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Five Frameworks to Approaching Architectural Materials Research

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Abstract
In current days from materials to products, and finally to practical applications in realised buildings includes many variables to manage. These variables can include updated building regulations, innovative construction methods, demands for sustainability, or unseen design and manufacturing variables. This complexity leads to new processes and practices. Integrating architectural practices, demands, emphases, and values in the early phases of these processes, this may make the process manageable. This paper presents five frameworks for use in approaching architectural-related multidisciplinary materials research. The boundaries of said research can be imagined with the help of these frameworks, which render the objectives of the research tasks and the duties of the participants more easily comprehended, and the process clearer and more easily managed. In architectural materials research and design, the process, the research facilities, methods, or even the objectives may not be clear to all participants during the research the phase. Three of the suggested approaches are based on Leon van Schaik's practical poetics approach. The other two approaches are conventional and are already somewhat in use in research related to architecture. These five-pronged frameworks have been applied to architectural materials research with the following concepts: *master idea*, in which materials research can be regarded as a continuity of a tradition; *blending process*, in which materials research blends equally with technological development; *idea generation*, in which materials research is subordinated to a design idea; *design oriented*, in which materials research is based on explorative design; and *science oriented*, when materials research is inspired by science. Each of the approaches have been further observed with sub-concepts familiar in architecture. The five frameworks have been tentatively observed within early phase cellulosic materials research studies. The practical implications of this framing will become clear when establishing materials research projects, comprehending the nature of multidisciplinary research, or steering ongoing research in a specific direction.

Keywords: Architecture, Materials development, Materials design, Materials research, Multidisciplinary,

Introduction
The current practices in materials research targeted to serve architectural applications are relatively fragmented and performed by several experts from different disciplines. Materials can be approached from the viewpoints of material properties, production, markets, end use, users, or material experience. At the research phase, the selected observation viewpoint defines the outcome of the

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research. However, while multidisciplinary or cross-disciplinary research approaches exist, the framework for how to focus on a research or development task might not be approached from the field of architecture.

In materials science, material experts are involved in the processes with a deep but narrow specialisation, then the different disciplines tend to focus on substantial aspects. The research process tends to be relatively linear. On a practical level, these can be related to modifying materials methods or clearing out meaningful material properties in the context of material science. In addition to the scientific approach, materials have been studied by means of design. The design has an important role, especially when a material or material characteristic is utilised in a novel way (Ballard Bell and Rand, 2014, p. 9). With this explorative approach, the process might not be as linear as when materials are studied by means of material science. Materials can be researched by making formal exercises or by utilising hands-on exploration. When studying the inherent language of the novel material or generating a new language for already known materials. From the viewpoint of architecture, both scientific and design-based approaches to studying materials are important.

The current practices in materials research targeted to serve architectural applications are relatively fragmented and performed by several experts from different disciplines.

It is not known whether a specific classification method for framing different types of multidisciplinary research approaches in materials research and development in the field of architecture exists. In general, different materials have been classified in accordance with a descriptive method, and the framing is relatively narrow. The materials can be defined by material types (bioplastics), properties (functional materials), or scales (nanomaterials). In addition to just denoting the type of the material, materials can be approached from their goal orientation, whereby the main driver guides the research. When materials are developed from the viewpoint of technology, recognising the end-user of the materials is important (Ritter 2007, p. 7). In this regard, the utilisation of technological innovations may improve or ease living conditions in several significant ways. For instance, responsive or phase-changing materials, air-purifying materials, or bactericidal materials have become important and positively affect our surroundings (Peters 2011, p. 10). Another key driver for materials research stems from environmental considerations. Despite their relatively recent emergence, the sustainability and life cycles of materials are important drivers alongside, or arguably even above, the functionality of materials (Peters 2011, p. 7). In material science and design, studies exist that make processes more comprehensive (Arróyave 2019, 103-126), but do not have clear origins in the architectural mindset.

This paper suggests five approaches, three new and two conventional, to classifying different kinds of material research and development projects. The demand for specifying the new approaches emerged with the need to order and categorise different kinds of materials research in the context of architecture. In other words, the objective is to divide material research into their smaller constitutive parts to generate coherent observation frames in which research objectives will find a natural basis or motives. Due to the multifaceted role of architecture in general, all five approaches contemplate themes such as creativity, science, traditions, technology, and ideas. The knowledge they elicit is likely to be useful when formulating research tasks, when framing new research, or when comprehending the nature of a research task in progress.

1. Role of the Architect

The role of an architect in society has altered through different periods or epochs. In the 1980s, the role was condensed into the following roles: Architect as Hero and Genius, Architect as Professional, Architect as Businessman, and Architect as Entrepreneur (Saint 1985, p. 1-18, 72-95, 96-115, 138-160). In more recent times, Leon van Schaik (van Schaik 2015, p. 13-24) has identified the different roles of architects by analysing international architectural cases, and he notes how architects have manifested practical poetics for architectural outcomes. His three approaches are termed 'Architect as Master Builder', 'Architect as Weaver', and 'Architect as Idea Generator' (van Schaik 2015, p. 13-24). In addition, the design task can have different functions to fulfil. Consequently, defining the role of the architect depends on the type or phase of the planned outcome. The design can be problem solving, decision making, communicating, and information processing, in addition to an artistic, formative process (Granath 1991, p. 65-66, 71).

One of the tasks of the architect is to make decisions concerning the proposed materials of a building at the design or constructing phase. The aim is to define the right material for the right purpose, noting the durability of the materials and user demands. Relatively often, the architect selects materials at a late stage in the design (Ballard Bell and Rand, 2006, p. 9). Sometimes, architects have the possibility to develop materials or products as part of the research and development task, during the ongoing building process. The process may be led by means of design, whereby the outcome is a designed material or building component; a façade element. An architect can also work as a specialist, such as an in-house designer in a commercial company. In this case, the material is developed for products, and applied for constructing projects later. Then, the objective is to understand the applicability of various aspects concerning materials and products.

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The observation direction for the design projects can vary depending on the task and level. The materials research typically starts from materials heading towards products, but the designer can feed the knowledge in a reverse order, towards the material research phase, resulting in improvements in the technical aspects, aesthetic values, or processing methods of a material (Won and Westland, 2017, p. 450-459). However, the roles, objectives, research facilities, and methods are applied on a case-by-case basis.

2. Role of the Material

An architecture consists of different units, patterns, or details (Alexander 1979, p. 126) and (Zumthor 2006, p. 15), whereby materials form one important part of the entity of a building. Due to this, materials can be understood as the most genuine, honest, and smallest representative of the entity of a building, including the same principles and practices as the building itself. Subsequently, it can be assumed that the same basic principles, which are common and meaningful in architecture, exist on the material level. In other words, the materials in architecture can also be approached from similar viewpoints as the ways in which they are utilised in architecture. In this paper, the aspects to be selected for observation are technology, performance, purpose, language, and meaning.

2.1 Reason-based Aspects

Approaching materials research from the viewpoint of technology and material performances gives an inherently scientific perspective to materials research. In addition, both are relatively commonly emphasised in current materials research. The outcomes of these two aspects are reasonably easy to measure or compare. In architecture, technology can mean methods for constructing buildings, aspects, which are related to information technology, or the whole infrastructure of networks (Braham and Hale, 2007, p. xiii). In addition, technology can be understood nowadays in a gentler fashion, when emerging technologies embed 'social, cultural, or psychological factors' (Braham and Hale, 2007, p. xiv). Performance. in this context of materiality, refers to qualities and possible quantified qualities, which aid, evaluate, and comprehend the material more precisely. Due to the user and utilisation aspects, industrial materials can be seen rather as defined more by performance than material properties (Peters 2011, p. 12).

Buildings consist of parts; each of these has a specific purpose to fulfil to complete the whole (Jeanneret-Gris 2007, p. 43). In architecture, one vital design principle that defines the outcome is purpose. When considering the wider perspective, the purpose of the building has connections within society, where it meets the daily needs of the users of the building, the inhabitants of a house, or the residents of an urban or rural area. In the smaller scale, the purpose of the material can include understanding of the phenomena in which use of the material in question is desirable or appropriate.

2.2 Emotion-based Aspects

In architecture, emotion-based aspects can be described in accordance with the concepts of language or meaning. Both aspects may have connections to personal experiences in the past. Perceptions and senses connect the individual to the surroundings. In architecture, the language of the materials plays a major role in spatial experience. In this regard, materials tend to have their own inherent language, in which human senses can play an important role in the rejoicing of the experience, though industrial processes might extinguish this uniqueness (Pallasmaa 2012, p. 16, 53). The tangible language of a material can be developed by modifying the material or making formal exercises to comprehend the idea of the nature of a specific material.

Meanings are related to humans settling in the environments and supporting existence in living environments, wherein the surrounding has a certain significance to the person or persons (Norberg-Schulz 1975, p. 221). In addition, the meanings in a broader perspective are generated when humans or even cultures qualify themselves (Zaera-Polo 2000, p. 85). Abstract meanings can be transformed into a tangible form in materials, where meanings can be experienced. Meanings can also be studied in materials, for example, the colour of a certain material in the context of household goods (Won 2017, p. 450-459).

3. Scales of Materials and Construction

Prior to defining the role and task of the material in the entity of a building, it may be possible to comprehend some boundary conditions. These are the use of a building and a recognition of the limits of constructing processes. The main structural parts of buildings are constructed on site, utilising on-site methods, or they are procured and prefabricated elsewhere. As such, the manufacturing site and method can vary.

The constructing materials define and enable processes during the construction phase of the building.

The constructing materials define and enable processes during the construction phase of the building. Moreover, the selected processes limit or enable design. In architecture, Design for Manufacturing (DFM) is a method whereby manufacturing defines the limits of products. Conversely, Manufacturing for Design (MFD) means that, in a specific design task, it is important that the boundary recognised and potentially stretched in accordance with the design needs (Gulling, 2018, p. 16). If materials have not been studied properly from the viewpoint of characterisation, the design aspects or manufacturing can become subject to tremendous risks in the product design phase (Ashby and Johnson, 2014, 182). Consequently, the construction phase on a building site may not be the place to test emerging materials or materials applied to products in practice for the first time. When considering DFM and MFD methods from the viewpoint of materials research and development, it is worth noting that materials research is performed on a smaller scale or in smaller batches. The construction of a building requires an enormous amount of materials, while at the research and development phase, the amount of materials can be relatively minor, perhaps just a few grammes of a particular material to perform the appropriate tests. Nevertheless, the scale of research and the demands of a material can vary due to the design or constructing task.

4. Methods and Materials

The research and development processes may be complex, due to many variables. The objective of the framing is to make materials research more comprehensive to researchers and developers. The hypothesis is that the concepts, methods, and practicalities of architecture can be shifted to the level of materials research and development. Subsequently, when the materials research or development has been finished, the outcome of the work is naturally closer to the end-use application. This is because the outcome has been generated from the same mental frame or atmosphere, or with the customs or norms associated with the context in which the architecture originates.

The hypothesis is that the concepts, methods, and practicalities of architecture can be shifted to the level of materials research and development.

A preliminary research question was to understand how current materials research in architecture is structured. Leon van Schaik's review of architectural projects under the category of practical poetics gave an idea of how architectural projects are observed on the grand scale, and how to potentially shift this practical observation frame to some extent in materials research. The next research question was related to understanding how the frames serving materials research could be composed, and what kinds of emphases are inside of the frames. The idea was to maintain the same mental frame as exists in architecture, and yet apply it on a smaller scale. It was clear from the beginning that some frames might already exist; however, the emphasis inside each frame might not be clear. These were recognised as materials research based and motivated by design and scientific materials research. In addition, the last question was related to what to include inside of the developed frames.

In multidisciplinary research, the participants come from different disciplines and share their knowledge for the benefit of a shared objective. The intention is to assist these groups to achieve a uniform result. The processes during the construction period, or the planning and design phase of a building, have been left outside of the scope of this study. Moreover, group dynamics and business-related aspects have not been included. The focus has, instead, been on the early life cycle of the materials research, development, or design. Materials and structure naturally intertwined, but in this paper the focus is limited to observe the materials, and the structures are assisting the idea or supporting the realisation, and yet not observed per se. Material culture in architecture has not been emphasised, because the assumption is that there is an architect present in the process. The assumption is that architects bring tacit knowledge as a form of material culture to the research in their own fields. The reason for the delimitation of the observation scopes for the relatively early phase of the materials cycle is that this phase has not been studied much, there are a lot of issues to resolve, and the theme is topical. The reason for this topicality is the recent urgency to improve materials as part of the drive to adapt more sustainable applications in the construction industry.

In multidisciplinary research, the participants come from different disciplines and share their knowledge for the benefit of a shared objective.

4.1 Five Approaches

In this paper, materials research has been framed with the five approaches, which in turn have been observed from five different viewpoints. Leon van Schaik's classification of different architecture projects has inspired the basis of the first three categories. In his book Practical Poetics in Architecture, van Schaik is looking for a certain language or mental frame, which is present in architecture and the design process (van Schaik 2015, p. 13-24). His methodology is based on conversation, observation, and completing this in writing. In materials research, it would also be desirable to elicit the notion of practical poetics in connecting materials to the material culture in general. The content of this paper has been inspired by van Schaik's framing, but the frames herein are separate and individual adapted. They are also observed in line with five aspects generally present in general in architecture. The material level observation shares the same mental frame and language, which lead the architectural design process to the finalised building, to the extent that the scale of result is tinier and the backgrounds of those involved are variously in research. The material level research is often conducted prior to the architectural design process and existing buildings. Due to this, materials research is preparatory for the larger scale process and realisation.

In the book, van Schaik uses the concept 'reading' when describing how to observe surroundings and material culture. When approaching materials from the viewpoint of architecture, this familiarity is beneficial if included in research and development. In every frame of this paper, the concept of language is present to give a specific role in each of the frames (Figure 1).

The three approaches from van Schaik's frame have inspired materials research under the following banners: *Materials research based on a Master Idea*, *Materials research as Blending Process*, and *Materials research based on Idea Generation*. The role of the architect, who was the actor in van Schaik's practical poetics in architecture, has been shifted to *Materials Research*. In addition to the three approaches applied from van Schaik's work, two conventional approaches are identified from materials research methods in the field of design and science. These two exist in the level of current materials, and have clear drivers that differ from those of the three frames generated in this paper. The frame that has a base in design and looks at the language of the material can be close to material experiences and material studies, which may make it easier for the architect and design students to become familiar with the new material. Studying the language of the material; shaping possibilities, forms, colours, tactile aspects, or the visual potentials of the new or old material. In turn, the last frame which has a base in science, and has a driver in technique and performance, has a similar viewpoint to materials and how materials are studied in science. The emphasis, here, is to clarify the technical data and other valuable and measurable information, to comprehend the material.

4.2 Content of the Five Approaches

Each of the five approaches contain different emphases and main drivers. The five aspects were observed with the help of visual charts (Figure 1). The chart is suggestive of a four-part SWOT analysis wherein questions and answers related to the observed topic are utilised so that more specific information can be generated. Instead of surveying strengths (S), weaknesses (W), opportunities (O), or threats (T), the aim of the chart is to observe aspects present in materials in architecture. The layout of the chart is divided along horizontal and vertical axes. On the left side of the horizontal axis, there are the substantial aspects. These aspects include concrete actions, tangible methods, creative works on a practical level, and measurable or observable data. On the opposite end of the axis, there are the abstract aspects, which can be approached from a conceptual level. These aspects have a background in values, preferences, or inclinations. Consequently, the substantive aspects on the left side of the chart are technology, performance, and language in materials; while on the right, the abstract aspects include purpose and meaning in materials. On the vertical axis, the reason-based aspects are situated at the top, and the emotion-based aspects are at the bottom. The reason-based aspects include technology, performance, and purpose, while the emotion-based aspects include language and meaning.

The reason-based aspects include technology, performance, and purpose, while the emotion-based aspects include language and meaning.

The role of the concepts – reason versus emotion and substantial versus abstract – are to elucidate and clarify the different qualities found in the materials.

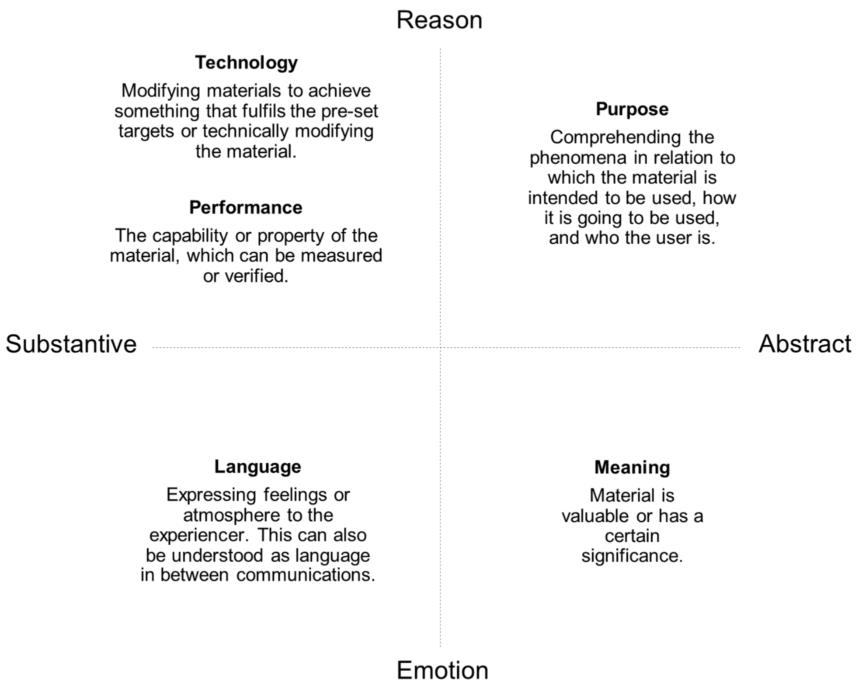


Figure 1. The chart of axis. The substantive and abstract aspects are presented along the horizontal axis, and the reason and emotion aspects along the vertical axis. Definitions of the five aspects (technology, performance, purpose, language, and meaning) have been applied from the Oxford English Dictionary (Oxford University Press 2022) to make descriptions accurate and representational.

5. Results: Frames for Materials Research

5.1 Master Idea – Materials Research as a Continuity of Tradition

In materials research, the process can be understood more as a continuity of materials research or as a development tradition rather than the specific conscious or unconscious action of a 'doer'.

The first of the three approaches that has been applied from Leon van Schaik's practical poetics approach, is "Architect as Master Builder". In this approach, the aim is not to imitate history. Instead, it is to comprehend that architecture is a constantly evolving continuity, carrying the past along with it while also maintaining a focus on the future. The theme of continuity has been discussed in the theory of architecture elsewhere (Giedion 2008, p. 20) and (Pallasmaa 2014, p. 97). In this study, the theme is applied to materials and referred to as Master Idea – Materials Research as a Continuity of Tradition (Figure 2).

In materials research, this approach differs from van Schaik's approach, as architects are not involved in the materials research process at the same level and intensity as in construction projects. In materials research, the process can be understood more as a continuity of materials research or as a development tradition rather than the specific conscious or unconscious action of a 'doer'. In this sense, science builds research upon previous findings, and equates to materials research. Due to this, the continuity of the improved culture of constructing is present in materials, processes, and constructing techniques. The traditions of constructing as well as the past scientific research findings must be regarded as a wide platform, wherein materials research in architecture can arise with the help of different disciplines.

The meaning-driven approach can facilitate research and development when the known material is researched with current methods, tailored methods, or novel applications of past methods. In addition, the material can be studied if the materials are involved in new meanings, values, or significances. Recognising previously presented aspects prior to starting the process may ease the process when establishing new research and comprehending how to set targets. In addition, identification may demystify the driver of the research.

5.1.1 Presence of the Five Aspects

The Master Idea approach is meaning driven. The aim is to focus on the abstract and emotional-related aspects or to begin with the ideas first, followed by the concrete actions later. The material itself might be imbued with certain significances, or the material is valuable in some other way (i.e., What kind of material is meaningful?). On a practical level, this intersection of meaning and continuity of tradition may ease the research and development process due to the presence of something familiar or predictable.

While the Master Idea process is meaning driven, purpose and language are strongly involved in the process, and the research and development process can be guided further. This guidance is based on recognising the material at the intersection of the continuity of a tradition. When the intersection is connected to language, the material can be observed in relation to a temporal perspective. The observation can focus on feelings awakened by the material, on the atmosphere created by the material, or on communicative aspects in the continuum of the living environment (i.e., What kind of language does the material enable?). When purpose is observed at the intersection of the continuity of the tradition, the long history of culture, in which materials are utilised may elicit results (i.e., What kind of material is desired?). From this viewpoint, it is possible to comprehend what the intended use for the material is, how it is going to be used, and who is the user. The objective is to facilitate the identification of the scenarios of end uses and to use the information to ease meaning-driven materials research and development.

5.1.1 Presence of the Five Aspects

With the Master Idea, technology and performance play a supporting role in the background. The content is often measurable or verifiable facts (i.e., What kind of role does technology play and/or what is its significance? What are the characteristics of the material?). These measured or verified facts enable a general understanding of the material and, thereafter, the resulting knowledge can be compared to previous knowledge. Both technology and performance can facilitate realisation and support an understanding of the viability of the material.

Figure 2.

Master Idea - when materials research can be understood as a continuity of tradition. The approach is mostly based on meaning generation (1), where language (2) and purpose (2) assists the idea. The research is focused mostly on abstract and emotional aspects. The numbers mark the emphasis of the aspects.

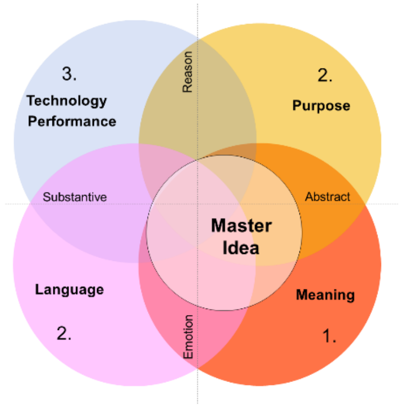
Blending Process where materials research blends equally with technological development. The approach blends many aspects during the research.

Idea Generation - when material research is subordinated to the design idea. The approach is mostly based on understanding purposes (1), where the material can be used. Technology (2), performance (2), and meaning (2) assist the approach. The research is focused mostly on abstract and reason-based aspects.

In Design-oriented materials research, the research is mostly controlled and goal-oriented experiments with materials. The focus is on finding a certain language (1) where technology (2), performances (2), or meaning (2) in materials have an assisting role. The research is focused mostly on the substantive and emotion-based aspects, achieved by concrete actions.

Science-oriented materials research, where the research is mostly based on practices and scientific methods to study materials. The focus is on finding new quantifiable information related to technology (1) or performances (1) of the materials. The language (2) and purpose (2) of the material assists. The research is mostly focused on substantive and reason-based aspects, in practical level this means concrete actions.

Master Idea
When Materials Research is Understood as Continuity of Tradition



Meaning driven, reinforced by purpose, and language

Technology
"**What** kind is the role or significance of technology?"
→ **Support** to make ideas concrete when modifying material

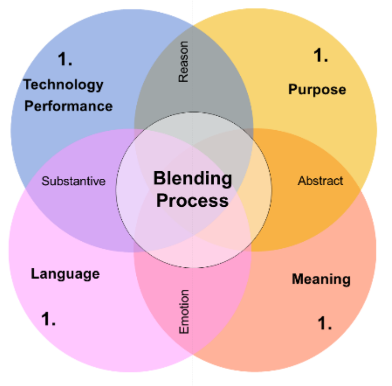
Performance
"**What** kinds of characteristics does the material have?"
→ **Support** to define the capabilities or properties of the material

Purpose
"**What** kind of material is desired?"
→ **Identify** concepts associated with the material

Language
"**What** kind of language does the material enable?"
→ **Identify** the material's potential for expressing feelings, atmospheres, cultural and personal connections, and language as communication

Meaning
"**What** kind of material is meaningful?"
→ **Evaluate** values and significances

Blending Process
When Materials Research Blends Equally with Technological Development



Blending technology, performance, purpose, language, and meaning

Technology
"**How** technology is present?"
→ **Evaluate** the role of technology

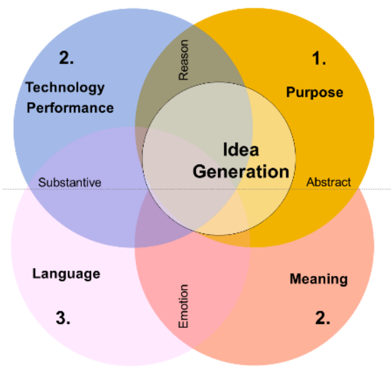
Performance
"**How** can performance be beneficial?"
→ **Evaluate** suitable properties and qualities

Purpose
"**How** do the end uses define the material?"
→ **Evaluate** the qualities that define end-uses

Language
"**How** can a specific language be unveiled?"
→ **Evaluate** the potential of a language

Meaning
"**How** can meanings be enabled in materials?"
→ **Evaluate** the potential meanings

Idea Generation
When Materials Research is Subordinated to a Design Idea



Purpose driven, supported by technology, performance, and meaning

Technology
"**What** kind of technology is desirable to fulfil the idea set for the material?"
→ **Identify** the technical aspects

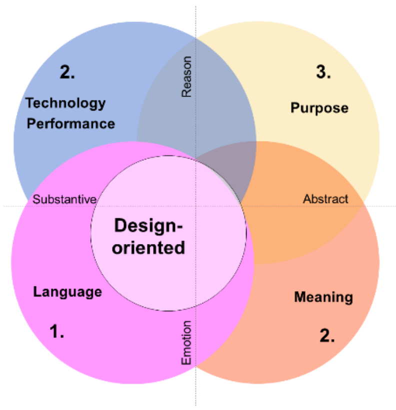
Performance
"**What** kinds of qualities or specifications are needed to fulfil the idea set for the material?"
→ **Identify** material qualities and properties

Purpose
"**What** kind of idea is set for the material?"
→ **Evaluate** the contexts in which use of the material is suitable, how it is going to be used, and who the user will be

Language
"**What** kind of language will develop when fulfilling the design idea (feelings, cultures, communication)?"
→ **Support** for the process to find the right language by exploration

Meaning
"**What** kinds of meanings does the material raise to fulfil the design idea?"
→ **Identify** personal or cultural meanings or best practises

Design-oriented
When Materials Research is Based on Explorative Design



Language driven, supported by technology, performance, and meaning

Technology
"**How** can technology facilitate design of the material?"
→ **Identify** the technological possibilities

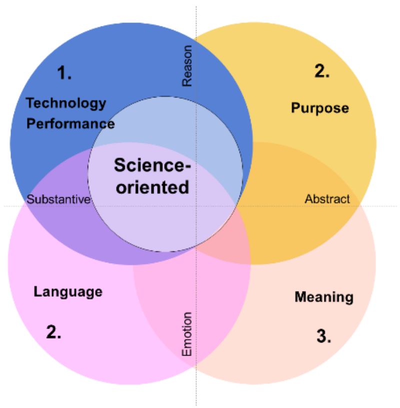
Performance
"**How** can performance facilitate the design of the material?"
→ **Identify** performance-related possibilities

Purpose
"**How** can the purpose facilitate the design of the material?"
→ **Support** to understand end-use of the material

Language
"**How** can language facilitate the design of the material?"
→ **Evaluate** the possibilities of language

Meaning
"**How** can meaning facilitate the design of the material?"
→ **Identify** the possibilities of meanings

Science-oriented
When Materials Research Gets Inspiration from Science



Technology, performance supported by purpose, and language

Technology "**How** can the technology-related aspects be developed?"	→ **Evaluate** the technological aspects
Performance "**How** can the performance-related aspects be developed?"	→ **Evaluate** the performance-related aspects
Purpose "**How** can the purpose-related aspects be developed?"	→ **Identify** the potential of purpose
Language "**How** can language-related aspects be developed?"	→ **Identify** the potential of language
Meaning "**How** can meaning-related aspects be developed?"	→ **Support** meaning generation in materials

5.1.2 Practical Application

In the case of materials research, meanings emerge in materials from significance in the frame of cultures when modifying, handling, or utilising the material. In addition, the material might have an inherent value depending on the culture or territory. In the case of cellulose, for example, cultural values can mean the history of inventing and developing papyrus or paper production into more refined cellulosic materials and finally into products utilised in architecture. This underlines the continuity of the tradition in general within the cultural context. In addition, other traditions exist when making material for communication purposes, such as papyrus manufacturing in ancient Egypt (Kurlansky 2017, p. 11) and (Kula, et al., 2014, p. 26). This has a close connection to the preparation of recently invented nanopaper (cellulose nanofibril films). Each of these – papyrus, paper, and nanopaper –utilise plant-based fibres, and the outcomes can be wrapped on rolls. The most recent of these inventions utilises plant fibres processed to a nanoscale to manufacture a thin film. Nanoscale cellulose is cast on a horizontal surface and later wrapped on rolls or cut sheets. Currently, the commercial utilisation of nanopaper in architecture is non-existent, even though paper products have been already been used in the construction industry. One such concept is the recycling of wastepaper, which fits the frame of the Master Idea. The reason for this lies in the values of the sustainability aspect, which are based on the responsible values surrounding the handling of materials. Newspapers or other cellulose-containing waste materials, such as cardboards, can be recycled if facilities for reuse are organised. After waste collection and material processing, new applications can be produced for commercial use. One implementation of this is cellulose-based insulation materials. Recycled cellulose can be utilised in bio-composites, boards for sound, or thermal insulation purposes, or it can even be pressed into a paper-mâché-like material for furniture (Peters 2011, p. 89).

5.2 Blending Process – Materials Research Blends Equally with Technological Development

The second approach, "Architect as Weaver" from Leon van Schaik's definition, proposes that architecture joins together equally technology and design (van Schaik 2015, p. 13-24). This process is experimental in nature, embracing and weaving together themes, such as materials and mathematical thinking. This second approach applied in materials research is described as a Blending Process – Materials Research Blends Equally with Technological Development (Figure 2).

When the Blending Process approach twists together material and technology, neither of these leads the process independently, while maintaining close contact and providing feedback to each other.

The experimental method of twisting materials and technology together can be applied without difficulty to materials research. The combination is nothing new in materials research; however, what creates the difference is that the frame is approached purely from the viewpoint of architecture. When the Blending Process approach twists together material and technology, neither of these leads the process independently, while maintaining close contact and providing feedback to each other. The approach can be implemented on a practical level by making iterative material experiments but also via formal exercises. As is the case in van Schaik's approach and in materials research, this approach also combines mathematical thinking. Materials have an internal exigency to appear in a three-dimensional form, one that can be presented by the width, depth, and height of the matter. In addition, materials can be viewed by zooming in to a smaller scale, where the laws of chemistry, physics, or biology define the material. These laws define how the materials appear, form, are structured, or interact with the environment. Because of these natural laws, the zoomed knowledge can be utilised on a necessary scale and where the materials are intertwined with technology. Nature can serve as an inspiration to utilise the laws of chemistry, physics, or biology for the benefit of the materials research.

In the field of architecture, the above approach could be used to study the possibilities of nature and utilise nature as an innovation tool when designers develop structures and later forms for architecture (Oxman 2010, p. 81, 83). In nature, materials are used efficiently, and the methods are effective on many levels. In addition, the results are pleasing to the eye (Dohmen and Zieta, 2012, p. 38). The materials in nature are formed in a way in which the density may vary to achieve better strength.

5.2.1 Presence of the Five Aspects

The Blending Process approach mixes together all five sub-aspects. The reason-based aspects (technology, performance, and purpose) blend equally with the emotion-based aspects (language and meaning). All aspects support and provide feedback to each other. In the approach, it may seem that technology would have the leading position. However, the Blending Process would then be technology driven. The frame, which is led by technology and performance, is referred to as the Science-oriented approach, and is explained in section 4.5 Science-oriented –When Materials Research Gets Inspiration from Science. Whilst in the Blending Process, all five aspects can facilitate research equally. The role of technology, here, can be evaluated when observing the manufacturing possibilities (i.e., How is technology present?). Performance assists to comprehend the usefulness of the material (i.e., How can performance be beneficial?). Moreover, purpose eases the identification of valuable end-use solutions (i.e., How do the end uses define the material?) whilst language generates the uniqueness of the material (i.e., How can a certain language be unveiled?), and meaning facilitates an understanding of the values and significances embedded in the material (i.e., How is it possible to enable meanings in materials?).

5.2.2 Practical Application

On a practical level, when combining technology with materials, it is meaningful to achieve the right balance. If a technology is combined with a certain material, assisted by material performances, as well as the proposed purpose of the material, the outcome might not yet seem to be successful. The reason might be that either of the emotional-related aspects (language or meaning) have remained in the background. Due to this, the outcomes might not look familiar, as it may be missing connections to culture or aspects related to human daily life. The implementation of intertwining materials research with technology can be seen in the emerging enthusiasm for 3D printing. On a large scale, the look of 3D prints in the field of architecture might be unfavourable, if there is only an interest in improving printing techniques or printers. After the development continues, it may be possible to achieve well-structured production technology, revealed material properties, defined purposes, and a well-studied language of the printing technique. Nevertheless, the application areas may be hazy when the wider meaning of the material combined with this specific technology is unveiled. Even with great shapes, appropriate materials, or applicable technologies, it might not be sufficiently convincing to use the technology. While new materials or technologies are developed intensively, the final acceptance will likely occur later on at the cultural level. In this phase, the connections to the users or a comprehension of the environment in which the prints are aimed and where the culture is present, can ease the acceptance of novel technology or methods. Thus, while it may seem that the Blending Process is future oriented, there is still a need to fill the gap to the past to find the right meaning in the continuum and to identify the reasons why a material with a certain technology is accepted in our culture. For instance, cellulose can be treated similarly to any other material in architecture when the approach is to blend a material with technology from the viewpoint of architecture.

5.3 Idea Generation – Materials Research Subordinates to the Design Idea

The third approach from Leon van Schaik's compiling of practical poetics in architecture is "Architect as Idea Generator". In this approach, the idea of design is superordinate to the building types or tectonics. This approach, like the Blending Process, inherently involves multidisciplinarity. As van Schaik notes, "it is characterised by a willingness to cross boundaries, to draw analogies from other fields, importing mental frames and "blending" them into poetics that are not entailed to either of the other histories" (van Schaik, 2015, p. 13-24). In materials research, the third approach is Idea Generation –Materials Research Subordinates to a Design Idea (Figure 2).

This Idea Generating approach is applied to materials research when the design idea is superordinate to the material research and development. This may occur in cases in which the development concerns the structures, technical issues, or outlook of the material. Due to this, it is important to understand the scope or field of the end product to which a material is aimed, recognising the situations in which materials are utilised, who the user is, and how materials are used.

The Idea Generation approach is applied to materials research when the design idea is superordinate to the material research and development.

In this process, the idea for the material has been generated in the first round when observed with the five aspects. After that, the idea shifts to the research and development phase. Nevertheless, in the purpose-driven Idea Generation, the scope of the research task might still be hazy. On a practical level, this means that the idea for the material must resolve some problems, that will benefit the end product of the research. The research scope can be easily revealed after the idea has been developed further in the research and development phase and re-observed utilising the five aspects presented at the theoretical foundation and in the proposed end product. This double observation clarifies the idea for the material for the researchers.

5.3.1 Presence of the Five Aspects

In this frame, the emphasis is mostly focused on the abstract and reason-related aspects. The main driver in the Idea Generation is the purpose. This means that the material has to fulfil certain demands related to the end use of the material (i.e., What is the idea for the material?). As already mentioned, the ideas for the material are generated first, and then the demands of technology, performance, and meaning are recognised. The language of the material has a supporting role and is in the background. When technology is observed at the intersection of the idea for the material, the focus is on how to modify materials (i.e., What kind of technology is desirable to fulfil the idea for the material?). When the material is observed from the viewpoint of performance, the aim is to map and collect vital material properties. At the intersection of the idea and performances, the suitable material properties can be considered to set the primary targets for development (i.e., What kind of qualities or specifications are needed to fulfil the idea for the material?). The meaning-related aspects can also facilitate a more comprehensive understanding of the idea for the material. Those aspects are the values and significance involved in the idea set for the material (i.e., What kind of meanings does the material raise to fulfil the design idea?).

The supporting role of the language ensures that the material is suitable for use and assists in achieving a tangible form for the materials (i.e., What kind of language will develop when fulfilling the design idea?), but the appearance is not developed per se. The language of the material may be related to feelings and embedded cultural aspects in the communication with the help of the material. The appearance of the material might not have a significant role or relation to the idea for the material. Similarly, it will not have a significant role in the research and developing process of the material. This is due to the fact that the material does not have a direct communicative role to be developed nor does it have an important role in generating atmospheres.

Later, when research and development is guided again with the previously mentioned questions, the second-round questions can be more accurate (i.e., What type of technology is in question? What are the material performances like? What is the purpose of the material?). As is the case in the reason-based aspects, the second round of questions are more accurate when there is an aim to develop the material and not the idea anymore (i.e., What kind of language is there? What kinds of meanings are there?).

5.3.2 Practical Application

Practical applications, when ideas are superordinated to materials research and development, are led by the purpose of the material. An example of this could be materials aimed at fulfilling sustainable-related aspects (Dohmen and Zieta, 2012, p. 38), which would have been emphasised when the materials are subordinated to the design idea (Edelholt 2012, p. 155-165). In addition, the case in which the idea for the material is leading the research and development may be such as responsive material for architectural use (Christiansen 2008, p. 87). One example of this approach could be the development work of an interdisciplinary group, whereby retroreflective concrete surfaces were developed to cope with surroundings in dark circumstances (Peters 2011, p. 12). In addition, the development of a relatively fragile, Mica-based natural-insulating laminate can be seen as a practical application of the process. In this case, there was a desire to further develop the original commercial material, which had been noticed during the development to be covered with Kraft paper and phenolic resin, in order to achieve a new product type, Formica, with better strength (Hirshinger 2006, p. 22-23). The case of Formica is a clear example of re-development of a material in which the purpose of the material led the process forward (i.e., the demand for greater durability when the material is used). The support of technology, performance, and meaning helped achieve the goal, which was specified by the purpose of the material. In cellulosic materials, the idea generated by the third approach may include replacing non-environmentally friendly materials with cellulosic materials. In addition, the Idea Generation approach could frame materials research, for example, so that cellulosic nanomaterials are developed to replace plastics. In this case, the idea for the material is supported by the novel processing technology, the superior material performances, such as improved tensile strength, or the comprehension of nanocellulose as a supermaterial from the point of meaning generation.

5.4 Design-oriented – When Materials Research is based on Explorative Design

The fourth approach, the Design-oriented Frame, enables the generation of new language for the material with the help of material experiments (Figure 2). Design-oriented research might not have direct practical or useful daily life implications, and the language of the materials is sought through iterations. In this case, the approach serves a platform to become familiar with the material. Within this research work, the nature of the materials can be studied by examining the colours, shapes, appearances, and so forth as patterns. This approach is valuable, especially when the materials need to be studied in a new way or when there is limited information or applications on which to base future research. This frame has a base that is close to material tinkering and exploring with materials and has, on a smaller scale, a strong background in materials design.

5.4.1 Presence of the Five Aspects

The fourth frame is mostly focused on the substantive and emotion-related aspects, and the driver is language. Due to this, research and development can focus deliberately on the outlook of the material (i.e., How can language facilitate the design of the material?). The designed language of the material can facilitate research on how the material affects the feelings of the experiencer, how the material may generate a special spatial atmosphere, or how the material can be harnessed for communicative purposes.

The fourth approach, the Design-oriented Frame, enables the generation of new language for the material with the help of material experiments.

In this approach, the technology, performance, and meaning assist the frame. The technology facilitates the approach by identifying methods for modifying the material (i.e., How can the technology facilitate the design of the material?). In addition, technology can be present by enabling the shapes, colours, or preliminary structures of the material. The material properties provide boundaries for creative materials research. Conversely, the boundaries can be explored by means of design, if the material is not well known. The role of performance enables an understanding of the material on a practical level (i.e., How can performance facilitate the design of the material?). When working with the material by means of design, the significance of the material may be consciously or unexpectedly noted. The meaning of the material facilitates the process in an abstract manner, indicating a basis for assessing how valuable the material is, or what kinds of significances are involved (i.e., How can meaning facilitate the design of the material?).

The purpose in this fourth approach has a supportive role in the background. The focus is not on developing realistic applications for industry with the help of this approach in the first place. However, the frame might be useful when studying future potentials or becoming familiar with the material, which may later lead to a commercial product (i.e., How can the purpose facilitate the design of the material?). The research and development work can be based on a later phase of a different frame presented in this paper.

5.4.2 Practical Application

This approach enables researchers to study the specific, unique nature of the material and to search for the limits of the design-related aspects. On the level of practice, materials can be studied by exploring the colours, structures, or shapes of the material. When technology, performance, and meaning are combined with the main driver, language, the limiting aspects or boundaries of the materials can be explored without direct targets bound to the applications and realistic uses of the material. Due to this, the method could be seen as valuable when new research is established as part of studying an unfamiliar material. Alternatively, the frame could also be applied to, for instance, an already known material to obtain fresh intuitive suggestions for new material applications or research developments.

5.5 Science-oriented – When Materials Research Gets Inspiration from Science

The focus of this fifth approach is to improve and develop the material with the help of technology (Figure 2). Materials can be improved by enhancing their performance or material capabilities. When studying materials from the viewpoint of science, knowledge can be gained as a basis for further research and development. This assists in defining suitable end uses and applications in a later phase, or new research can be started, steered, and potentially framed using another approach presented in this paper. The fifth approach is closer to already existing practices for how to perform materials research in the fields of material science.

5.5.1 Presence of Five Aspects

The fifth frame is mostly focused on the substantive and reason-related aspects. In the Science-oriented approach, while technology and performance are the drivers, purpose and language are also involved in the process. The two main drivers support each other when the focus is either to improve manufacturing capabilities or enhance materials properties (i.e., How can the technology-related aspects be developed? How can the performance-related aspects be developed?).

The fifth approach is closer to already existing practices for how to perform materials research in the fields of material science.

The purpose facilitates the research and development when there is a demand to identify the preliminary targets for the research and development (i.e., How can the purpose-related aspects be developed?). This means that a specific potential use of the material may aid in the comprehension of the research objectives and assist in how aspects related to technology (e.g., manufacturing) or performance (e.g., a certain material capability) can lead the process. Moreover, language generation may complete the process. The role of language is not only to become familiar with the material but also to point out the creative potentials that pure science alone may not reveal (i.e., How can language-related aspects be developed?). The meaning supports the process in the background (i.e., How can meaning-related aspects be developed?). This may mean that during the research and development process, value-laden aspects or significance are not focused during the initial exploration.

5.5.2 Practical Application

Measured and evaluated information have an important role in architecture when materials are defined for use. Technology or performance-related aspects might be motivations to establish new research in the engineering or chemistry fields. In materials research and development, when the focus is on aspects associated with technology and performance, materials research can be understood as following a rather linear action of testing, improving, or modifying materials. The information may be involved in the durability or strength of the material when evaluating the best option. Due to this, the approach suits researching and developing materials that are either close to the end use, almost finished products, or materials about which limited information has been gathered.

5.6 Diverse Research Processes

All five approaches mentioned herein differ from each other. The main difference in the approaches relates to the diverse drivers. The frames have the same base as the five aspects, but the emphasis varies. In addition, there is a difference in how the processes are taken forward (Figure 3). The Master Idea, Design, and Science-oriented approaches have the simplest process, whereby the five aspects are evaluated once and the information is fed into the research and development process. The Idea Generation approach has the same basis as the previously mentioned approaches, but it differs in that the idea for the material is observed during two rounds. The Blending Process approach has the most diverse process. In that process, all five aspects have the same emphasis to facilitate materials research and development.

The frames have the same base as the five aspects, but the emphasis varies.

5.6.1 Master Idea

In the Master Idea approach, the knowledge serving the materials research and development is generated, condensed, and disclosed prior to the research phase. In other words, knowledge generation is a prerequisite for the realised research and development work. This is similar to architecture, when an architect collects information regarding a building site, user needs, or building permit requirements before starting a design task. In materials research, this knowledge gathering phase can be seen to generate a strong connection to the past methods, innovations, projects, or the means with the help of the different emphases of the five aspects.

5.6.2 Blending Process

In the Blending Process approach, knowledge is mixed together and processed during the research and development phase. The method for observing the material is close to the learning-by-doing method, wherein the process provides feedback and teaches the 'doer'. This method is common in crafts, where the knowledge is generated while working with the materials. In this process, the knowledge is tacit or sometimes explicit knowledge. Due to this, it is valuable in the research process to recognise a researcher's expertise and capabilities, due to the nature of the learning process as a research method. The Idea Generating approach is a method that is common in cases in which a preliminary study is executed first with the aim of gathering information for an upcoming research or study task. In architecture, this could be similar to a historical building report or a preliminary study of a novel research topic to evaluate the feasibility of the future design or research phase.

5.6.3 Idea Generation

In the Idea Generation approach, the preliminary idea for the research aims must first be clarified, and then the idea for the material can be formulated more specifically by analysing it with the help of the five aspects. After this, the research phase can start. The resulting knowledge is transferred to the researched and developed material. After this phase, the idea will be re-observed with the five aspects, through more detailed questions.

5.6.4 Design-oriented

The Design-oriented approach is close to the design-driven method in materials research, with the difference being that the frame is in architecture. The Design-driven approach has been successfully used in materials research in the field of design, where materials are aimed at smaller scale applications. When considered from the viewpoint of architecture, the aim of the Design-oriented approach is not to develop durable, technically perfect materials for production and use, but the approach is more likely to find new openings for future materials research. The practical materials studies have been reflected in this paper in Chapter 5.7.1. Relation to Early Cellulosic Material Research Cases, in which materials have been loosely approached by means of the Design-oriented approach. However, the classification did not yet exist then.

5.6.5 Science-oriented

The Science-oriented approach is close to the means and manners for how materials research is performed in the engineering sciences. In this respect, repetition, validation, and comparison are the ways of executing the research. The difference, here, is that the research is performed from the viewpoint of architecture. The practices, habits, and culture of constructing from the viewpoint of architecture guides the research and development, even when the emphasis is on technology and performance.

5.7 Utilisation of the Tool – Two Examples

If the potential research approach is not clear for the researchers, the process starts by selecting the main driver for the research. The main diver can be any of the five aspects (technology, performance, purpose, language, or meaning). Next, the approach where the aspects is the main driver is selected. Studying the five aspects in the approach gives a more coherent understanding of the intended research task. The questions presented as examples in this paper may assist in guiding the process and sharpening the objectives. After this, research questions can be formulated and knowledge applied in practice with help of the specific frame.

The framing can be applied in practice if the research task has been started, but there is also a demand to steer the process in a new direction or sharpen the focus of the research. The first task is to define the current frame and evaluate if the frame is appropriate or needs to be replaced. When the selection is done, the new or replaced approach must be studied. With help of the generated questions presented in this paper or with help of the emphases and definition of the five aspects, the ongoing research may be observed and evaluated. After evaluation, the research project can be steered by applying the generated knowledge to the ongoing research task.

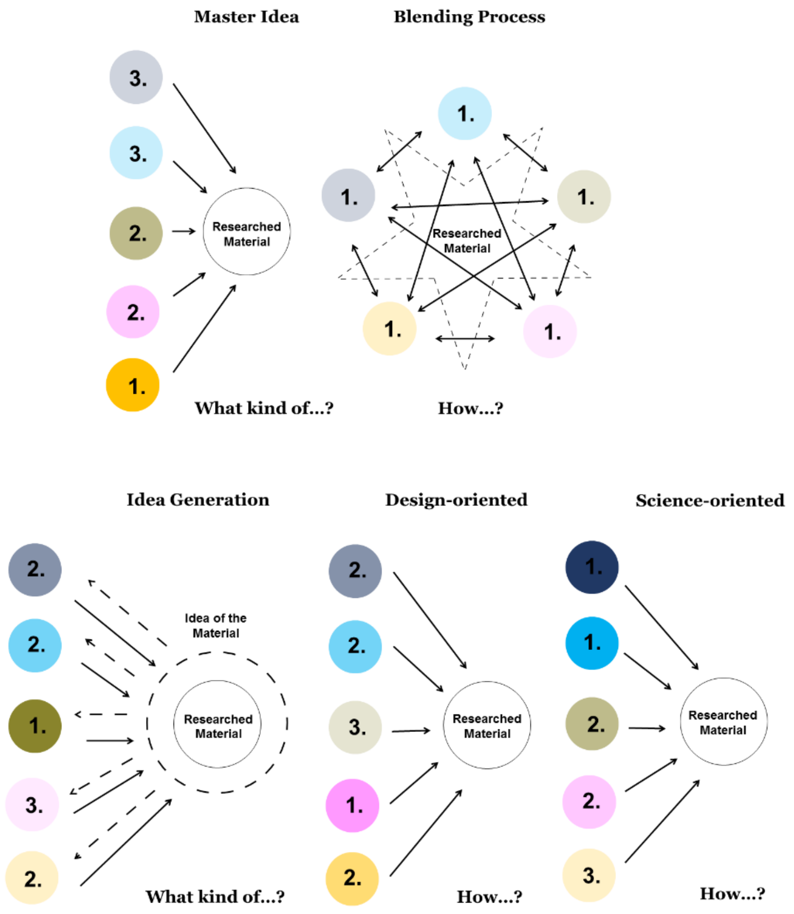


Figure 3. Suggested research processes of the five different approaches. The sizes of the arrows indicate the emphasis of the five aspects or directions of the knowledge generation in serving materials research and development. The numbers mark the emphasis of the aspects.

5.7.1 Practical Example: Relation to Early Cellulosic Material Research Cases

To test the framing in practise, the aim was to apply the framing in early phase material research. The seven material research cases, in which the base material is cellulose or nanocellulose, have been tested to fit the suggested frames (Figure 4.). The research group, which concentrated on cellulosic materials, was Design Driven Value Chains in the World of Cellulose DWoC 2.0. As the method of the DWoC 2.0 research group was design driven, this method influenced how the early phase material research cases were studied. The design-driven method of the research group is closest to the Design-oriented approach presented in this paper. This is due to the fact that the role of the early phase materials research was scouting new openings and application areas, and it is a natural way to study material from the viewpoint of a creative industry via the methods involved in language generation.

Figure 4.

Top left:
Foamed Material
Research team: H. Turunen Aalto University, J. Lehmonen VTT

Natural Dyes
Research team: H. Turunen Aalto University

Cellulose Nanofibril Films
Research team: H. Turunen Aalto University, T. Kaljunen, V. Kunnari VTT

Lower left:
Casted Wood
Research team: H. Turunen Aalto University

Nanocellulose Textiles
Research team: H. Turunen, Aalto University

Laminated Material
Research team: H. Turunen Aalto University, A. Harlin, T. Kaljunen, J. Kunnari, J. Pere VTT

Nanocellulose as a Coating
Research team: H. Turunen Aalto University, J. Kunnari, J. Pere VTT

Photos: Eeva Suorlahti

The material research cases were early phase draft materials, not aimed at developing products yet. The cases were as follows: Casted Wood, Cellulose Nanofibril Films, Nanocellulose as a Coating, Natural Dyes, Nanocellulose Textiles, Laminated Material, and Foamed Material. As a result, all of the cases fit into the Master Idea and Design-oriented frames while the other cases fit most of the frames. The greater part of the material cases would fit more than one frame. All of the material research cases can be placed in the Master Idea frame. The reason is that it is possible to point out a continuity in the past in which the case originates. The continuity can be pointed out in different disciplines in architecture, chemistry, or product development related to cellulosic materials. For instance, Casted Wood can be seen as a continuity of either casting or loosely as engineered wood products. In the case of the Cellulose Nanofibril Films, the films can be also called nanopaper. In paper production, there exists a long history of paper making. Moreover, Nanocellulose as a Coating can be situated within the history of paints for protective or decorative purposes and natural dyes were the predecessors to artificial dyes, which have obviously been the basis for the Natural Dyes case. Textiles have been utilised as coverings, laminated material is close to plywood or other laminated materials, and foams are related to insulation materials.

The Blending Process, the second approach, in which material and technology are equally blended together fits most of the cellulosic cases. This approach can emerge especially in Cellulose Nanofibril Films. When producing nanofibril films, the technology is a vital part of the process for achieving a smooth, thin, translucent sheet. In addition to films, Casted Wood can be regarded as a case in which technology plays an equal and important aspect to shape the material. The reason is that the casting technique creates its own unique trait, it is not a conventional method to shape wooden materials. The casting technique is also applied to Nanocellulose Textiles, which gives a thin shape to the material combination. The cases that gain the benefit from the second frame are Natural Dyes, Foamed Material, Laminated Material, and Nanocellulose as a Coating. In architectural applications, dyes produced from nature are very common in restoration projects. In this case, the materials are dipped in boiling water with colorants from nature, or through-dyed by mixing colorants in the material to colour directly. This case would fit the second approach in consideration of the fact that the method would have been applied in a new way. In the case of foams and laminates, the foams in the form of insulation or sheet laminating in the form of plywood are relatively common methods used in products in architecture. The technique shapes the materials, but it does not play a major role if the design aspect is added. In coatings, brushing and spraying are common methods when applying the paint. Due to these facts, the Blending Process approach needs a new emerging technology, an old technology applied in a new way for a specific material, or a very strong design emphasis for intensive material development, which extensively utilises the technology.

The third approach, in which the materials research is based on Idea Generation already presumes more defined frames in which the materials can be utilised. On the level of practice, materials research needs to be subordinate to idea generation. In this approach, the existing knowledge of material properties, clear target areas, or other important knowledge, such as production methods, should have been available on some level before starting the materials research phase. In the cellulosic cases presented in this paper, some material properties of the nanocellulose were researched, though there might be a need for considerable information, which would be more meaningful from the viewpoint of architecture. Some cases can be applied directly to the Idea Generation approach, especially where the material properties or production is the clearest. The current information related to the cases exists in Cellulose Nanofibril Films, Nanocellulose as a Coating Laminated Material, Foamed Material, and Natural Dyes. In Idea Generation, after data collection and knowledge generation, there would be firm ground on which to base ideas of all kinds pertaining to cellulosic materials when technology, material properties, and meanings in materials support the idea approached from the purpose of the material.

The Design-oriented approach can be described as aiming to find a new or inherent language for an old material in a new context, a new material in an old context, a new material in a new context, or an old material in an old context. In all of the materials research cases, language was researched by means of design, which was due to the design-driven method in the DWoC 2.0 project. Due to this, all the cases fit in this category, and the estimations are based on draft materials, whereby new emerging languages are studied to facilitate future research.

The fifth, the Science-oriented approach has close connections to the methods utilised in materials science. In this approach, the knowledge is gathered by comprehending materials by means of science. Only some of the cases can be placed in this category. The reason is that the focus in the DWoC 2.0 research group was not on testing materials with scientific methods due to a design-driven approach. However, in the research group, the bending stiffness of the Foamed Material and the bending strength of the Laminated Material were measured. The information was required to map qualities for the future use of the materials and to generate knowledge for comparing researched materials to the existing materials.

6. Discussion

Mixing different disciplines, such as architecture, materials science, engineering sciences, and chemical science, with different methods, skills, and thinking might need differently classified frames, which are common to either of those disciplines.

Mixing different disciplines, such as architecture, materials science, engineering sciences, and chemical science, with different methods, skills, and thinking might need differently classified frames, which are common to either of those disciplines. Such approaches have been assumed to not have been developed in architecture, which would set frames or limitative aspects in which multidisciplinary materials research could operate in a scientific context. However, in scientific experimentation, the blending of material with technology is common. The culture of multidisciplinary research in architecture, which would take into account multifaceted viewpoints, occurs on the level of the practical applications of constructing, but it is not a common method when architecture is combined with research or development.

As architecture is extremely practical, the suggested approaches presented in this paper need validation and testing in practice. Future studies might indicate that the three suggested approaches and two conventional approaches might not be enough. In addition to the five approaches, it might be valuable to develop a sixth or seventh approach. During the research, it was not known how the focus remains inside the predefined frames. As previously mentioned, the Blending Process in the case of 3D printing might need to fill a gap in the past. This might mean that, at least in this case, the Blending Process has something in common with the means of the Master Idea approach, when the emerging technology is trying to become rooted in practice. Due to this, there might be a need to widen or even merge the approaches depending on the research cases.

In this study, the five approaches have been tested by observing cellulosic material cases afterwards with the generated approach to gain a practical understanding of the approaches. The intention of generating the approaches was not just to serve cellulosic materials development nor early phase materials research but to generate frames that are applicable for the other materials researched in the context of architecture. The framing produces unique results, even though the research materials are relatively similar, and the approaches are different or vice versa. The reason is that the outcomes are varied in terms of a range of different factors. Those factors in the different approaches can be a research emphasis depending on the researchers' backgrounds, the researched materials, the target readiness level, research facilities, research cultures, or other important aspects that can define or shape the research process. Due to this, the approaches are not too limiting with regards to the duties inside of each approach. In addition, the classification is inductive and interpretative, allowing for the generation of new knowledge. However, one question remains open: could this kind of approach, which arises from a certain discipline – in this case, architecture – have the potential to be applied to or facilitate research in the other fields, which has some connection to creative industries or practitioners? In this paper, the approaches have been set after the cellulosic material cases have been done, but in future it might be valuable to take note of research related to emerging research in materials, novel technologies, or different industries related to architectural product fields.

7. Conclusion

This study presented three new approaches and two conventional approaches for framing multidisciplinary materials research for architecture. The three suggested new approaches are based on Leon van Schaik's division of practical poetics in architecture. The two conventional approaches have a basis in design or in science. Moreover, the objective of the study has been to structuralise materials research in the starting points, which are familiar in architecture, or when there is a need to create order in materials research and development. In addition, the emphasis was to aid researchers when the process, methods, or targets are opaque. The three new approaches are Master Idea, Blending Process, and Idea Generation. The Master Idea can be seen as a continuity of the architectural tradition; Blending Process blends material with technology in the context of research. Furthermore, Idea Generation is based on aspects arising mostly from the inherent or designed aspect in the material, which guides the research further. The two conventional approaches are Design-oriented and Science-oriented. Inside these five approaches, materials research and development may be observed with five concepts common in architecture. These aspects include technology, performance, purpose, language, and meaning. These five aspects sharpen the framing and make it easier to identify the valuable aspects inside of the approaches. The five approaches have been tentatively tested with the case materials made during Design Driven Value Chains in the World of Cellulose DWoC 2.0 research group. As a conclusion, all the materials research cases presented in this study can be observed to some extent in almost any of the approaches. The five approaches could be utilised to frame materials research and development and make the process more coherent. Applying the frames in practice might be useful when establishing new research, framing upcoming research, or steering materials research forward.

The five approaches could be utilised to frame materials research and development and make the process more coherent.

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