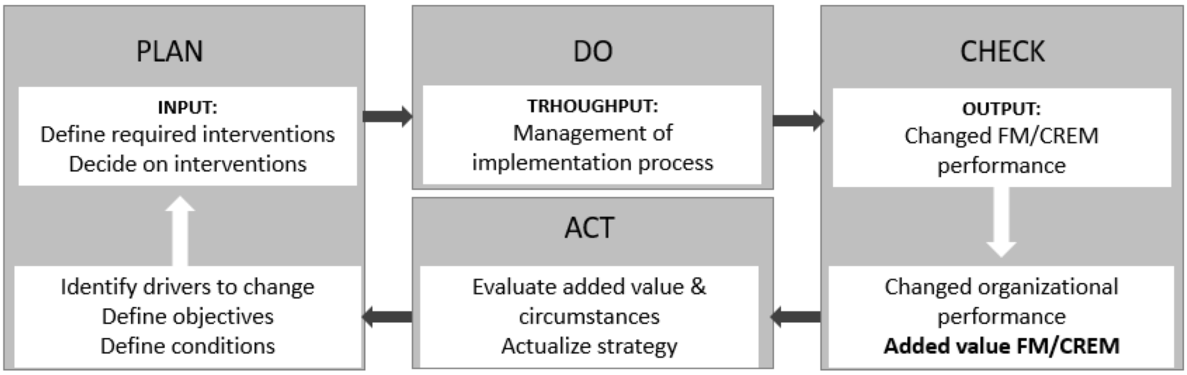

Figure 1 FM Value Map (Jensen and Van der Voordt, 2016)

The FM value map (a process model) implies that Facility Management resources (input) and processes could generate FM provisions (output), which impacts societal, customer, staff, and owner outcomes (Jensen & Van der Voordt, 2016). Facility management is a multidisciplinary topic that requires the collaboration and coordination of different stakeholders (Mannino et al., 2021). Consequently, FM must deal with changing expertise demands and renewals because investments in FM and CREM have become more complex. Not only in the department, but internal decision making in general became more complex due to social and environmental considerations and interactions with increasingly more stakeholders (Choi et al., 2019). The scope of today's real estate and facility management investments have a broader scope and are therefore more complex. As a result, the FM has difficulty managing these projects (Van der Voordt & Hoendervanger, 2023). In many companies, there exists a dual challenge of minimizing the Total Cost of Ownership (TCO) while simultaneously enhancing various outcome variables, of which sustainability is just one among multiple organizational objectives.

Complexity of ICT costs in FM and CREM investments

Appel-Meulenbroek and Danivska (2021) have conducted a review study in which they found that business case descriptions from 2013 onwards compared to business cases before 2013 contained more detailed and specific information and more steps per phase. One of the explanations is the multiplication of stakeholders due to the inclusion of technology. Not only the complexity of IT-infrastructure in the existing spatial environment but also the incurring significant costs of IT entails more detailed know-how in business cases. The IT-infrastructure, the maintenance of software and hardware, responsible computing such as datacentres, data usage, system, and impact besides the stakeholders (ICT, management, and participation councils) add to the complexity of smart buildings projects. To keep grip on such complex IT projects including the financial implications the FM must be a jack-of-all trades. The diverse range of areas in which benefit-cost analyses are utilized underscores the universal demand for a deeper comprehension of the process, both theoretically and practically. Moreover, the review highlights several prominent fields currently demonstrating a keen interest in enhancing organizational efficiency, notably IT, sustainability, and health. Additionally, it emphasizes the necessity for compelling evidence displaying the value of internal expenditures as worthwhile investment.

A recent study conducted by Papadakis & Katsaprakakis (2023) reveals that the operation and maintenance phases constitute a substantial portion, ranging from 50% to 70% of the total annual operating costs for facilities. Effective building management necessitates the integration and analysis of diverse data and information generated by various stakeholders. Consequently, augmented management of data and information can significantly enhance building performance. This has led to a widespread interest in the utilization and amalgamation of Internet of Things (IoT) and Building Information Modelling (BIM) technologies for gathering and storing data throughout the building’s entire lifecycle.

In recent years, numerous innovations have emerged in this regard. IoT and smart connectivity hold immense promise in streamlining Facility Management (FM) activities, such as inventory and document management, bolstering building security, optimizing logistics and materials tracking, monitoring the lifecycle of building components, and regulating building energy consumption. It is a paradox; while the implementation of smart building technologies can be intricate and costly, a well-executed approach ensures efficiency and sustainability. Moreover, effectively implementing such technologies necessitates a fusion of FM knowledge and expertise. Alsafery and colleagues conducted a review study and identified similar challenges for the FM manager in the context of smart building (2023). As a facility manager you need to be aware of privacy and cyber safety legislation, deal with data uncertainty (placement of sensors in the built environment), dealing with computational power (sTable and fast network), robust storage systems and building heterogenous data sources. A critical component when using smart building systems are the monthly fee for using software. The charge for software licences increases quickly if it is not purchased carefully. All these challenges could add cost to the project or impact the services provided.

METHOD

The research and development of the FM Living Lab was part of a larger study into circular business operations between 2020 – 2022 (The Hague University of Applied Sciences, 2022). 'The cycle for practice-oriented research and innovation' by van der Donk and van Lanen (2016) was the leading methodology for this sub-study. The plus of this methodology is the ability of 'applied learning in the context of the workplace environment.' It leads to natural forms of knowledge exchange between professionals. For this viewpoint paper researchers have had various conversations with different stakeholders like facility & building managers of the national government and universities of applied sciences. For two years, there has been a dialogue where also the supplier of smart building systems within THUAS participated. Topic of the dialogues was to discuss different outcomes of both the study into circular business operations and the use of smart building within facility operations. The result of the contributed to our viewpoint into the smart building paradox. In the following section the lessons learned from the FM living lab and the challenges that arose will be combined with literature about these themes.

FINDINGS

There are many providers for the delivery of smart building concepts. The FM living lab has been developed with the current contract partner of the technical installations of THUAS. In dialogue with our contract partner requirements were defined, based on a budget ceiling. The input for the smart building concept was based on gaining valuable information on inter alia occupancy and indoor climate. The output was an innovative smart building platform with which acquired knowledge and new skills could be gained. The associated platform and dashboarding had to enable, apart from evaluation tools, augmented analytics in favour of teaching method within the school of FM.

Viewable and hidden costs of the FM living lab

With a budget of €150.000, = THUAS was able to create a FM living lab including a maintenance contract of four years for the associated IT-infrastructure and software licences. Although the run-up and the construction of the smart building systems were partially delayed due to corona, the unfamiliarity and ambiguity of close collaboration between the housing department, the IT department of THUAS and the school of facility management as commissioner was a steep learning path. With the benefit of the hindsight better specified requirements and an improved preparation for integrated collaboration would have eliminated 'noise' between different stakeholders.

For example, it turned out to be much more complicated and costly to connect different IT-systems. To illustrate IT security, privacy requirements and shared ownership due to the cost had not been sufficiently thought through because of a lack of knowledge. Finally, linking the FM living lab dashboard to the facility management information system (FMIS) and the building information model system (BIM) of THUAS turned out to be more complex than expected. Extra cost has been incurred for having an API-interface written apart from the purchase of additional sensors. Furthermore, additional software had to be developed to ensure seamless integration of all IT systems, although it had not been budgeted for. Lastly, expenditures on IT licenses experienced turbulence. In the end more time and money has been invested.

Total Cost of Ownership of smart building technology

The FM living lab have learned the hard way over the past four years. The framework of Van der Voordt & Hoendervanger (2023) on the Total Cost of Ownership (TCO) was helpful in the context of a 'nuanced understanding' of implementing IT-technology. The research established that a clear understanding of the TCO is essential to display the added value of the initial investment. The FM living lab has experienced that the similar TCO rules apply for novel technology as in the field of FM & CREM; the *operational costs* mount up more than *initial investments*. For this reason, a 'TCO analysis delves into the ongoing operational expenses, such as energy bills, software licensing, and personnel training' (Van der Voordt & Hoendervanger, 2023). Moreover, novel technology requires continuous system upgrades, software updates, and addressing hardware malfunctions to ensure optimal performance, which is costly but also ineviTable. *Maintenance and upgrades of* IT-systems and software are recorded in the IT-licences, but the speed of new and therefore more sustainable technology is hard to predict and not always included in the contract terms. This can lead to additional hidden cost. But either way, smart building and technology is a future proof infrastructure and add value to be e*nergy efficient and sustainable*. As Van der Voordt & Hoendervanger (2023) conclude: 'TCO evaluates the long-term benefits of reduced energy consumption, potentially resulting in cost savings and environmental advantages.

The explosive pace of advancements in the field of IT and electronics, request also *end-of life considerations* of system components. The speed of replacement of both software and hardware accounts for decommissioning costs and potential replacements. Partly because the recycling, refurbishing, or repurposing of software and hardware is still in its preliminary stages.

CONCLUSIONS

The FM living lab unravelled the gordian knot of smart building, novel technology, TCO and the role of facility management. This project and experiment have demonstrated that smart building and novel technology is valuable input for a better performance of the built environment and the wellbeing of building's occupants. However, a successful implementation requires a structured project approach that faces the complexity of IT. The starting point is a detailed business case where besides, an elaborate stakeholder analysis, all the aspects of TCO are specified. The TCO framework of Van der Voordt & Hoendervanger (2023) is a good starting point. Moreover, implementing novel technology requires a comprehensive approach. It requires cooperation and coordination between internal and external stakeholders such as the IT-department, and the engineering services of the own organisation but also with IT-suppliers. One must be aware that the complexity of IT can be experienced by facility managers as Gordian knots. For this reason, we note that the facility manager, likened to the proverbial spider in the web, must develop new expertise at the intersection of IT, facility management, and corporate real estate management. Meanwhile, IT expertise remains a mysterious realm for a broader group of facility managers. A better adaptation of IT knowledge, skills, and qualifications within the field of FM will accelerate the implementation of smart building concepts to achieve the sustainability objectives of the Climate Act. We believe that higher education in FM could and is playing a significant role in this need for 'flexpertise' (Frie, 2023) on novel technology, IT, and a comprehensive approach of a smart building project. This viewpoint paper advocates the rapid adjustment of current FM competence profile where the importance of technology in general is discussed and IT is seen as a related professional domain (Vereniging van Hogescholen, 2017). Future FM professionals must possess the skills to integrate sustainable smart building technology within organizations. It demands for a comprehensive understanding of various stakeholders, emerging technologies such as AI and building automation, further legislation, and market expertise. As a final tip, the facility manager should assess the scope of a smart building project. The FM living lab experienced that a small-scale project is a starting point for deploying a smart building concept. It also became a process of trial and error which consumed time, energy, and money of project's participants. A detailed business case ensures a wider implementation, saves both money and time. This is the challenge and the paradox of implementing novel technology: finding balance between 'as small as possible' to avoid the waste of resources, time, and money and 'noticeably large' to make a real difference towards sustainability and wellbeing. In conclusion, the journey of the FM living lab has shed light on the intricacies of implementing smart building concepts, emphasizing the need for a structured project approach and enhanced IT knowledge within the field of facility management. As the landscape of technology and sustainability evolves, it becomes imperative for future FM professionals to embrace 'flexpertise' and integrate sustainable smart building technology effectively, thereby contributing to the advancement of both organizational performance and environmental stewardship.

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Scenario-Driven Approach for Enabling Sector-Coupled Energy Systems by Adapting Site Operations

Krämer, M. & Srivastava, R.

Faculty 2 - Technology & Life, HTW Berlin
Contact: markus.kraemer@htw-berlin.de

ABSTRACT

Background and Aim. This paper is based on the ongoing research of the second phase of the Mobility2Grid project, which aims to develop efficient, interconnected systems for a climate-neutral city. The focus of this paper is to investigate the impact of Corporate Services carried out for site operations on Sector-Coupled Energy Systems.

Methodology. A scenario-driven approach is employed to leverage the usage of on-site renewable energy sources by balancing energy usage and production already at the planning level. Therefore, multiple sectors e.g., photo voltaic, wind energy, district and gas heating are combined. A model-based concept is used which integrates BIM-Models with a model of Facility Service Operations. This resulting Building Service Model is subsequently linked with a simulation model based on the open energy modelling framework (oemof) for validation.

Results. The paper shares findings from a prototype implementation of the first iteration (initial scenario) from the so-called transfer site Max Planck Institute for Human Development, Berlin. It explores concepts of the scenario-based integrated Building Service Model and provides an outlook of the energy simulation part.

Originality. This research offers innovative concepts to bridge the gap between Digital Building Models and business process-based Services Models, providing a comprehensive view of scenarios to optimize site operations concerning the site energy systems. This study aims to broaden the perspective to encompass building operations and their impact on sector-coupled energy systems.

Practical Implications. The methods developed in this research will facilitate practitioners and energy consultants in designing and simulating comprehensive scenarios of site operation concepts, along with the sector-coupled energy systems in the early project stages.

Type of paper. Technical

Keywords. building information modelling (BIM), building operations service model, scenario model, simulation model of energy systems, open energy modelling framework (oemof)

INTRODUCTION

Addressing climate change is a global need as outlined in the Paris Agreement. Nations must reduce greenhouse emissions by 2030 and achieve net-zero emissions by 2050 (United Nations Framework Convention on Climate Change, 2015). To achieve these objectives, it is essential to widely adopt renewable energy sources within campuses and buildings. By integrating renewable energy, even if consumption levels remain constant, the building sector can significantly reduce their carbon footprint (IEA, International Energy Agency, 2023b). According to the United Nations 2020 Global Status Report for Buildings and Construction, buildings account for approximately 38% of the total carbon dioxide emissions when combining operation and construction (United Nations environment programme, 2020). However, this call to action will only succeed if solutions in the sector of electric energy, heat supply and transportation are combined, a concept referred to as 'sector coupling' (IEA, International Energy Agency, 2020).

This applies in particular regarding time disparities between the availability of renewable energy and the demand for energy when looking at campus and neighbourhoods. These issues can be addressed at the level of the national grid, real estates can also be operated in a "grid-friendly" way on a local level. Those decentralized grids can offer greater flexibility in terms of demand management (IEA, International Energy Agency, 2023a). Therefore, in future Facility Management (FM) organisations will therefore need to manage demands efficiently to ensure satisfaction among building users while also enabling microgrids to function mostly independently. The implementation of demand management strategies becomes crucial within the decentralized energy systems (Ferreira, 2022).

Managing sector coupling systematically on the level of real estates and buildings is a new field in building operations. In addition to technical issues the primary deficiencies lie in the incomplete understanding of its significance and benefits. Another critical area in need of attention is the absence of effective strategies to optimize sector coupling within microgrids on campuses, essential for enhancing grid integration and compatibility. Furthermore, there is a noTable lack of efficient methodologies how building operations and related business services can dynamically contribute to supporting sector-coupled energy systems, considering the various strategic goals of building operations, such as cost efficiency, customer convenience, self-sufficiency of energy supply or decarbonisation. The interdisciplinary nature of sector-coupled energy systems remains inadequately addressed, emphasizing the urgent need to integrate various modelling domains such as building dynamics, operations, and energy management. Lastly, the challenge of translating operational scenarios into actionable energy demands poses a significant obstacle, particularly in the early planning phases of site development. This underscores the necessity for research efforts to enable accurate and timely forecasts of energy demand patterns. These identified deficiencies serve as the focal points of our research project, where we aim to address few of them within the scope of this paper.

Aim of the Paper

The aim of this paper is to develop a comprehensive approach for examining how building operations influence sector-coupled energy systems. It seeks to enhance the understanding of building operations, thereby enhancing the efficiency of energy management strategies within the built environment, particularly at a decentralized level. The paper primarily focuses on the development of this holistic approach (method) while sharing insights from a prototype implementation using an example of a research institute's property. This prototype approach serves as a validation and acts as a starting point for the research, providing a foundation for further exploration and refinement for the next phases.
The paper delves into the concept of a scenario-based integrated Building Service Model. This model appears to be a key aspect of the developed approach, likely serving as a framework for analysing how building operations interact with energy systems. Additionally, the paper provides a preview or glimpse into the energy simulation aspect, which is crucial for validating the developed methodology. This

indicates that the paper not only develops the theoretical framework but also considers practical implementation and validation processes of the developed framework.

In summary, the paper aims to develop a holistic approach to understand how building operations affect energy systems, particularly at a decentralized level. It focuses on introducing a methodological framework, shares insights from a prototype implementation, and provides an overview of the validation process. This comprehensive approach will contribute in advancing our understanding of building operations and energy management strategies in the built environment.

Mobility2Grid research project

This paper discusses the initial results of the ongoing research of the second phase of the Mobility2Grid (M2G) project. The project M2G aims to develop efficient and interconnected systems for a climate-neutral city by investigating the mutual benefits of combining data networking and processing for mobility and energy systems.

From 2022 to 2027, the second phase will focus on dissemination of solutions developed in the first phase at the Euref Campus in Berlin Schöneberg. Hence, in phase two, new locations are considered, and the project aims on how to adapt business models to changes in the markets, how to utilize network capacities, and how to achieve controllability of vehicle fleets in a grid-friendly way while prioritizing citizen interests. Involving 38 partners from science and industry, the project comprises eight work packages, including 'transfer areas' which adopt a bottom-up approach to integrate sector-coupled energy systems within selected real estate campuses (Jefferies, 2023).

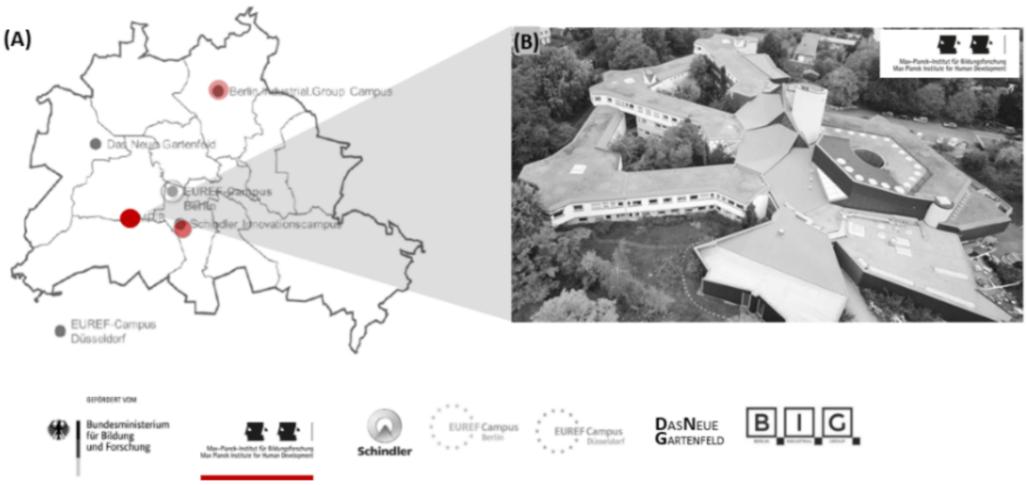

Figure 1 Mobility2Grid Transfer Areas, Source: (A) Mobility2Grid e.V. (B) MPG e.V.

To achieve this, six sites located mainly in Berlin that adhere to sustainable development models were selected, from which the 'Max Planck Institute for Human Development, Berlin (MPIB)' as one of three sites was selected by HTW (Figure 1). The paper specifically focuses on the transfer area MPIB, part of the Max Planck Society, which faces challenges in transforming its energy system to sustainability amidst planned refurbishments and increased energy demands. The Transfer Area is already developed (brownfield). However, with the planned refurbishment of the newly purchased Dillenburger Straße building in 2020 and the addition of two new magnetic resonance imaging machines (MRI) with heavy electric and thermal loads, there is a high demand for transforming the local energy system to an integrated sustainable one.

LITERATURE REVIEW

To achieve our research objectives, it is crucial to identify which corporate services in a facility influence energy consumption and how to determine the frequency and timing of energy demand. This knowledge will enable us to specify effective energy efficiency measures and understand how FM services can impact load shift and energy savings. To accomplish this, a literature review has been conducted that explores Facility Management and Energy Management standards, extracts relevant practices and applies them to our research objectives. The review will cover standards and publications in the area of Business Processes in Facility Management, Energy Management Systems, Load Management and model-based approaches such as Building Information Modelling (BIM) and Energy Simulation.

Facility Management Processes

To gain a better understanding of the FM processes for energy efficiency enhancement adjustments, it is necessary to conduct a more detailed investigation of standard methodologies such as process modelling, process mapping, and process performance. A broad overview of FM processes in practice and research work is provided by Alexander, et al. (Keith Alexander, 2008). Krämer, et. al. (Krämer et al., 2018, p. 85) explain different approaches to structure FM process model frameworks and compares common standards such as DIN EN 15221-5 (DIN EN ISO, 2015) or GEFMA 100-1 (GEFMA, 2013). The authors propose different modelling methods depending on the hierarchy level of the processes. For the purpose of this research the process framework of DIN EN 15221-5 provides the basic structure. The value chain diagram method is used due to its fairly simple representation at the process mapping level. For semantically richer modelling, the Business Process Model and Notation method (BPMN) is used, which, as a widely recognized standard for process modelling, offers a high degree of interoperability.

What all process frameworks have in common is that they distinguish between Facility Management Services (FMS), which can be located on strategic, tactical or operational level, and Facility Services (FS) for execution at an operational level. Both types of corporate services (FMS or FS) can affect the energy system of the building / real estate in two ways. Firstly, they can reduce the total energy demand (energy savings). Secondly, the corporate service can cause a load shift in energy demands. In this case, the total amount of energy consumed remains the same, but the energy will be demanded at different times.

Energy Management System and Load Management

In addition to the FM processes which together form the Facility Management System today the implementation of an Energy Management System (EMS) is almost obligatory. Energy management standards and norms are crucial for organisations to closely monitor and efficiently manage their energy consumption. ISO 50001, (DIN EN, 2018) provides a comprehensive approach to developing, implementing, maintaining, and continuously improving an EMS. It consists of organisational information and data structures, including technical assistance for energy data management and information channels.

There is an overlap between the processes of EMS and the Facility Management System in practice. Therefore, it makes sense to have a look into the EMS from the perspective of FM as is done in the GEFMA standard GEFMA 124-2 (GEFMA, 2013). Here, methods are described for efficient energy management, involving simulations, calculations, optimisation, and load management within EMS. These further aid in managing load and preventing peaks. The standard GEFMA 124-1 (GEFMA, 2021) highlights enhancing energy usage while ensuring occupants' comfort and regulations compliance. The method developed within this paper was mirrored against this standard and business processes described in the standard also provides input for the FMS / FS framework chosen in section Research Methodology.

As explained in the previous section, to achieve energy flexibility, we first need to identify which corporate services in a facility have an impact on the energy systems and further how to recognize the frequency or timing of energy demand of an energy system in a facility. The impact will be translated to load profiles. Load profiles are a timeline of assumed or measured energy demands whereby the sequence of values can be provided in different resolutions such as every 15 min or one value per hour. They assist in monitoring consumption, forecasting demand and designing energy systems for buildings or districts (Schellong, 2016, p. 375). If no measured load profiles are available, Standard Load Profiles (SLP) can be used. SLPs are derived from historical data of different customer and facility groups and help utilities to predict and efficiently manage fluctuations in electricity consumption. Frequently, SLPs from BDEW (Federal Association of the Energy and Water Industry, 2023) are used in practice. Nevertheless, due to potential variations, accurate analysis may often require on-site measurements.

BIM based Energy Simulation and Sector Coupling

BIM-based simulations are essential in identifying the dynamic interactions between Building Energy Systems, renewable energy sources and factors like weather and user behaviour. Simulation methods are necessary for evaluating complex real-world scenarios in buildings and properties. These simulations rely on digital building models, based on the BIM method, as they contain in-depth information about building elements and their relationships. Integrating simulation tools into BIM software aids in generating energy demand and use calculations, enabling the creation of scenarios within the digital building models while mimicking the what-if scenarios. Furthermore, combining digital building models with simulation models and monitoring data enables the creation of comprehensive digital twins, enhancing understanding and management of building performance throughout its lifecycle (Krämer et al., 2023, p. 99).

Oemof is an open-source tool written in Python. It allows users to adapt and modify it accordingly, offering flexibility and transparency. It aids in the assessment and optimisation of energy systems by facilitating tools for simulating various components of energy systems such as power plants, grids and storage system. Four main components compose the structure of an oemof.solph, these are Source, Sink, Linear Transformer and Generic Storage and are interconnected by a bus. The connection between the components and a bus is referred to as Flows (Hilpert et al., 2018). Thus, oemof can be used to model and investigate the interactions between various energy sectors within a sector-coupled system. By integrating algorithms and information related to sector coupling into oemof models, one can examine the influence of sector coupling approaches on energy system performance, for example factors like cost, energy supply security and environmental impact (Nagel, 2019, pp. 7–12).

RESEARCH METHODOLOGY

The methodology employed in this study as part of M2G work package five follows a bottom-up approach. As a starting point, the selected transfer areas of the project are evaluated and assessed with the methodology presented next. Based on the findings of the initial application of the methodology from the first site, it will be then generalized, adapted and reapplied to the next transfer areas. In this way the methodology will be iteratively improved to become a generic transfer method which also transfers knowledge (in terms of 'how-to') from one transfer area to another.

Solution Space and Scenario-Driven Approach

For this purpose, it is essential to firstly consider the specific restrictions of the distinct transfer area and secondly to ensure that no potentially applicable optimization solutions are overlooked. Therefore, a three-dimensional methodology is selected, referred to as 'solution space' or 'solution room', shown in the Figure 2 on the left side. As illustrated the solution space is spanned across the three dimensions 'technologies', 'processes and management' and the 'phases and methods'. The solution space serves to identify, implement and validate solution modules that combine technological, organisational and methodological concepts.

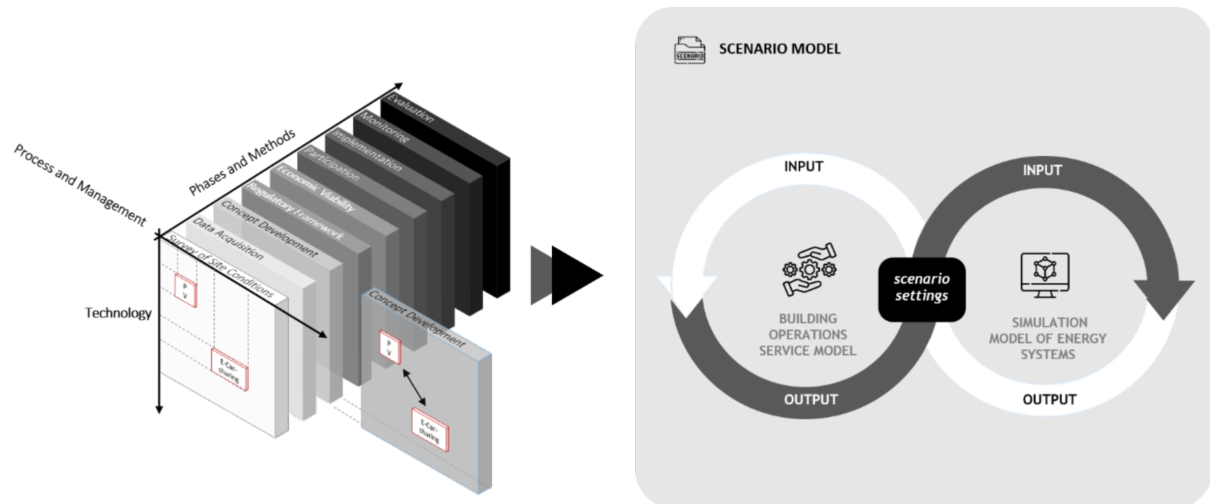

Figure 2 Solution Space and Scenario Model Cycle, Source: By Authors

The dimension 'technologies' focus on the energy system of the site. Currently, the technological solution modules 'District heating', 'Combined heat and power (CHP)', 'Photovoltaics (PV)', 'Electric battery storage', 'Air-to-water heat pump', 'Brine-to-water heat pump', 'Groundwater heat pump', 'waste heat recovery', 'Thermal storage tank' and 'Underground thermal storage tank' are available. The dimension 'processes and management' comprises all aspects of building operations impacting the energy system, including the building services already mentioned (FMS, FS, EMS), but also the business objectives of the site such as 'carbon free campus' or 'most economical solution'. The 'methods and procedures' covers the projects phase such as 'Survey of site conditions', 'Data acquisition', 'Conceptional design development' up to 'Monitoring' and 'Evaluation'.

In principle, the solution space encompasses all plausible combinations of solution modules from these three dimensions. However, in reality, the specific conditions of the transfer areas limit the solution space individually, as not all technological or organisational aspects are equally significant for each transfer area. On the one hand, this approach enables standardisation and comparability in the course of the research project, but above all a sensible focus on the real conditions of the areas under consideration.

The selection of aspects from the solution space for a specific transfer area leads to a scenario that should be evaluated using oemof simulation. Modifying the scenario by changing the parameter settings for the baseline (or initial) scenario, a scenario-driven approach is applied in which sometimes rivalling scenarios are systematically refined with each iteration. However, this approach requires consistent mapping of the scenarios in a model that allows to track the progress of scenario iterations. By framing the process in this manner, it becomes apparent that advancement occurs through successive iterations of scenarios, which improve the overall understanding of the solutions, for example, to increase utilization of on-site renewable energy sources. The parameters of the technologies dimension refer to the technical limitation and sizing of the possible solution modules on site, e.g., the usage of the district heating will be restricted or the storage sizes will be limited. From the process and management perspective specific FMS such as 'Occupancy Management' is chosen and for example, a different scheduling of office use on premise is evaluated. In consequence, this will lead to specific scenario settings. In the case of the organisational dimension, those settings of the business processes will lead to different energy demands. The demand will be represented by load profiles, in which the timing of energy usage and production is balanced at the planning level. In the case of the technologies dimension, it will be represented by energy production profiles. For instance, the production profile will cover an assumed production of electric energy by PV elements based on the location and orientation of the buildings. Based on these scenario settings the simulation model is conFigured. The simulation tool based on oemof will then simulate energy demands (energy sinks) and local energy production or energy supply by the power grid (energy sources) connected via energy busses over one year, for example in 15-minute steps (Figure 2, right side).

Modell-Based Approach

All the information of the scenario is stored in the scenario model shown in Figure 3. The scenario model acts as a repository that contains the setup, settings and results of the scenario describing how building operations impact the energy system, validated by the simulation of a transfer area. Therefore, the left side of the scenario model shown in Figure 3 is built by the Building Operations Service Model. To reduce complexity and to make use of existing modelling approaches, the Building Operations Service Model is not a 'one-size-fits-all' approach. Instead of using a monolithic model, three models are combined (linked) in this research.

The first partial model is holding the built environment of the transfer site. For this purpose, the BIM method is used. The so-called 'site model' is a BIM model in which the building objects are reduced to the minimum of information and geometric details needed for the purpose. Therefore, the model can be called a BIM light model. In the research, the BIM authoring tool Revit is used for model creation. To ensure interoperability the open standards Industry Foundation Classes (IFC) and gbXML are used.
For representing the technical components of the energy system and for holding additional alphanumeric data the database of a Computer Aided Facility Management System (CAFM) is used. This design decision was made based on the assumption that today's FM organisations will regularly be supported by an existing CAFM system, which holds most of the technical equipment and plants for maintenance purposes. In the project, the standard CAFM tool pitFM is used for integration, which already has a powerful BIM integration, based on IFC standard.

Thirdly the organisation of the building users and its FM organisation is modelled by the use of an Enterprise Business Process Modelling tool (BPM tool), which is capable to store the business process models for building operations. These tools commonly use different modelling methods which are already interconnected. In this research the well-known BPM tool ARIS is utilized, using the modelling methods organisational chart, value-added chain diagram, technical term diagram and Enterprise BPMN collaboration diagram. Currently, the link between the ARIS sub-model and the BIM-CAFM model is maintained manually by providing object IDs (in some cases IFC GUID) in both linked models. In future, an automatic integration based on semantic web technologies is planned to be used.
Besides the reduction of complexity, this approach will also enable the use of already existing models in future.

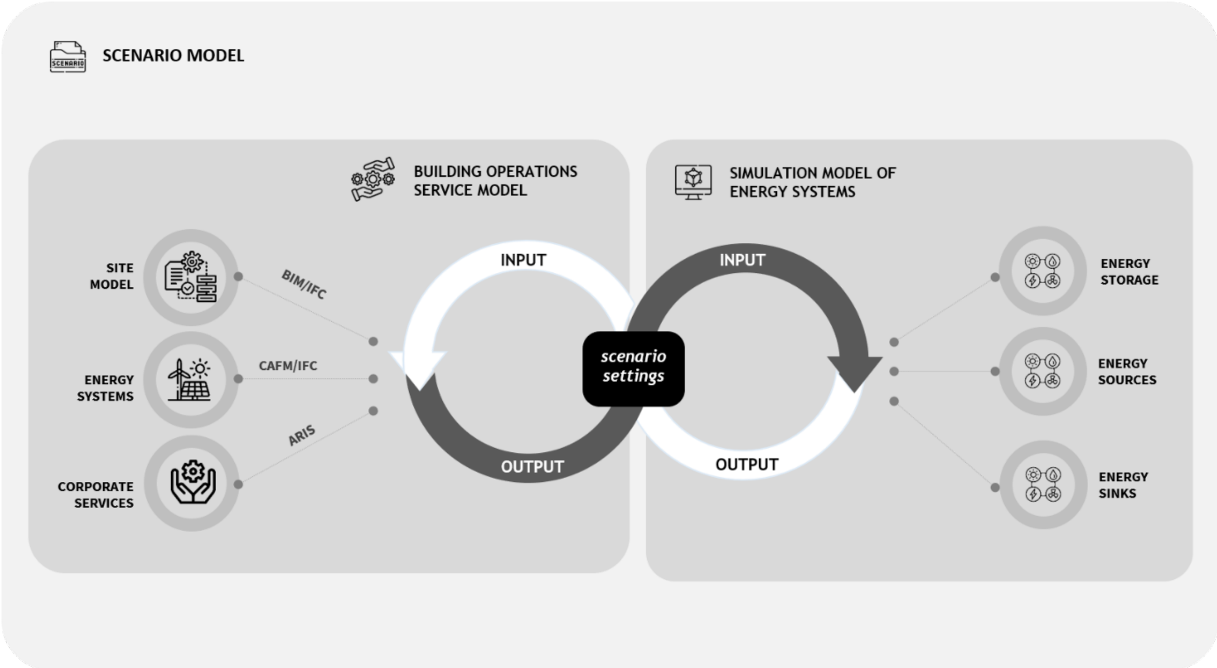

Figure 3 Linked Model Approach of Scenario Model Structure, Source: By Authors

RESULTS OF THE FIRST PROTOTYPE AT MPIB

The first scenario cycle was implemented at the transfer area MPIB demonstrating the initial outcomes of the research approach and methodology. The prototype focuses on creating the scenario model itself ready to be used for simulation. Within the scope of this paper, the simulation was executed, but simulation results have not been yet calibrated.

The prototypical creation of the first scenario at the MPIB campus is situated in Berlin and comprises two buildings (MPG e.V., 2024). Building one accommodates various facilities, including offices, laboratories, servers, a library, a data centre and a canteen. Apart from checking the roof space for being used for photovoltaic modules, no extensive construction measures are currently planned. Building two houses a 3T MRI facility. Plans for this building include two additional MRIs, a wave field laboratory, and expanded office space, that should be operated as shared desk environments. Regarding the energy system, a network of electric and thermal energy between buildings is in consideration, particularly concerning heating systems.

The initial step involved creating a simplified BIM-based site model of the MPIB site. Deciding the level of geometry (LoG) and level of information (LoI) played crucial roles. Given the refurbishment project in building two, the model was developed with a higher level of geometry and information (**Figure 4**). The site models act as a reference to export essentially geometric and topological information to further tools (e.g., PV*Sol, DesignBuilder and Green Building Studio). Alphanumeric data related to facility services and operations were extracted from the CAFM system Archibus from MPIB FM team. The identity data from the CAFM system of relevant building objects were used to establish model links to Revit and IFC.

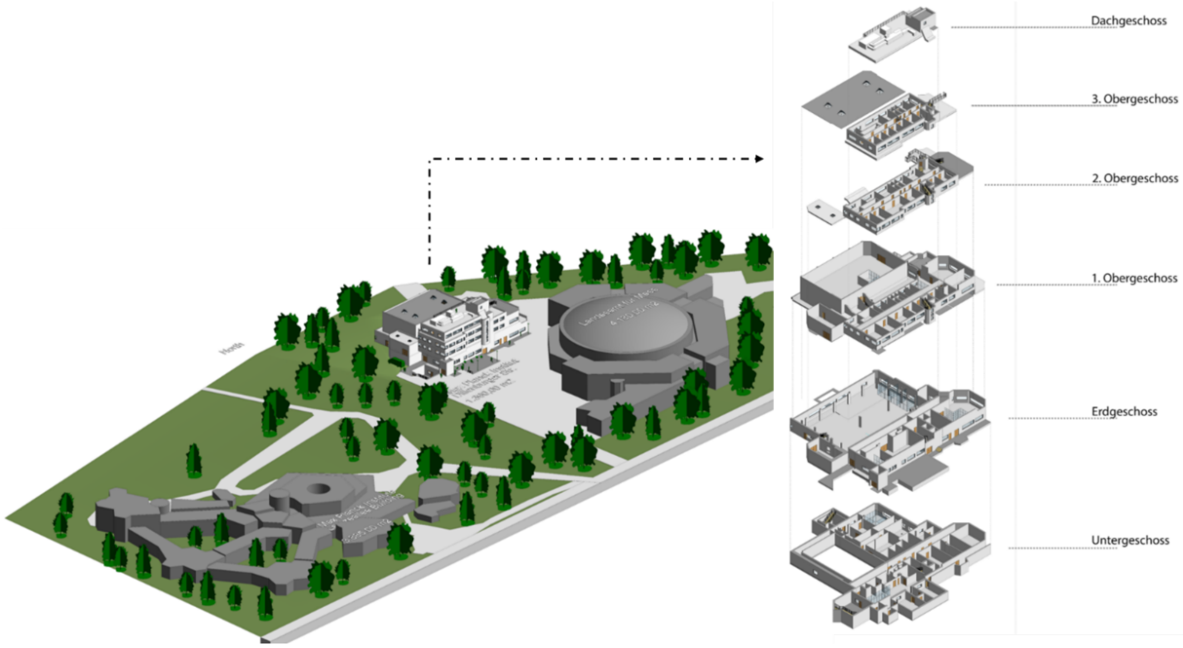

Figure 4 BIM Site Model Showcasing Dillenburger Strasse Building (Building 2), Source: By Authors

Information about building operations regarding the organisational structure is mapped to an organisational chart model (organisational units, roles), which are linked to spaces (link to site model). Based on the generic FMS framework, available as a value-added chain diagram, the relevant services were selected. Further information of the scenario settings is stored in technical term models.

To implement the first scenario cycle, the FMS 'office occupancy management', influenced by the widespread adoption of home or remote offices following the COVID-19 pandemic. This phenomenon has resulted in a significant decrease in office occupancy levels. MPIB is considering desk sharing and a room booking software. Subsequently, a scenario is being developed to optimize the use of space to shift the loads in the entire building and save energy. In the initial scenario model, no conversion of office space to activity-based offices is considered. Likewise, no combined consideration of office and laboratory use was applied yet.

The technical data collected from MPIB in terms of office occupancy management is as follows: The crucial input parameters for simulations include 10,274 m² Net Room Area. Of this, 3,338 m² is designated as office space, while 3,459 m² is allocated to other uses. The traffic area covers 3,077 m², and the technical areas encompass 400 m². Additionally, data regarding heat and electricity consumption were gathered. The total heat consumption is about a high six-Figure amount of kWh/a. Similarly, the total electricity consumption is reported low seven-Figure amount of KWh/a. The setup of the initial scenario involved evaluating the BIM light model and determining the space allocated for offices. Further optimization, particularly for activity-based offices, was deferred to subsequent stages. Additionally, the available roof space for the installation of photovoltaic (PV) panels was assessed using the site model. For this purpose, the engineering software PV*Sol was used based on the information from the site model.

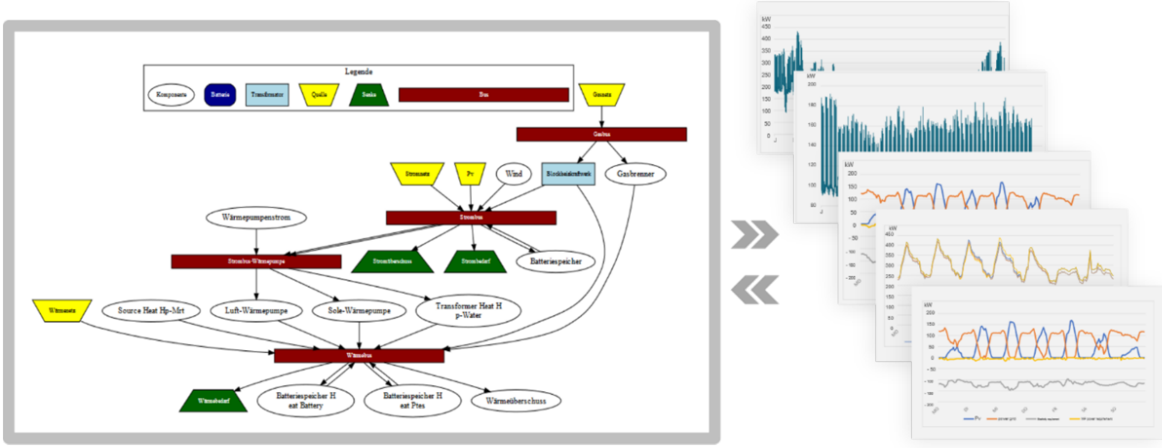

Figure 5 Oemof Model on the left and Load Profiles on the right, Source: Skorka (2023)

To translate the Building Operations Service Modell to scenario settings for the oemof simulation engine, energy load and production profiles must be provided. Therefore, a measured electric overall load profile (1 h resolution over 3 years) from MPIB was transformed to a reference load profile and then adapted to the specific office usage scenarios '50% occupancy' and 'load shift scenario', in which occupancy on Mondays and Fridays was reduced to 10%. To achieve this, the consumption of a standard office room was scaled up to the total number of office space and then subtracted to get a baseline without office usage. In the next step, the two office occupancy scenarios are added. Since MPIB has no measured thermal load profiles (only the total amount per year) the Standard Load profile and Basic Supply Ordinance (GKO) of Federal Association of the Energy and Water Industry (BDEW) was scaled to the total consumption of MPIB. The adaption to the scenarios was calculated accordingly making use of the demandlib tool provided by oemof (Figure 5).

Using the data collected from the models, the economic and ecological parameters of the selected technology options were determined and passed through Excel sheets to the oemof simulation model. Figure 5 shows on the right side the schematic depiction of the MPIB energy system generated by the simulation engine. For MPIB's initial scenario the following technology options were conFigured: district heating (with a limitation to 50%), CHP, PV (full usage on the roof of Lentzeallee), heat exchangers (for the MRI), heat pumps, and electric and Underground thermal storage tank. The simulation results provided dimensions for the different technology options utilized. Notably, the thermal local storage was underutilized due to the economic viability of district heating. Consequently, a separate scenario excluding fossil fuel energy sources was simulated. The effects of adjusting the load profiles to reflect the different occupancy scenarios, shows up in the dimensioning of energy system components.

DISCUSSION AND CONCLUSIONS

Concepts to transform local energy systems of real estate campuses into more sustainable ones by using renewable energy sources timely on site will only be successful if the different sectors of electric energy, thermal energy and electric mobility are integrated into a sector-coupled energy system. Therefore, load balancing between energy demand and supply has to be assessed dynamically. The proposed method comes along with a simulation engine which evaluates different technical scenarios in terms of economic and ecological parameters already at an early planning stage. By integrating the simulation engine (specifically oemof in our project) with a Building Operation Service Model, it becomes easier to map modifications in service operations to what-if scenarios and then run a subsequent scenario simulation to assess consequences to energy demands and the underlying energy system. This means that change to operations can be assessed already on the planning level. This method allows for a comprehensive analysis of potential energy requirements arising from variations in operational processes, thereby strengthening strategic planning and decision-making capabilities.

While the absolute values of the simulation are not yet meaningful, as the simulation environment has not yet been calibrated, it is still possible to demonstrate the effects of the varying operating scenarios on the energy system. During the development of the initial scenario, it turned out that a model-based approach to systematically describe the entire scenario in the Building Operation Service Model increases the transparency of scenario settings. The integration of the buildings itself into the model, by linking a BIM-based site model helps to locate the effects of energy efficiency measures within the buildings. Furthermore, the Business Operation Service Model acts as a reliable repository for additional engineering tools used in parallel for example, for the approximate design of PV systems.

However, the creation of the models is critical. Making use of already existing models (either BIM models or CAFM models) by linking them to the site model is a promising approach to reduce effort. In the future, extending the BIM model to include business processes natively, might make the integration of external BPM tools such as ARIS obsolete. This means that not only the building with its rooms, equipment and spaces, but also the operating processes are natively stored in the BIM model itself. The IFC standard available for BIM models already offers initial constructs for this, such as the IFCProcess and IFCTask classes. However, these possibilities are currently only being used to a limited extent. Another critical aspect is the generation of load profiles which fit to the different operating scenarios. Using standard profiles is a powerful approach, but the adaption to specific scenarios is still a high-effort manual task. The project teams think of providing a tool which generates new load profiles based on standard scenario components extending the functionality of the demandlib tool.

The interplay of site-specific parameters shapes the formulation of research questions unique to each location, emphasizing the central role of the methodological approach in identifying research priorities. This approach, employed by the ‘Sites and Neighbourhoods’ research core, complements the EUREF-Campus's top-down strategy and facilitates the transfer of research findings to other areas, enhancing the broader impact of transfer research. The next step of the project will be the application of the method to the other different transfer sites, thereby the evaluation of further corporate services and the extension and calibration of the simulation engine.

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Exploring the Home Office with Participatory Photography

Beckers, R.

HAN University of Applied Sciences, School for Facility Management
Contact: Ronald.Beckers@han.nl

ABSTRACT

Background and aim. In regular office environments, facility managers put a lot of effort in facilitating workplaces. Nevertheless, literature and practice show that after two years of Covid-19, many knowledge workers prefer working from home (WFH) over going to the office. This paper addresses the characteristics of workplaces of employees WFH.

Methodology. The paper first outlines a theoretical framework for the home office. It then presents the findings of a study based on participatory photography, in which 47 respondents took pictures of their home office and completed a questionnaire. The photos and results of the questionnaire were analyzed based on the developed framework.

Results. The paper presents the findings of a photo study resulting in a typology of the physical aspects of home offices.

Originality. This study is original because not many studies about WFH focus on the characteristics of the home office. Also, participatory photography is rarely used in facility management research. However, this established qualitative method, frequently used in studies to gather data from individuals about their environments, proves to be a valuable tool for examining the work environment at home.

Practical or social implications. The findings of this study contribute to a better understanding of the physical work environment at home. These results could be used by organizations and facility managers as input for a WFH policy and to help employees conFigure the workplace at their home office.

Type of paper. Research (full).

Keywords. home office, participatory photography, working from home (WFH)

INTRODUCTION

Working from home (WFH) for knowledge workers has been prevalent for several decades and has been studied since the 1980s (Arkesteijn et al. 2021). For the historical context of working from home, Vartiainen (2008) cites a 1984 study by Olson and Prims on telecommuting, which involves working from home using computers. In the Netherlands, remote office work was formalized in the 1990s by Dutch governmental organizations and large companies like Interpolis and Rabobank. Back then, WFH was introduced as teleworking which was popular because of two often-claimed benefits: a better work-family balance for employees and a comforTable work environment at home (Fan Ng 2010). The development of information and communication technology increased WFH this century as part of 'new ways of working' (Brunia et al. 2016; Bijl 2007; Kotera & Correa Vione 2020). Since the turn of the century, many countries such as the UK, US, Finland, and Germany have seen a rise in the number of remote workers (Vartiainen, 2008) and post-Covid, a significant portion of knowledge workers finds remote work a viable alternative to office work. A large study (N=126,969) by Leesman in 2020 (Angerer 2023) showed that 66% of the office workers prefer to work three days or more from home during the week. Research from the Center for People and Buildings in the Netherlands indicates that a substantial 85-90% of approximately 30,000 respondents work about 35% of their time from home and prefer to continue doing so (La Brijn et al. 2020).

Many studies on remote work were conducted during the Covid-19 pandemic in 2020-2021, a period when employees were extensively working from home. Examples include research in Finland (Blomqvist et al., 2020), the Netherlands (La Brijn et al., 2020; Arkesteijn et al., 2021), Australia (Marzaban et al., 2021), and the USA (Yang, Kim & Hong, 2023). Since Covid, the combination of WFH and working in the office is often referred to as 'hybrid working' (Appel-Meulenbroek et al. 2022). Unlike pre-Covid times, WFH as part of hybrid work is now seen more as a right than a mere option.

Nevertheless, a study of Statistics Netherlands (CBS, 2024) reveals significant differences between countries. The Netherlands is a leader in terms of WFH in Europe, closely followed by Sweden, Finland, Luxembourg, and Ireland. More than 51.9% of Dutch people work from home either regularly or occasionally, while the average across the 27 EU countries is 22.5%. In countries like Romania and Bulgaria, the percentage of people WFH is still less than 5%. In most Northern European countries such as the Netherlands, there is government legislation supporting WFH, and companies are increasingly making agreements about remote work for their staff. However, this is not the case, or much less so, in a large part of Europe.

In various studies on remote work, the emphasis often lies on the motives of employees for working from home (La Brijn et al. 2020), the factors affecting employee performance when WFH (Amri et al. 2022), the influence of WFH on perceived productivity (Arkesteijn et al. 2021) or the effects of the home office on well-being and mental health of employees (Bergefurt et al. 2023; Marzban et al. 2021).
However, there is relatively less research on the physical aspects of remote work. If addressed, research often focusses on ergonomic issues related to WFH (Davis et al. 2020; Marzban et al. 2021). Several studies shed light on employees' satisfaction with the facilities available for remote work, as well as the functionality and comfort of their home office (Voll & Pfnür 2023; La Brijn et al. 2021; Marzban et al. 2021; Margariti et al. 2021).

Some research addresses that WFH is not without risks, particularly when using workspaces that do not meet occupational health and safety guidelines (Van den Heuvel et al. 2021; Davis et al. 2020; Bevan et al. 2020). While office spaces in a building must adhere to a list of legally mandated requirements, this aspect is often overlooked in the context of remote work. There is a lack of background and understanding of the home office in terms of physical and affective dimensions (Margariti et al. 2021).
Davis et al. (2020) accentuated that poor ergonomics in home offices might cause physical complaints. The study by Leesman (Angerer 2023) indicates that not even half of remote workers (40%) have a 'dedicated' workspace or office at home. 31% report having a workspace at home where they can leave their belongings (which does not need to be cleared for other activities at home when not working), but it is not in a separate room. 29% of the respondents state that they work from home in a space that cannot be characterized as an office workspace (i.e. at the kitchen Table, on the couch, in bed, on the

floor, etc.). The poor circumstances of WFH could increase companies' bottom line through treatment costs, compensation costs and absenteeism and presenteeism (Davis et al. 2020).

Therefore, it is relevant to learn more about the key characteristics of home workplaces which knowledge workers use to work from home. This paper addresses the appearance of workplaces at home related to a theoretical framework for the physical home office.

HOME OFFICE FRAMEWORK

In the literature, several studies address the characteristics of the home office, building upon aspects from research in environmental psychology (such as privacy, personalization, territoriality, crowding, noise, and personal space) and in workplace design (including furniture, lighting, color, aesthetics, IT facilities, temperature, biophilic elements, and work surfaces). The aspects of the home office attended to in literature depend on the perspective of the study. Bergefurt et al. (2023) conducted a scoping review of home workplace characteristics related to the mental health of people who WFH. They addressed seven aspects including noise, acoustics and privacy; light and daylight; thermal comfort and temperature; indoor air quality and ventilation; layout and design; biophilia and views; look and feel.

Davis et al. (2020) focussed on the ergonomics of the home office during the pandemic and classified the characteristics of the home office in four categories: type of chair, type of workstation (Table/desk/other), type of input device and type of monitor. They also identified concerns such as poor lighting and the shape of the workstations at home. Margariti et al. (2021) classified their findings in basic ergonomic aspects, visual cues and peripheral constraints, and comfort and ambient aspects. Marzban et al. (2021) mentioned the physical environment and the human perspective as important features of the home office. Challenges in the physical environment included furniture ergonomics and technology (equipment and internet connectivity), while the human aspects of WFH were related to the difficulty in finding an adequate space to work from and the challenge of concentrating during WFH.

A less recent study by Fan Ng (2010) provided an overview of literature examining the home offices of teleworkers. Fan Ng found the following environmental variables in home offices: physical aspects such as space requirement, size, location in the home, layout and use, as well as ambient factors such as noise, lighting, view outdoors. Fan Ng also highlighted job equipment, including storage and specific IT devices, as important features of the home office. Psychological aspects such as privacy, territory, status, image and personalization, were indicated as relevant aspects of workplaces at home.

Based on the literature, the various aspects of the home office can be categorized into two main perspectives: a physical and an individual perspective. The physical perspective refers to layout, design and ambient aspects. The individual perspective refers to personal and psychological aspects. The two perspectives can be operationalized in a home office framework (Table 1) with items that were derived from the literature. The next section presents the findings of an empirical study based on the home office framework outlined in Table 1.

Table 1 Characteristics of the home office

Perspective	Home office features	Description	Derived from
Physical	Workplace location	Which room is used for WFH e.g., workroom, living room, kitchen	1, 4, 6, 8, 9, 11
	Workplace functionality	Is it a workspace or another type of place e.g., couch, armchair, bed	3, 5
	Design of the workplace	Are there specific design aspects e.g., shape	5
	Size of workplace	How much workspace is available for WFH e.g., small (<1 sq. m.), medium (1-2 sq. m.) or large (>2 sq. m.) surface	1, 3, 4
	Furniture: desk	What kind of desk/Table is used for WFH e.g., office desk, Table	4, 5, 6, 7, 8, 9, 10, 11
	Furniture: chair	What kind of chair is used for WFH e.g., office chair, Table chair, stool	4, 5, 6, 7, 8, 9, 10, 11
	IT-infrastructure/devices	Which IT-devices are used for WFH e.g., desk top PC, laptop, printer	5, 6, 7, 9, 10, 11
	Storage	What kind of storage is used for WFH e.g., book shelf, bookcase, storage on working surface	6
	Specific equipment	What specific equipment is used to facilitate WFH e.g., specific furniture, IT-equipment, storage, tredmill, desk bike	5
	Lighting	How much and what kind of natural and artificial lighting is available in the workplace and what is the position of the lighting	2, 3, 4, 5, 6, 7, 8
	Color	How much color was used in the workspace	1, 8
	Decoration	What decorations were used in the workplace e.g., art, pictures, curtains, carpet, visual cues	1, 8
	Plants/biophilia	Are there plants present	1, 8
	Temperature	How is the temperature of the workplace regulated e.g., central heating, electric heater	2, 3, 8, 9
	Views	What do you see when you look outside e.g., trees, garden, house, street	1, 3, 4, 6, 8
Individual	Personal information	Gender, family conditions e.g., partner and/or children, living situation e.g., small (<90 sq. m.), medium (90-180 sq. m.) or large (>180 sq. m.) home, avarage hours per week WFH	2, 3, 4, 6, 7, 8, 9, 11
	Privacy/territoriality/personal space	Are there more people in the room working from home, are there people with other activities in the room that could destract e.g., cooking in the kitchen, playing children, television, computer games	1, 2, 3, 6, 9, 11
	Noise	How much noise is there in the workplace from inside the house, but also ambient noise from outside	2, 3, 4, 6, 7, 8, 11

[1] Arkesteijn et al. 2021; [2] Bergefurt et al. 2023; [3] Boegheim et al. 2022; [4] Bonenberg & Lucchini 2022; [5] Davis et al. 2020; [6] Fan Ng 2010; [7] Garcia et al. 2024; [8] Margariti et al. 2021; [9] Marzban et al. 2021; [10] Van den Heuvel et al. 2021; [11] Yang et al. 2023

RESEARCH METHODOLOGY

The aim of the empirical part of this paper was to study the characteristics of home workplaces: which locations do employees choose for remote work and how do these spaces look like. A scoping review of literature by Bergefurt et al. (2023) revealed that the majority of research on physical work environments at home is based on traditional, mostly quantitative methods. Often, research focuses on the perceptions or satisfaction of remote workers regarding their physical work environment at home.

Hardly any research uses objective data to map the home office. The Covid-19 period, provided us with daily insights into the home offices of our colleagues during the many online sessions we were forced to have. The images depicted the situation as it was. Therefore, for this study, participatory photography was used as a method for data collection. Participatory photography is a qualitative research method which puts the camera in the hands of the people, encouraging them to document and co-share their own reality through photos (Singhal et al. 2007). Participatory photography is grounded in the 'photovoice' method of Wang and Burris (1997). The method is also known variously as 'visual voices', 'photo safari' and 'photographic essay'. We use the term 'snapshot method', where a snapshot is a photo that is 'shot' spontaneously and quickly, most without artistic or journalistic intent and usually made with a relatively cheap and compact camera. Of course, nowadays, people use their phones to take snapshots. The studies by Davis et al. (2020), Margariti et al. (2021) and Bonenberg & Lucchini (2022) are three of the few that utilized photographs of remote workers to gather information about their physical work environment at home. Davis et al. (2020) conducted a study on WFH using photos of home offices of 41 staff members from a university. Margariti et al. (2021) employed photographs of 13 participants as one of the data collection methods in their study and Bonenberg & Lucchini (2022) collected data using a questionnaire, where some of the respondents supplemented the questionnaire with photographs illustrating home-arranged workspaces.

For our study, respondents were asked to take pictures to provide as much information as possible of the place(s) where they work from home. The question was to upload one photo of the place where they usually sat when WFH, showing the workplace furnishings (desk, Table, chair, laptop, PC). Additionally, they were asked to upload two photos of the workplace in the room. If someone works in multiple places in the house, they could upload photos from multiple places. Alongside the photos, respondents were asked to fill in a short questionnaire to provide the researchers with necessary background information (anonymously). MS Forms was used for the questionnaire, where the last question offered the option to upload the three photos. The questionnaire was anonymous and the respondents were given the opportunity to choose whether to display personal information in the photos or not.

The study was conducted at the HAN University of Applied Sciences in the Netherlands, with the sample selected from employees of the Academy for Organization and Development in Nijmegen. The uploaded photographs of the homework settings were viewed and analyzed by three teams of two researchers for the purpose of inter-rater reliability, using an assessment format based on the theoretical framework presented in Table I. Figure 1 shows some examples of analyzed pictures.

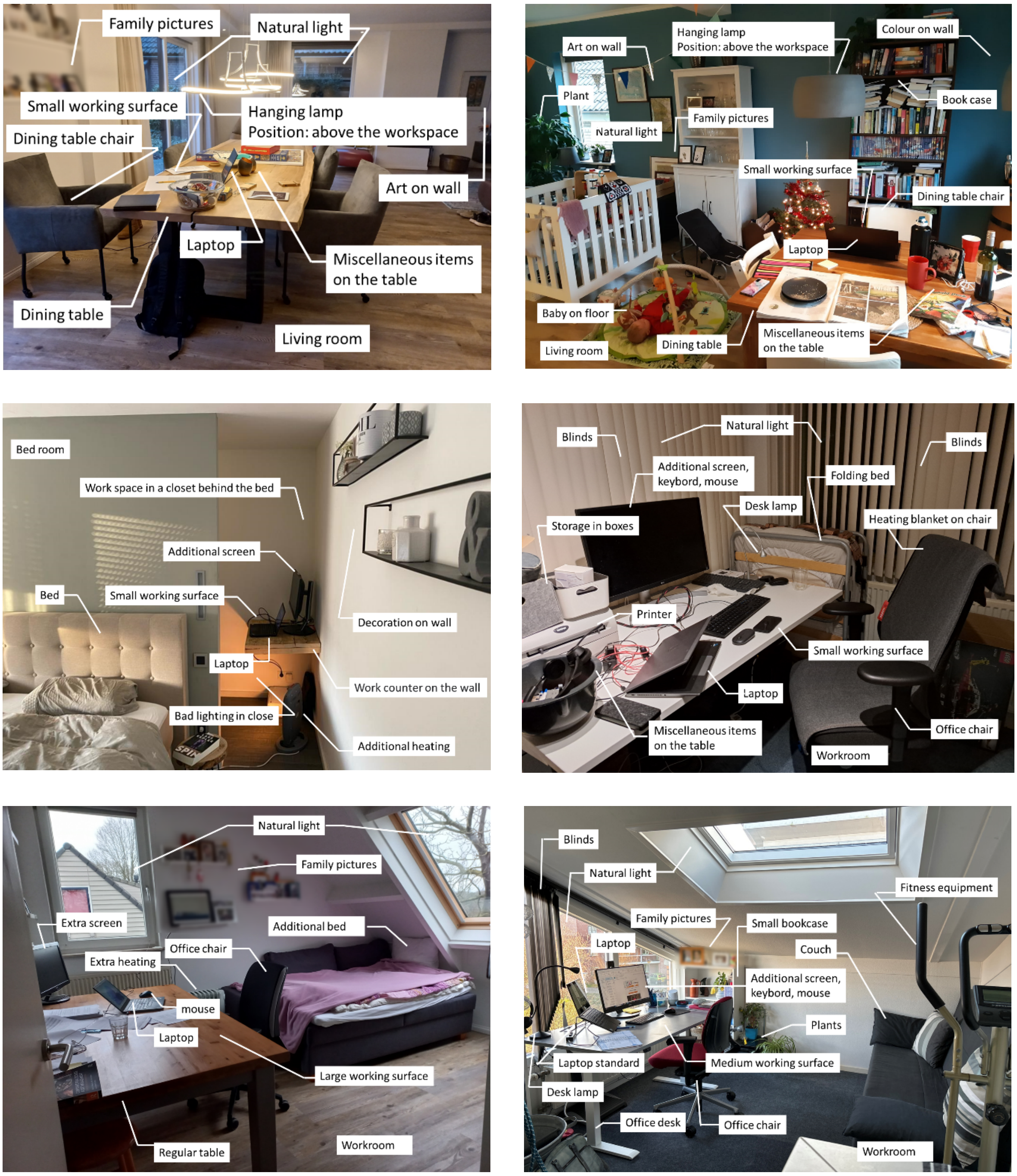

Figure 1 Snapshot analysis

RESULTS

Descriptive statistics

The questionnaire was completed by 47 respondents, 16 (34%) male and 31 (66%) female. 55% of respondents reported working from home up to 1 day a week. 38% work at home a maximum of 2 days per week. The remaining 6% work at home more than 2 days per week. Most respondents (68%) live in an average home with a size of 90-180 sq. m. (270-540 sq. ft). 30% live in a home larger than 180 sq. m. Only 1 respondent (2%) lives smaller than 90 sq. m. In the questionnaire, respondents also indicated what their home situation was like. Most respondents (62%) live with a family with one or more children. 14% live with a partner and 6% live alone.

Finally, respondents indicated the main reasons for the place where they WFH, where they could give multiple reasons. The home office is mainly a place where there are no other people (53%) and a place that is tailored to the activities of the moment (43%). As many respondents (43%) indicated that the design of the home office (chair, desk, IT devices) was a determining factor in choosing the place to work from home. Other relevant reasons influencing the choice of a home workspace included the temperature of the selected place to work (38%, considering the survey took place in the winter months), the privacy offered by the place (34%), the ability to leave belongings (34%), the decoration of the space (26%), the size of the work surface (26%), the view from the place (17%) and a place with as little ambient noise from outside as possible (11%).

Snapshot study

The 47 respondents who completed the questionnaire each uploaded a maximum of three pictures of their home workplace. Some respondents shared images of two or three different locations in their homes that they use frequently for remote work. Consequently, the study identified a total of 60 unique home workspaces. The analysis of the 60 home workplaces revealed 37 instances (62%) of ‘traditional desk settings’. This term refers to a desk or Table with a desk chair, specifically arranged for remote work. Most of these setups were observed in dedicated home office rooms (32 instances). Only two photos featured a desk setting in the living room, while three were in hobby rooms and one in a bedroom.

The majority of respondents (32) primarily work in a designated home office room. A smaller number (13) work in the living room or kitchen (6) with a few cases of a workstation in a hobby room (3) or a garden shed (2). Only one respondent had set up a workplace in the bedroom. Occasionally, a home office room also includes a guest bed or folding bed (4) or an armchair (3). Respondents working in the living room or kitchen typically utilize available furniture, such as a dining Table or kitchen Table with a dining Table chair or a kitchen chair. Out of the ‘traditional desk settings’ only 16 as also 27 office chairs adhere to occupational health and safety guidelines applicable in office buildings.

Most pictures depicted various IT devices, including laptops (36), additional computer screens (29), additional keyboards (26), printers (11), computer mice (34), and various other devices (desktop computers, mouse pads, Tablets/iPads, headphones, etc.). Only 18 pictures featured some storage specifically designated for remote work, such as bookcases, bookshelves, drawer blocks, or additional Tables for books, paper, and small storage containers.

Upon analyzing the photos, the researchers determined the average workplace surface. The majority of workplace surfaces (30) were classified as medium (1.2 sq. m.), 19 as small (less than 1 sq. m.), and 10 as large (more than 2 sq. m.).

Lighting emerged as an interesting aspect of workplaces. While office buildings adhere to strict guidelines for lighting, the pictures of home offices predominantly showed daylight (54) and additional lighting such as ceiling lighting, desk lamps, and hanging lamps. Although the pictures couldn't be used to measure the amount of light, they did reveal some clues. Most images depicted lighting in a logical position, such as directly above the desk or Table (37) or placed logically in relation to the natural light/sun light (26). However, 29 pictures indicated an illogical workplace position due to incident sunlight on the computer screen, a wrong position of artificial lighting or backlight behind the screen.

Finally, the pictures offered insights into ambient factors. Thirty-three images featured plants, 27 incorporated color on the walls, 18 showed family pictures near the workplace, and 26 displayed art on the walls. Other items as carpets on the floor, Christmas decorations, pets, and even a baby were visible in some pictures. However, 16 pictures showcased potential distractions, including kids' toys, laundry, clothes, an ironing board, Table clutter, food leftovers, paper, keys, and other miscellaneous items. The study's findings have been integrated into Figure 2, resulting in a typology that captures the various aspects present in the photographs.

DISCUSSION AND CONCLUSIONS

After Covid-19, knowledge workers extensively carry out office tasks from home, and many organizations even expect their employees to work remotely for a significant portion of the week. Regarding workplace research, most studies focus on office environments, with few examining the home workplaces. The increased prevalence of remote work has heightened the need for knowledge and insight into home office setups.

This study aimed to investigate the characteristics of home offices. The results reveal that many people have a designated workspace in their homes, often in a separate workroom or study, to isolate themselves from other household activities. This aligns with Margariti et al. (2021), who found in their study that over half of the respondents indicated the need for a fixed workspace in their homes. Marzban et al. (2021) also suggested that having a private space dedicated to work with ergonomic furniture would be a sustainable solution to support WFH. However, the home office setups often do not comply with the ergonomic guidelines applicable in office spaces. Based on our study, Davis et al.'s (2020) conclusion that 40% of remote workers report issues with furniture ergonomics is well understood. While the quality of chairs used for remote work is generally sufficient, it is still slightly lower than the 58% reported by Davis et al. (2020). For facility managers, this is an important consideration. In offices, significant attention is given to the importance of office furniture. Leesman (2023) investigated 23 workplace features and sought input from office workers regarding their significance. The results highlight that the desk (84% of respondents) and the chair (82%) are perceived as the most crucial workplace feature by users. Facility managers can provide significant added value to home offices simply by offering a good desk and a comforTable chair to remote workers.

Next, home workspaces are often not very tidy, as evident in the photos showing miscellaneous things on both dedicated home office setups and other areas in the house where individuals set up their laptops for work. Margariti et al. (2021, p7) reached a similar conclusion that "[…] domestic lived workspaces look necessarily messy and chaotic". Additionally, home office workrooms are often not aesthetically pleasing, suggesting that functionality, particularly having a quiet space to work, takes precedence for remote workers. Respondents in Margariti et al.'s (2021) study expressed a preference for having a dedicated space at home, as working in common domestic areas like the living room or kitchen poses distractions. An extensive Finnish study conducted during the Covid-19 pandemic showed that only 24% of the over 5,000 respondents perceived the home-office as a distracting work environment, whereas 71% of the respondents did not (Blomqvist et al. 2020). Regarding IT devices, it is noteworthy that hardly anyone uses a desktop computer at home. Most remote workers use a laptop, often complemented by an external monitor (or multiple), an external keyboard, and an external mouse. Printers at home were limitedly visible in the photos.

The study's outcome, supported by photos, resulted in a typology with roughly three levels. The first level pertains to the room in the house used for work (e.g., workroom/study, living room, kitchen). The second level refers to the type of workspace used (e.g., regular office desk with an office chair, regular Table with an office chair, or another type of workspace). The third level addresses usage aspects in the home office, such as the multifunctionality of the workspace, IT devices used, clutter on the worksurface, and the size of the worksurface. This tripartite classification lends itself well to an elaboration in pattern language, similar to the method developed by Alexander in 1977. Alexander developed patterns as a tool for discussing the performance of spatial settings, representing the current best guess for an arrangement of the physical environment that works for the end user. Despite it not being the purpose of this study to convert the photo analysis results into practical patterns, it could be a valuable next step in the research.

The 'snapshot' method used in this study provides interesting and rich data, particularly on the layout and design of home offices and some ambient factors. However, photos make it challenging to make statements about all characteristics of the home office framework in Figure 1, such as noise, heating, ventilation, views, status/image, and territory. Noise, for example, is challenging to discern from a photo, and several other aspects may not always be visible. Moreover, while the photos themselves are objective data, the interpretation of what is depicted in the photos remains subject to a degree of subjectivity, even if analyzed in pairs of researchers. Technological developments in AI offer opportunities for computers to analyze images, especially useful when dealing with large amounts of data (photos), but it requires substantial investments. Given the differences between countries regarding WFH, as indicated in the introduction, it is important to emphasize that this study was conducted in a specific context: the Netherlands, with respondents from a university. Furthermore, the study's scope was limited to 47 participants. To provide more meaningful results, it would be interesting to conduct similar studies using the snapshot method in various countries and contexts. Starting in countries where remote work is becoming increasingly standard, such as in the United States, Australia, the United Kingdom, and Scandinavian countries, could add valuable insights.

Workplace location/room	Workroom 53%	Living room 20%	Kitchen 10%	Hobby room 7%	Other (attic, bed room, shed, …) 10%
Workplace	(semi) permanent workplace 62%	Temporary workplace also used for other activities 32%	Other 6%		
Setting, desk	Office desk 27%	Table 63%	Other (work counter, secretaire, coffee table, …) 10%		
Setting, chair	Office chair 46%	Dining or kitchen table chair 39%	Other (couch, desk bike, stool, …) 15%		
IT devices	Laptop 60%	Additional PC screen 48%	Additional keyboard 43%	External mouse 57%	Printer 18%
Working surface	Small 32%	Medium 50%	Large 17%		
Lighting	Natural 90%	Desk lamp 43%	Hang lamp 32%	Ceiling lamp 17%	Other (Christmas lighting, floor lamp, …) 23%
Position lighting	Logical (artificial light on the working surface) 62%	Logical (no hindrance from natural light in computer screen) 43%	Illogical (potential hindrance from natural light in computer screen) 40%	Illogical (present artificial light but not on working surface) 8%	
Ambient factors	Storage near the workplace 53%	Decoration / color on walls, curtains, carpets 45%	Art 43%	Potential distractions due to miscellaneous items near workspace 27%	
	Plants 55%	(family) pictures 30%	Other ambient factors near workspace 32%		

Figure 2 Typology of home office characteristics

To conclude, the home office presents an intriguing and unexplored research field. Facility managers would benefit from acquiring more knowledge about how their colleagues operate from home to better support remote work. For researchers, this study could serve as a step toward developing methods and tools to further investigate the relationship between the physical work environment and individual or organizational outcomes. Additionally, further research into home workplaces could provide architects with insights for designing homes that accommodate the unstoppable trend of remote work.

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Developing a Community-Supporting Office Layout for Academics: A Case Study

Colenberg, S.[1], & Du Preez, M.[2]

[1] Delft University of Technology, Department of Human-Centred Design, Delft
[2] Center for People and Buildings, Delft, The Netherlands.
Contact: s.e.colenberg@tudelft.nl

ABSTRACT

Background and aim. Currently, many organisations are struggling to adjust their offices to a hybrid working model and attract people to the office to facilitate in-person interaction, co-worker bonding, and collaboration. However, academic work also requires deep-focused work and online collaboration. This paper aimed to contribute to the user-centred design of academic workplaces by providing a short case study of developing a community-supporting office layout.

Methods. For a 43-person community, a new office floor plan was developed based on scientific knowledge and case-specific quantitative and qualitative data on the users' perceptions, preferences, and behaviour. The proposed floor plan was evaluated in two focus groups.

Results. The users' needs included more quiet workspaces and opportunities for socialising without disturbing others. The most appreciated features of the new floor plan were the addition of small rooms, increased diversity of workspaces, a stronger social core, and a more hospitable entrance displaying the identity of the users. Additionally, the evaluation provided insights for further finetuning to the community's unique needs.

Originality. This paper indicates discrepancies between an intended 'collaborative work environment' and the actual needs of academic researchers. It provides examples of interior design solutions that could serve as hypotheses for future research on academic workspaces.

Practical implications. The paper presents possible design solutions for community-supportive offices and illustrates how employees can be involved in office layout optimisation. Additionally, it presents an evidence-based design approach to identifying employees' needs and contextualising scientific knowledge.

Type of paper Research (short)

Keywords. Academic workplace, Layout, Offices, Sense of Community, User-centred design.

INTRODUCTION

Due to the consequences of the COVID-19 pandemic, many organisations are faced with a profound change in the way employees make use of their work environment (Sailer et al., 2023). Although the increased working from home may support short-term productivity and a better work-life balance, in the long run, a lack of spontaneous encounters at the office may reduce employee engagement and innovation (Allen et al., 2015; Appel-Meulenbroek et al., 2023). Popular media already report that employees are more task-focused, busy and technologically overwhelmed when working from home, while at the same time experiencing less impact and fewer connections with colleagues outside of their immediate team (Cavendish, 2022). Whilst in academic work environments, work is increasingly flexible, on-demand, augmented and participative in the work processes, placing increased emphasis on the interaction between colleagues (Alfes et al., 2022).

These developments imply that the office increasingly serves as a social anchor (Fayard et al., 2021), requiring workplace design that supports social interactions and fosters belonging. However, studies analysing office concepts, e.g. open-plan versus traditional cellular offices, often ignore that the office's specific spatial configuration may differ significantly from one design to another; adequately responding to this uniqueness requires case-dependent research (Sailer et al., 2009). This paper aims to contribute to more nuanced user-centred designs by reporting a case study on the alignment between workplace design and specific user needs in an academic work environment.

LITERATURE STUDY

The nature of academic work requires a specific approach to workplace design. Since it involves alternating frequently between teaching, supervision, administrative tasks, and focused work, the balance between facilities for interaction and concentration is especially important (Indergård & Hansen, 2023). Traditionally, universities offered private offices or small shared rooms but recently a trend towards activity-based working. This usually involves desk-sharing and more open spaces although this may reduce productivity and well-being if employees are not engaged in the design decisions (Muhonen & Berthelsen, 2020). A large international study (Khoshbakht et al., 2020) found that in both academic and commercial office buildings, perceived productivity was highest in solo offices and decreased with the increase of occupants. Regarding shared workspaces, academics preferred fewer than six occupants, whereas at commercial workplaces users preferred six to nine.

The physical work environment is capable of impacting community-building behaviour and experiences, such as the social ritual of small talk (Methot et al., 2021). Some studies show that informal and unplanned interactions enhance employee's job satisfaction, productivity, and organisational commitment, while in others the benefits of increased interaction are undermined by the disadvantages of disruptions and disturbances (Kim & de Dear, 2013). This implies, that supporting community building among academics requires a careful balance between encouraging social interaction and offering privacy. The layout, referring to the spatial organization and boundaries within an office building and the arrangement of office furniture, is essential to facilitating social interaction and privacy. For example, access to breakout areas can increase the ease of communication (Davis et al., 2019) and workers tend to gather at shared amenities such as water coolers and printers (Fayard & Weeks, 2007). Design strategies to facilitate informal interactions include manipulating walking routes and creating attractive, comforTable, and demarcated social spaces (Colenberg et al., 2023). Fayard et al (2021) recommend a large variety of social spaces to suit organisational needs in the hybrid era.

METHOD

To develop a community-building layout, a mixed-methods single case study design was employed. Single cases are useful for studying a group of people, such as work communities; they help to uncover nuanced aspects of a phenomenon in its context and provide insights into the underlying mechanisms and dynamics (Yin, 2018). In 2019 an in-depth interview with the community manager provided data on the history and purpose of the existing layout and data about user perceptions was collected through a survey. Additionally, social interactions were mapped during four different workdays, eight times a day, at one-hour intervals between 9:30 AM to 4:30 PM, and following a predetermined route. After the COVID-19 pandemic, a new floor plan was developed, replacing and adding walls, doors, and furnishings while keeping the main structure and re-using amenities. In 2023, current and previous users were asked to reflect on the redesign in two focus groups (eight and three participants).

Case description

The unit of analysis was one office floor in a Dutch university building. Its design was dedicated to stimulating social interactions and collaboration and building a community. In 2012, many interior walls were removed to create an open-plan workspace. With time, more separations were necessary to reduce distraction from focused work. Two large, shared workspaces were created and facilities for social interaction and gathering were introduced, such as seating arrangements, a kitchen, a picnic Table and large meeting rooms with folding walls to accommodate bigger groups (see Fig. 1).

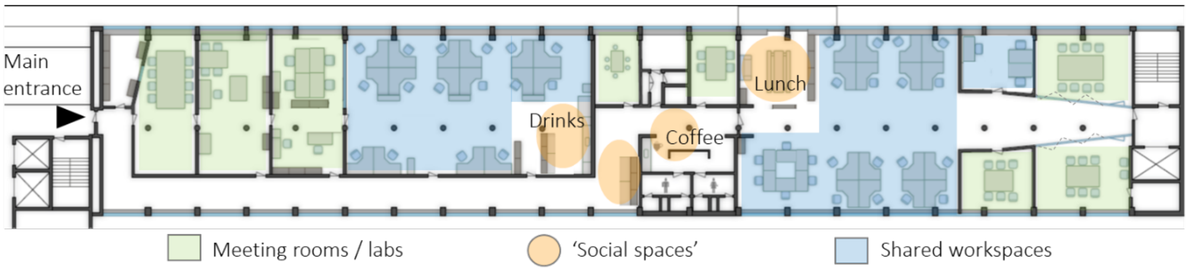

Figure 1 Current office floor layout

Originally, the redesign was not accompanied by a desk-sharing policy but recently, the community has started to gradually adopt desk-sharing to increase the occupancy, and therefore liveliness, of their premises. The office floor featured 38 desks assigned to full-time staff and seven desks for flexible use by part-time staff and graduate students, six meeting rooms, and a room dedicated to design experiments (prototyping). The main entrance of the office floor is on the left side (see Fig. 1); the one on the right side is used less frequently and only accessible to employees, not students or visitors. The toilets, coffee machine and a printer are located in the centre. The work area and meeting spaces on the right side have soft flooring, the other floors have a hard finish. The upper side of the floor plan parallels the outside façade of the building which receives direct daylight; the bottom is adjacent to a large atrium and therefore lacks daylight and outside views. Load-bearing columns are placed in a straight line parallel to the façade, approximately in the middle of the floor.

RESULTS

Case context

The initial open-plan office resulted from the then occupants' desire to support creativity and collaboration and build a community of like-minded researchers who wanted to integrate design processes into their research projects. To support this community-building, two employees were assigned as community managers and allowed to spend 10% of their working hours managing the environment, organizing activities, and introducing new members. The current layout aimed to create a workspace for iterative design processes and mingling and a quieter workspace for more focused work towards the 'dead end' of the floor. The picnic Table area and the kitchen inside the 'mingle space' aimed to facilitate social gatherings. Throughout the years, minor changes and additions have been initiated by employees to further improve the environment, for example, placing whiteboard walls, a modular couch in the corridor, and a room divider next to the picnic Table.

User perceptions and behaviour

In total, 36 questionnaires were distributed and 34 were completed, a response rate representing 79% of the community's population. According to the respondents, the existing environment provided sufficient possibilities to meet others, personalize their workspace, and experience a sense of community but lacked visual and auditorial privacy and protection against distractions. Almost one out of five respondents regularly (27%) or sometimes (61%) reported using earphones when working in this environment, half of them to block noise. Other reasons were getting inspired by music (37%), getting energized or using the headphones as a 'do-not-disturb' sign. They did not feel crowded, probably due to the large L-shaped desks.

Regarding the most frequently used locations for their informal chats, 32% referred to the coffee machine, 26% to the picnic Table, and 15% to the hallway, all of them open spaces where you run into each other or have lunch. In contrast, favourite spots for personal or confidential talks were locations at a distance from the workspaces and in enclosed spaces, preferably those with solid walls and a glass door which provide more visual privacy than the glazed folding walls of the bigger meeting rooms. Remarkably, the coffee machine and hallway were still considered suitable for sensitive conversations by a small number of users, possibly because others were passing by rather than sitting within earshot which enables following the entire conversation. The self-reported hot spots of informal chats do not completely align with the observed locations of social interaction (Fig. 2), maybe because only visible interactions were recorded and not the nature of the conversation (informal or task-oriented).

Figure 2 Place-centred behavioural map of observed social interactions

Furthermore, the behavioural mapping shows that the users are looking for privacy when making telephone calls; they try to find an empty meeting room or move to the hallway (Fig. 2), which resonates with the preferred locations for confidential talks reported in the survey. Headphone use was observed predominantly in the open workspaces in line with blocking noise as the most frequently reported reason.

Floor plan re-design

In the new floor plan (Fig. 3), the adopted hybrid working model was taken into account by providing additional spaces for video conferencing and considering desk-sharing as the standard. To reduce distractions, smaller workspaces were created by adding walls, both glass and solid for a choice between eye contact with passers-by and visual protection. Additionally, visual privacy was increased by placing plants on the desks. Private booths were added for short stretches of focused work or video conferencing. The open 'mingle' workspace was maintained but the kitchen was moved to the floor's centre. One of the large meeting rooms was sacrificed to create smaller multi-use rooms.

Figure 3 The proposed re-design and its main features

Possibilities for spontaneous meetings and informal chats were increased by clustering social facilities at the centre and entrance. The coffee machine was kept in place but the rooms nearby were dismantled to create a larger meeting space accommodating the kitchen and picnic Table. Standing Tables were added to facilitate spontaneous engagement in chats while having coffee or being on the move to other places. To support expressing the community's identity a more prominent entrance to the office floor was created with space for informal meetings and displaying meaningful objects. In the new layout, efficient space use and smaller desks allowed 40 workstations supplemented with train seats and lounge seating.

Evaluation of the proposed layout

In the focus groups, most participants took their assigned desks and preferred workspace as the point of departure for evaluating the proposed layout. Especially the PhD candidates expressed their contentedness with the increased possibilities for focused work although they preferred even more enclosed spaces. They explained that nowadays, most design processes are digitalised and writing is taking up most of their time. They would like to control distractions by working in a small room and signal their openness to a chat by moving to a social space. Others indicated they preferred a larger room with semi-permanent roommates to build relationships. Overall, the participants welcomed the increased diversity, more hospitable entrance, and the larger social core with more room for chats 'without having to move constantly because someone wants to pass'. The usefulness of the couches was questioned but they liked the train seats. Additional ideas for facilitating social interaction were proposed, such as a 'maker space' where social encounters and work can co-occur.

DISCUSSION AND CONCLUSIONS

In this paper, we indicated the increasing need for supporting social interaction and community-building in the academic work environment, brought about by hybrid working. We presented a case study to illustrate an evidence-based and user-centred approach to contextualising the problems and needs in academic work environments. The findings indicated a discrepancy between the intentions underlying the existing layout and the academics' needs which the re-design aimed to reduce. The evaluation of the proposed solutions with the end users closed the first iterative loop of the design process, making use of their expert view to highlight pitfalls and opportunities.

The low post-pandemic occupancy rates impacted the user participation in the focus groups. Although numerous users were invited to comment on the proposed design only staff who were at the office participated in the first feedback round. Therefore, long-term users were personally invited to participate in the second. IneviTable to conducting a single case study, the generated design solutions are not generalizable to other academic workplaces. However, they could inform design projects and the employed approach could serve as a basis for multiple case studies and field experiments. Future research on community-supporting layouts could use space syntax analysis for additional evaluation.

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The Role of Facility Management in University Startup Ecosystems: A Startups' Perspective

Wang, C.[1], Jääskeläinen, R.[2], Luostarinen, V.[1], Kankaala, S.[3], & Jylhä, T.[1]

[1] Aalto University, School of Engineering, Department of Built Environment
[2] Helsinki Regional Transport Authority
[3] Aalto Campus & Real Estate (ACRE)
Contact: chuyao.wang@aalto.fi.

ABSTRACT

Background and aim. Globally, universities are actively promoting startup entrepreneurship. This means the traditional university environment is expanding into university startup ecosystems (USE). This research studies the role of FM in USE from the startups' perspective.

Methods. This research selected a startup center called A Grid at the Aalto University campus in Espoo, Finland as a single case study. The data was collected via a startup journey workshop with 35 startups. The data was analyzed via a data-driven thematic analysis.

Results. In addition to providing flexible space and facilities, FM also facilitates connections within the USE and supports business development. Startups expect an affordable campus environment with flexible spaces, convenient proximity to students, the university community, peers, and the city, and support for their primary processes, including socialization and business development.

Practical or social implications. The optimization of FM can be aimed at enhancing connections and business development in the USE. It is suggested to implement flexible strategies in space and facility sharing and provide various services regarding networking and business development within USE.

Type of paper. Research (short)

Keywords. case study, facility management, university startup ecosystem, startups, university campus

INTRODUCTION

As universities and academic institutions around the globe are actively taking various actions to promote startup entrepreneurship, the university startup ecosystem (USE) has received increasing attention in existing studies. USE comprises elements like entrepreneurs, investors, support organizations, the city, student incubators, prototype development services, and academic research (Tripathi et al., 2019). Besides the physical environment, various interactions occur within USE (Stephens et al., 2022). However, a comprehensive understanding of how facility management (FM) practices intersect with and impact the USE is still lacking. While FM is crucial in the physical university environment (Hayter, 2018), its specific roles in USE and its implications for startups need more studies. By addressing this gap, insights can be provided into strategies to optimize FM practices to support startups in their journey in the USE. Therefore, this research aims to identify the role of FM in the USE from the startups' perspective.

THEORETICAL BACKGROUND

Based on Stam (2015), USE is a collection of elements combined to encourage startup entrepreneurship in a particular university area. Spigel (2017) emphasizes the interplay of social, economic, political, and cultural elements in USE that fosters the establishment and development of startups and supports the risk-taking of new businesses. Tripathi et al. (2019) give examples of USE elements, including stakeholders (e.g. entrepreneurs, investors, support organizations, the city, and university representatives), services (e.g. prototype development services), and academic research. The existing USE studies focus not only on specific geographic boundaries, but also on the broader relationship space of USE (Spigel, 2017; Prokop, 2021). In addition to on-campus attributes, USE has also broader regional/city elements, such as local government and external startups (Miller and Acs, 2017).

Regarding the role of FM, as an organizational function that integrates people, places, and processes within the built environment (e.g., Jensen, 2008; ISO 41011:2024), FM ensures that the physical infrastructure adequately supports startup activities in the USE. Some studies emphasize FM's function as physical infrastructure and a geographical boundary that supports the establishment and growth of small-scale startups (Tripathi et al., 2019; Hayter, 2018). While FM primarily focuses on services that support and enhance the effectiveness of core activities (Rytkönen, 2016), existing studies lack a comprehensive understanding of the specific services needed within USE. In the ecosystem, sharing among participants facilitates the connection between demand and supply, with platforms acting as the intermediary (Aumüller-Wagner & Baka, 2023; Leung, Xue & Wen, 2019). Therefore, considering the sharing of facilities within the USE, FM holds potential as a platform to connect demand and supply, promoting connections among ecosystem participants.

METHODS

To gain a deep understanding of the role of FM in the USE from the startups' perspective, this research follows a qualitative, single-case study approach. As a type of empirical research, a single-case study explores a specific case deeply, which could be for a location, individual, or policy (Green and Thorogood, 2018). This research selected a startup center called A Grid at the Aalto University campus in Espoo, Finland as a single case study. Home to approximately 150 startups and partners, A Grid is a gateway to resources, talented students, advanced research, and infrastructure in the Aalto USE.

This study collected primary data through a workshop with the startups in A Grid. During the workshop, the experience of the startups was collected along the so-called A Grid's startup journey including six phases: 0) inspiration, 1) ideas and team formation, 2) product development and validation, 3) business establishment, 4) growth and investor engagement, and 5) expansion. The 35 workshop participants were asked to write down their experiences along the startup journey on post-it notes. A total of 75 post-it notes were generated, 14 of which were unclear and needed to be excluded from the analysis. The analysis is therefore based on 61 post-it notes.

The data was analyzed by an inductive data-driven approach. Thematic analysis is used to explore the subjective reality of startups' experiences. By thematic analysis, codes, keywords, and themes can be identified to gain meaningful insights, reveal subjective reality, and build research frameworks (Naeem et al., 2023). The analysis process follows Braun and Clarke (2006) and involves first getting familiar with the data, then creating code, then generating themes through search and review, and finally analyzing and interpreting themes.

RESULTS

Through an inductive data-driven analysis, four themes are identified to represent startups' experience in the USE, including *space and facilities, proximity, networking services, and business development support* (Table 1). Some experiences are double counted in different themes. Next, these themes are presented.

The *"space and facilities"* theme, mentioned 16 times, highlights experiences with physical space and facilities. The most highlighted factor is flexibility in space to easily access more areas, such as meeting rooms and larger offices, crucial in early and late phases. Furthermore, below-market rents are valued throughout the startup journey. Startup founders have experienced the benefits of further developing their dedicated office concepts to adapt to the changing needs of their growing and evolving organizations. Easy access to special spaces, such as laboratories and crafting studios, that support prototype building and provide a proper environment for product testing, was recognized as important. Lastly, some start-uppers highlighted the importance of common spaces for the startup community, as well as spaces for restoration, such as rest spaces.

The "*proximity"* theme, based on 23 experiences, highlights the close proximity between startups and other USE participants on the same campus. Proximity offers startups the opportunity to connect with the university community and benefit from the campus' inspiring atmosphere. In addition to peer support, startups are seeking connections with students, the wider university community including teachers and researchers, and with the city, especially in the initial stages and growth (phases 0, 1 and 4). However, the degree of connections varies depending on startups' experiences. For example, some mentioned that common spaces or online communication channels did not support these connections during inspiration and expansion phases (0 and 4), while others did not see a problem. A consensus is that although startups aim to connect with students, for example, to hire summer workers for their development projects, it is challenging to establish contact. One possible factor is the separation of education and entrepreneurial activities on campus. Education is typically concentrated in certain buildings that are different from startups' building. Thus, despite sharing the same campus, connecting with students requires extra effort. While all the buildings on campus operate under the same brand aimed to foster collaboration, this alone does not guarantee effective connections within USE.

The "*networking services*" theme is based on 7 experiences with services provided for socialization and networking opportunities. Startups intend to use the A Grid on campus as a platform to communicate and network, especially at the beginning phases (0, 1, and 2). The results show that startups benefit from the regular social events held at the building. Startups also appreciate people here with diverse socio-cultural backgrounds and knowledge of different fields. However, some responses expressed the need to improve official communication through dedicated channels to prevent delays, such as in event sharing.

Table 1 Main themes in each phase of the startups' journey in results

	Phases 0-6							
	Inspiration	Idea & team formation	Product dev. & validation	Business est.	Growth & investor engagement	Expansion	Exit	Sum
Space & facilities	**1**	**4**	**2**	**4**	**-**	**4**	**1**	**16**
Below-market rents	-	1	-	2	-	1		4
Flexibility in access	1	1	-	-	-	2	1	5
Offices	-	-	-	2	-	1		3
Special spaces	-	-	2	-	-			2
Common spaces	-	2	-	-	-			2
Proximity	**6**	**5**	**1**	**1**	**8**	**2**	**-**	**23**
With students	4	1	-	-	3	1	-	9
With uni community	2	2	-	1	2	-	-	7
Peer support	-	2	1	-	2	1	-	6
With City	-	-	-	-	1	-	-	1
Networking services	**1**	**4**	**2**	**-**	**-**	**-**	**-**	**7**
Business development support	**3**	**2**	**4**	**4**	**6**	**2**		**21**
Coaching	3	1	2	2	-	-		8
Financing			1		4	2	-	7
Legal advisory		1		1				2
Marketing					1			1
Employer branding			1		1			2
Procurement support	-	-		1			-	1

Finally, the "business development support" theme, mentioned 21 times, covers assistance support for startup business growth and development throughout the entire startup journey. It includes sub-themes like coaching, financing, legal advisory, marketing, employer branding, and procurement support. Coaching is particularly valued for coaching on business establishment processes, best practices, and political considerations. Financing support, crucial in growth and expansion, highlights assistance services in securing funding and finding investors. Legal advisory, marketing, employer branding, and procurement support for example in equipment are also identified to aid startup businesses.

Within the USE, all identified themes can be classified into two distinct categories, i.e. campus environment, and support services (Figure 1). Specifically, themes of "*space and facilities*" and "*proximity*" fall under campus environment, while "*networking services*" and "*business development support*" are classified as support services. The campus environment of USE emphasizes the importance of providing flexible spaces and facilities and exploiting the benefits of proximity between startups and the university community. The support services throughout the startups' journey are also key in USE. In USE, there is a need to provide startups with services that contribute to networking opportunities and business development. Therefore, this categorization highlights the dual nature of resources available to startups, emphasizing both the campus environment and support services essential for the USE.

Figure 1 Categorization of the identified themes

DISCUSSION

Through the case study, the result shows that FM plays a crucial role in the USE. Firstly, the three common aspects of FM in previous literature, i.e. places, people, and processes (e.g., Jensen, 2008; ISO 41011:2024), are all identified and valued by startups in the USE, as the results involve the physical space and facilities, proximity, and networking with peers and the wider university community, and the different support services at each phase of the startups' journey. Moreover, the results reflect the importance of support services in addition to physical space and facilities. Aumüller-Wagner & Baka (2023) stated that the ecosystem service provider can be the bridge between startups and other actors to foster stakeholder alignment and collaboration. An ecosystem framework of the sharing economy, mediated by a platform, will form a triadic relationship between provider, consumer, and platform (Leung, Xue & Wen, 2019). Therefore, FM not only plays a spatial and geographical role but also acts as a platform to promote connections and a support function for startup business development within the USE.

CONCLUSIONS

The traditional university campus environment is evolving into USE due to increased interest in promoting startup entrepreneurship by universities. However, previous studies lack a comprehensive understanding of the role of FM in USE. In this study, the results are based on a case study conducted at a startup center called A Grid at Aalto University, Finland. The results suggest that startups expect an affordable campus environment that offers a wide range of spaces and flexibility throughout the startup journey, along with convenient proximity to students, the university community, peers, and the city, but also support for their primary processes. Specifically, startups need to be provided with networking opportunities to socialize with people from different socio-cultural backgrounds. In addition to the social aspect, startup businesses are also expected to be supported via services such as coaching, financing, legal advisory, marketing, employer branding, and procurement support. However, this study has limitations in terms of applicability in other contexts, such as in other countries. The data sample is limited to one workshop at a time and does not track the entire journey of the individual startups. Therefore, future research on the role of FM in the USE should be conducted in different contexts and follow the entire journey of individual startups.

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Campus Transformations and Student Preferences

Poutanen, J.

Tampere University, Faculty of Built Environment, the School of Architecture
Contact: jenni.poutanen@tuni.fi

ABSTRACT

Background and aim. This paper examines a university campus transformation through its supply of spaces. In recent years, many universities have invested in developing campus spaces to accommodate societal, pedagogical, and technological changes. Instead of the expansion of campuses, the focus has been on the transformation of premises. This study investigates whether the new or transformed spaces are represented in student preferences, thus implying their impact.

Methods. The study is three-fold. First, the teaching and learning spaces are categorized according to their condition (original, original/ extension, newbuilt, transformed). Secondly, the identified transformations are structured into types of adaptations (refurbished, repurposed, and retrofitted). Thirdly, the supply is compared with student preferences to evaluate if the recent developments are presented in the preferences.

The material consists of the plan analysis and the space allocation lists of a case university teaching and learning spaces, site visits, and a Soft-GIS questionnaire on preferred learning spaces conducted on the case campus in 2018. The results are formulated on descriptive statistical analyses.

Results. The results show the extent of campus transformation and its transition towards adapting existing premises and their types. The students' preferences highlight the recent teaching and learning space developments, indicating the developments meet users' needs.

Originality. The extent of a campus transformation and its learning space supply are scarcely analysed systematically according to their condition nor compared with student preferences.

Practical or social implications. The results benefit sustainable development of facilities to meet the user needs.

Type of paper. Research (full)

Keywords. adaptation, campus, socio-technical transition, teaching and learning spaces, transformation.

INTRODUCTION

The campus premises have faced pedagogical, technological and societal pressures to change to meet the changing user needs, especially during the last 10 to 20 years (Fisher, 2019; Whitton, 2018; Marmot, 2014; den Heijer, 2011; Neary & Saunders, 2011; Harrison & Hutton, 2014). Development of education, mobile technology and university reformations on funding and policies have globally led to adapting the existing facilities and new buildings (Marmot, 2014; Harrison & Hutton, 2014; Ellis & Goodyear, 2016). According to Goodyear (2022), Lamb et al. (2021) and Jandrić et al. (2018), higher education has entered an era of post-digital learning where technology is immersed in all learning situations.

Acceleration of hybrid learning and teaching activities (Lamb et al., 2021; Raes, 2022) has led universities to evaluate their need for physical space (Fisher, 2019), but the physical campus sustains (Marmot, 2014; Goodyear, 2022; Rytkönen, 2016; den Heijer, 2011). Universities have transformed the campuses by constructing new buildings (Whitton, 2018) but also reduced their spaces and instead focused on efficiently using their facilities (e.g., den Heijer, 2011; Marmot, 2014; Harrison & Hutton, 2014; Whitton, 2018). Thus, these large complexes can be interpreted to change continuously (over time). However, it is unclear if the claim of acceleration of recent developments is accurate, i.e., founded on evidence, and instead, the adaptation and construction of premises are constant.

Aligned with the investments and development of campuses, the literature on higher education teaching and learning spaces (LS) has expanded during the last two decades (Ellis & Goodyear, 2016; Whitton, 2018). One key area of interest in LSs has been students' preferences for spaces (e.g., Harrop & Turpin, 2013; Wilson, 2017; Beckers et al., 2016a; Beckers et al., 2016b; Sandberg Hanssen & Solvoll, 2015). Despite the acceleration of LS literature, the *type of changes* on the campus premises are seldom the focus per se, and studies measuring *the extent of transformation* in the width of a campus seem scarce. Examining the extent and types of the transformations also needs to be scrutinized in relation to the (student) preferences. First, this would benefit the design and development of campus premises by enabling the evaluation of whether the existing premises and campus environments are adapTable and able to meet the users' needs. Secondly, comparing the transformed spaces to the whole supply and its condition may reveal if a change was initially needed, measured by student preferences. In contrast, the whole supply, both the old and new, might be meaningful in student preferences.

This study investigates the supply of LSs in a case campus and compares those with student preferences. It measures the extent of transformed or newly built spaces in the supply. Thus, it compares how well the transformed or newly built spaces are presented in user preferences to the ones in their original condition. While the study hypothesizes that the transformed or newly built space represents a new way of using the spaces, it refrains from categorizing the types of LSs. Instead, the study categorizes the type of transformation to signify the difference between renovations of spaces without and with a change of use. The purpose is to evaluate if the transformation of the campuses has accelerated and if such transformation has been meaningful. This study does not investigate the reasons for change but the timeframe and types of change in premises.
The research questions are:

1. what is the extent of changes to the premises?
2. what is the condition (status) of the case campus premises?
3. When have the campus LSs been built or adapted?
4. How are the student preferences aligned with the condition of LSs?

LITERATURE STUDY

Theoretically, behind the campus transformation is a possible systemic change that can be seen as having influenced how and what kind of LS developments are conducted on campus. Along with the pedagogic and technological changes, universities have faced e.g., financial pressures (Marmot, 2014). The campus development literature reflects this change. Dober (1996, originally published in 1963) highlights that ensuring the growth of campus is paramount, while den Heijer (2011) raises the importance of using facilities efficiently and the need to share resources. Thus, in this study, a university campus entity is seen as a socio-technical system in transition (STT) (Geels, 2011; Geels & Schot, 2007; Geels & Kemp, 2007). The system consists of, e.g., the space supply, digital technology, and people's activities in using them (Rytkönen, 2016).

According to Geels (2011), a socio-technical system continuously transitions due to external pressures, i.e., societal changes, e.g., the global pedagogical and technological advances that influence the system at different levels and parts (Geels, 2011). However, the system also alters due to the internal interaction between actors in the system and the system components (Geels & Schot, 2007), here, the users and the premises of the campus. Such a system is 'governed' by a regime, and the STT framework is interested in regime-level changes (Geels, 2011; Geels & Schot, 2007). In this study, the regime is interpreted as the design and development of campuses, i.e., how the context is developed, and the possible transition of the regime is measured on the changes to the system, i.e., campus premises, that can be seen as an indication of the regime change (by the amount and type of changes).

This study examines system change within the built environment, which typically constrains regime changes (Geels & Kemp, 2007, p.443). Consequently, in the context of campus premises, the capacity to adapt to changes (Brand, 1994; Schmidt & Austin, 2016) also defines the system components. The adaptability of facilities increases their longevity and sustainability (Pelsmakers et al., 2020; Schmidt & Austin, 2016). According to Brand (1994) and Schmidt III & Austin (2016), buildings are comprised of distinct layers, each exhibiting varying life cycles and adaptation capabilities. This study focuses on the 'buildings as layers' model's inner layers (Schmidt III and Austin, 2016). The layers of social, stuff and space plan are the least connected to the other layers and relatively short in lifespan (Schmidt & Austin, 2016), accommodating user-driven changes. According to Schmidt III and Austin (2016), the social layer contains all human-related aspects from the individual to the organisational scale. In this study, the term is interpreted as allocation of function. The stuff layer consists of objects within the space, e.g., furniture settings. The space plan layer entails the objects that create the spaces, including their non-loadbearing walls and spatial configuration.

In Nordic universities, a series of 'campus retrofitting' projects were conducted in the 2010s. These retrofitting concepts were intended to meet the changing needs and requirements of more sustainable solutions. (Nenonen, et al., 2016a; Nenonen, et al., 2016b; Eriksson, et al., 2015.) Eriksson et al. (2015) highlight that retrofitting projects can enable a way to execute campus visions. Also, the concept of 'retrofitting' in campuses can be understood not only from a technical perspective but can also refer "*to changes in the performance of user*", e.g., new space types (Eriksson et al., 2015, p. 331). Nenonen et al. (2016a) state that the transformations of learning environments are conducted in locations that do not meet the functional requirements and thus do not provide value for the users.

Globally, many LS authors have investigated both newly built and adapted spatial solutions that have been constructed to respond to the needs of the HE pedagogy and technology (e.g., Bryant et al., 2009; Goodyear, 2020; Haines & Maurice-Takerei, 2019; Jankowska & Atlay, 2008; Holder & Lange, 2014; Cox, 2019; Cox, 2018; Riddle & Souter, 2011; Salter, et al. 2013; Sandström & Nevgi, 2019). The developments of campus learning spaces have led to a situation where the academic library or teaching spaces are not the sole places for students' learning, but the campus is an interconnected ecosystem of various learning spaces (DeFrain et al., 2022).

Sandström et al. (2022) examined cases of spatial changes and concluded that the drivers for refurbishing the teaching and learning spaces were well-being, new digital technology and the location of the learning environments. In their study, the 'location' refers to a suboptimal original condition with the intention of increasing the attractiveness of the space with the refurbishment. In the collaborative learning classroom case that Haines and Maurice-Takerei (2019) studied, the institutional goal was to reduce the building footprint and design new buildings that fit teaching and learning practices. However, Neary and Saunders (2011) found in their research that institutional aims are often underplayed, and innovation and creativity are restricted in moving from the design phase to the project phase of developing the LSs. Acton (2018) highlights that evidence is conflicting regarding whether the spatial transformations would lead to pedagogic changes; rather, the spaces should be seen as facilitating learning.

The preference studies often focus on the supply of contemporary campus LSs, the preferred qualities and how spaces meet the users' needs (e.g. Harrop & Turpin, 2013; Sandberg Hanssen & Solvoll, 2015; Wilson, 2017; Beckers, et al., 2016a; Beckers, et al., 2016b). In these studies, the type of 'construction' or transformation is not the focus. This study examines the student preferences as locations, narrowing the qualities or types of LSs from the inspection. Beckers et al. (2016b) found a significant correlation between students' LS choices and their individual preferences, personal characteristics and the learning activities they were committed to. Following the supply-demand model, this research evaluates the supply of spaces the organisation provides, i.e., their condition, and compares those with the users' needs, i.e. demands for spaces (Vande Putte & Jylhä, 2023). Demands are here measured as preferences on spaces.

RESEARCH METHODOLOGY

This study employs mixed method design with qualitative and quantitative data collection methods (Saunders, et al., 2019) to investigate the transformation of the campus LS supply and the student preferences in a case study. Case studies are (often) qualitative by nature (Yin, 2014). According to Creswell & Creswell (2018), in the mixed method design, the data sets are merged in the analysis. This procedure of merging two different databases allows investigating different issues and perspectives than without the merger (Creswell & Creswell, 2018). This study follows inductive logic and aims to describe the characteristics of the studied phenomena and to establish association patterns between phenomena (Blaikie, 2010).

The study examines a single case—a physically large campus with various embedded units (Yin, 2014). The units under examination are the supply of spaces and student preferences. The selected campus, situated in Finland outside the capital region, represents a typical Humboldtian/American campus model (Landsmark, 2011). Indeed, one-third of European campuses were established in the same era (den Heijer & Tzovlas, 2014). The campus has undergone significant transformation over the past decade, making it an ideal case for studying campus adaptations. Moreover, since its establishment, the campus has undergone a gradual expansion in phases (Häikiö, 2015), rendering a suitable case study for examining its adaptability and comparability to other European campuses.

The research consists of two main steps. First, it measures the extent of the supply of teaching and learning spaces, their status, the timeframe for their erection or adaptation and the type of their status (condition). Secondly, it compares the supply and its condition to students' preferences. Aligned with the steps, the data consists of two sets: the supply data and the student preferences data and their merger.

In a cross-sectional study (Saunders, et al., 2019), the first data set was formulated in two stages and focused evaluating the supply of LSs. During the initial stage, qualitative and quantitative evaluations were conducted through plans in the ArchiCAD program, site visits, and timetabling documents during 6/2019-2/2020. Concurrently, an Excel sheet (datasheet A) was employed to collate information for each space. Site visits at this stage consisted of observations on the condition of the LSs, the furniture and the surfaces. For the analysis, an Excel sheet was exported out of ArchiCAD that contains the plan information about each coded space (datasheet B). At the second stage (fall 2023), completion years of buildings and extensions were documented based on public records (e.g., Häikiö, 2015; Nenonen, et al., 2015). Conditions and estimated completion years for each analysed space were tabulated to datasheet B. LS appearance was not evaluated.

The second data set, i.e., students' preferences on spaces, was gathered employing a web-based Soft-GIS questionnaire in 2018 pre-covid (that can be seen as a limitation to the results). The Soft-GIS allows respondents to allocate preferences on map locations (Kahila & Kyttä, 2009). The students of the case campus formed the population of the questionnaire (Creswell & Creswell, 2018). Respondents pinpointed four preferred locations on campus building plans: one related to their curriculum (a teaching space) and three free-choice spaces, i.e., a 'learning' space not necessarily dictated by their curriculum. Each of four pinpoints had an accompanying question set that focused on the location description and reasons to prefer. The 'curriculum space' question set consisted of open answer questions and the three 'free choice spaces' question sets of closed questions with possibilities for open answers. The questionnaire response locations were imported into ArchiCAD and analysed qualitatively. The preferred space information to an Excel sheet (datasheet C) and merged with datasheet B. Thus, the merged data consists of both student preferences and supply condition information. All results employ descriptive statistical analysis and graphs.

RESULTS

The results focus on the condition of the campus LS supply to evaluate the possible transformation of the premises. The results are presented in the order of RQs.

The condition (status) of the campus LSs

This section responds to the RQs 1. "What is the extent of changes to the premises?" and 2. "What is the condition (status) of the premises?". The results are founded on site visits and plan analysis. The case campus consists of approximately 102 200 square meters (m2) of premises (Campus Development, 2019, p. 6). Through the plan analysis, we identified 30170,36 room-m2 spaces *available for students to use with different access conditions,* here referred to as the LSs, i.e., the teaching and learning spaces. The identified supply consists of 348 LSs. They are either a part of students' curriculum, i.e., spaces for mainly teaching, or spaces that students can use freely. In other words, the supply consists of a wide variety of different types and sized spaces for various purposes, but the focus here is on their condition and e.g. functions are not included in this study.

Based on the site visits, the conditions of the LSs were observed to be very different but altogether well-maintained. The identified LSs were categorised according to their status into six categories: 1. Newbuilt, 2. Original, 3. Original/ extension, 4. Refurbished, 5. Repurposed, and 6. Retrofitted. The first indicates spaces located in the latest campus building, erected in 2015. The second means the condition of the LS is as its host building's completion year. The third category entails spaces whose conditions are original and have not been adapted per se. Instead, they are located in an extension of an original building and are newer than the LSs in the original building. The fourth condition category, 'refurbished', indicates the LS has been renovated *without change to its functions*. This considers the surfaces and furniture, but the layout is as originally. On the other hand, the fifth category entails repurposed spaces where *the original function has been changed*. Spaces in the last category are 'retrofitted', here meaning that the initial space has been *added with a function (an area of LS) that was not originally a part of it*.

Employing these six categories, Table 1 shows that 52,6 per cent of identified LSs are in original condition or in an extension. This means almost half of the LSs are either adapted (Refurbished, Repurposed and Retrofitted together: 31,9%) or in the newest building (15,5%). The building X supply consists of a sports hall and is therefore narrowed from further analysis. The amount of LSs supplied in the newest building, A, seems aligned with the other buildings. The average number of LSs in the seven buildings (without the building X) is 49,6, with the median at 51. Therefore, the latest addition can be interpreted to substantially transform the case campus LS supply.

The Refurbished spaces consist of 8% of the LS supply, which does not yet indicate the transformation of the campus functions. Then again, the Repurposed (17%) and Retrofitted (6,9%) spaces can be interpreted to have transformed the supply, totalling closer to one-fourth of the supply (23,9%). Together with the newbuilt spaces, assumed to represent the contemporary needs of the users, they consist of 39,4% of spaces. It is hard to evaluate if this is substantial compared to other campuses, but the number of transformed spaces seems somewhat large.

Table 1 Number of identified LSs distributed by condition and location

Building	Newbuilt	Original	Original/ extension	Refurbished	Repurposed	Retrofitted	Total
A	54						54

F		14				3	17
K		28		6		7	41
P		11		6	34		51
R		1	10	8	20	4	43
S		48	6	8	5	6	73
T		64				4	68
X		1					1
Total	**54**	**167**	**16**	**28**	**59**	**24**	**348**
	15,5 %	**48,0 %**	**4,6 %**	**8,0 %**	**17,0 %**	**6,9 %**	**100,0 %**

Comparing the number of LSs to the distribution of m2, Table 2 shows that 48,4% of the LS supply in m2 is in original condition or in an extension. While the newest building LSs create 18,7% of the total supply in m2, and the adapted spaces, i.e., Refurbished (8,6%), Repurposed (14,8%), and Retrofitted (9,5%), consist of 32,9% of the LSs supply. The spaces representing the transformation, i.e. The New, the Repurposed and the Retrofitted spaces, formulate 43% of the LSs in m2.

In closer examination, differences between adaptations can be observed. The Repurposed spaces seem to be smaller (on average 4474,8m2/59 = 75m2 per space) than the Retrofitted spaces (on average 2861,7m2/24 = 119m2 per space). This can be seen as an indication of the differences between the transformation types. Repurposed refers to a change of function/use, whereas Retrofitted refers to an added function that may imply a demand for more space.

Table 2 Total square meters of identified LSs distributed by condition and location

Building	Newbuilt	Original	Original/ extension	Refurbished	Repurposed	Retrofitted	Total
A	5654,5						5654,5
F		1321,1				472,4	1793,6
K		2043,4		645,8		792,0	3481,3
P		333,8		194,2	2379,6		2907,5
R		147,6	1209,2	1060,7	1302,6	319,3	4039,5
S		2672,9	294,7	695,1	792,7	1015,1	5470,5
T		4491,3				262,8	4754,0
X		2069,5					2069,5
Total	**5654,5**	**13079,7**	**1503,9**	**2595,8**	**4474,8**	**2861,7**	**30170,4**
	18,7 %	**43,4 %**	**5,0 %**	**8,6 %**	**14,8 %**	**9,5 %**	**100,0 %**

The timeline of the campus LSs

This section responds to the RQ 3. "When has the campus LSs been built or adapted?". The results are based on plan and document analysis, as well as site visits. As indicated earlier, approximately half of the LSs are in original condition. However, the range of their completion year varies, and all decades are represented since the establishment of the first building on the campus in 1973. Table 3 presents each identified LS distributed according to their host building, type of condition and estimated year of completion or adaptation. The times are based on both public documents and project documents, such as emails, concerning some of the Refurbished, Repurposed and Retrofitted spaces. Noteworthily, other extensions exist, but those spaces are not mapped here as this evaluation concerns LSs and not offices or research laboratories.

Table 3 The timeline / completion years of the case campus LSs supply

Building	A	F	K	P	R	S	T	X	Total	
Newbuilt	**54**								**54**	15,5 %
2015	54								54	
Original		**14**	**28**	**11**	**1**	**48**	**64**	**1**	**167**	48,0 %
1973			28						28	
1978						48			48	
1983				11					11	
1984					1				1	
1995		14							14	
2001							64		64	18,4 %
2002/2013								1	1	
Original/ extension					**10**	**6**			**16**	4,6 %
2000						6			6	
2001/2003					10				10	
Refurbished			**6**	**6**	**8**	**8**			**28**	8,0 %
2006				6					6	
2013			4						4	
2014					7				7	
2020					1				1	
2010's			1						1	
c. 2015/2016						8			8	
c. 2016			1						1	
Repurposed				**34**	**20**	**5**			**59**	17,0 %
2014					20				20	
2017				34					34	
circa 1990's						1			1	
circa 2017						4			4	
Retrofitted		**3**	**7**		**4**	**6**	**4**		**24**	6,9 %
2012			2						2	
2014					2				2	
2015						1			1	
2018		1							1	
2019		1			2				3	
2010's			3						3	
2015 & 2019		1							1	
c. 2015/2016						5	3		8	
c. 2016			1						1	
c. 2018							1		1	
c. 2019			1						1	
Total	**54**	**17**	**41**	**51**	**43**	**73**	**68**	**1**	**348**	100 %
%	15,5	4,9	11,8	14,7	12,4	21,0	19,5	0,3		

Table 3 shows that the timeline of supply of LSs is rather divided according to their condition. The oldest spaces in Original condition are located in the first building of the campus from 1973 and consist of a surprisingly large portion, 8% (28/348), compared to the whole supply. In general, the supply of LSs is rather old as the second oldest building from 1978 houses 13,8% (48/348) of spaces in Original condition and the second newest building from 2001 entails 18,4% (64/348) of the LS supply.

Then again, half of the supply of LSs can be viewed as relatively recent, as the oldest adapted spaces seem to be from the year 2006. The Refurbished spaces are from 2006 to 2016. The Repurposed spaces are even more recent, from 2014 to 2017, with one exception from 1990. Then again, the Retrofits of spaces were conducted between 2012 and 2019. Calculating together all the adapted spaces completed *after 2010* totals 104 spaces, which is 29,9% of all identified LSs. Together with the newbuilt spaces from 2015, they create 45,4% (158/348) of the total supply. This can be seen as a relatively large portion of very recent spaces, less than fifteen years.

In contrast to the LSs in the Original condition, Table 3 shows that the adapted spaces, especially Refurbished and Retrofitted spaces, are distributed across buildings rather than clustered like the ones in the Original condition. However, the Repurposed spaces are located in three buildings, mainly in buildings P and R. Building P has 9,8% (34/348) of the Repurposed spaces from year 2017 and building R has 5,7% (20/348) of the Repurposed LSs from year 2014 compared to the total case campus LSs supply.

Students' preferences and the types of developments

The last section responds to RQ 4, "How are the student preferences aligned with the condition of LSs?". In other words, it inspects if the 'recent' developments have been effective, measured by the preferences of the users. The results are founded on the merger of data sets of the plan analysis and the allocated student preferences.

A total of 512 space preference responses were included in the analysis by 146 respondents. These responses are allocated to either a space or a larger area, and based on that, the condition of the supply information was coded to the space preference response. Table 4 illustrates how the responses are divided according to the type of change/condition.

Table 4 The condition of the supply present in space preference responses

CONDITION OF THE SUPPLY	PREFERENCE RESPONSES	PERCENTAGES OF TOTAL RESPONSES
ORIGINAL	147	28,7 %
ORIGINAL/EXTENSION	21	4,1 %
NEWBUILT	122	23,8 %
REFURBISHED	28	5,5 %
REPURPOSED	138	27,0 %
RETROFITTED	56	10,9 %
TOTAL	512	100,0 %

A third of the preference responses were allocated to spaces in their original condition, as the Original (28,7%) and the Original/extension (4,1%) together create 32,8% of the responses. However, if a direct comparison is made, this is notably less than their amount in percentage (52,6% together). Interestingly, the second-most preference responses were allocated to the Repurposed spaces (27%) and the third-most to the spaces in Newbuilt condition (23,8%). The spaces in the Retrofitted condition gained 10,9% of the preference responses and the Refurbished 5,5%. The Repurposed and Retrofitted spaces represent the adaptation of existing facilities and change in function, and together, they gained 37,9% of the preference responses. Compared directly with the amount of Repurposed and Retrofitted spaces (23,9%), they are clearly more popular than their numbers on campus.

Inspecting the whole campus transformation, not just an adaptation of premises, together the Newbuilt, Repurposed and Retrofitted spaces were present in 61,7% of the space preference responses. As stated earlier, these spaces constitute 39,4% of the campus spaces, that is 43% of the supply in m2. Therefore, it can be stated that the case campus has been physically transformed with the erection of a new building and with changes in the use of the spaces and that these changes are present in the students' preferences for spaces.

DISCUSSION

The findings of this study are seen as indicating a clear shift in the regime of the campus design and development. The case campus seems to present well the campus development trends of its establishment era, from expansion to adaptation of existing facilities. According to den Heijer and Tzovlas (2014), one-third of European campuses are established in the 1960s or after. The location of the campus was intended to secure its growth (Häikiö, 2015) as in Dober's (1996) guidelines. During the decades from the 1970s to the 1990s, the case campus grew with the construction of buildings, one or two per decade, with the last field-allocated building from 2001 (building T). A shift is noTable in the early 2000s as development moved to construct extensions to existing buildings rather than stand-alone buildings. After this period, the adaptations of existing premises started, first mainly with refurbishing of spaces and later with repurposing and retrofitting. Fifteen years later, in 2015, was erected the newest building (A) but it can be seen as representing a new era for campus development as it is not field-allocated and it introduced altogether new facilities and services to the campus, e.g., rental offices to non-academic companies.

Furthermore, the literature has indicated that the transformation of the campuses has accelerated globally in the last 10 to 20 years by constructing new buildings (Whitton, 2018), but also with more efficient use of existing facilities (den Heijer, 2011). The results of this study show that this acceleration of new or adapted premises is evident in the case campus, as 45% of the LSs are less than fifteen years old. This is seen as another indication that the built environment of the campus system has transitioned into representing a new system. However, this study did not investigate the reasons for the systemic change nor the content of the transformation of the premises. It focused on the *types of changes* to the campus, implied but rarely studied previously. Rytkönen (2015) studied the spatial transformation of the campuses from the business-model viewpoint, with results indicating that the campuses are transforming spatially in practice.

The study findings reveal that campus transformation remains constant, shifting from expansion to premises adaptation. The results imply that the design guidelines of LSs have changed. For campus development, this regime change can indicate e.g., managing more frequently smaller scale adaptations rather than large constructions. Additionally, the focus is more on updating the purposes rather than physical condition maintenance. Challenges arise due to evolving transformations; some spaces have changed since data collection. Here, the merger of the data sets was 'locked' to the situation when the student preferences data was collected to allow comparison. Thus, some spaces are known to be drastically changed since, and in a few instances, these results describe a past situation. While this campus has transformed, the prevalence of this type of change across campuses remains unclear. Comparing with other campuses would shed light on broader trends, despite LS literature suggesting change. Within the case university, three campuses differ significantly, and the case campus faces a decline in LSs due to planned demolition and reconstruction.

Recent campus transformations, driven by student LS demands, coexist with spaces in their original condition. The entire supply of LSs across various locations holds value for students. However, the large proportion of very recent adaptations reveals a need for change in purposes that is met in student preferences. Despite pre-COVID preference data, these transformations align with literature emphasizing varied spaces for learning in the post-digital era (Acton, 2018; DeFrain, et al., 2022; Harrison & Hutton, 2014; Goodyear, 2022; Raes, 2022). Rather, the covid era only accelerated the needs of the post-digital learning and thus, the popular adaptations of existing premises in various locations can be seen as a strategy for future campuses. While previous LS literature has investigated the spatial changes and user needs, this study is one of the first to investigate the transformation types and periods of a whole campus LS supply that is then compared with location-based preferences. These results indicate that the adaptations of existing facilities, in the least connected layers of 'social', 'stuff' and 'space plan', is a valid strategy for accommodating the changing needs in user-centred, efficient and sustainable way.

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What is the “FM Value Guide” – and How to Make a Value Guideline?

Jensen, P.A. [1], Nielsen, S.B. [2], & Rasmussen, H.L. [3]

[1] Department of Technology, Management and Economics, Technical University of Denmark
[2] Rambøll
[3] DFM. Danish Facilities Management association
Contact: pank@dtu.dk

ABSTRACT

Background and aim. The FM Value Guide is a management decision support system developed by the Danish Facilities Management association (DFM). The purpose is to support facilities managers to create added value to their organizations. The aim of this paper is to present the guide, the ideas behind it, and to give advice on how to develop similar guidelines.

Methods. The development is carried out in workgroups with practitioners and researchers based on literature, cases, and experiences. The authors of this paper all have a combined research and practice background and are involved in the development of the FM Value Guide.

Results. The development has resulted in the first FM Value Guide with six parameters (Branding, Economy, Flexibility, Productivity, Risk, Environmental sustainability), and two additional guidelines are under development for the parameters Circular FM and Social sustainability. The paper communicates the process of developing guidelines, to support others to develop additional guidelines for improving value creation. A template for a guideline is included in Appendix.

Originality. The FM Value Guide is a unique FM tool, which can be adapted to various FM scopes and parameters and this paper promotes it internationally.

Practical implications. The FM Value Guide is a management tool for practitioners to support value creation and continuous improvements as recommended in ISO 41015 (2023) on influencing organizational behaviours for improved facility outcomes.

Type of paper. Technical

Keywords. facilities management (FM), added value, ISO 41015, FM Value Guide, circular FM

INTRODUCTION

The FM Value Guide is a management decision support system, which includes guidelines concerning various values for which Facilities Management (FM) can create value to support and improve the core business of an organization. It was developed by the Danish Facilities Management association (DFM) with a first version including six parameters (Branding, Economy, Flexibility, Productivity, Risk, Environmental sustainability) available for free on DFM’s website (DFM, 2021). The purpose of the system is to support facilities managers to create added value to their organizations. The system is being further developed with two new guidelines under preparation.

Continuous improvements and added value are a significant part of any FM system in any context according to ISO 41001 (2018) and the related guiding document on improved facilities outcome: ISO 41015 (2023). FM Value Guide can inspire the demand organisation to make e.g. actions plans focused on a single parameter, as well as holistic business cases with a scope of several parameters. But to include other parameters such as Circular FM or Social sustainability, new guidelines should be developed to support practice. The purpose of this paper is to give advice on how to develop additional guidelines for values of particular interest.

The FM Value Guide is partly based on many years of research and development on the added value of FM. This work was inspired by the related field of Corporate Real Estate Management (CREM). Work on the added value of CREM started around 1990 in the USA. One of the most influential of the first papers was Nourse and Roulac (1993). From around year 2000, this was followed by several studies in the Netherlands (e.g. Krumm, 1998; De Vries et al., 2008; Den Heijer, 2011) and a study in Finland Lindholm & Leväinen, 2006). The first study on the added value of FM took place in Denmark resulting in development of the FM Value Map, which was published in a book and based on cases from the Nordic countries (Jensen et al., 2008) and later in a journal paper (Jensen, 2010).

This formed the background for establishing a EuroFM Research Group in 2009 with researchers from Denmark, Finland, the Netherlands, Switzerland, and UK, combining FM and CREM backgrounds. This collaboration resulted over the next decade in publication of many research papers and two anthologies culminating in the book Jensen & van der Voordt (2017). The book was based on a simplified model named Value Adding Management (VAM) shown in Figure 1. The model is based on Interventions as input, which with proper Management as through-put can be implemented in such a way, that it leads to added value in relation to one or more of 12 parameters.

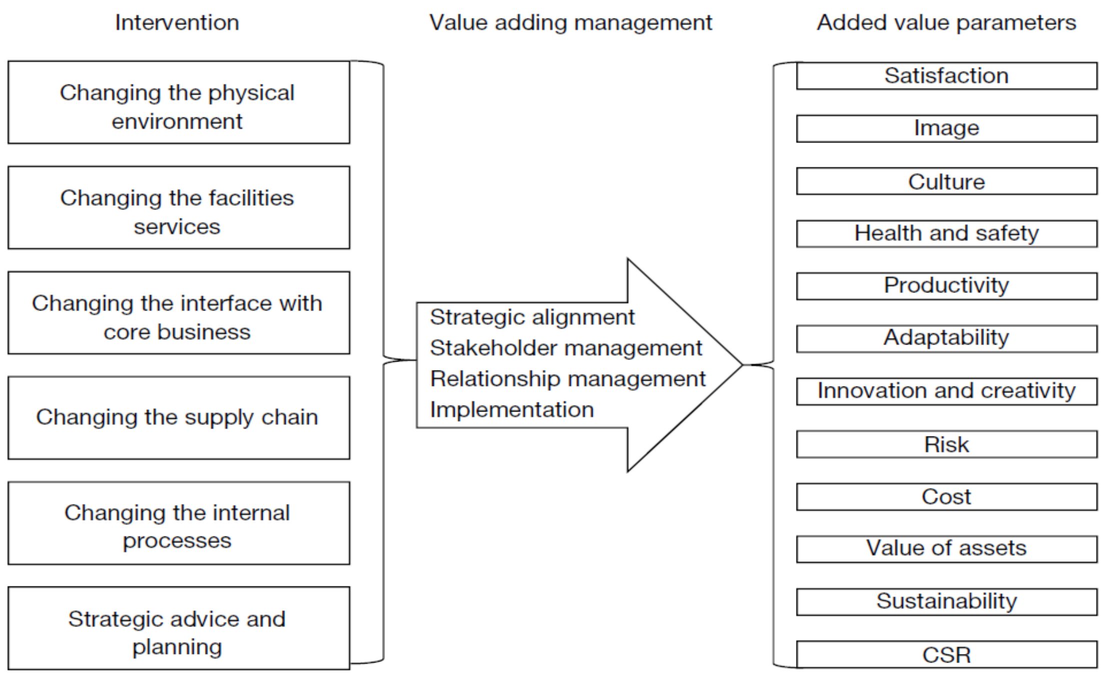

Figure 1 Value Adding Management (Jensen & Van der Voordt)

The book was a direct inspiration for developing the online FM Value Guide in DFM with guidelines for practitioners. The FM Value Guide was developed by a workgroup with mostly practitioners, but also by the authors of this paper, all with a combined research and practice background. The group worked closely together to develop the guide system, and the six first guidelines were prepared by sub-groups. The recent experience from preparing two more guidelines has shown, that it is difficult for new members to understand the concept of the value guide. Therefore, we found it necessary to develop a guideline on how to develop FM value guidelines. Thus, the immediate target group for such a Danish guideline, was new members involved in developing value guidelines in DFM and in Danish companies. The aim of this paper is to present the guide and the ideas behind it in English and make it available to a broader international audience and give researchers and practitioners in other countries advice on how to develop similar guidelines.

The paper is structured with the presentation of The FM Value Guide in the second section and the third section presents the guideline to develop value guidelines. A template for a value guideline is included in Appendix. The guideline uses an example from the ongoing work on preparing a guideline for Circular FM and this is the topic of research paper for this symposium (Jensen & Nielsen, 2024). Thus, it is recommended to read the two papers in connection to each other. This paper finishes with a short discussion/conclusion on the relation between research and development of standards and guidelines and implications for practice.

THE FM VALUE GUIDE

The project to develop the FM Value Guide was initiated by DFM and the management consulting company EY in 2019, see Jensen et al. (2022; 2023). The project was initially called FM Value Taxonomy. It was carried out by a workgroup with a FM-expert from EY and DFM-members with support from DFM's secretariat. The project has not had any external financial support.

In the first of three phases the workgroup developed the concept for the FM Value Guide and identified and selected the parameters to focus on and defined the various scopes of FM. The concept included a matrix with combinations of parameters and FM scopes, see Table 1. The selected value parameters were based on the 12 parameters in the Value Adding Management (VAM) model shown in Figure 1. For the initial FM Value Guide six value parameters were selected: Branding, Economy, Flexibility, Productivity, Risk, and Environmental sustainability. The FM scopes were adapted from a classification in a FM textbook (Jensen, 2021) with a division in five classical FM scopes:

1. Portfolio Management: Managing real estate portfolios
2. Project Management: Managing building and change projects during the use phase
3. Space/workplace Management: Managing space allocation and workplace design
4. Property Management: Managing operation and maintenance of buildings-in-use
5. Service Management: Managing support services

Jensen and van der Voordt (2020) concerns productivity as a value parameter and used the same classification. They wrote that the main difference between the five scopes is the scale level, ranging from portfolio and buildings to spaces and services, whereas property management focuses on buildings-in-use.

The concept was verified through hearings in a reference group of six experienced FM practitioners and in a network group with heads of FM organisations facilitated by a management consultant from EY, who also was part of the workgroup.

In the second phase the guidelines were developed with a definition and a description for each value parameter. The descriptions included a value tree and a Table with suggested Key Performance Indicators (KPIs) for each scope as well as specifications of external and internal stakeholders and advice on communicating the information. Value trees are graphical tools to analyse the benefits of different actions and their benefits and sacrifices, which are used to support multi-criteria decision making in operations research (Mustajoki & Hämäläinen, 2000). An example af a value tree is shown is Figure 2.

Table 1 Matrix for the initial FM Value Guide (Jensen et al., 2023)

FM Values \ FM Scopes	Portfolio management	Project management	Space/ workplace management	Property management	Service management
Branding	●	●	●	●	●
Economy	●	●	●	●	●
Flexibility	●	●	●	●	●
Productivity	●	●	●	●	●
Risk	●	●	●	●	●
Sustainability	●	●	●	●	●

For each parameter there was a general discussion of synergies and trade-offs with other parameters and a list of references and websites. The guidelines were developed by sub-groups, which for most parameters consisted of a participant with a research background and one or more practitioners. General definitions and descriptions of the five scopes were also developed. Drafts for the guidelines were discussed during meetings in work group and commented by the members of the reference group to ensure validation of the FM Value Guide.

In the third phase an information system was developed, where the guidelines were incorporated. The information system gives the possibility to access a guideline for each of the 30 combinations of the six parameters and the five scopes and was launched at a seminar in 2021, where members of the sub-groups presented the guidelines for each of the six parameters and where practitioners, who were not member of the project group, evaluated the value guide from their perspectives. In the FM Value Guide system, you can as a user access a value and find an introduction with a general definition and description. Similarly, you can access one of the five scopes and arrive at a general scope definition and description. If you approach a combination of a value and a scope, you arrive at a guideline.

In 2023 the work on developing two new guidelines to supplement the initial system with a second version began. The new guidelines are both related to DFM's sustainability committee and is elaborated in workgroups on Circular FM and Social sustainability. The next section includes an example from the paper for this symposium on the ongoing work on a guideline for Circular FM (Jensen & Nielsen, 2024). The section partly describes the overall approach and partly how it may be filled in for Circular FM as example.

GUIDELINE TO DEVELOP VALUE GUIDELINES

The purpose of these instructions for making a guideline is partly to help members of the two ongoing workgroups in DFM to develop the new guidelines in a uniform way, and partly to help others who want to develop a new guideline. It may be in new workgroups in DFM that will contribute to a third version of the overall value guide at DFM's website, but it can also be in an FM organization that wants to develop a guideline for use in its own company. The guideline is structured in the following steps:

1. Identify and define the value
2. Create a value tree for each of the five scopes
3. Create a Table of suggested KPIs for each scope
4. Prepare the description

The work is best done in a group, where work is distributed among the five scopes according to the members' competences, experiences, and interests. For each scope, it may be a good idea to start with a joint brainstorm about possible enablers (value-creating efforts, levers, means, etc.) to create a preliminary value tree. During the work, the group should continuously discuss and give feedback on each other's work. When a first edition of the guide is available, it should be sent for consultation with relevant stakeholders.

1. Identify and define the value

The starting point for developing a guideline is to determine the value parameter that the guide must cover. A value parameter is a topic where FM creates or is expected to be able to create value for the core business - and particular for sustainability also for society. Value is thus an effect and an outcome of a value-creating effort. It will be particularly relevant with a parameter, where you expect that there is a potential for more value creation, but you are not aware in advance of which initiatives you need to implement to create added value, and where you want to target your efforts with a view to value creation.

Once you have settled on and named a particular value, you must define more precisely what is to be understood by the value in question. In this connection, it may be a good idea to find out if a generally used definition exists; perhaps in dictionaries, standards, or official documents such as laws or circulars, and investigate other definitions within FM or related fields. Internet search can give many results, but you need to sort a lot among these to find useful information. In addition, it may be relevant to define other terms that can be used in the guide, e.g. by sub-dividing the value in relation to the individual scopes. In the following, an example is given with Circular FM.

Circular FM is seen as an FM value because it can contribute to the sustainable development of the entire company and society. However, it is not a commonly used term. Searching for the term 'circular FM', 'circular facilities management' or ' circular facility management' you will find i.e. a new guideline on: ”Circular Economy: Transforming Facilities Management in 2023”. This could be a reference for your work. If you search for 'circular construction', you will get many results but probably only a few useful. In the DFM workgroup on Circular FM, we for construction focus on the transformation of existing buildings, and if you search for 'transformation' or 'transformation of buildings' you will find many notices. Since the topic is related to the more general concept Circular economy, it may also be relevant to see what is typically included in this. Remember to make a note of relevant links and references so it is easy to find them when you need to write text for the guideline.

2. Create a value tree for each of the five scopes

Value trees are essential in a guideline. Work with this is initially easiest by using a spreadsheet such as Excel with the following columns:

- Detailing
- Enablers
- Sustainability
- Benefits
- Potential negative consequences

Detailing (Scope specific detailing of the parameter): You start by sub-dividing the scope in question into the overall focus areas where it is estimated that value can be created. Table 2 shows elements in a value tree for Circular FM for the scope Project Management of building and change projects for buildings in use.

Table 2 Elements in a Value tree for Circular FM for scope Project Management of buildings in use (preliminary version, see a graphical value tree in Figure 2)

Detailing	Enabler	Sustainability	Benefits	Potential negative consequences
Buildings in use	Material savings	Environmental	Less resource consumption	Perhaps increased construction costs
	Optimize function	Economic	Improved productivity	Physical limitations
	Optimizing land use	Economic	Lower operating costs	Perhaps increased construction costs
	Better indoor climate	Social	Health and satisfaction	Perhaps increased construction costs
	Architectural quality	Social	Experiences and image	Perhaps increased construction costs

Enablers: (Enablers for value creation). For each detailing, an assessment is made of which specific means can create value, e.g. material savings, optimization of functions, and space utilization as well as better indoor climate and architectural quality, as shown for the first of the overall focus areas in the Table.

Sustainability: You then assess what kind of sustainability the specific enablers can support. The column with Sustainability is new compared to the previous guidelines, but it is extremely relevant for Circular FM, as it is important for all three pillars: Environment, social and economy. For other values, which are primarily important for one of the three pillars, it is less relevant, so the column can therefore be omitted.

Benefits: For each enabler, the positive effects of each of them are then assessed.

Potential negative consequences: Correspondingly, any negative consequences are assessed at the end for each enabler.

The procedure follows the process horizontally for the rows in Table 2, but you can off course also carry out the process vertically for each column depending on your temperament.

3. Create a Table of suggested KPIs for each scope

In the next step, a Table is drawn up for each scope with proposals for KPIs. The Table can e.g. made in Word or Excel. The following columns are provided:

- Aspect: This corresponds to the detailing of the value tree
- KPI: For each aspect, one or more quantitative KPIs are selected
- Measurement: Indicates how the individual KPI is calculated; typically, as a fraction
- Comment: A comment can be entered here for each individual KPI, e.g. how it can be interpreted such as best as high or as low as possible.

It is not necessarily possible to design meaningful quantitative KPIs for all enablers. Table 3 shows an example of KPIs for Circular FM for the scope Project Management for building and change projects for buildings in use, which can be used for inspiration.

Table 3 KPIs for Circular FM for the scope Project management of building and change projects (Preliminary version)

Aspect	KPI	Measurement	Comment
Buildings In use	Recycling of materials that are dismantled	Recycled materials' share of all materials before transformation (%)	Possibly. divided into material types. As high as possible
	Recycling of materials from dismantling and demolition	Recycled materials number of all materials before transformation that are not recycled (%)	Possibly. divided into material types. As high as possible
	New materials	New materials share of all materials after transformation (%)	Possibly. divided into material types. As low as possible
	Land use before transformation	The share of the usable area of the total area before transformation (%)	As high as possible
	Area utilization after transformation	The share of the usable area of the total area after transformation (%)	As high as possible
	Change of land use	Change in the useful area after compared to before transformation (absolute and % points)	As high as possible
	Indoor climate before transformation	User satisfaction with indoor climate before transformation (%)	As high as possible
	Indoor climate after transformation	User satisfaction with indoor climate after transformation (%)	As high as possible
	Change in satisfaction with indoor climate	User satisfaction with indoor climate after compared to before transformation (% points)	As high as possible

4. Prepare the value guideline

The last step in the development of the first draft of the guide is to formulate the value guideline itself. A template is provided in Appendix, which can be used to write in. The template is divided in the following sections:

GENERAL VALUE DEFINITION*:* Based on the result from step 1, a general introduction to the guideline is written with general definition and description.

VALUE DESCRIPTION FOR EACH SCOPE*:* A description is prepared divided into each of the five scopes with a graphic presentation of the value tree, and text with a review of the value tree and a brief statement of proposals for external and internal stakeholders and communication, concluding with a Table of KPIs. An example of a simplified value tree is shown in Figure 2 and examples of KPIs were shown in Table 3.

VALUE SYNERGIES AND TRADE-OFFS*:* A short section is written about possible positive and negative correlations between the current value and other FM values.

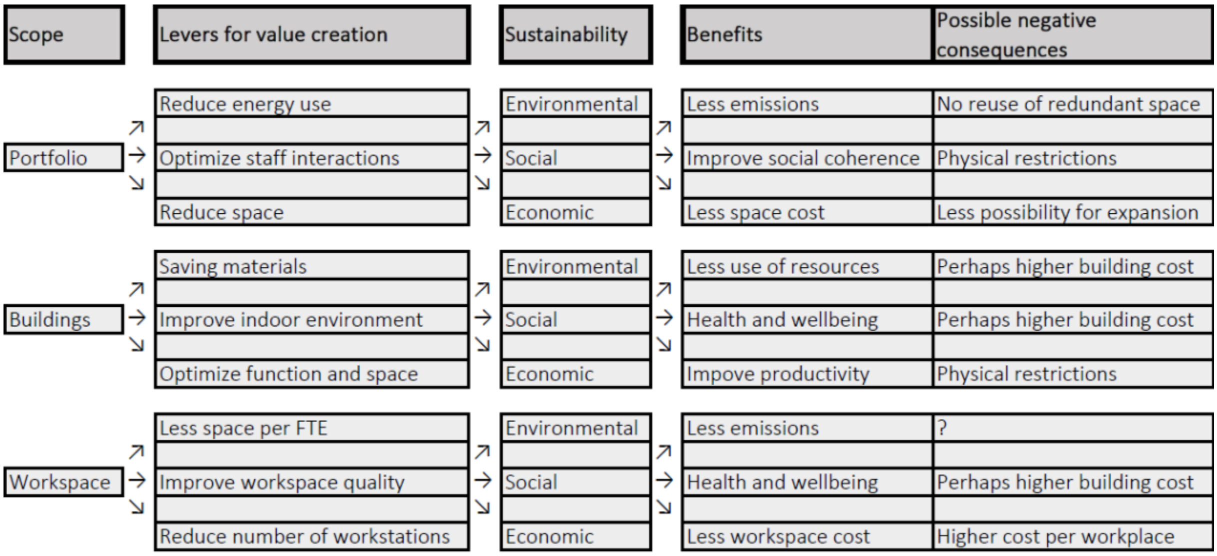

Figure 2 Value tree (Jensen & Nielsen, 2024)

LINKS AND REFERENCES*:* A list of relevant sources of information and inspiration is drawn up; both with those that were applicable in step 1 and in the preparation of descriptions for the five scopes. The list is arranged alphabetically. divided into links and references to specific documents and literature sources.

DISCUSSION AND CONCLUSIONS

The FM Value Guide is still quite new, and we have no information about how much it has been used and what the experience with using it has been, except that the web-page with the guide has been visited about 900 times in the first 2 years. As shown in this paper, it is based on more than 15 years of research and development on the added value of FM. This indicates that there can be a long way from research until practitioners gets directly involved in developing practical guidelines. In the recent journal article (Jensen et al., 2023) we have investigated collaboration between researchers and practitioners on developing Facilities Management standards and guideline with particular focus on the added value of FM. The study shows that researchers not only participate in FM standardization and development of guidelines for practitioners, where they contribute with their knowledge on the topic, but also that specific research results on the added value of FM has directly been incorporated in FM standards and guidelines. A constructive collaboration between researchers and practitioners is essential to achieve this. The most prominent examples of this are the international standard ISO 41015 (2023) and the FM Value Guide (DFM, 2021). Another recent research paper by Klungseth et al. (2023) has also studied the collaboration between researchers and practitioners, and they conclude that some studies have shown how standards influence research, but only a few have explored how research influences standards. The FM Value Guide is a research based methodology to support FM practitiones to work more professionaly with value creation. Together with the new international FM standards it provides a more solid foundation for FM. The FM Value Guide might be difficult to use directly, but it can be a catalogue for inspiration and increase the consciousness among practitioners and provide a terminology to discuss and demonstrate the value of FM both internally and with their stakeholders. It can also be an inspiration for researchers, teachers and student of FM.

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APPENDIX A: TEMPLATE FOR A VALUE GUIDELINE

Front page:

FM Value Guide

Version X
[Date]

Authors:
....
Value: [Value]

Scopes:
Portfolio Management
Project Management
Space/workplace Management
Property Management
Service Management

The general Scope definition is common to all guidelines.

Page 2:

Table of Contents

Page 3 +

1. General Value Definition

[Introduction with value definition and description]

2. Value descriptions

Value descriptions are presented divided into five scopes illustrated with value trees. The value trees identify a number of potential enablers for value creation for specific sub-areas for each scope. For each enabler, the potential benefits and negative consequences that may be in relation to the enabler in question are indicated. Information on stakeholders and communication as well as a Table with KPIs for each scope is also provided.

[Value] by Portfolio Management

[Insert value description]

Value tree for [Value] in Portfolio Management
[Insert value tree]

Stakeholders and communication for [Value] in Portfolio Management
………….

KPIs for [Value] in Portfolio Management

Aspect	KPI	Inventory	Comment

[Value] in Project Management
[Insert value description]
[Same sub-headings etc. as for Portfolio Management]
[Value] by Space/workplace management
[Insert value description]
[Same sub-headings etc. as for Portfolio Management]
[Value] by Property Management
[Insert value description]
[Same sub-headings etc. as for Portfolio Management]
[Value] by Service Management
[Insert value description]
[Same sub-headings etc. as for Portfolio Management]

3.Value synergies and trade-offs

……….

5. Links and references

……….

Transformation of Outsourcing and In-Housing Practices in Corporate Real Estate Management

Ekman, I.[1], Jylhä, T.[2], & Penttinen, N.[1]

[1] CBRE, Advisory & Transaction Services
[2] Aalto University, School of Engineering
Contact: Ida.Ekman@cbre.com

ABSTRACT

Background and aim. The COVID-19 pandemic led to unexpected disruptions and changes in the global business environment. As a result, companies are now re-evaluating their sourcing strategies for their real estate function. Therefore, this research studies the current CREM in-housing and outsourcing drivers and how the sourcing practices are constantly transforming.

Methods. The research collects data via semi-structured interviews in seven technology organizations.

Results. The findings include five drivers for outsourcing and five drivers for in-housing CREM services, spanning from the lack of internal resources to accessing market expertise, and from gaining full control to minimizing distractions. Similarly, the analysis revealed six ongoing transformations, including the strategically significant transformation of CREM, prompting organizations to establish onboarding programs to retain new talent.

Originality. This explorative research examines global organizations' sourcing practices.

Practical implications. The study showed a need for transformations in CREM in-housing and outsourcing practices in technology companies. Thus, companies need to be able to adapt to changes in-housing and outsourcing CREM by re-evaluating their CREM outsourcing and in-housing.

Type of paper. Research (short)

Keywords. case study, corporate real estate management, in-housing, outsourcing

INTRODUCTION

The outbreak of the COVID-19 pandemic caused unforeseen disruptions and changes to the global business environment. Following the pandemic, many companies have reassessed their sourcing strategies in their business-supportive operations, such as their CREM function. Generally, companies can manage CREM tasks in various ways. According to scholars like Haynes, Nunnington, and Eccles (2017) and McDonagh and Hayward (2000), organizations may opt to handle CREM tasks internally, outsource to strategic partners, or utilize a combination of both methods. They emphasize the importance of ongoing evaluation of CREM service delivery to ensure optimal value for the core business. Therefore, this explorative research examines CREM sourcing in the post-COVID-19 landscape, with a specific focus on technology companies. The research aims to identify the current CREM in-housing and outsourcing drivers and how the sourcing practices are constantly transforming, especially posed by the COVID-19 pandemic in global technology companies.

LITERATURE STUDY

In principle, all CREM tasks can be outsourced. However, the literature indicates that certain tasks are more suitable for outsourcing than others. Tasks such as facility services, architectural and workplace design, property management and maintenance services (Jensen, 2019; Heywood and Kenley, 2013; Matsham and Heywood, 2012), as well as leasing, acquisition, and portfolio management (Heywood and Kenley, 2013; Matsham and Heywood, 2012), are recognized in the literature as highly suitable for outsourcing. Conversely, strategic planning and client relationship management are stated to be less suitable for outsourcing (Jensen, 2019; Heywood and Kenley, 2013; Matsham and Heywood, 2012).

Both in-housing and outsourcing have their advantages and disadvantages. In-housing allows organizations to maintain full control (Jensen, 2019; Bernhold and Wisweg, 2022) offering straightforward opportunities to align CREM tasks with the company's primary processes. Additionally, in-housing fosters employee loyalty (Jensen, 2019) and ensures that knowledge and lessons learned stay within the company (Bernhold and Wisweg, 2022). On the contrary, in-housing means that there is no competition or limited competition (Bernhold and Wisweg, 2022). This also means that both the resources and costs are fixed with limited negotiation power (Jensen, 2019). Additionally, when the field is developing fast, the organization may lose some expert knowledge with fixed in-house resources (Bernhold and Wisweg, 2022), and if in-housing resources are non-incentivized, the CREM function might not be able to adapt to the fast changes (Jensen, 2019).

When outsourcing, the service provider leverages knowledge gained from collaborating with multiple clients, offering a broader expertise and specialized knowledge in CREM (Lindholm, 2008; Jensen, 2019; McDonagh and Hayward, 2000; Matsham and Heywood, 2012). This collaborative experience enhances the service provider's ability to deliver innovative solutions to clients' needs (Lindholm, 2008). For some clients, outsourcing provides a needed market presence, for example, globally or in a region (McDonagh and Hayward, 2000). Outsourcing is also stated to provide cost reductions (McDonagh and Hayward, 2000; Matsham and Heywood, 2012; Jensen, 2019) and flexibility, when resources can be adjusted to the demand (Lindholm, 2008; McDonagh and Hayward, 2000; Matsham and Heywood, 2012).

The typical disadvantages of outsourcing are lack of control (Jensen, 2019; McDonagh and Hayward, 2000; Matsham and Heywood, 2012) and higher dependence on the service provided, for example, in service delivery and data management, along with insufficient communication between the parties, which typically causes dissatisfaction (McDonagh and Hayward, 2000; Matsham and Heywood, 2012). One major concern is also the lack of shared culture, including organizational values and goals (Jensen, 2019; McDonagh and Hayward, 2000; Matsham and Heywood, 2012). While there are advantages to serving multiple clients, it also entails assuming third-party responsibilities, which can be a disadvantage for the outsourcing organization (McDonagh and Hayward, 2000).

RESEARCH METHODS

The research adopts a qualitative multiple-case study approach based on Yin (1994), including seven case companies in the technology sector. Case organizations were decided to select from one field assuming that the experts from the same business sector would likely exhibit similar CREM activities. The technology sector was specifically chosen due to its considerable significance in the Nordic countries, which represented the target areas for this study. Based on this, the cases were chosen to represent global technology organizations based in Nordics, with a mix of medium to large-scale entities. Four of the cases (A, B, C, and D) represent companies with established market positions, while the remaining three (E, F, and G) are growing in the market. These selection criteria assume that these companies possess substantial CRE portfolios, indicating greater experience in sourcing decisions.

The data collection and analysis followed Yin's (1994) approach. An initial examination of each case organization and its CRE unit was conducted using publicly available information and business-related sources. Subsequently, in line with Hirsjärvi and Hurme (2022), semi-structured interviews were held with a globally responsible CREM representative. These interviews covered four key themes: background information on the CREM function, factors influencing in-house or outsourcing decisions, the impact of the COVID-19 pandemic on sourcing decisions, and the need for service providers to develop their support to technology companies. This paper focuses on the second and third themes. Anonymity was ensured to enable interviewees to openly discuss their company's sourcing practices.

All the interviews were conducted and recorded online in Teams and transcribed. Each interview lasted approximately an hour. In the data analysis, the drivers for outsourcing and in-house decisions were identified and grouped into themes following a theory-driven approach, as outlined by Tuomi and Sarajärvi (2009). To identify the impact of COVID-19 on sourcing decisions, a data-driven grouping was employed due to the limited evidence available in the existing literature on this topic.

RESULTS

The results section is divided into the following topics: identified drivers for outsourcing and in-housing, and the transformation of sourcing practices before and after the COVID-19 pandemic. The analysis identified five reasons why companies choose to outsource CREM services. The first reason, mentioned in all cases (A, B, C, D, E, F, and G), is the absence of internal resources to handle CREM tasks. These resources, as described in the interviews, include skills, knowledge, personnel, and time. The interviewees presented this reason as follows:

> *"The internal resource shortage is like the very first one". (Interviewee C)*
> *"The decision-making model pretty much goes so that, through the fact that your FTE number is locked. And all the services after that is then bought from outside."* (interviewee A)
> *"The starting point is that if we have the expertise internally, we will use internal resources and if there is time for it, depending on the level of urgency."* (Interviewee E)
> *"There is not enough time, there are not enough people or skills".* (Interviewee C)
> *"The question is also that do we have time to do it ourselves, [...]."* (Interviewee G)

For the second driver, the analysis identifies companies' need for global, scalable CREM expertise and market presence that they lack internally (cases A, C, D, E, F, and G). Additionally, as the third driver, companies also require specialized or niche knowledge that they obtain externally (cases A, B, C, D, E, and G). The following citations illustrate these drivers:

"…you could also think that there is a kind of specialisation thing, that we are an IT company. We do not need to, so why would we do, so outsourcing is kind of a specialisation aspect." (Interviewee C)

"Every time we move further and further away from our core business and scalability of resources. And if there is scalability, then we use a partner." (Interviewee D)

"I would say that above all the decision depends on the available internal resources and on the local knowledge, that is needed if we are signing a lease in another country." (Interviewee G)

The fourth driver was identified as seeking cost savings. However, only two interviewees (E and F) mentioned this.

"The costs are the reason and also the overall market knowledge in each of the areas we are in." (interviewee F)

Finally, one interviewee mentioned the enhancement of innovation as a reason to outsource:

"If you solely rely on your personnel for development, nothing new is proposed." (Interviewee A)

Similarly, the analysis identifies five reasons to keep CREM tasks in-house. Firstly, the primary reason for doing so was to maintain full control. This was mentioned in almost all cases (A, C, D, E, F, and F). Additionally, in some organizations, this aspect was linked to the organization's ability to align CREM tasks with its primary processes and culture.

"Keeping development in your own hands." (Interviewee A)

"If a large organization outsources, then of course you will lose control of the matter. You can be dependent on someone else's expertise or know-how." (Interviewee D)

"We also want to hold on to [CREM] in a certain way and steer in a certain direction. (Interviewee F)

"To keep the corporate culture together to be able to represent the company in a good way because it may be more difficult for an external party to do." (Interviewee G)

Thirdly, the analysis suggests that conducting small-scale projects in-house is simpler than outsourcing them (cases C, E, and F). Another reason is that the CREM function has dedicated staff and internal expertise to handle the tasks (cases A, C, D, E, and G):

"Depends on how big of a project and also if the locals have any possibilities to do it on their own." (Interviewee C)

"In a way, we see that for these smaller branches, we can operate quite agilely ourselves. Typically, when it comes to a small location being one of our small branches, we know what the key options are, and we can directly handle them." (Interviewee F)

The final reason for keeping tasks in-house was to ensure the continuity of certain CREM tasks to avoid interruptions and to ensure smooth support for the company's primary operations (cases A, F and G):

"*In our organisation, where there is a high demand for employee experience and ensuring that the spaces truly serve their purpose, I see it as challenging to solely rely on external sources in terms of continuity, and also considering the specific local characteristics [...].*" (Interviewee F)
"I see that if we only buy from outside the challenge would be preciously the continuity perspective and from the perspective of how the local needs can be acknowledged." (Interviewee G)

Next, the identified ongoing transformations in sourcing practices are presented. The analysis identifies seven ongoing transformations in CREM in-housing and outsourcing practices. Firstly, there is a clear and continuous shift towards enhancing strategic CREM planning and goal setting. While this transformation has been underway, its significance is highlighted in the interviews:

"I intend to create a long-term real estate strategy and establish FM guidelines. These guidelines will outline the factors to consider and the contracts to make when searching for space, as well as who the contact persons are and who should be contacted before starting the search." (Interviewee E)
"Well, I would say that as a kind of early strategy creation and goals and other things like that is probably wanted to be kept within own control, but what is needed is the opportunities, mapping the opportunities. What is possible? Or finding out what others are doing." (Interviewee C)

Secondly, the analysis found that the ongoing reduction of office space due to remote and hybrid working is leading to further adjusting the amount of CRE services and service providers accordingly. However, user requirements have increased, leading to a higher demand for CRE services overall.

"And interesting is this to say this subcontractor model at the moment, that if the number of premises is reduced somewhat throughout the time so should subcontractors' kind of these fixed persons to flex in some direction. On the other hand, user requirements have increased all the time." (Interviewee A)

Thirdly, the findings show that the expected response time has decreased. Changes are expected to be addressed swiftly by aligning CREM in-housing and outsourcing practices accordingly. Swift responses require real-time market knowledge and information, leading to increased demand for regularly acquiring real-time, in-depth information on the environment from the knowledge partners:

"The reaction speed has changed, in one quarter, you should already get a lot done." (Interviewee D)
"We are looking for partners who would bring information to us on what happens around us at all times. So that our understanding would increase all the time." (Interviewee A)

Fourthly, two case companies (Case A and B) mentioned that the COVID-19 pandemic has pushed the development of stronger onboarding programs for new employees. From a CREM perspective, the office environment has supported casual interactions and team building. Remote working did not support this type of relationship building.

"We focused on particularly on that when new employees would come to the company, that we onboard them, that is done virtually and that is difficult. Because people experience the bond and trust and commitment for the firm the better if they get kind of human connection, so you have to come up with new ways." (Interviewee B)

Fifthly, in two case organisations (cases A and D), the primary processes showed an increased interest in CREM activities. Strategic CRE decisions gained recognition for their importance in the company's overall strategy, establishing a direct line of communication from management to the CREM unit.

> *"...never has the companies' management been so enthusiastic about premises issues as they are at the moment. In other words, it is a very direct line of communication."* (Interviewee A)
>
> *"We are deep in it. We talk with all those people whose lives we are influenced and talk with the decision makers from the same business units and on the other hand, we are an internal service production unit in the sense that they are my customers."* (Interviewee D)

Lastly, many companies referred to outsourced CREM service providers as partners rather than mere service providers. Among the case organisations, which are global technology firms, there appears to be a strong demand for global partnerships to access local CREM services and knowledge worldwide:

> *"Back then, the model was that all the people were internal employees. There were also a lot of internal people in the CREM services, and after that, we started to look for partners throughout the whole organization." (Interviewee A)*
>
> *"If you think about it from a partnership perspective, I see it support need by the fact that a global player, has global contacts and we are a global player."* (Interviewee E)

CONCLUSIONS

The explorative research examined the current CREM in-housing and outsourcing practices, along with the ongoing sourcing transformations in the CREM sourcing regime of technology organizations. Utilizing a multiple case study method, an initial study based on materials was conducted, followed by semi-structured interviews with the CREM representatives from seven technology companies. To summarize the results, outsourcing in technology companies was driven by the absence of internal resources, the need to leverage CREM expertise globally, access to specialized or niche knowledge, cost savings, and ensuring innovative solutions. Conversely, in-house decisions were typically driven by the aim to have full control and to align CREM tasks with primary processes. Some tasks, such as small projects, require more effort when outsourced. Additionally, maintaining continuity of service delivery and avoiding interruptions for the primary processes is a reason to keep tasks in-house. The ongoing transformation in sourcing is evident in the increasing strategic significance of CREM to provide real-time support for evolving business needs. It is acknowledged that CRE services, including a number of service providers, will adjust to reduced demand for office space. Furthermore, knowledge partners are expected to provide regular real-time information to support CREM decision-making. Additionally, onboarding programs have become crucial for CREM functions for retaining talent within the organization. The open communication channel from top management signals a focus on optimizing space utilization. Lastly, service delivery is increasingly built on collaborative partnerships. This research is limited to seven case studies involving CREM functions within global technology companies. While the findings may apply to some degree, particularly in other global organizations like banking, media, or insurance, comprehending the velocity and magnitude of these transformations necessitates broader research with a larger sample size. Additionally, it is advisable to undertake a more extensive longitudinal study on real estate practices, examining, for instance, the past 20-30 years to acquire a more profound insight into the evolution of global organizational dynamics.

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Carbon Benchmarks for Non-Medical Services in Hospitals

Pelzeter, A., Martinovic, M., Bustamante, S., & Prüße, H.

Hochschule für Wirtschaft und Recht Berlin
Contact: martina.martinovic@hwr-berlin.de

ABSTRACT

Background and aim. With an increasing importance of using carbon footprints of services or processes for management and reporting in healthcare organisations, the question of carbon benchmarks is raised. This paper aims to show a coherent set of carbon benchmarks for eleven non-medical services in hospitals, compare them and discuss challenges arising when working with them.

Methods. Carbon benchmarks were created based on data collected from three German hospitals. The development procedure comprised the calculation of service carbon footprints by applying a bottom-up method according to GEFMA 162-1, their normalisation using four factors and the computation of carbon benchmark values by building arithmetic means of normalised values.

Results. For each of the eleven services considered, four carbon benchmark values representing CO2eq emissions per (planned) bed, patient, inpatient day and DRG case mix point are shown, resulting in a total number of 44 carbon benchmarks. Moreover, the employee and patient logistic, laundry, laboratory and waste disposal services were identified as the five highest emitting processes.

Originality. The present study builds the first in-depth investigation on a coherent set of carbon benchmarks for a range of non-medical hospital services.

Practical implications. The study provides healthcare and facility managers with a helpful basis for understanding carbon intensive non-medical areas in hospitals in general and in the healthcare facilities they manage in particular. It therefore supports them in pursuing a continuous change process towards more ecological sustainability.

Type of paper. Research (full)

Keywords. benchmarking, carbon footprint, greenhouse gas emissions, services

INTRODUCTION

Against the background that the provision of healthcare is responsible for a considerable amount of greenhouse gas emissions (Karliner et al. 2019), which represent the main driver for climate change (European Commission n.d.), the healthcare sector with its single actors is called to control and reduce its environmental impact urgently (Karliner et al. 2019; Pichler et al. 2023; Zhang et al. 2022). In 2014, the global healthcare climate footprint amounted to two gigatons of carbon dioxide equivalent (CO2eq), which corresponds to the annual greenhouse gas emissions of 514 coal-fired power plants (Karliner et al. 2019). In Germany, the healthcare sector emitted in 2019 68 million t CO2eq, representing approx. 6% of the total annual German carbon footprint (Pichler et al. 2023). Within the healthcare sector, hospitals have been revealed to be the most intensive emitters (e.g. Weisz et al. 2020; Wu 2019). In addition, it was shown that the largest share of CO2eq emissions, namely 71% globally (Karliner et al. 2019) and 80% in Germany (Pichler et al. 2023), stem from the consumption of goods and services in the healthcare supply chain (so called Scope 3). The latter include a variety of purchased non-medical services such as cleaning, laundry or maintenance services.

Even though the topic of climate protection in healthcare has gained strongly in importance in both, research (Drew et al. 2022) and practice (Pichler et al. 2023), there is still a great need for action. Severe gaps in practice are existing, for example, regarding the tracking (Pichler et al. 2023) and reporting of greenhouse gas emissions (Quitmann et al. 2021), which play a fundamental role in the attempt to reduce or minimize them. This is not only from an ecological viewpoint problematic. It is also critical from a business perspective in view of increasing reporting obligations resulting from laws such as the Corporate Sustainability Reporting Directive or the German Supply Chain Due Diligence Act.

In the context of emission reduction, the management method of benchmarking, or more specifically carbon benchmarking, can make an important contribution (Tomar 2023). In principle, a benchmark represents a reference or measurement standard that is used for comparisons (Castro et al. 2015). A benchmarking describes a process that includes organisation and planning, data collection, analysis or comparison against benchmarks, and subsequent action to realise improvement (Pantall 2001). In this study, a "carbon benchmark" is understood as a reference or measurement standard for the carbon footprint of a specific reference variable (e.g. a service) that can be used for comparisons. Analogously, "carbon benchmarking" refers to the process in which carbon benchmark values are used to identify improvement potential and realise it.

Although it is apparent that a) hospitals have an urgent and strong need to reduce their carbon footprints, especially in the area of Scope 3 emissions comprising various non-medical services, and b) carbon benchmarking can play an important role for it, much research still needs to be done in the area of carbon benchmarking for non-medical hospital services. As will be shown in the following chapter, existing studies dealing with carbon footprints of non-medical hospital processes are differing in various aspects (e.g. process definitions, calculation approaches, applied normalisation factors) which impairs the comparability of results and prevents individual hospitals from using them for comprehensive (i.e. various relevant processes encompassing) and target-oriented carbon benchmarkings in their facilities. In order to enable such benchmarkings, a coherent set of carbon benchmark values for a range of non-medical hospital processes, allowing comparability between those, would be needed. The development of such a set was, to the best knowledge of the authors, not investigated to date. As such an investigation would provide a supporting evidence base for healthcare decision makers and facility managers to improve hospitals´ environmental sustainability, this work aims to tackle this gap. Within this study, carbon benchmark values for eleven non-medical hospital processes will be presented; they will be compared in order to identify those processes with the greatest impacts; and challenges arising when working with the presented carbon benchmarks will be discussed. The focus is put here on the German context. As Germany is the country with the highest number of hospital beds and the second highest number of hospital beds relative to its population size in the European Union (Eurostat 2023), it represents an important country for inquiry.

LITERATURE REVIEW

Within literature there are to date some publications that are dealing with the calculation of carbon footprints of non-medical processes in hospitals and in this way provide reference points for carbon benchmark values for them. These publications comprise works that are focussing exclusively at analysing single services or processes (studies at a service- or process-level) as well as studies that are investigating non-medical processes within the larger context of the carbon footprints of hospitals (studies at a hospital level).

Studies at a service- or process-level

At a service- or process-level, different studies are dealing with single non-medical hospital services or processes such as sterile processing, cleaning, laundry, mobility or logistics as well as catering. For the service of *sterile processing*, Rizan et al. (2022) investigate the decontaminating (steam sterilisation) and packaging of surgical instruments in a UK in-hospital sterilisation unit. They present insights on direct and indirect greenhouse gas emissions for different functional units (including one cycle of each decontamination machine and one surgical instrument) that were calculated mainly with a bottom-up approach. They show, for example, that one cycle of a washer/disinfector emits 3.74 kg CO2eq and one cycle of a steam sterilizer produces 12.13 kg CO2eq. Besides, Pelzeter et al. (2023) estimate the carbon footprint of the sterile processing service for two German hospitals for the reporting year 2021. Data used in the study are created by applying a bottom-up methodology. Overall emissions ranging from 85,987 to 170,219 kg CO2eq, as well as emissions per sterile supply unit ranging between approx. 6 and 11 kg CO2eq, are reported. Respective the *cleaning service* a currently valid Environmental Product Declaration (EPD) for the cleaning and disinfecting of hospital premises exists from the company Rekeep S.p.A. (2020). Within the EPD an emission value of 0.81 kg CO2eq per m2 of surface kept clean over a one-year period is presented. It was calculated based on a bottom-up approach, where employee mobility and service-related management were not within the system boundaries, in an Italian hospital with an area of 80,515 m2.

Similarly, for the *laundry service*, an EPD from the company Servizi Italia S.p.A. (2020) is currently valid. It investigates the provision of the supply, rental and reconditioning (washing and disinfection, sterilisation), maintenance and logistics (transportation, collection and distribution at customers) of sterile drapes and gowns in reusable technical fabric, packed in sterile barrier systems. The EPD reports carbon footprint values of 12.30 kg CO2eq (fossil) or respectively 31.50 kg CO2eq (biogenetic) per 1 kg of washed and sterilised drapes and gowns in one year of service. The values were calculated by applying a bottom-up methodology, using data from three Italian production sites (laundries with attached laundry sterilisations) of the company. In regard to *mobility or logistics* processes, including the travel of staff, patients and/or visitors, Bozoudis and Sebos (2021) assess the carbon footprint of the transport activities of a military hospital located in Greece for the year 2018 by means of a bottom-up calculation approach. They show that total emissions amount to 1,402 t CO2eq and that 86% of these are due to the movement of patients to and from the hospital. Additionally, they point out that the greenhouse gas emissions per patient range between approx. 0.3 kg CO2eq and 11 kg CO2eq depending on their mode of transport. Jayakrishnan and colleagues (2023) take a deeper look at the carbon footprint of employee commutes in three health systems in the US with a bottom-up approach. They estimate total annual emissions to range between approx. 11,999 and 36,006 t CO2eq and annual greenhouse gas emissions per study participant to range between 1,750 and 3,333 kg CO2eq for the different systems.

Finally, in relation to the service of *catering,* Vidal et al. (2015) quantified the carbon footprint of 18 different hospital diets based on data from Spanish hospitals. They found that the type of diet influences the carbon footprint. For example, while a normal diet provided to patients without special dietary requirements had a carbon footprint of approx. 5 kg CO2eq per day, a high-protein diet had a remarkable higher carbon footprint of approx. 8 kg CO2eq per day.

Studies at a hospital level

At a hospital level, for instance, Keller et al. (2021) investigate the emissions of 33 Swiss acute care hospitals in the year 2018. Within their study, they are covering several areas directly representing non-medical processes (e.g. waste, catering) as well as other more general areas (e.g. pharmaceutical, heating, paper use and printing). Emissions are calculated based on a bottom-up approach and presented per healthcare services provided by one full-time equivalent (FTE) for one year. Results reveal that an average hospital emits 3.28 t CO2eq per healthcare provided by one FTE per year in total. Furthermore, looking at areas related to specific non-medical processes, the study reports that the carbon footprint of an average hospital in the areas of catering, waste, and laundry and water use is 570, 175, and 74 kg CO2eq per healthcare provided by one FTE per year respectively.

Besides, Keil (2023a) puts the focus on a German hospital and presents emissions calculated using a hybrid approach (i.e. bottom-up methodology for Scope 1 and 2 emissions, top-down methodology for Scope 3 emissions) for the year 2019. Within Scope 3 different cost groups such as medical supplies, maintenance as well as food and drinks, partly intersecting with non-medical processes, are taken into account. Emission values are normalised using various sizes comprising the healthcare services provided by one average FTE staff member over the course of one year, the revenue and the Diagnosis Related Groups (DRG) case mix, the total number of patient days, the available number of beds and the hospital area. Results show that the investigated hospital emitted between 10,398 and 11,147 t CO2eq in the year under consideration and that Scope 3 emissions made up between 4,842 t CO2eq (47%) and 5,591 t CO2eq (50%) of total emissions. Within Scope 3, the cost groups of food and drinks, acquired services and maintenance were associated with approx. 360 t, 590 t and 273 t CO2eq respectively. Downscaled to reference units the following normalised values are presented among others: per patient day overall emissions range between approx. 158 and 169 kg CO2eq, Scope 3 emissions between approx. 73 and 85 kg CO2eq; per available bed emissions overall amount to approx. 34,432-36,912 kg CO2eq and for Scope 3 to approx. 16,034-18,515 kg CO2eq.

In sum, looking at the current state of literature, it can be stated that the different studies vary in several aspects including the following: They work with different process definitions and, if several processes are considered at the same time, make different process delimitations. They are characterised by different calculation bases (geographical contexts, sample sizes, reporting years), apply different calculation approaches and use different normalisation factors for downscaling total emissions to reference units. Overall, as described in the previous chapter, this affects the comparability of results and hinders single institutions to apply the determined values in the framework of own comprehensive and target-oriented carbon benchmarkings. Such benchmarkings would be enabled by the introduction of a coherent set of carbon benchmark values for a range of non-medical hospital services that allows comparability between the single services but is missing to date. The following study aims to fill this research gap.

METHODS

The work described in this study was conducted in the framework of the research project "Klimaneutrale Sekundärprozesse im Krankenhaus" which aims at analysing climate-relevant emissions of non-medical hospital processes and identifying measures for emission-savings. The practice-oriented project is funded by the German Federal Ministry of Education and Research (BMBF). It comprises a variety of practice partners including hospitals and their service providers who supplied the data underlying this study. In more detail, the carbon benchmarks presented here were built based on data of three German hospitals for the reporting year 2021. The hospitals differ in terms of their characteristics (see Table 1) but have in common that they are dealing with their environmental impact and strive to reduce it.

Table 1 Sample description

Hospital type	N	Hospital size	N	Number of patients	N
General hospital	2	< 600 planned beds	2	< 100,000	1
University hospital	1	≥ 600 planned beds	1	≥ 100,000	2

Within this study, eleven non-medical hospital processes belonging to five different categories are considered (see Table 2 and Appendix A). They were selected mainly based on the results of a materiality analysis conducted in the research project. In this analysis, over 40 identified non-medical hospital processes were evaluated by project group members in terms of their (climate) impact and changeability potential and subsequently grouped into three cluster (i.e. A, B and C cluster with decreasing levels of need for action) (Bustamante et al. 2023). All processes included here, except the patient logistic, were classified as A- or B-processes. The patient logistic (although representing a C-process) was additionally included in this study because data analyses run within the project have revealed its importance compared to the other assessed non-medical processes.

Table 2 Included non-medical services/processes and their categories (based on Ball & Künz 2018)

Category	Service/Process	Category	Service/Process
Cleaning and hygiene services	Cleaning Waste disposal Sterile processing	Logistics	Logistics (patients) Logistics (employees)
		Catering services	Catering
Clinical care services	Central bed supply Laundry Laboratory	Technology maintenance services	Maintenance of technical building equipment Maintenance of medical technology

The carbon benchmark development process comprised three important steps:

(1) For each of the three single hospitals total annual carbon footprints for each non-medical service were calculated (where data were available).

(2) The calculated service carbon footprint values were normalised using four different factors/ reference sizes. This means that the total service carbon footprint values were broken down to different individual units comprising one (planned) bed, one patient, one patient day and one DRG case mix point.

(3) Carbon benchmark values were built for each service and each reference size by calculating the arithmetic mean of the associated normalised service carbon footprint values. Overall, this led to a total number of 44 carbon benchmark values (eleven services with four reference sizes each).

Respective the first step, the calculation of total annual CO2eq emissions for each service, a bottom-up methodology based on the guideline GEFMA (2020) "Carbon Management for Facility Services" (No. 162-1) was applied. This guideline, issued in 2020 by the German Association for Facility Management e.V. (GEFMA), gives insights into the estimation of CO2eq emissions in facility services. According to it, CO2eq emissions are arising in four different areas: (1) operating equipment, (2) operating consumables, (3) transportation and (4) service-related management. The first category comprises CO2eq emissions connected with the equipment recurrently used in a service such as workwear or different devices (e.g. machines). In order to compute the CO2eq emissions of this area, for every equipment a single annual carbon footprint is calculated and subsequently all single annual carbon footprints are summed up. A single annual carbon footprint is thereby created by dividing a specific carbon footprint for a product by the lifetime duration of this product (in order to generate an annual contribution) and multiplying it with the number of this product used in the service as well as its usage share in the service. The specific product carbon footprints are either taken from EPDs (where available) or existing studies or are based on own estimations. The second category covers the CO2eq emissions associated with the consumption of consumables (e.g. cleaning agents, energy, water) needed for the service. Similar to the previously described category, the emissions of this area represent the sum of single annual carbon footprints for the different products or resources used. The latter are calculated by multiplying specific carbon footprint figures for individual products or resources (coming from EPDs, studies or own estimations) with individual annual consumption data for them. Within the third category, CO2eq emissions resulting from the transportation of goods and/or commuting of individuals such as employees or patients are included. They are determined using the distances (e.g. from home to place of work and back) and the underlying key figures for the means of transportation used, which are associated with different emissions produced per kilometre. Finally, the fourth category includes CO2eq emissions produced by service-related management activities such as work planning/ organisation or quality control. This comprises emissions associated with the use of office space (heating, energy), office equipment (e.g. PC, paper) and the commuting of corresponding employees. Calculations are made analogous to previous descriptions and emissions are added pro rata, i.e. according to the proportion of hours spent on the service in relation to the total hours of the corresponding employees per year. A more detailed description of the calculation methodology on the exemplary process of sterile processing can be found in the study of Pelzeter et al. (2023). In addition, Excel-Tables for calculating the emissions of selected processes are available in the guideline GEFMA (upcoming). For some of the eleven services considered here, some of the four categories needed to be excluded from the scope of investigation. Additionally, for the process of waste disposal a specific calculation approach was implemented. Appendix A shows the calculation approaches and scopes of investigation for each process and depicts from how many hospitals data were obtained.

With regard to the second step, the normalisation, data were downscaled using four different reference sizes, namely the (planned) number of beds, the number of patients, the number of days of inpatients, and the DRG case mix of each hospital. The (planned) number of beds refers to the number of beds that a hospital may operate according to a state´s hospital plan, regardless of its actual occupancy (Gesundheitsberichterstattung des Bundes 2023). An inpatient day is understood "as every day a bed is occupied by a patient, where the day of admission counts as one day and the day of discharge is not counted" (Keil 2023a, p. 4). Finally, the DRG case mix depicts the sum of all DRG points a hospital has earned. "DRG points describe the cost intensity of the treatment of a specific diagnosis group in relation to the average resource use of a treatment. For example, if a treatment of a diagnosis is twice as expensive as an average treatment, the hospital would earn two DRG points." (Keil 2023a, p. 4). To date no standardised reference size is existing (Keil 2023a) and hospitals may work with different variables. Overall, the four reference sizes selected here were chosen mainly in order to foster a wide use of the study results. The reference sizes are covering both, variables that can be considered as "input" measures ((planned) number of beds) as well as variables that can be seen as "output" measures (number of patients, number of days of inpatients, DRG case mix). While the former are related to a hospital´s ability to offer healthcare services, the latter are referring to services actually provided (Keil 2023b). In addition, the selection of reference sizes contains numbers that hospitals are asked to track and it includes more general as well as more Germany specific variables. Although further reference sizes such as the hospital area or FTEs are existing, they were excluded within this study mainly due to a limited or missing data availability.

RESULTS

Table 3 presents the carbon benchmark values for the eleven investigated non-medical hospital processes. They are reported in kg CO2eq per reference unit, i.e. per (planned) bed, per patient, per inpatient day and per DRG case mix point. Overall, 44 carbon benchmark values are depicted. In the category of cleaning and hygiene services, waste disposal has the highest carbon benchmarks with values of approx. 586 kg CO2eq per (planned) bed, 3 kg CO2eq per patient, 2 kg CO2eq per inpatient day and 12 kg CO2eq per DRG case mix point. Among the clinical care services considered, the process of laundry is the top emitter with carbon benchmarks of approx. 941 kg CO2eq per (planned) bed, 3 kg CO2eq per patient, 3 kg CO2eq per inpatient day and 16 kg CO2eq per DRG case mix point. Within the logistics category, the mobility of employees scores higher than the mobility of patients with values of approx. 3,282 kg CO2eq per (planned) bed, 18 kg CO2eq per patient, 12 kg CO2eq per inpatient day and 63 kg CO2eq per DRG case mix point. And in the category of technology maintenance services, the maintenance of medical technology is characterised by higher benchmark values than the maintenance of technical building equipment (with values amounting to approx. 47 kg CO2eq per (planned) bed, 0.2 kg CO2eq per patient, 0.2 kg CO2eq per inpatient day and 1 kg CO2eq per DRG case mix point).

Table 3 Carbon benchmark values for non-medical services

Service/Process category	Service/Process name	kg CO2eq/ (planned) bed	kg CO2eq/ patient	kg CO2eq/ inpatient day	kg CO2eq/ DRG case mix point
Cleaning and hygiene services	Cleaning	336.0	2.5	1.3	8.5
	Waste disposal	586.4	3.3	2.2	12.1
	Sterile processing	366.6	2.7	1.5	9.3
Clinical care services	Central bed supply	165.9	1.2	0.6	3.9
	Laundry	940.9	3.4	3.3	15.9
	Laboratory	740.3	3.2	2.6	12.4
Logistics	Logistics (patients)	1,415.6	7.5	5.2	27.7
	Logistics (employees)	3,282.3	17.5	11.9	63.4
Catering services	Catering	426.6	2.3	1.4	7.0
Technology maintenance services	Maintenance of technical building equipment	41.6	0.2	0.1	0.7
	Maintenance of medical technology	47.2	0.2	0.2	0.8

Regardless of the reference size, the highest values are found in the logistics category. They are followed by the clinical care services (with the exception of the central bed supply service), the cleaning and hygiene services and catering categories and finally the category of technology maintenance services. This order of precedence can be seen even more clearly when processes are ranked based on the height of their carbon benchmark values (see Figure 1).

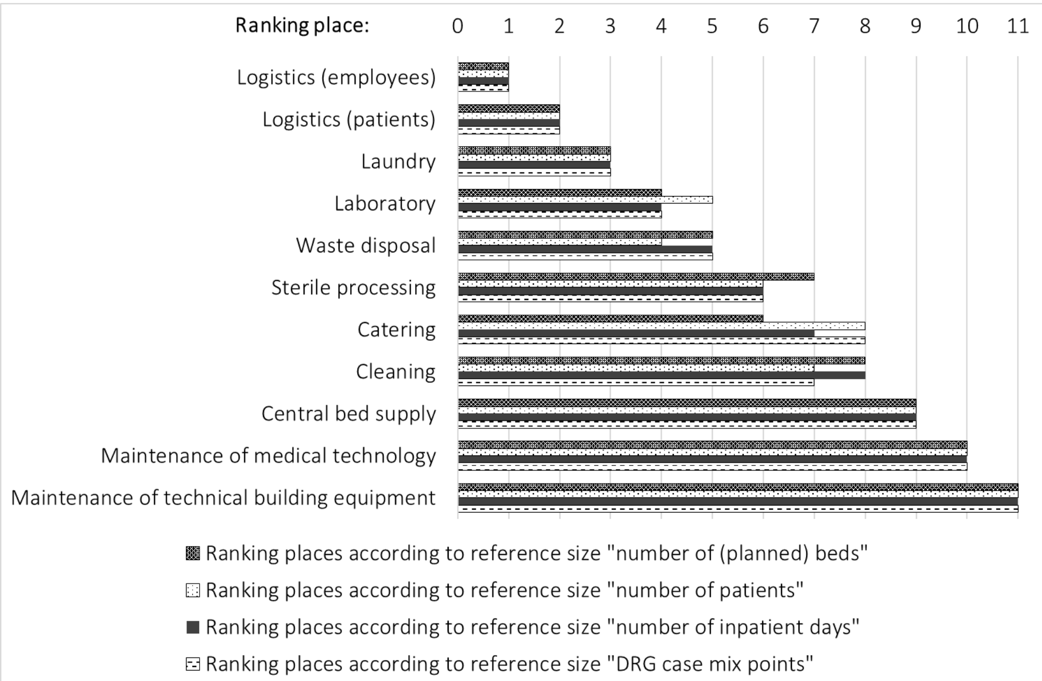

Figure 1 Ranking of non-medical services based on their carbon benchmark values

The first five ranking places (places 1-5) are occupied by the processes logistics of employees, logistics of patients, laundry, laboratory and waste disposal. Ranking places 6-8 are occupied by the services of sterile processing, catering and cleaning. And the last three ranking places (places 9-11) are taken by the central bed supply, maintenance of medical technology and maintenance of technical building equipment processes. Put in other words, if healthcare decision makers and facility managers would like to understand which of the investigated non-medical hospital processes are top emitters in general and should be tackled firstly by them, the recommendation based on the results would be to focus on the processes of employee and patient logistics along with the laundry, laboratory and waste disposal services.

DISCUSSION

In the previous chapter, 44 carbon benchmark values for eleven non-medical hospital services (i.e. four values for each of the eleven services) were introduced, with the aim to facilitate hospitals and service providers to conduct comprehensive (i.e. various relevant processes encompassing) and target-oriented carbon benchmarkings in their own facilities. The presented carbon benchmark values for the single services are based on a uniform data basis (with several exceptions), as far as possible the same calculation logic and consistent reference sizes. This allows comparability within the presented set. When it comes to a comparison of the calculated carbon benchmark values with results from previous studies, it has to be stated, however, that a direct comparability is not given due to various differences existing between the present and previous works. These differences relate, e.g., to process definitions used, system boundaries, calculation bases and approaches applied as well as reference sizes utilised.

Besides that, when working with the set of carbon benchmarks presented earlier, users are confronted with four important challenges that should be highlighted in the following. First, users should always be aware of the fact that the main goal of benchmarking lies in the recognition and realisation of improvement potentials (Pantall 2001). Therefore, after having used the carbon benchmarks presented in the paper to compare own carbon footprint values against the benchmark values, the next necessary steps are always to identify in which processes room for improvement exists and by which measures this could be realised. A major advantage of the carbon benchmarks presented here is that the calculation methodology on which they are based (i.e. the application of a bottom-up calculation approach and the division of emissions into the four different categories operating equipment, operating consumables, transportation and service-related management) not only allows, but also significantly supports that such measures are identified. As an orientation basis when identifying measures, also studies (e.g. Mazzeo et al. 2023; Seifert & Guenther 2019) and other collections from practice (e.g. Zukunft Krankenhaus-Einkauf n.d.) can be used as an important assistance.

Second, as this study is embedded in the German context, it is in particular applicable in hospitals in Germany. If a hospital located in another country than Germany aims to work with the set of carbon benchmarks its transferability has to be assessed prior to its usage.

Third, the set of carbon benchmarks presented here has some limitations in regard to its development methodology that has to be taken into account when using the values. This comprises that the underlying database only includes three hospitals, of which some have not provided data for all processes, and which differ in relevant characteristics such as their size, the number of patients treated or the services offered. As various studies on (carbon) benchmark development have shown that larger sample sizes are important for the formation of robust values (e.g. Castro et al. 2015; Zimmermann et al. 2021) and that group-specific benchmarks can be formed in the case of heterogeneous groups (e.g. Castro et al. 2015; Keller et al. 2021), the aim in the future is to expand the database and thereby substantiate and supplement current results. Another limitation associated with the small sample size is that so far only averages of normalised service carbon footprint values could be used to form the carbon benchmarks, but not statistical values such as medians, quartiles or percentiles, which are usually used in other benchmarking studies (e.g. Castro et al. 2015; Practice Greenhealth 2021; Zimmermann et al. 2021) and are planned to be calculated in future with the enrichment of the database. Moreover, it should also be taken into account that not all of the four categories (i.e. operating equipment, operating consumables, transportation and service-related management) could be considered in the carbon footprint calculation of every single process and that a specific calculation approach had to be selected for the waste disposal process. In general, the carbon benchmark development procedure applied in this study could be transferred to other samples as well as other reporting years, ideally with a richer database.

Finally, users should always be aware that the carbon benchmark values presented are only a snapshot of a certain time: They are based on a specific reporting period (in this case 2021), which is characterised by a certain level of knowledge and technological development (Zimmermann et al. 2021). Therefore, the values developed are subject to continuous updating.

CONCLUSIONS

Against the background that hospitals are urgently called to reduce their carbon footprints, which could be strongly supported by carbon benchmarking, this study aimed to present carbon benchmarks for eleven non-medical hospital processes included in five categories, compare them and discuss challenges arising when using them. Underlying data stemmed from three hospitals located in Germany related to the reporting year 2021. Four carbon benchmark values for each of the eleven services – representing CO2eq emissions per (planned) bed, per patient, per inpatient day and per DRG case mix point – were introduced. Overall, this results in a total number of 44 carbon benchmark values presented in the study. Moreover, the five most emitting processes were elaborated to be the logistics of employees and patients and the services of laundry, laboratory and waste disposal. In addition, looking at single categories, it was shown that the process of waste disposal had the highest carbon benchmark among the cleaning and hygiene services, the process of laundry among the clinical care services, the employee mobility among the logistics processes and the maintenance of medical technology among the technology maintenance services. Beside those results, the following four aspects that users should keep in mind when working with the set of carbon benchmarks were depicted: the importance of the identification of improvement potential and concrete measures for its realisation subsequent to the use of carbon benchmark values; the applicability of the results for the German context and according necessity to assess their transferability when planning to use them in other geographical contexts; the relevance of continuous updating of presented values; as well as several existing limitations in regard to the development methodology. The latter comprise the small and diverse underlying sample, the (slightly) differing calculation approaches for the various processes and the current impossibility to calculate benchmark values based on statistical variables other than the average. In future, it is planned to extend the underlying database and build additional benchmark values based on further statistical variables (e.g. median, quartiles). In this way, the evidence base introduced here, which can help healthcare decision makers and facility managers to improve the environmental sustainability of hospitals by conducting comprehensive benchmarkings, can be further substantiated and strengthened.

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APPENDIX A Non-medical services descriptions, scopes of investigation, and data availability

Service/ Process	Service/Process description and explanation of the scope of investigation (Notice: only categories included in the scope of investigation are presented, i.e. if a category is not listed, it was excluded from the scope of investigation)	N
Cleaning	Cleaning of the various hospital rooms *Operating equipment:* resources recurrently used in the process such as workwear, various devices with manual operation (e.g. window cleaner/glass squeegee, cleaning trolley) or electrical operation (e.g. scrubbing/suction machine, vacuum cleaner, washing machine) *Operating consumables:* electricity consumption of devices used in the process, cleaning agents (e.g. glass cleaner, sanitary cleaner), other consumables (e.g. gloves) *Transportation:* employee mobility *Service-related management:* heat and electricity consumption of office space used, employee mobility, technical office equipment (e.g. PC, printer), paper consumption	2
Waste disposal	Disposal of central waste fractions, taking into account burdens (caused by the hospital) and credits (through recycling, obtained from the disposal company) *Specific approach:* various waste fractions considered (e.g. waste paper; used glass; organic waste; infectious waste), transportation to the place of disposal/recycling generally included	3
Sterile processing	Cleaning, disinfection, sterilisation and provision of medical products (small devices) including packaging, storage and transport/distribution *Operating equipment:* resources recurrently used in the process such as workwear, devices with manual operation (e.g. transport trolley, sterile goods container) or electrical operation (e.g. washing disinfection device, steriliser) *Operating consumables:* electricity and steam consumption of devices used in the process, waste water, various consumables (e.g. fleece, face mask), cleaning agents (e.g. disinfectant cleaner) *Transportation*: employee mobility, transportation of sterile goods *Service-related management:* heat and electricity consumption of office space used, employee mobility, technical office equipment (e.g. PC, printer), paper consumption	2
Central bed supply	Cleaning/disinfection and preparation of patient beds *Operating equipment*: workwear, where available equipment for automated decontamination (e.g. bed washing system) otherwise resources for manual cleaning, other equipment (e.g. cleaning trolley) *Operating consumables*: electricity consumption of devices used in the process, waste water, various consumables (e.g. disposable apron, bed cover, hand disinfection, soap) *Transportation*: employee mobility *Service-related management*: heat and electricity consumption of office space used, employee mobility, technical office equipment (e.g. PC, printer), paper consumption	2
Laundry	Collection, washing, drying, packing and delivery of laundry to and from the hospital by service provider *Operating equipment*: laundry items (detailed calculation of tops, pants and bed linen sets; extrapolation to all laundry fractions) *Operating consumables*: detergents and disinfectants, electricity consumption, waste water *Transportation*: transportation of goods	1
Laboratory	Analysis of patient samples (in-house and at partners) *Operating equipment*: workwear and cell phones of employees *Operating consumables*: laboratory tests *Transportation*: employee mobility	2
Logistics (patients)	Patient transportation *Transportation*: arrival and departure of emergency patients and patients with planned examinations/interventions	3

Logistics (employees)	Mobility of hospital employees *Transportation*: employee travel to and from work, company cars, business trips. Adjustment for employee mobility recorded in other processes.	3
Catering	Procurement and production of food as well as dishwashing organization *Operating consumables*: food for patients´ lunches, kitchen energy and water consumption	1
Maintenance of technical building equipment	Inspection (monitoring), servicing and repair (minor repairs) of electrical systems and devices (can take place remotely outside the facility) *Operating equipment*: resources recurrently used in the process such as workwear and various devices (e.g. cordless screwdriver, Tablet, safety tester test case) *Transportation*: employee mobility (internal and external technicians) *Service-related management*: heat and electricity consumption of office space used, employee mobility, technical office equipment (e.g. PC, printer), paper consumption	2
Maintenance of medical technology	Inspection (monitoring), servicing and repair (minor repairs) of medical technology devices (can take place remotely outside the facility) *Operating equipment*: resources recurrently used in the process such as workwear and various devices (e.g. oscilloscope, infusion pump testing device) *Transportation*: employee mobility (internal and external technicians), goods shipments for maintenance purposes *Service-related management*: heat and electricity consumption of office space used, employee mobility, technical office equipment (e.g. PC, printer), paper consumption	2

The Integration of FM and Healthcare Departments in the Context of Food Production and Delivery Processes

Mutsaerts, H., Altan, M., & Mzembe, A.

Breda University of applied sciences (BUas)
Contact: mutsaerts.h@buas.nl

ABSTRACT

Background and aim. The complexity of managing hospitals has increased nowadays. Executives are constantly seeking ways to provide the best care at the lowest cost. The role of FM is increasingly acknowledged. However, relevant research mostly covers the interface with patients and visitors, instead of the organisational requirements itself. However, limited research has been conducted on the further integration of soft FM services and healthcare, such as patient food services within acute care hospitals. In addition, little literature describes the hospital food services' managerial perspective in hospital food services, exposing an apparent knowledge gap. This research paper aims to position the contemporary role and potential of healthcare FM, through the lens of hospital food services. Also, the importance of the multiple stakeholders is investigated: hospital management, (para)medical staff and the FM department.

Methods. Qualitative, single case study approach is chosen, leaning on an acute care hospital located in Belgium. Semi-structured interviews were conducted with 16 managers from the hospital, representing a variety of stakeholders. All interviews were transcribed verbatim, and thematic coding-analysis was conducted.

Results. By predominantly approaching food services as a cost-cutting endeavour, executives miss out on the benefits it can have on the overall patient experience. Those benefits could be better exploited when (soft-)FM activities are made accountable and are shared with relevant primary care stakeholders.

Practical or societal implications. An in-depth analysis of current food processes is provided, leading to operational recommendations, integrating the stakeholders' perspectives in the present research.

Type of paper. Research (full)

Keywords. food concept, food services, healthcare, production method, stakeholders

INTRODUCTION

Background and objectives

The volatile landscape of hospitals underscores the critical role of facility management (FM) within hospitals. Across European countries, the healthcare industry copes with major challenges such as an ageing population, rising healthcare demand, the associated complexity of care (Christensen, Dolbhammer, Rau, & Vaupel, 2009; Gerkens & Merkur, 2020), as well as an increase in more advanced and expensive diagnostics and treatments. And as these trends develop whilst expenditures in public health and care spending tend to decrease, the integration of FM and healthcare processes becomes increasingly relevant (Lennerts, 2009, p. 168). However, despite the assumed added value of FM in supporting hospital operations, a gap remains in academic literature regarding how to optimally align with primary care activities, despite some earlier research initiatives (Majeed & Kim, 2023; Shohet &

Lavy, 2004; Lavy & Shohet, 2007; Lavy & Terzioglu, 2023). This paper aims to address this gap pertaining to the integration process by an exploratory study investigating the integration of FM and healthcare departments in the context of food production and delivery processes. We particularly focus on food services and argue that while most research pertaining to food services focuses on the perception of the patient (Majeed & Kim, 2023; Yang & Kirillova, 2023; Doorduijn et al., 2015; Hartwell et al., 2015; Johns, Hartwell, & Morgan, 2009; Young et al., 2016), little up-to-date research is conducted on the perception of the other stakeholders involved. Therefore, the interface with patients and guests, as well as their perception of food services is beyond the scope of this paper. But this is not without recognising that over the past decade numerous hospitals across Europe have taken inspiration from hotels in terms of facilities and (food) services offered to patients and their relatives. Numerous hospitality concepts can be applied to the field of healthcare, and it is the authors' stance (in line with Donini et al., 2008), that meal provision in hospitals is to be considered as part of the clinical treatment instead of a mere routine. Furthermore, to provide an understanding of the context within which healthcare facility management (HFM) operates, this paper touches upon the complexities of financing, governance, and strategic initiatives that influence healthcare facility management within the Belgian healthcare system. Through this exploration, the aim is to contribute to a deeper understanding of how FM can effectively support hospital operations in the face of challenging healthcare dynamics. Using a Brussels-based hospital as a case study, this study was therefore undertaken to achieve two objectives: a) to analyse the stakeholders' current insights into the importance of hospital foodservices and underlying processes and b) to describe possible distinctions between various stakeholder perceptions in relation to these services.

The case

The case hospital focuses on acute care for a total of 406 beds, with an average length of stay of 2.5 days. The staff groups participating in this research are management, dietitians, medical staff and an external caterer. In this study, we focus on food services that is an integral part of the food system. The hospital follows the food system which is decoupled and based on cook-chill, being regenerated on site by the caterer (Beck, et al., 2001; Blades, 2000; Hartwell et al., 2006; van Velse, 2015). The system is based on outsourcing which is often to enhance the cost and operational efficiency (Afande and Maina, 2015). To minimise the hospital tax obligations, the food is served by staff under contract with the hospital (and not staff employed by the caterer). And although the positive effects (in terms of satisfaction and overall experience) of social interactions between patients and food service providers are supported by numerous studies (see Etemad-Sajadi et al., 2023), this dimension is beyond the scope of the present research. The case hospital in the present research is considering changing food system, aiming at improving the overall patient food experience.

LITERATURE STUDY

The unique nature of hospitals

The healthcare industry is currently facing many changes such as an ageing population, increase in co- and multi-morbidity, limited public budgets, labour shortages in primary care roles and increased competition and consumerism. Although the changes in healthcare- and more specifically in hospitals imply a shift in the role facility management (FM) must play, this has not received enough academic attention recently. Hospitals represent an inherently unique business environment; they provide uninterrupted services delivered by multiple specialists, even when faced by (unforeseen) external events and shocks (Lavy & Terzioglu, 2023). This, therefore, makes hospitals complex to manage (Wagenaar et al., 2020).

Financing models: the fuzziness of soft FM and impact of changing demographics in healthcare

It is important to understand the nature and philosophy behind healthcare systems, as well as its ramifications in particular when the FM processes are also considered. In our case, the hospital is operating under the state healthcare system and its inherent limited financial resources arising from the fact that Belgium spends 10.3% of its GDP on healthcare (Healthy Belgium, 2022; Wendt et al, 2009). Applying the conceptual framework of Wendt et al (2009) to the Belgian health care system, one could argue that the financing is done through both mandatory (proportional to one's income) and the voluntary health insurance payments and taxation (Healthy Belgium, 2022). The nursing and non-medical activities (for example FM services and facilities) are state-financed annually through a fixed close-ended budget based on a set of parameters and criteria, such as average length of stay, number of treatments and surgeries, and number of day treatments (Gerkens & Merkur, 2020). Budgets are separated between primary and secondary purposes such as FM. Notably, budgets for primary purposes are specified much more than the budgets for secondary purposes with FM activities often defined at an aggregated level. This is in line with Lennerts (2009) who stated that primary care activities are often well specified and accounted for, whereas secondary FM activities often remain fuzzy and are accounted as general overhead costs.

Facility Management in healthcare

FM makes up for 20-30% of hospital budgets (Lennerts, 2009) representing a significant share of the business operations. ISO (2024) defines FM as an "organizational function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business". Furthermore, Wiggins (2020, p. 28) considers FM, or 'property estates management' as both hard, technical services (hard FM) and soft, support services (soft FM) with ICT being the integrating force that is omnipresent in both hard and soft FM (Wiggins, 2020, p. 23). She considers soft FM elements such as food services are prone to subjectivity, because they impact the people and their feelings, engagement, satisfaction and effectiveness (Wiggins, 2020, p. 24).

In hospitals, facility management consists of any service or activity that is not directly linked to the primary activity of providing direct patient care (Lennerts, 2009) – such as catering and housekeeping according to Shohet and Lavy (2004). And in line with the latter, the focus in the academic field lies on hard services (Lavy & Terzioglu, 2023; Liyanage & Egbu, 2008; Njuangang, et al., 2018; Lavy & Shohet, 2007; Shohet and Lavy, 2004; Wagenaar, et al., 2020; Lennerts, 2009). Little scholarly interest is dedicated to the soft services and the integration of FM into healthcare processes, the topic at the core of the present research. It is evident that the interdependence between FM and healthcare organisations cannot be overstated. But the complementarity between primary and supporting functions remains weak (Heng & Loosemore, 2013), despite the need to align primary and secondary (FM) activities in shaping effective care paths (Lennerts, 2009). This is leading to a situation whereby FM is often perceived as being a cost centre, rather than as a function that could improve both the hospital performance and the patient experience (Lennerts, 2009).

Food Service Processes as soft-FM in healthcare

The hospital food service environment has changed over the past decades, supported by extensive research that emphasise the fact that proper nutrition should be considered as an integral part of the cure process of patients (Edwards and Nash, 1997; Goeminne et al. 2012). This is a significant development in the field considering that nutrition in hospitals has been a subject of concern for decades and generally has a bad image (Menzis, 2016). Several strategies have been developed about how best to bring together multi-disciplinary approaches to food and food service in hospitals: training and development, communication, sharing of information, proper leadership and support from management (Yinusa et al., 2021). Nurses, physicians, dietitians, facility managers as well as caterers have been searching for synergies between their respective work areas to improve productivity and ultimately the patient care. This is in sharp contrast with the literature covering the perception of stakeholders towards food in healthcare, as shortcomings are known: the lack of involvement of the hospital management in food provision has been highlighted by Beck et al. (2003). It has been suggested that such a lack of interest stems from the low priority management had accorded to food provision, a lack of recognition of the crucial role food provision services can play in the patients' care. Arguing for a more interdisciplinary approach, Kondrup (2004) suggested management should increase the attention given to the co-operation between physicians, pharmacists, nurses, dietitians and food service staff. Apart from management' attitude towards food services, the expertise of dietitians is often underestimated by physicians (Keller et al., 2015). This despite the fact that in principle clinical dietitians are on par with physicians and other specialized healthcare professionals. Dietitians often feel undermined in their role towards patient care (Hartwell et al., 2006) and feel that they fulfil an advisory service whereby their recommendations are not always implemented (Keller et al., 2013). The underestimation of the clinical expertise of dietitians may partially be caused by inefficient organisational structures that can negatively affect their professional credibility (Rasmussen et al., 1999). In addition, research by Ross et al. (2011) suggests that different disciplines often experience a similar sense of overall powerlessness to address known barriers in inter-disciplinary issues. Additionally, the latter also states that educating healthcare professionals improves the nutritional intake of patients and stimulates nutritional discussion in multi-professional teams. Research by Watling (2009) identifies similar benefits when dietitians are an integral part of the healthcare team. Close collaboration can stimulate learning and development of people, resource utilisation, work performance, and improvements in the provision of nutritional patient care. The study by Ross et al. (2011) further shows that there is no coordinated approach between nurses, dietitians and practitioners, a lack of communication between the departments and that the sense of a shared responsibility is missing when it comes down to food. An example of this is that nurses believe dietetic staff or family of the patient should assist with meals, while the practitioners believe nurses should provide this assistance. It is relevant here to note that the actual provision of the nutrients to the patient is generally taken care of by nursing or ward staff. But the poor relationships and communication amongst individual employees and departments alike, can negatively impact the quality of the foodservices (Riddiford et al. 2000). Especially ward-level staff and catering staff experience difficulties communicating. On top of this, the nursing staff tends to lack knowledge (Kondrup, et al., 2002), interest (Rasmussen et al. 1999) and respect (Goeminne et al. 2012) for clinical nutrition. Considering the catering departments, these have chronically suffered from a lack of proper funding and are often regarded as the poor relation by hospital management (Allison, 2003). The latter illustrates quite well where food services stand today in the field, and the work to complete for such soft FM service component to better align with primary care activities.

RESEARCH METHODOLOGY

A qualitative and exploratory single case study has been developed, leaning on semi-structured interviews in order to have the interviewees reflect on a number of elements as reflected in Table 1 (Bryman & Bell, 2015). An interview guide has been used to collect data from a total of 16 respondents, included based on judgmental sampling. As patients were not interviewed, no research ethics clearance was required. Data collection was stopped when reaching a point of data saturation. All respondents were provided with an information sheet prior to the interviews and signed a consent form when these started. Each interview averaged approximately 45 minutes. A summary of the interview guide can be seen in Table 1, together with the job profile of the respondents. The interviews were transcribed in Word and analysed by coding using NVivo12, following thematic analysis.

Table 1 Summary of interview guide and profile of the respondents

Elements covered in the interviews	Profile of the respondents (H)= Hospital and © = external caterer	
Perspective of the stakeholders focusing on	**Administrative staff (H)**	**Medical staff (H)**
Foodservice elements	Facility & procurement manager	Dietitian
Production method	Assistant purchaser	Nurse
Ordering system	Purchaser	Patient care manager
	Director of finance	
	Infrastructure and techniques manager	**Catering company ©**
	Director of human resources	CEO caterer
	Strategic policy officer and quality coordinator	Catering manager
	Infrastructure staff employee	Director medical branch caterer
	Patient experience officer	

Based on a generic coding structure in line with the literature, all three researchers conducted their respective coding and compared the findings before finalising the analysis. The final themes as well as interpretation of the transcripts were reviewed by several respondents to ensure reliability.

RESULTS

In this section, various respondents touch upon topics pertaining to foodservice elements, the current production method, issues with the ordering system and the menu as well as overall patient satisfaction.

Perspectives of the stakeholders

Representing ***management***, the CEO states that food is an important aspect for patients during their hospital stay, as it influences how a hospital is perceived: "*Food is an important aspect of the patient experience, people expect the medial part to be good but the real experience is determined by other aspects*". He emphasises the hospital' patient-oriented strategy, but doubts whether this is achieved at this stage: "*Based on what I saw and my experience, the answer to this is no [*interest of patients is not taken into account*] and it's not okay if you look at it from a patient perspective*". This is supported by the ***patient care manager*** who mentions meals are considered to be a peripheral service at best, not fitting today's requirements. The ***medical staff*** (nursing) is responsible for the querying of patients at admittance and, if needed, to assist patients in consuming their meal. The ***patient care manager*** observes that they often lack time to assist patients in consuming their meal. Food intake is not measured, and frequent mistakes from the nurses (not putting through dietary requests for patients) results in more work for dietitians. Currently the **dietitians** have more of a background task within the food provision in the case hospital. They are helping in the kitchen or sorting out admin tasks, dealing with nutritional forms and last-minute adjustments. The ***facility & procurement manager*** would prefer to see dietitians more often at ward level and develop personal contacts with patients. The ***patient care manager*** considers digitalisation of the ordering system is an important element to achieve this, freeing up time for dietitians to focus on their core business: advising patients about their meals. Considering food systems, it is relevant to note the system of the hospital and the one of the caterer are not interfaced. Despite the demands of the caterer to work on interfacing systems, the ***facility & procurement manager*** argues this is hindered by security issues in terms of digital data sharing. She also states that she is very unhappy about the current ordering process, that is described as outdated. The ***patient experience officer*** elaborates that she feels the querying of patients upon arrival on a ward is not done properly because of other priorities (from nursing staff), hence restricting choice options for patients. The ***patient care manager*** states in this regard that "*a lot of administration is involved which doesn't fit the current way of working anymore*", with dietitians having to enter patients' food preferences manually into the information systems linked to the patient files. According to the ***catering manager***, the integration of systems comes down to and aversion to change and a need to change mentality. All interviewees are satisfied about the collaboration between the hospital and the caterer. Within the financial constraints imposed to the latter, however. The ***patient experience officer*** quotes in this regard: "*in my opinion, they're doing the best they can. They are just trying to work with the resources they have and what they're allowed to charge us for*". It is relevant to note the hospital doesn't keep track of waste produced, nor energy usage by the kitchen. Considering the lack of resources pointed at hereabove and the impact on patient satisfaction, is it worth mentioning the hospital serves the meals at set moments and shows no flexibility in this regard. A well-known dichotomy is apparent in the case hospital, with management conscious about the need to improve food quality and patient satisfaction - but at the same time stating that costs are important and must be contained. Patient satisfaction with regards to food is not being surveyed properly at this moment. The ***facility & procurement manager*** stresses questionnaires are filled in by patients, but the outcomes are not being communicated towards the caterer. The former states "*they are also not being judged on patient satisfaction as this is not in their contract currently*". On top of this, the ***patient experience officer*** mentions the survey consists of eight general questions in which the meals are not even included. The hospital does not have any measurable data about patient satisfaction regarding the food.

Other: presentation of the food, issues of trust and information and exchange of information between parties

The **patient experience officer** mentions that little time is invested into how the food for geriatric patients is presented on the plate (geriatric patients receive blended food which makes consumption easier). She elaborates further by stating that malnutrition is a problem among these patients and the food seems to be *"thrown onto the plate like a great heap"*. Besides, she also states that breakfast is very simplistic right now with a few pieces of brown bread, no yoghurt or fresh fruits, for example, are offered and that she thinks the breakfast *"looks very tasteless"*. The **CEO** states that the cultural component of food is an important aspect: *"We offer a traditional Flemish kitchen and I think the hospital didn't evolve together with the cultural component (referring here as Halal meals)"*. With regards to the increasing demand for the latter, the **patient experience officer** quotes *"If you would offer Halal, we should show that the Imam of (name of town) is behind it and confirms it's Halal as they [the patients] wouldn't trust it otherwise"*. She concludes by saying she believes patients would trust the Halal option when the hospital starts providing (more) information about their meals as this would help in building a trusting relationship with their patients.

DISCUSSION

Management in this hospital recognises the importance of food as part of the patient experience. This approach in sharp contrast with various authors (Beck et al., 2001; Donini et al., 2008; Hartwell et al., 2006) who argue that management rarely perceives foodservice as an important part of the healthcare provided. Whether management can and is willing to invest in food-related matters is another issue. Limited budgetary resources do affect quality food provision in the case hospital, by subsequently affecting processes and time constraints from staff (e.g. nursing) because of competing demands. These observations are similar to research from Greig and Garcia (2018) as well as Keller et al. (2014), apart from the fact that the culture change is already voiced by management. In line with Beck et al. (2001), management should now also acknowledge responsibility of food services and nutritional care of patients from a financial perspective. Considering the latter, it is noticeable that several core elements are not measured at this stage: patient intake, satisfaction nor food waste. This is partly due to the rather complicated and hierarchical organisational structure of such traditional hospital (in line with Degadt and Hereck, 2013), making it difficult to convince hospital management of the beneficial effects of proper food services. Properly mapping out cost-containment opportunities benefitting stakeholders as well as patients would assist in integrating FM and primary care activities, as it has to be supported by exchange of data and an increased degree of involvement (of all parties concerned) with regards to food-related processes. A digital ordering system would positively impact employee deployment and patient satisfaction, in line with Prgomet et al. (2019) that also discussed the positive impact on food consumption and decreased food waste. Interfacing ordering systems from the hospital as well as the caterer is a prerequisite to avoid patients missing a serving due to a medical procedure (a common problem in hospitals working with fixed mealtimes, as stated by Hartwell, 2004). Such fixed mealtimes do have an impact on patient satisfaction (Dickinson, et al., 2005, and Mahoney & Zulli, 2009, as cited in Doorduijn et al., 2015) as well as eating environment, staff and choosing a meal one day ahead of consumption. This approach also impacts food waste, as appetite may change during the day (Goeminne et al., 2012). Williams and Walton (2011) further substantiated this by stating that difficult order processes can have a negative influence on food consumption. To conclude this point and as stated by Grimshaw et al. (2002), management should place a greater emphasis on the administration of food-related costs, improving the organisation's ability to operate under budgetary constraints. This also has implications for the caterer and the type of contractual agreements made. Duerksen et al. (2014) also stresses a hospital should be able to utilise their nurses' unique position optimally. But in line with Goeminne et al. (2012), nurses tend to lack interest in patients' nutrition, or are constrained in doing so because of their workload in this particular case hospital. These elements illustrate numerous issues related to communication between staff groups, with an adverse influence on the quality of hospital food services (Riddiford et al., 2000; Hartwell et al., 2006). The Patient Care Manager observes that they (nurses) often lack time to assist patients in consuming their meal. This is a form of neglect in terms of hospital nutrition, whereby management has an important role in influencing employee behaviour (Mayer et al., 2008). Johns et al. (2009) found that menus can be used to build a relationship with patients and enhance the meal experience and that informing the patients about the ingredients and various choices helps to build this relationship. In this specific case, a lack of communication between the various stakeholders leads to a situation whereby food is disregarded by specific patient groups (e.g. Hallal meals).

CONCLUSIONS AND RECOMMENDATIONS

Addressing the issue of alignment of soft FM factors such as food service and primary care activities of the case hospital, the present research uncovers a wide variety of factors having a significant (albeit negative) impact on food operations. There is a significant gap between managerial strategies and the front line, with the various stakeholders in between having different views on the relevance of catering. Key components and possible solutions are discussed next, aimed at enhancing the degree to which secondary FM activities (such as catering) are well specified and accounted for - in line with the approach of Lennerts (2009). The cost-saving potential of catering is not utilised, partly because of management' limited understanding of how these cost-savings may be achieved. The value of proper nutrition is not recognised by all stakeholders in the case hospital, and the choice for a new food service system is the perfect opportunity to undertake several actions to improve the situation. In line with Tappenden et al. (2013) healthcare professionals who have been taught about nutrition do value this discipline more highly than their un-educated colleagues and stimulate the nutritional discussion in inter-disciplinary environments (Suominen et al., 2007). Dietitians could educate the other stakeholders on the importance of nutrition to the recovery of the patient, and they should share their expertise by joining the nurses and physicians on their rounds. Positioning catering in the field required efforts at all levels, involving various staff groups in the process.

Improving interdepartmental communication by providing trainings on effective communication could provide helpful tools to all parties concerned, on top of the need to clarify the task division as well as the lines of communication across departments. Involving all stakeholders when redesigning food processes would also be helpful, and this at an early stage of the process. Sharing nutritional values of the meals with patients and other stakeholders will benefit knowledge sharing and levels of trust towards food services within the case hospital. Digitalisation would also enable introducing specific food surveys, support offering more choices and enable further customisation. Another important aspect of food cost is food waste which is also a performance indicator on its own. As it appears the case hospital does currently not measure food waste, it should be taken into consideration as food often implies a hospital is not meeting the nutritional needs of the patients. Soethoudt and Snels (2016) illustrate how 25% of the meals purchased is being wasted., whilst the annual cost saving can be up to €200.000,- in an average Dutch healthcare facility. Hands-on approaches to waste reduction and consisting of different steps (identification, measuring, analysis and reporting) are to be advised. Apart from waste management, calculating the impact of electricity usage for food services within the case hospital is to be considered. Considering future research, the latter could be integrated in emerging concepts such as developed by Majeed and Kim (2023) when drawing on the notion of the hospital-hotel. Ultimately, the objective being the enhancement of the patient-guest experience (PGE) and his overall health well-being (HWB). Recent tools contribute paving the way for such approach, with the validation of staff questionnaires to identify barriers and enablers to nutrition and mealtime care on hospital wards (see Young et al. 2023). And as emphasized in the present research as a prerequisite, budgets for secondary FM activities are to be well specified and accounted for. Finally, this research has several limitations. The sample used in the analysis is small, and limits generalisability. As the food production method is context-specific, it is not clear whether the output is transferable to other hospitals. However, the literature covering this subject area tends to be overarching and not solely linked to specific approaches to food production or delivery.

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