Görsch, Christopher; Seppänen, Olli; Peltokorpi, Antti; Lavikka, Rita

Construction Workers' Situational Awareness – An Overlooked Perspective

Published in:
28th Annual Conference of the International Group for Lean Construcion (IGLC)

DOI:
10.24928/2020/0022

Published: 01/01/2020

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Görsch, C., Seppänen, O., Peltokorpi, A., & Lavikka, R. (2020). Construction Workers' Situational Awareness – An Overlooked Perspective. In *28th Annual Conference of the International Group for Lean Construcion (IGLC)* (pp. 937-948). (Proceedings of the Annual Conference of the International Grouo for Lean Construction). IGLC.net. https://doi.org/10.24928/2020/0022

Görsch, C., Seppänen, O., Peltokorpi, A., and Lavikka, R. 2020. "Construction Workers Situational Awareness – An Overlooked Perspective." In: Tommelein, I.D. and Daniel, E. (eds.). *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28),* Berkeley, California, USA, doi.org/10.24928/2020/0022, online at iglc.net.

CONSTRUCTION WORKERS' SITUATIONAL AWARENESS – AN OVERLOOKED PERSPECTIVE

Christopher Görsch[1], Olli Seppänen[2], Antti Peltokorpi[3], and Rita Lavikka[4]

ABSTRACT

The construction industry is claimed to suffer from low productivity often caused by its complex, individualistic and unstructured nature. The construction workers' situational awareness (SA) is an insufficiently investigated and overlooked perspective in current project and production management literature to increase productivity in construction projects. This paper discusses the role of construction workers in planning and control of production and the possible impact of SA for on-site processes integrating knowledge and expertise from construction workers. The paper reviews the literature concerning construction workers' on-site situation, integration in production planning and control processes and the possibilities for empowering workers with SA. Providing real-time situational data can empower workers to make better decisions based on accurate, transparent, structured and trustworthy data. It is concluded that a better understanding and availability of the project information and progress can free up workers' workload, to focus their capacity on the task delivery. This will ultimately lead to a boost in productivity on-site. Furthermore, the paper opens avenue for further research and how to capture the current state of on-site SA of construction workers through a methodical approach including quantitative and qualitative methods.

KEYWORDS

Workflow, lean construction, production planning, construction worker, situational awareness

INTRODUCTION

The construction industry is recognised as a knowledge-based industry (Amaratunga and Haigh, 2005), whereby the skills and experiences of people are drivers for competitive advantage. Furthermore, competitiveness relies heavily on the ability to create, organise, transfer and leverage knowledge. This competence leads people to realise what is given data and needed information for decision-making processes to meet the goals of specific tasks (Irizarryet al., 2013).

[1] Doctoral Candidate, Department of Civil Engineering, Aalto University, Espoo Finland, +358 50 411 8924, christopher.0.gorsch@aalto.fi, orcid.org/0000-0001-9632-4031

[2] Associate Professor, Department of Civil Engineering, Aalto University, Espoo Finland, +358 50 368 0412, olli.seppanen@aalto.fi, orcid.org/0000-0002-2008-5924

[3] Assistant Professor, Department of Civil Engineering, Aalto University, Espoo Finland, +358 50 371 6613, antti.peltokorpi@aalto.fi, orcid.org/0000-0002-7939-6612

[4] Senior Scientist, D.Sc. (Tech.), Smart Energy and Built Environment, VTT Technical Research Centre of Finland, Espoo Finland, +358 50 384 1662, rita.lavikka@vtt.fi, orcid.org/0000-0003-1200-4773

Different from other sectors, the construction industry has not shown a noticeable increase in labour productivity in the last three decades. An inability to adopt knowledge management practices and strategies might be a cause for the productivity stagnation (Leal et al. 2017). Underlying reasons for this can be found in the characterisation of a construction project as an object and action-driven joint organisation, which itself is being developed while the building is being created (Dossick and Neff, 2011). Subsequently, project organisations are not stable but under a constant state of being recreated and demobilised (Chia, 2002). Team members come and go according to project needs. The sector depends strongly on given policies, practical norms, individual experiences as well as interdisciplinary action via communication and collaboration. As a result of this, most of the knowledge and expertise are domain-specific tacitly handed over (Cicmil and Marshall 2005). Trade partners are hired for specific and specialised jobs, where applied knowledge and expertise become the competitive advantage of their business ("knowledge is power"). Individual task completion becomes more critical than the overall project success. On the one hand, silo mentality and the hesitation of knowledge sharing is not an atypical phenomenon on construction sites (Javernick-Will, 2012). Furthermore, the hectic and complex construction project environment leads to a lack of time in knowledge-sharing (Carrillo and Chinowsky, 2006). An additional barrier to distributing knowledge is a low awareness of the value and benefit of possessed knowledge to others (Riege, 2005). Through such an on-site environment and organisational framework, the construction industry struggles to provide enablers to share knowledge to increase labour productivity.

On the other hand, craftsmen´s knowledge and on-site real-time data are insufficiently integrated to production planning and control. Information usually flows unilateral, from management to the worker level (top-down-based). Designs and schedules contain the level of information designers, and planners deliver, determined by their disciplinary views and contracts. Found in an Australien study, the achieved level of information is not fulfilling the on-site information requirements of construction workers (Loosemoore, 2014).However, among others, it needs the availability, transparency, and trustworthiness of data and information to trigger increased on-site productivity. Only then information can flow promptly, and the variation of the workflow can decrease, to enable better and profound decision making (Naoum, 2016).

These targets of information availability, trustworthiness and transparency can be found in lean construction principles. The Last Planner® System (LPS) follows lean percepts and tries to overcome unilateral and high-level planning by integrating lower-level personnel within the process (Ballard 2000). LPS strives to build relationships, create conversations and secure promises of action, to operate on trust and commitment-based common ground at the right level and the right time. It seeks for work packages and their readiness to assign them into a short-term work plan. This social process of integrating information at different times, from different people and different levels can update technical production systems to stabilise and improve the workflow (Priven and Sacks 2015). LPS approaches can be seen as a method to increase knowledge sharing and to capture an on-site situation picture. It integrates different actors and real-time process data through a manual social process. The term "last planner" refers to the person who is responsible for creating final assignments. As shown in several studies foremen and superintendents are last planners during the construction phase (Ann et al. 2011; Berroir et al. 2015; Friblick et al. 2009). Here, the involvement of the workers level is weak and seems to be a barrier to a successful implementation of LPS. We assume that the integration of workers' SA can create a more concrete and comprehensive situation picture of the project status and progress. This integration will improve the data, information and knowledge foundation for profound and more reliable decision making. Consequently, variability in plans and work tasks can be decreased and lead to a boost in resource and flow efficiency.

This research presents a literature review, which considers on-site productivity and knowledge sharing from the perspective of construction workers. It is shown what the current gaps in lean construction literature according to the involvement of workers in planning and control are and how SA can support on-site decision making to boost productivity. The paper presents on-site situation perspectives of workers related to information flow, knowledge sharing and the consideration of it. The role of SA and its applications in different sectors is pointed out. Following, the contribution of construction workers to on-site situation awareness for production planning and control is described. Conclusively, the last two chapters, derived from the literature review, summarise and discuss the previous essential chapters and show how future research can capture on-site SA of construction workers. The aimed outcome, the contribution of construction workers to a comprehensively shared project situation picture will benefit the individual needs on- and off-site stakeholders with up to date information of the project progress, which ultimately boosts productivity on-site.

ON-SITE SITUATION OF CONSTRUCTION WORKERS

The design and construction industry is classified by a high amount of different roles and players in the process to deliver a project. Thereby, construction workers are one of the last actors in the production chain when it comes to plan, construct and control the end product. Their on-site situation is dependent on players upfront in the supply chain.

Workers are heavily relying on the designs and plans of architects and engineers. The quality of project production management is strongly related to the constructability of designs and plans. Poor designs and plans are barriers to productivity on-site and a common problem as well as delivering those documents with a high documentation quality where needed (Horner and Duff, 2001). Design documents are created according to the designers' individual expertise and contractual requirements. Designers are often underpaid and under time pressure, which are poor prerequisites to high-quality design documents as well as their efficient documentation and distribution. As in an Australian study carried out, a trade-contractor mentioned it is not unusual to have only 20 % of the needed design information. Another barrier for on-site productivity is the tendency of planners´s optimism, which can result in unrealistic plans. This bias is known as planning fallacy, whereby plans tend to be close to best-case scenarios (Kahneman and Tversky, 1979).

Inter alia if designs and plans are distributed down the chain to apply as compiled, without real-time adaption and commitment, production management becomes unpredictable and workflows unreliable (Aslesen and Tommelein, 2016). Production as a sequence of inter-connected blocks needs the ability to understand and balance the output from the interconnected upstream processes (Ballard 1999). Considering "outside views" and distributional knowledge, e.g. the expertise of construction workers to plan and execute construction projects more realistic can be one cure for the planning fallacy (Flyvbjerg, 2006; Kahneman and Lovallo, 2003) as well as for an overall upstream variability.

However, so far, production planning and control evolve from insufficient and too optimistic designs, schedules and documentation. The associated risk of cost and time overruns is thus transferred from design and planning to production. It needs critical reviews of designs and plans through decision-makers with on-site knowledge. Unfortunately, many general contractors "[…] have forgotten how to build because they don't employ labour anymore and they have lost the old supervisor who understood […]" (Loosemoore, 2014) on-site processes from a users perspective. From a trade contractor´s point of view, this leads to a situation, where those risks are even further transferred to blue-collar workers. Loosemoore pointed out that they are left alone with the responsibility to manage and coordinate tasks by themselves.

Construction workers are usually lately involved in the supply chain and most likely slightly integrated into production planning. Furthermore, in most production projects, they do not have access to production control to update and improve given plans and designs. In this procedure, trade-contractors often start constructing a few days after signing the contract (Loosemoore, 2014). Such a kick-start leads additionally to little possibilities to influence designs and schedules. The focus then is more on coordinating themselves according to the given plans. To prevent from running over budget and time, planning is neglected and constructing starts immediately from scratch based on given plans with transferred risks (Hamzeh et al. 2019). Trade-contractors and workers are left alone with disciplinary and interdisciplinary communication as well as the coordination of tasks, assignments, materials, tools, and equipment. This individual managing leads to an interruptive working environment. Here, insufficient ad hoc decisions have to be made, and the production process is slowed done.

One study using beacon technology in residential and office building projects in Finland, showed via real-time resource tracking, that workers spend 25%–36% of their time during working hours in the assigned work locations according to the schedule (Zhao et al. 2019). These results are indicating approximately 70 % of working time as non-value adding time. Furthermore, they show, among other things, the deviation from given plans and standard procedures. This deviation can be identified as improvisation of work, which describes the usage of cognitive abilities to make ad-hoc decisions according to an unexpected situation by perceiving data, connecting information and applying knowledge. Improvisation occurs among other things in the absence of optimal information and resources in an uncertain and complex working environment (Endsley, 1995; Smith and Hancock, 1995; Hamzeh et al. 2012; Hamzeh et al. 2019). To increase productivity and avoid waste, it is not the task to eliminate improvisation. The task is to support better-improvised decision making by providing more accurate, flexible and fluid data and information in moments when needed (Abdelhamid et al. 2009; Hamzeh et al. 2019). Decentralised planning and control approaches like LPS provide solutions to integrate up to date data of the project progress and multiple actors on-site, to shield production from upstream uncertainty and variability (Ballard et al. 2007). However, blue-collar workers' expertise, knowledge and situational understanding as a direct input to provide a comprehensive situation picture to production planning and control are neglected, as different studies pointed out (Ann et al, 2011; Berroir et al. 2015; Friblick et al. 2009).

Based on the literature, an understanding of construction workers' on-site processes and methods on how to capture their explicit and implicit expertise for SA is needed. Such an understanding can contribute to be a considerate source of knowledge to shield production from upstream variability and boost on-site productivity. Thus, the paper will focus on building a modular concept for capturing this understanding. This opens opportunities to integrate innovations in the process and to contribute improvements (Loosemoore, 2014), due to the fact "[…] that improvisation is used as a method for continuous improvement and not just as a reaction to things that go wrong" (Hamzeh et al. 2019).

SITUATIONAL AWARENESS IN CONSTRUCTION

The above-described perspective is one reason why construction tends to be complex and chaotic. In many construction projects, no one has accurate and adequate information about completed design and construction activities, real-time data from on-site and an overview of upcoming task during the next weeks (Kärkkäinen et al. 2019). From this perspective, it can be concluded that the construction industry is facing an underutilised situational awareness (SA) of its players on-site. With this, information seldom flows promptly from the right group to another, in aproper format, with the right information and access as well as with the sufficient amount of data which is needed (Bråthen and Moum, 2015). The availability of SA is the foundation, on which decision making in complex and dynamic environments heavily relies.

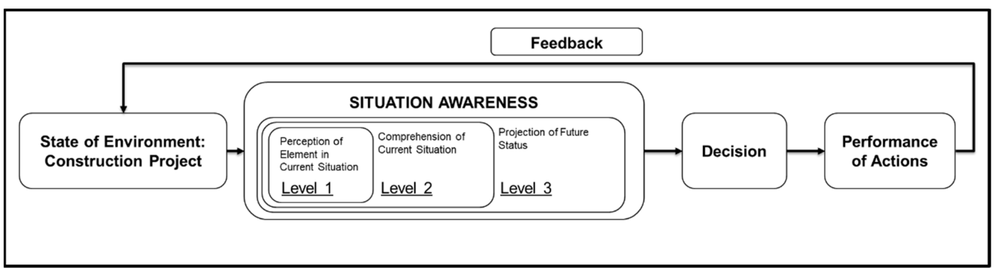

Figure 1: Model of Situation Awareness (adopted from Endsley (1995))

It is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley 1995). Figure 1 shows a simplified model of SA. It is divided into three hierarchical phases: Perception of elements in the current situation (Level 1: Data stage); Comprehension of the current situation (Level 2: Information stage); Projection of future status (Level 3: Knowledge stage). In many domains, SA is applied and plays a vital role in environments where fast and accurate decisions are critical for the project performance, for instance, in electronic systems, space operations, and automation technologies. It was first applied in the construction industry in relation to safety management (Gheisari et al. 2010). SA describes an understanding of what is happening around an individual in relation to the project progress, in order to make decisions based on profound, trustworthy and transparent data in the present and future. This relates to the preconditions of a construction task to establish a flow (Koskela, 1999).

However, due to the messy and complex on-site situation of construction, it would be the wrong way to blame craftsmen for failing in making right decisions about actions in an unsound process and unpredictable project environment. Data, information, and knowledge from and through a unilateral distribution channel do not seem to sufficiently meet the preconditions of a construction task to equip personnel with the right information at the right time (Koskela 1999; Ballard 2000; Kahneman and Klein 2009; Loosemoore 2014).

Hence, it needs research, which illuminates and understands the disciplinary and interdisciplinary information needs, but also the knowledge contribution of construction actors for better decision-making in a more regulated environment. These information requirements and contributions need to be mapped and categorised. Such a classification can contribute to constructing methods for collecting, refining and delivering the right information at the right time and for the right people to develop more predictable environments (Gheisari et al. 2010; Kärkkäinen et al. 2019). Once, SA is going to be increased by the integration of decentralised data through tracking, sensing and perceiving real-time information and knowledge, it has a vast potential to increase labour productivity. Due to a more stable and predictable environment based on more adequate and accurate data, workers can improvise on a more profound level of information to increase productivity and decrease waste (Hamzeh et al. 2019; Kahneman and Klein, 2009).

WORKERS' OVERLOOKED ROLE

With a focus on construction workers, several studies have shown the critical but also the most overlooked role of them in terms of productivity and production management (Amaratunga and Haigh 2005; Green et al. 2004; Holt et al. 2000; Loosemoore, 2014). Designs, schedules, and processes are planned and controlled by designers and managers but brought together, applied, adjusted and executed by on-site personnel.

In a knowledge-based industry, it is people and what they do with their skills and expertise to do the actual production work and achieve competitive advantage (Drucker et al. 1996). Hence, workers and their knowledge are the keys to deliver projects successfully (Cooke-Davies 2002; Amaratunga et al. 2005). The allocation of workers' diverse range of backgrounds, cultures, and qualities of expertise, their different capacities, and skills as well as within that the management of their tacit knowledge has become highly relevant to develop business performance and sustain competitiveness during individual projects and beyond. (Amaratunga and Haigh 2005; Green et al. 2004). Plenty of knowledge is available in the industry, but it remains in human memories, where best practices and tacit knowledge move from one project to another. Sometimes it is not transferred at all. For instance, one reason for failed plans is that they are developed without considering on-site realities. It is notable that in one takt project, one paint job was done in approximately one hour instead of as-planned one week (Salerto, 2019). In this study, up to four trade-contractors worked in the same location, even though takt plan included only one contractor in one location each takt time. After busy periods corridors were partially empty for several days.

Currently, craftsmen's knowledge is not considered in planning and control of production management, because too much of this individual knowledge is unknown to others as well as unmapped and unrecorded or simply not recognised valuable. As Egan (1999) has shown, it is known over decades that the construction industry does not recognise its greatest asset and treat them as such, even though "[…] construction cannot afford not to get the best from people […]" (Egan, 1999). It is assumed that construction workers have a very good understanding of how to apply their production processes most efficiently and which information is needed to do so. For a more realistic production planning and control the gathering, usage, and distribution of knowledge and real-time data coming from and impacted by workers is underutilised and not sufficiently captured yet. This would support a profound decision making which goes beyond a disciplinary understanding and project progress interconnections to reduce sources of waste and increase labour productivity.

However, according to current practices, the construction workers' role can be seen as an information receiver and task executor. His knowledge, expertise and on-site experiences are not sufficiently considered beyond these duties. Hence, a craftsman cannot be seen as an information sender, task definer, on-site investigator, and task controller. This current understanding does not fit or only partially to transfer competitive advantage in a knowledge-based industry over decades and to create on-site SA.

CAPTURING ON-SITE SA OF WORKERS

To enter an era of on-site SA to decrease waste in construction and increase production productivity we need to understand, automate and digitalise processes to empower decentralised planning and control from a multidisciplinary and collaborative point of view. Inter alia this requires a shift in thinking of blaming workers for insufficient processes and low productivity rates. Such a change needs to be directed toward utilisation and distribution of (inter-)disciplinary knowledge to support all actors as best as we can and create prompt information flow for decision making. As long as non-standardized information and non-explicit knowledge, like face-to-face communication, tacit knowledge itself and insufficient documents (design and schedules), are the primary sources of on-site decision making, productivity will not significantly increase. It needs less interpretable and more robust information. Such data sources would be more trustworthy, systematic and actor related distributed as well as lead to fewer changes of workflows in construction projects (Liu et al. 2010; Loosemoore 2014). For this purpose, innovative technologies like location tracking of resources and workers (Zhao et al., 2019) or automated progress recognition (Masood et al. 2019) can help to create a situation pictures supporting decision making. However, with these methods, situational awareness of workers cannot be fully understood and explained. Due to individual and mental processes of planning, executing and controlling a task cannot be captured through such technology. To make construction less dependent on individuals' capabilities and to lead it towards a systematic production, we need to start planning and managing it differently. Figure 2 shows preliminary research steps on how we plan to capture the current state of on-site SA of construction workers through quantitative and qualitative methods.

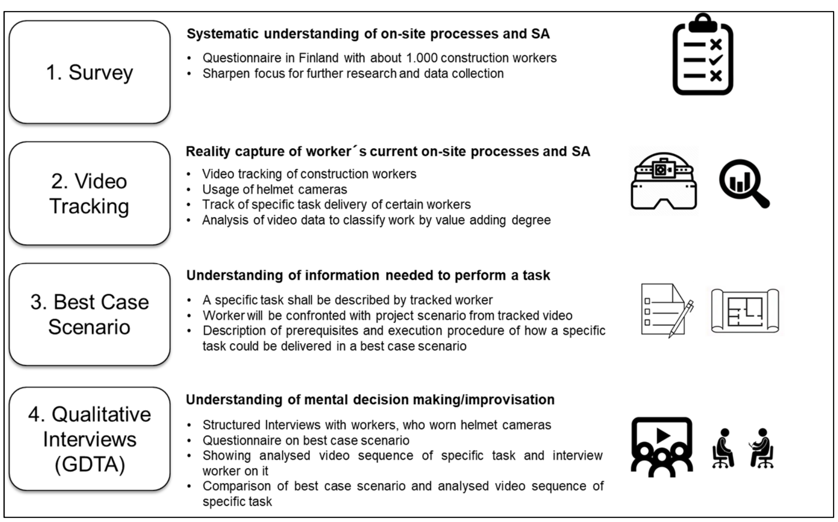

Figure 2: Described preliminary procedure of capturing on-site situation awareness of construction workers

SURVEY RESEARCH

The perspective of construction workers and their on-site situation seems to be a starting point to investigate SA. A survey is going to be developed to study the complex and chaotic field of construction, where knowledge is rarely expressed explicitly. The questionnaire tries through quantitative research to test hypotheses and draw conclusions from a large group of participants. The survey is going to be addressed to the level of craftsmen and aims for 1.000 participants from different trades, age groups projects, and companies in Finland. Therefore, it is designed in three different languages Finnish, Estonian and English. To guide the responding process, the questionnaire is using the format of closed questions with multiple choice answers. Furthermore, instructions on how to answer questions are given to clarify original intentions.

Through 29 key research questions, five umbrella themes (on-site social interaction, knowledge transfer, usage of hardware and software, workers' routines and understanding of project progress) are covered. Additionally, eight general questions have been designed. Within this given framework, the goal is to build up a baseline understanding of workers' perspectives and routines as well as their on-site SA of production processes. At the end of the first step, trends and generalisations can be made to sharpen the focus for the upcoming research steps.

VIDEO TRACKING

In lean and safety construction literature, different studies have been measuring productivity, waste or safety through on-site observations. Here, a limiting factor can be the observer itself, who affects the data collection through presence on-site (Kalsaas, 2013; Kalsaas, Gundersen, and Berge, 2014; Mitropoulos and Cupido, 2009). A different way of resource efficiency based on-site observations are integrated cameras in the working equipment of the observed subject (Han and Lee, 2013). We are supposing to capture on-site SA by tracking construction workers via helmet cameras. It is planned to film different work scenarios from several construction workers over a certain period of time. From this video material, dynamic moving and behaviour according to the construction schedule and a rapidly changing working environment can be captured. From a project performance and workforce-related point of view locations, used materials, equipment, tools according to planned tasks will become visible and can be compared (Mitropoulos and Cupido, 2009).

From this point on specific tasks of individual workers shall be analysed from the video data. Firstly, a process model of a particular task delivery shall be drawn from the captured video data. Within the model, single tasks are described as process steps, which contain information, such as used material, equipment, tools, location and time. Afterwards, the individual process steps will be classified into value-adding, supportive value-adding and non-value adding working time. The 'context-aware' data collection via video capturing of the observed subjects and its surroundings can become an issue of ethical concerns. Thorough managerial considerations are needed to communicate and mitigate the negative effects of vision-based monitoring. Therefore, subjects of observation need to be informed about the monitoring process, its purpose, and usage of captured data upfront (Seo, Han, Lee, and Kim, 2015). To further address privacy issues, the study will take approaches that anonymise identities into consideration. However, the privacy policy of the analysed construction project and its involved organisations needs to be critically reviewed in advance to solve privacy concerns for 'context-aware' video capturing of the workforce (Han and Lee, 2013).

Best Case Scenario

One study measuring workflow and waste in construction pointed out that measurements taken by observations can give limited insights into root causes. Therefore, interviews and or self-reporting (by the investigated subject) methods can broaden the understanding of observed data (Kalsaas et al. 2014). The "Best Case Scenario" part intents to develop in collaboration with tracked craftsmen a task description. The task to be described will be the same; the worker delivered on the video. The worker will be confronted with the same scenario as captured in the video. Following, the construction worker shall describe which preconditions are needed and how his individual execution procedure would look like, to deliver the task most productive and with minimal waste occurrence from his point of view. The purpose of this step is to capture the understanding of construction workers' information needs for efficient task delivery.

Qualitative Interviews (GDTA)

The results of the video tracking and "Best Case Scenario" analysis are going to be compared through the application of Goal-Directed Task Analysis (GDTA). Hereby, In the form of qualitative interviews, SA is going to be studied, captured, and assessed. GDTA was used in different sectors as well as in construction to assess SA on how needed information is addressed to make decisions (Gheisari et al. 2010; Hamid and Waterson, 2010; Kaber et al. 2006). It was originally developed by Endsley (1995).

Based on the described "Best Case Scenario" task, workers are asked to identify their primary goals and how to achieve them through sub-goals. Afterwards, the defined task sequence shall be connected with the sub-goals and how it leads to decision making by linking individual information requirements to the described actions. Before the second step of the interview is going to take place, the so-far analysed logic, interconnections, and information requirements are documented. From here on the captured video data is going to be shown to the worker. With this review, it is possible to compare the video material with the interconnected "Best Case Scenario" from the first step of the interview. Through structured interviews, reasons for possible improvisation related to preconditions and deviations from plans and the "Best Case Scenario" will be detected and critically reviewed. Overall, these methods shall enable the capturing of on-site SA, investigations of what leads to improvising and an understanding of individual and mental processes of planning, executing and control of construction workers on-site.

DISCUSSION AND CONCLUSIONS

Through a literature review, this research derives the importance of understanding and integrating workers' on-site processes and knowledge. The study shows how to capture SA of construction workers to provide more sound preconditions of a task to improve the disciplinary and interdisciplinary coordination of individuals and crews as well as their overall decision making. With this, it is possible to move from an individual point of view (resource efficiency) to a more global understanding of the project status and progress (flow efficiency).

The proposed methods for capturing SA can be seen as a first step to classify and document tacit process knowledge of construction workers. The methods include a high amount of monitoring, analysing, processing, listening and documenting. Firstly, the investigating methods can be prone to failure and misinterpretation because of the high amount of manual work. Another challenge is to ensure the monitoring process does not disrupt the worker's activities and behaviour while being observed in the field as well as privacy issues.

The current work contributes by pointing out gaps in contemporary lean construction literature related to the involvement and the contribution of workers in planning and control, as well as how SA can support on-site decision making to boost productivity. Further, this study derives research and investigates methods to close these gaps. The approaches point to promising directions, which can open a venue for new technologies and applications in the future. The aimed outcome, the contribution of construction workers to a comprehensively shared project situation picture, can benefit the individual needs of on- and off-site stakeholders with up to date information of the project progress, which ultimately can boost productivity on-site. However, more research and methodological development are needed.

ACKNOWLEDGMENTS

This work has been supported by DiCtion (Digitalizing Construction Workflows) project funded by Business Finland and a consortium of companies and the Building 2030 consortium of Aalto University and 19 companies.

REFERENCES

Abdelhamid, T. S., Schafer, D., Mrozowski, T., Jayaraman, V., Howell, G., and El-Gafy, M. A. 2009. “Working through unforseen uncertainites using the OODA loop: An approach for self-managed construction teams.” *Proc. 17th Ann. Conf. Int. Group Lean Constr.*, 573-582.

Amaratunga, D., and Haigh, R. 2005. “Recognising the importance of “Tacit” skills of the construction worker in a knowledge environment.” *ACROM Doctoral Workshop*. University of Huddersfield Repository Pathirage.

Ann, D., Brady, D., Tzortopoulos, P., and Rooke, J. 2011. “*An Examination of the Barriers To Last Planner Implementation*.”

Aslesen, S., and Tommelein, I.D. 2016. “What “makes” the Last Planner? a typology of behavioral patterns of last planners.” *Proc. 24th Ann. Conf. Int. Group Lean Constr.*, 43-52.

Ballard, G. 1999. “Improving work flow reliability.” *Proc. 7th Ann. Conf. Int. Group Lean Constr.*, 275-286.

Ballard, G., Howell, G., Tommelein, I., and Zabelle, T. 2007. “*The Last Planner Production System Workbook.* ” P2SL, Univ. of California, Berkeley, California, USA.

Ballard, H. G. 2000. “The last planner system of production control. ” The University of Birmingham, UK.

Berroir, F., Harbouche, L., and Boton, C. 2015. “Top down vs. bottom up approaches regarding the implementation of lean construction through a French case study.” *Proc. 23rd Ann. Conf. Int. Group Lean Constr.*, 73-82.

Bråthen, K., and Moum, A. 2015. “Bridging the gap: taking BIM to the construction site.” *Proc. 32nd CIB W78 Conf.*, 79-88.

Carrillo, P., and Chinowsky, P. 2006. “Exploiting Knowledge Management: The Engineering and Construction Perspective.” *J. Manage. Eng.*, *22*(1), 2-10.

Chia, R. 2002. “Essai: Time, Duration and Simultaneity: Rethinking Process and Change in Organizational Analysis.” *Organ. Stud.*, *23*(6), 863-868.

Cicmil, S., and Marshall, D. 2005. “Insights into collaboration at the project level: Complexity, social interaction and procurement mechanisms.” *Build. Res. Inf.*, *33*(6), 523-535.

Dossick, C. S., and Neff, G. 2011. “Messy talk and clean technology: communication, problem-solving and collaboration using Building Information Modelling.” *Eng. Project Organ. J.*, *1*(2), 83-93.

Egan, J. 1999. “*Rethinking Construction - The Report of the Construction Task Force*.

Endsley, M. R. 1995. “Measurement of situation awareness in dynamic systems.” *Hum. Factors*, *37*(1), 65-84.

Endsley, Mica R. 1995. “Toward a theory of situation awareness in dynamic systems.” *Hum. Factors*, Vol. 37, pp. 32-64.

Flyvbjerg, B. 2006. “From Nobel Prize to Project Management: Getting Risks Right.” *Project Manage. J.*, *37*(3), 5-15.

Friblick, F., Olsson, V., and Reslow, J. 2009. “Prospects for implementing Last Planner in the construction industry.” *Proc. 17th Ann. Conf. Int. Group Lean Constr.*, 197-206.

Gheisari, M., Irizarry, J., and Horn, D. B. 2010. “Situation awareness approach to construction safety management improvement.” *Proc. 26th Ann. ACROM Conf.*, 311-318.

Hamid, H., and Waterson, P. 2010. “Using Goal Directed Task Analysis to Identify Situation Awareness Requirements of Advanced Paramedics.” *Int. Conf. Adv. Hum. Factors Ergon. Healthcare*, (June), 672-680.

Hamzeh, F., Faek, F., and AlHussein, H. “2019. Understanding improvisation in construction through antecedents, behaviours and consequences.” *Constr. Manage. Econ.*, *37*(2), 61-71.

Hamzeh, F.R., and Albanna, R. 2019. “Developing a Tool to Assess Workers’ Understanding of Lean Concepts in Construction.” *Proc. 27th Ann. Conf. Int. Group Lean Constr.*, 179-190.

Hamzeh, Farook R., Morshed, F. A., Jalwan, H., and Saab, I. 2012. “Is improvisation compatible with look ahead planning? An exploratory study.” *Proc. 20th Ann. Conf. Int. Group Lean Constr*.

Han, S., and Lee, S. 2013. “A vision-based motion capture and recognition framework for behavior-based safety management.” *Autom. Constr.*, *35*, 131-141.

Horner, M., and Duff, R. 2001. “More for Less: A Contractor´s Guide to improving Productivity in Construction. ”

Irizarry, J., Gheisari, M., Williams, G., and Walker, B. N. 2013. “InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach.” *Autom. Constr.*, (33), 11-23.

Javernick-Will, A. 2012. “Motivating knowledge sharing in engineering and construction organizations: Power of social motivations.” *J. Manage. Eng.*, *28*(2), 193-202.

Kaber, D. B., Segall, N., Green, R. S., Entzian, K., and Junginger, S. 2006. “Using multiple cognitive task analysis methods for supervisory control interface design in high-throughput biological screening processes.” *Cognit. Technol. Work*, *8*(4), 237-252.

Kahneman, D., and Klein, G. 2009. “Conditions for Intuitive Expertise: A Failure to Disagree.” *Am. Psychol.*, *64*(6), 515-526.

Kahneman, D., and Lovallo, D. 2003. “Delusions of Success: How Optimism Undermines Executives ’ Decisions.” *Harvard Bus. Rev.*, *81*, 56-63.

Kahneman, D., and Tversky, A. 1979. "Intuitive prediction: Biases and corrective procedures." *TIMS Stud. Manage. Sci.*, (12), 313-327.

Kalsaas, B. T. 2013. "Measuring Waste and Workflow in Construction." *Proc. 21st Ann. Conf. Int. Group Lean Constr.* 33-42.

Kalsaas, B. T., Gundersen, M., and Berge, T. O. 2014. "To measure workflow and waste. A concept for continuous improvement." *Proc. 22nd Ann. Conf. Int. Group Lean Constr.*, 835-846.

Kärkkäinen, R., Lavikka, R., Seppänen, O., and Peltokorpi, A. 2019. "Strategizing and Project Management in Construction Projects: An Exploratory Literature Review." *10th Nord. Conf. Constr. Econ. Organ.*, *2*, 155-161. EmeraldPublishingLimited.

Koskela, L. 1999. "Management of production in construction: a theoretical view." *Proc. 7th Ann. Conf. Int. Group Lean Constr.*, 241-252.

Leal, C., Cunha, S., and Couto, I. 2017. "Knowledge sharing at the construction sector - Facilitators and inhibitors." *Proc. Comput. Sci.*, *121*(January), 998-1005.

Liu, M., Ballard, G., and Ibbs, W. 2010. "Work Flow Variation and Labor Productivity: Case Study." *J. Manage. Eng.*, *27*(4), 236-242.

Loosemoore, M. 2014. "Improving construction productivity: a subcontractor's perspective." *Eng., Constr. Archit. Manage.*, *21*(3), 245-260.

Masood, M. K., Pushkar, A., Seppänen, O., Singh, V., and Aikala, A. 2019. "VBuilt: Volume-based automatic building extraction for as-built point clouds." *Proc. 36th Int. Symp. Autom. and Rob. Constr., ISARC 2019*, 1202-1209.

Mitropoulos, P. T., and Cupido, G. 2009. "The role of production and teamwork practices in construction safety: A cognitive model and an empirical case study." *J. Saf. Res.*, *40*(4), 265-275.

Naoum, S. G. 2016. "Factors influencing labor productivity on construction sites." *Int. J. Prod. Perform. Manage.*, *65*(3), 401-421.

Priven, V., and Sacks, R. 2015. "Effects of the last planner system on social networks among construction trade crews." *J. Constr. Eng. Manage.*, *141*(6), 1-10.

Riege, A. 2005. "Three-dozen knowledge-sharing barriers managers must consider." *J. Knowl. Manage.*, *9*(3), 18-35.

Salerto, S. 2019. "Hukan mittaaminen tahtihankkeessa." *Master Thesis*. *Department of Civil Engineering. Aalto University. Espoo.*

Seo, J., Han, S., Lee, S., and Kim, H. 2015. "Computer vision techniques for construction safety and health monitoring." *Adv. Eng. Inf.*, *29*(2), 239-251.

Smith, K., and Hancock, P. A. 1995. "Situation awareness is adaptive, externally directed consciousness." *Hum. Factors*, *37*(1), 137-148.

Zhao, J., Seppänen, O., Peltokorpi, A., Badihi, B., and Olivieri, H. 2019. "Real-time resource tracking for analyzing value-adding time in construction." *Autom. Constr.*, *104*, 52-65.