

Research Dialogue between Materials and Products in Architecture

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The materials life cycle consists of several phases. If application areas are targeted for architecture, comprehending the demands of the end-use phase might not be clear at the research and development phase, leading to an entity appearing fragmented. The aim of this study is to help bring order to the material research or development phases. The objective is to generate a review tool, which helps to observe different areas where architecture operates, and contemplate simultaneously the aspects during the different phases of the material development. The review tool of the material life cycle consists of tracking the raw materials until the re-used raw material, resulting in eight different stages of the material life cycle. In addition, each of the eight stages of the material life cycle is possible to observe with the five different viewpoints, which are present in architecture. These eight material life cycle stages and five aspects have been formulated as a chart. The chart consists of 40 different approaches facilitating discussion between different operators during the different phases of the material development. The chart might help set goals, frame areas, and improve comprehension of the research and development processes of the materials, especially when interdisciplinarity is involved in the research process.

Keywords: architecture, interdisciplinarity, materials development, materials life cycle, materials research.

In architecture, construction materials have certain characteristics and aspects to fulfil depending on where and how they are applied. Traditionally, practitioners have obtained an intrinsic understanding of the materials by gathering knowledge when interacting with the materials on a practical level. Professionals, who are specialised in understanding the role of materials or methods in constructing, such as construction workers, craftspeople, builders, and architects, must understand the relatively simple processes involved therein. Due to this basic understanding, the communication between professionals is effortless because the targets are easy to discuss; the concepts are clear; and the materials or processes are well known. Though, when new technologies or materials are intended to be applied in the construction industry, special expertise is required (Giesekam et. al 2016).

In architecture, materials are not just thought to constitute the protective shells, carry loads, or divide spaces. The material palette utilised in architecture is in general extremely versatile. Different materials must play well together leading to a meaningful and pleasant spatial experience, noting the function of the building, demands of the user, cultural aspects of the context, and overall cost of the constructing. Without a holistic perspective, the outcomes might be very practical or technically competent, but they may not necessarily be easy to implement in a living environment, where various aspects are meaningful.

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Abstract

Introduction



Due to the new demands of sustainability, which can be an enabler of cross-disciplinary co-operation, to improve the material palette for architecture, new methods for co-work may be a requirement. Currently, the materials variety is much wider (Ballard Bell and Rand 2014), and there is the possibility to design materials with the help of technology (Ballard Bell and Rand 2006). As such, it may be wise to recognise those areas with the greatest potential for cross-disciplinary development. In architecture, the development of commercial products might involve many steps, and along the journey of the material, professionals involved in the design or construction phase might not have had a role in that process nor had an opportunity to influence the material characteristics in relation to the intended end use.

In architecture, traditional methods and best practices exist, which may be considered, when developing new products for the market. In general, the designed outcomes are customised, but there is demand, due to large production units, for including repetition in the designs (Gulling 2018). When processes become complicated, the knowledge and skills involved turn out to be fragmented due to specialisation (Hirshinger et. al 2006). This fragmentation may be an undesirable trait in cross-disciplinary material research and development. In fragmented specialisations, the processes are led by experts from different disciplines focused on specific phases, methods, or processes, and they are not necessarily concerned with the designed outcome or entity. Due to this, the fragmented knowledge at the level of materials is fused to one selected best outcome with a hierarchical evaluation by several experts during the process. As such, a wide comprehension of the entire material life cycle might be helpful to comprehend. In addition to this, it might be beneficial to understand the mindset of a person – an architect – who can influence the material selection in a building or living environment and can be educated to focus on the use-phase of the building. By combining these two aspects of the life cycle and where the architecture exists, the process and the outcome can be approached more holistically to facilitate materials research and development.

Consequently, the main objective of this study is to facilitate co-operation in architecturally related materials research and development. When objectives and research tasks were examined empirically from an architectural point of view, a large gap was found between the preliminary research and the commercial products. This may be due to different emphases, objectives and practices of research and development activities as well as different stages of the process. After noticing the gap, the intention arose to approach the research and development tasks with valued aspects in the final products, and to reflect the knowledge to the different stages of the material research and development process. The results of research and development tasks, if they are intended to support product development, must take into account the stage of use and the user. The architect is an expert who is aware of the requirements of both of these. Materials research has several tools, but lacks a connection to architectural practices and values when the goal is to develop materials for architecture. In practice, valuable and meaningful information can be produced at the intersection of different stages in the research and development process and valued aspects in architecture. The related task has been to develop a chart-based review method generating valuable information for facilitating materials research and development. Generally, material scientists or other material-related experts are exceedingly aware of the processing methods and technical aspects of materials during materials development. However, there remains some disconnect between this knowledge and its practical application in architecture. Given this, the aim of the study has been to generate knowledge of aspects valued in the combination of the life cycle of materials and architecture and provide the information to those involved in the material development work. The applications of the method presented in this paper are highly practical. The method generates knowledge of the user of the building at the level of experiencing the surroundings with their senses. In addition, with the assistance of the method, it is possible to discuss the profitability of the material from the point of view of material economy, social influence, or technology. These emphasised aspects might not be clear among individuals with specific tasks at the material research stage.

Fractured Material Development

Materials research and development cover already in themselves various disciplines. The goals can vary from developing existing materials with enhanced properties to entirely new materials. On a practical level, the research and development may concentrate on developing natural materials or artificial materials. The result of both can be materials with more refined characteristics. At its simplest, materials research and development may concentrate on only improvements to one material whilst a more advanced study can concentrate on adjusting several parameters due to a combination of different materials. For instance, smart materials or semi-smart materials have a specific functionality, property, or change in appearance (Ritter 2007). Currently, the design of materials can be elevated to an even more advanced level with bio-design, where materials are or have been living during the life cycle of an organism (Antonelli 2014), or those materials can be adjusted by means of chemistry. Similarly, materials can reach a next level in design due to metamaterials, which are engineered to achieve outcomes, which may not exist in nature. Wide themes, in which a multidisciplinary approach is required, could be a replacement for plastics with bio-based alternatives, leading to sustainable construction materials, or production of super-materials with currently unidentified features. Moreover, material research may apply knowledge of various disciplines to obtain pre-set targets. Prior to that, the knowledge of experts, disciplines, or demands to facilitate research and development is valued and required.

In the study of materials, the research phase differs substantially from the product development phase. Materials research is typically conducted prior to the product design phase, especially in the cases where the end uses are not strictly defined. In the product development phase, the outcomes are defined more accurately. The frames for the development work have been documented, for instance, at the design brief, where the objectives are presented and delivered for developers, participants, or stakeholders. In the research phase, experts from the various fields might be present, and knowledge sharing of different disciplines is exceedingly valuable. In scientific research projects, the practical end-use application might not be specified precisely in the research phase. Due to this, even if the potentials and properties of the material has been established to a certain level, these do not necessarily guide or determine the development process towards a certain product. This may be due to the fact that in materials research and development, scientists may study materials from specific viewpoints, such as at the level of the chemical composition. In between chemically modified materials and the end-use application of a material, there is long journey to bridge.

Role of Materials in Architecture

In architectural design, both technological aspects and artistic creativity are present. Architecture can be thought of as the practical fulfilment of different functions whilst, in contrast, architectural construction has a close relationship to the artistic approach (Mordaunt Crook 1987). In architecture, this differentiation has been considered to be significant, especially after the industrial revolution (Giedion 2008). The twofold approach of technology and art can be zoomed in and observed in limited sections. The chosen materials, for instance, can be in their smaller constitutive parts observed from the standpoint of both domains. At this level, the aspects can be related, for instance, to technical features or artistic creativity in materials.

Various Viewpoints of Architecture

Architecture can be observed from various viewpoints. In addition to just evaluating different aspects of a material, such as material properties or artistic potentials, there are present aspects, which are meaningful in architecture on a wider perspective. The meaningful aspects can be observed from the perspective of an architectural historian (Giedion 2008). The observation can focus on an architect as designer where different disciplines are present within which architecture

operates (Aalto 1978). The topic can be approached from the perspective of values, which affect the work of an architect (Ukabi 2015). In addition, the focus can be directed to the framework of architectural design (Eilouti 2018). Above mentioned wider perspectives have been compiled in Table 1. In that table, the content of each of the above mentioned perspectives have been grouped and colour coded to fit the technical, social, human, spatial experience, cultural, economic or miscellaneous sub-frames. The purpose of this list is to facilitate the comparison of different contents from broader perspectives, but also to note similarities.

The most common aspects in these four broader perspectives seem to be related to the social and techno-scientific sub-frames. These are present in all of the four above mentioned broader perspectives. In addition to these, human and cultural aspects were common as well as spatially bound experiences. The economic aspects are present in all perspectives, except in the final perspective. In that case, the frame is narrower than the other perspectives, due to a focus on the design process. The reason for this might be that economic aspects can be comprehended as enablers to the design task. Due to this role, these are clarified prior to the design task.

Table 1

Different aspects which are valuable or present in architecture or architects' work

Perspective of values which affect architects' work [11]	Framework for architectural design [12]	Architect's listing where architecture operates [10]	Architectural historian listing of aspects present in architecture [9]
Scientific	Technical	Technical	Technical
Mathematical	Social	Social	Scientific
Social	Human	Human	Social
Aesthetic	Aesthetic	Psychological	Ethnological
Environmental	Materialization	Economic	Economic
Traditional	Functional		
Economic	Cultural		
Novel	Contextual		
Gender-based			

Technical
Social
Human
Spatial experience
Cultural
Economic
Miscellaneous

Sorting or Selecting Materials

Numerous aspects influence how a material is selected to fit the design needs. These aspects have been mapped and studied recently from the standpoint of architecture (Wastiels et. al 2007), (Wastiels and Wouters 2008). The aspects are related, for instance, to the material experience. A researcher, who works with materials, may not concentrate on the aspects, which are related to aesthetic issues or how materials feel to the touch (Wilkes et. al. 2016). Experiencing a material is a multisensory experience, where space and time have a role embedded with significances (Fujisaki et. al 2015). At a practical level, sensory-related experiences might concern the visibility or acoustic aspects of materials. Both aspects can provide spatial feedback of the surroundings for the experiencer and are valuable to recognise when selecting the materials for a built environment. Aspects related to the use or maintenance of materials generate knowledge for the selection phase, when evaluating if the material is valuable to be selected. In addition, the quality of the materials in general and the profitability of the materials in terms of costs are taken into account in somehow when the architect selects the materials. The material selection and evaluation can focus on the surfaces or the other visible parts of a building. The selection process might focus on completing the specific use of a single room with suitable material choices or on a certain need for creating a specific atmosphere. In addition, the evaluation can focus on structures, which divide or create spaces. Due to these aspects, in the architectural design process, various aspects must to be considered at the material level.

During the design phase of the construction process, the architect makes decisions when selecting unprocessed materials or commercial products composed of certain materials. The materials selection of the design phase can be based on a certain frame or criteria. This frame can be facilitated to comprehend the entity and demands of the research or development processes. Recently, there has been studies on the selection method of an architect or designer (Karana et. al 2008), (Wastiels and Wouters 2012) and on the developing tools to aid materials selection (Karana et. al 2010). The decisions of architects or designers may be based on tacit knowledge, which steers the design process forward unconsciously. This tacit knowledge is formed from past experiences. When selecting materials, some decisions are based on reasoning, and those are the results of evaluation and comparison. An architect or designer can execute selections with the help of material samples provided by manufacturers. In addition to these, the selection can be based on previous well-chosen and successful selections. Moreover, materials libraries act as a bridge between designers and scientists (Wilkes et. al 2016).

Knowledge Generation and Sharing

In the design process and constructing phase, various experts from different disciplines are often involved. The information exchanged between participants can be shared in the form of various types of documents. In that process, the drawings represent one method to share information. For knowledge sharing during the construction period of a building, meaningful information can be collected in a "Building Description" (Rakennusselostusohje 2015) or "Construction Description" (Rakennustapaselostus 2016). These are both made by utilising text forms. In the field of design, a more-or-less similar approach is termed the "Product Design Specification" (Rodgers and Milton 2011). These documents encapsulate the project in a written format. With their help, the information of separate, but meaningful, aspects can be provided to people involved in the project, even in the early phases. These documents condense aspects, which are necessary to know even when the actual design work has not yet begun. Information collection is important to facilitate and frame the design phase. Materials are present in these specifications to some extent, though the focus is more on a designed object or building.

At the material level, several methods to organise, comprehend, and share knowledge are common. In particular, these are valuable, when developing new products, evaluating material choices, or assessing the impacts of life cycles. The assistance can be in several forms, such as checklists during the product design phase to facilitate the discussion between engineers and designers (Rousseaux et. al 2017). When evaluating the effects of materials, selections can be based on favouring green choices (Spiegel and Meadows 2010) or following the ISO 14040 standard at Life Cycle Assessments (LCA) (ISO 2006). In addition to LCA, which concentrates on minimising environmental impacts, other analysis tools can be employed, such as Life Cycle Costing (LCC), which concentrates on costs during the life cycle, and Sustainable Life Cycle Assessment (SLCA), which focusses on impacts related to socio-economic aspects (Halog et. al 2016). In recent years, the sustainability of materials and material cycles have aroused interest among consumers (Peters 2011). The aim is that waste materials, agricultural materials, or single-use materials can be taken back into the material loop (Peters 2011). For industry, eco-tools are valuable to reduce environmental impacts, when developing processes and products. These can be designated into four categories: 'inventory tools, improvement tools, prioritisation tools, and management tools' (van Berkel et al. 1997). For example, the Materials, Energy, and Toxicity (MET) Matrix is one inventory tool that has been developed to analyse materials, assessing their impacts on the environment (van Berkel et al. 1997). In addition, there are several eco-design tools which are purely aimed to facilitate choice evaluation within the construction industry (Rousseaux et. al 2017). In addition to the abovementioned, the design phase or process can be directed to focus on a certain frame, such as 'modular design, design for material substitution, design for disassembly (DFDA), design for recycling or design for life extension (Ljungberg 2007).

Results: Review Method Structuring Valuable Information for Research

This paper presents a method to facilitate multidisciplinary materials research and development from the viewpoint of architecture. The method is based on different aspects as to how architecture related material research can be framed and later observed. The outcome of the research is a flexible chart. The chart can be employed as a tool to generate valuable knowledge for the materials research phase. In addition to facilitating materials research, the chart can be used creatively as a checklist or a reminder to map various aspects, which must be taken into account when materialised outcomes in the research are related in the buildings or living environments. The chart can also be utilised to determine the boundaries to the research work in a way that the people involved in the process are able to succinctly comprehend the idea of the material. The chart can be seen a notebook or classification platform with which to generate remarks on the desired material features. Another use of the chart could be to collect important information to be shared, such as the building specification utilised in architecture. In this paper, the chart has been presented with a case example. With the case example, the aim has been to disclose how the knowledge facilitating the research can be produced.

As previously mentioned, the chart is generated to recognise different viewpoints, which can facilitate the mapping and collecting of valuable knowledge for research. The viewpoints are a combination of different steps of the material development phases and other diverse aspects, which are present in architecture or architectural design. Depending on the focus or demands of the materials research or development task, the viewpoints can be narrowed to focus on just the essential aspects, or the chart can be utilised as a whole to gain a comprehensive overview, especially when the research scope is not yet defined.

In the chart, the considerations for what is needed to be taken into account, excludes detailed technical material properties or manufacturing details. These aspects are important and can be discussed in small groups of experts during the development work. In addition, the excluded research areas, which might not get the full benefit of the chart, could include technical materials, such as the functional layers in the building envelope, or fittings, such as supplies for HVAC installations. These might not necessarily possess an important role in the spatial experience from the viewpoint of architecture. In generally, the functional material layers are defined by civil engineering, and the materials are hidden inside of the wall structures. The fittings, such as supplies for HVAC installations, are usually produced from standard materials. In addition, the materials or products are not in general defined by an architect. However, the chart might be beneficial, especially when mapping knowledge in architecture, when new supplies for HVAC installations are developed, or there is a demand to understand detailed technical information of materials.

Structure of the Chart

The chart consists of horizontal and vertical aspects (Table 2). The eight steps in the chart (marked 1 – 8) present the journey of a material from raw material to the re-use of the material. Horizontally, on the top of the chart, there are placed five aspects, which are present in material development (marked A – E). Those aspects are based on Alvar Aalto's listing within which architecture operates (Aalto 1978). The reason for selecting Alvar Aalto's listing was because the definitions were comprehensive enough, but not too complex. In addition, he participated in practical design work, and contemplated the relationships between the construction of materials and structures in his writings (Aalto 1978). The horizontal aspects indicate how architecture can be approached from the viewpoint, which is familiar in the culture of designing and constructing. The information discloses views on how an architect observes materials in the built environment. Overall, the eight steps in the life cycle of a material, and Aalto's five-part classification generate 40 different valuable aspects as to how materials research in architecture can be observed.

The objective of the chart is to facilitate research and development phase (A2, B2, C2, D2, E2), which is also present at the chart. The gathered information from other 35 viewpoints, excluding

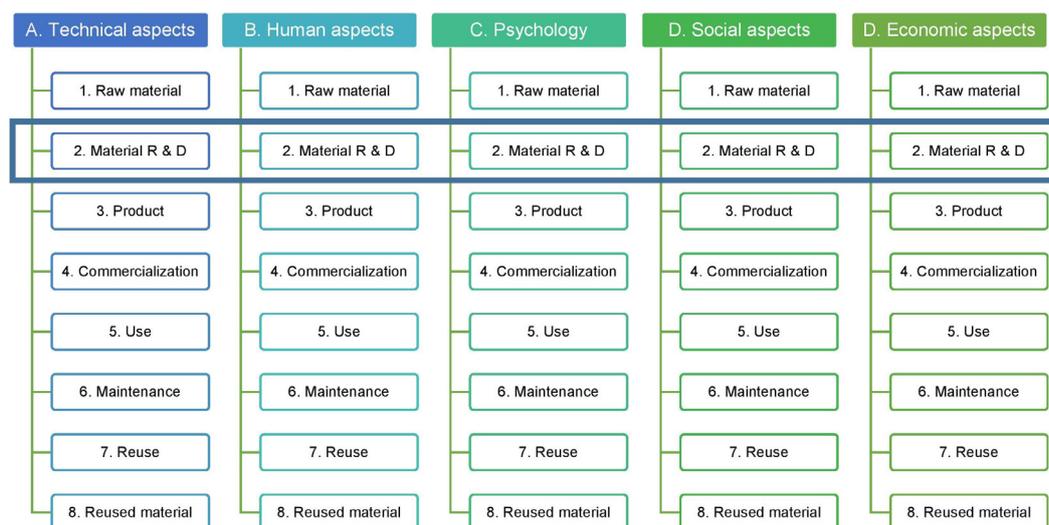


Table 2

The chart presents the vertical and horizontal aspects within which architecture operates during the life cycle of the material. The research and development phase is highlighted in the table (A2, B2, C2, D2, E2)

the mentioned five horizontal thematic areas of Research and Development phase, are fed into this phase. In addition, at the research and development phase it is possible to generate knowledge various aspects related to materials. At this point, the chart can aid in identifying boundaries and limitative aspects.

Vertical Thematic Areas

The vertical thematic areas include eight steps. Each of the steps presents a different phase in the life cycle of the materials. The aim of this has been to divide the life cycle of the materials into smaller parts for more specific observations. Due to this, more detailed and focused knowledge can be generated to facilitate research. The vertical thematic areas during the material life cycle are:

1. Raw Material,
2. Material Research and Development,
3. Product,
4. Commercialisation,
5. Use,
6. Maintenance,
7. End use,
8. Re-used Raw Material.

The first phase, Raw Material, consists of simple processes prior to delivering the material for sale or further developed raw material. Material Research and Development is the phase to which the work of this paper is aimed—to facilitate research by collecting valuable information generated with the help of the chart. At this stage, the research work can be executed at universities, research institutes, or commercial companies. The research work can vary due to the objectives, research material, and research facilities of the interested parties. The knowledge generation in the Research and Development phase can be related to mapping research facilities, suitable tests, research methods, or the desired skills of the researchers. In the Produced phase, the knowledge generation can be related to the qualities and requirements of the end use of the material before the material is launched onto the markets. In the Commercialisation phase, the potential challenges and boundaries of the material are discussed when the material is developed for the market, or the material is part of a commercial product. In the Use phase, the knowledge generation is related to daily life and use of the material, and in the Maintenance phase, an understanding can be generated as to the serviceability of the material. At the end of the material life cycle, there are possibilities to generate knowledge of the potential end uses of the material. If the material can be utilised as a raw material again, the aspects can be pondered in the Re-used Raw Material phase. At best, the material life cycle and knowledge generation may start again in the first phase, Raw Material, and the material loop is closed.

Horizontal Thematic Areas

In the horizontal thematic areas, the materials can be classified into five different aspects for observation. This division is based to Alvar Aalto's notions of the aspects which are present in architecture. The division was selected because it is general enough to fit the scheme of multi-disciplinary material research, and flexible enough to include different considerations, which the constantly evolving field of architecture faces intermittently. The horizontal thematic areas include the following:

- A. *Technical Aspects,* C. *Psychological Aspects,* E. *Economic Aspects.*
B. *Human Aspects,* D. *Social Aspects,*

In this study, the technical aspects include the measured data of materials, and methods for how to process materials. In addition, these include interpretations and evaluations on a general level, such as how the material can tolerate water. This section can generate knowledge as to how the material can be modified, or what kind of technical knowledge is valuable. In addition, it is possible to consider manners, tasks, practicalities, methods, or machines. Moreover, any necessary or existing technical information can be discussed in this section. Valuable knowledge can be generated if the emphasis is on how the technical aspects fit the demands of research, development, or design. The desired information might be applied on a wider basis than in the regular technical data sheets or process overviews. In addition, the information may be tied to design practices. The information outside of the technical data sheets might deal with aspects, such as moisture sensitivity, weathering, wearing, and tearing of the material. Aspects included in the technical thematic areas are wide and extensively present in architecture. Human, psychological, social, and economic aspects are present in materials, but they might not have been studied that widely compared to the technical aspects of materials from the viewpoint of science. In Human Aspects, the safety of the material and its adaptation to human use can be considered. In Psychological Aspects, the materials can be observed from the viewpoint of material experiences. The focus here can be on how the material affects the experiencer or experienced space, noting that the experiences are personal. Sensing the material through touch or experiencing the space where the material is utilised might be worth considering in order to ascertain if the material is optimal for a given purpose. When thinking of the relationship between material and society, there might also be a demand to consider themes, such as how the material fits to the existing culture and traditions and how the material adapts to living environments in general. The wise use of resources could be included as the focus of the last section, Economic Aspects.

Review Process

Material development is a long-lasting process influenced by various aspects. Thus, the aim of the review method is not to create a permanent structure but an active review method, which varies depending on the different material research tasks, end-use visions, frames where the material would be used, and disciplines of the persons involved. Due to this lively nature, the focussed observation areas can be narrowed very tightly, if the observed areas are desired to be specific. The observation areas can be selected according to needs, such as product from the viewpoint of psychology, use of the material from the viewpoint of society, or maintenance of the material from the viewpoint of economy. In turn, the observation points can be selected for only a certain phase of the material life cycle, such as maintenance observed from all five horizontal thematic areas in which architecture operates.

Consequently, the direction of the observation can generate different knowledge. The chart can be observed from raw material towards products, where the starting platform is wider, due to delimiting knowledge. From the opposite side, the chart can be observed according to the demands of the use phase towards raw materials. In this case, the aim is to curate the right material

to be developed among the draft materials. The demands of use-phase visions limit and frame the material research. Due to these aspects, the observation direction from the material towards products, or in the reverse order, can generate different results.

The process starts by defining the preliminary research approach. In the process, all 40 aspects or selected aspects according to the defined research approach are present. In the selected scope, the framing can be limited, such as A. Technical aspects and 3. Product, which generates a narrower view to understand these valuable aspects. The knowledge here is generated with the help of questioning. The nature of the question – answer – question method is mostly achieved through debate, where the aim is to encourage knowledge to emerge. The reason for this method is that most of the information regarding the scientific research might be clear for the professionals in specific areas but opaque to all other participants. The knowledge might not be visible at all, or the knowledge exists as tacit knowledge. Due to nature of tacit knowledge, it can be difficult to share with others. With the help of the systematic method presented in the article, the knowledge has a better possibility of being revealed and shared. After answers have been generated, the final focus on the narrow topic may reveal a more accurate comprehension. After that, the generated information can be fed into the research and development process of the material. This final phase provides advice on how to proceed further. (See Table 3).

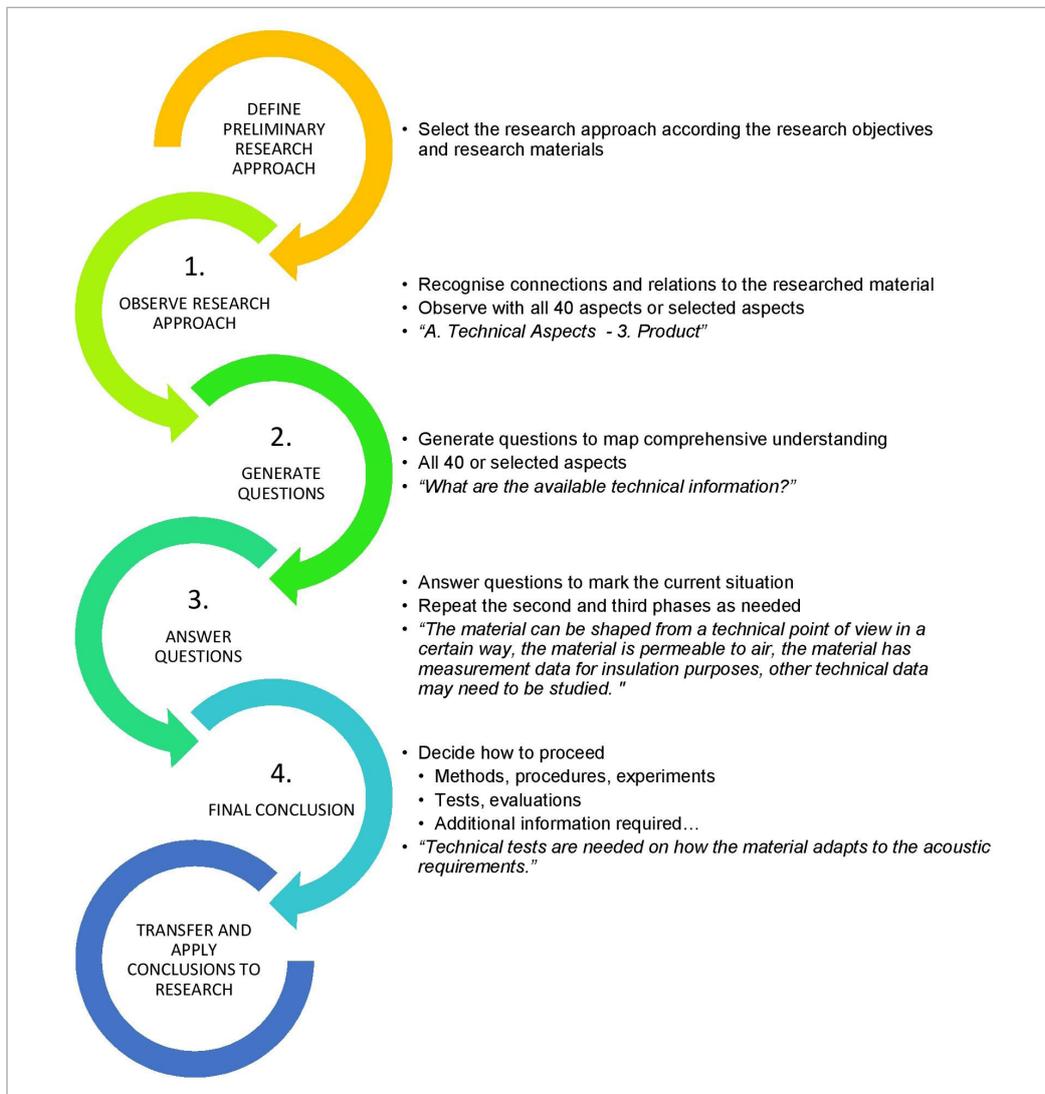


Table 3

Process for utilising the chart

Increasing Knowledge with Questions

In the review process, the research data is collected in the requisite frames, or all 40 aspects, with the help of question generation. The objective is to return the strictly limited and framed knowledge back to the materials research to facilitate discussion. In addition, the aim is to generate research objectives more comprehensively. The first question round is generated to survey and study the material whilst further questions, if needed, can generate more specific knowledge. If the chosen method of observation in the first step (see Table 3) is chosen to be very narrow, as the material produced is observed at the intersection of psychology (C. Psychology - 3. Product, see Table 2), the questions can be related to the experiences, which the material awakens, when experiencing the material as a spatial experience in the proposed physical space. On a practical level, the outcomes of the questions can be notions that the material muffles or reflects sounds; both of these affect the acoustic experience. When developing answers for the questions generated for the second round, the outcomes may be that the acoustic properties might need some improvements during the research phase. As a result of the process, more specific knowledge can be generated to serve the material development. On a practical level, the observation could concentrate on how to adjust or improve the acoustic properties when additives are planned to be mixed into the material.

Evaluation: Testing Review Method

The review method has been tested in practice by evaluating an early phase material research studies. In this practical test, the perspective where the questions have been approached involves the research material cellulose. The preliminary objective of the cellulose research includes knowledge generation of the potentials of this abundant material for new research openings. Among several material cases, Foam Material was selected to reveal the method presented in this paper (Fig. 1). The sketch material reveals how the method can be utilised if evaluating the potentials of early stage materials research. The selected Foam Material has been developed during Design Driven Value Chains in the World of Cellulose, DWoC 2.0 research project, 2015 – 2018.

Cellulose is a material which appears as a structural material in plants or tree trunks. The cellulosic materials are derived from renewable resources and are inherently biodegradable. The raw material of this case study is wood-based cellulose. In architecture, cellulose as a material in products has been utilised in insulation materials or building papers.

The review method has been preliminarily tested with one DWoC 2.0 material research case. The results of three other DWoC 2.0 cases were presented in a short conference paper at the Proceedings of the Nordic Wood Biorefinery Conference (Turunen 2018). In the conference paper of the conference proceedings, the cases have been observed in either a bottom-up approach from materials towards products or vice versa in a top-down approach. In this study, the life cycle of the material is widened to cover raw materials and re-used raw materials. The case study of Foam Material was observed from one vertical aspect A. Technical aspects, but in all the life cycle stages of the material from 1. Raw material to 8. Re-used raw material. The purpose of the evaluated case study presented in this article is to reveal general information to assist the architect in the early stages of the material development. Due to this, the views on how questions are created have been based on the approach and mind set of architects. If the observer would represent another field, the questions and information collected would have a different emphasis. In both observation tasks, however, the results of the inquiry are tied to architecture and facilitate research and development of architecture-related materials, regardless of the evaluator's background. The reason for this is that the framing directs the process to stay within the boundaries of the architecture.

Research Material Case

In this article, the method is evaluated with a material sample, where cellulose was foamed and then compressed into stiff boards. The foamed material may be utilised as a structural material. In

this study, the material has been modified by patterning the material, printing on the material, and shaping the material with a commercial water jet cutter. The material samples were early phase sketch materials, anticipating future research in the field of architecture. With the assistance of the review method, the material cases were studied, which in turn generated a deeper knowledge.

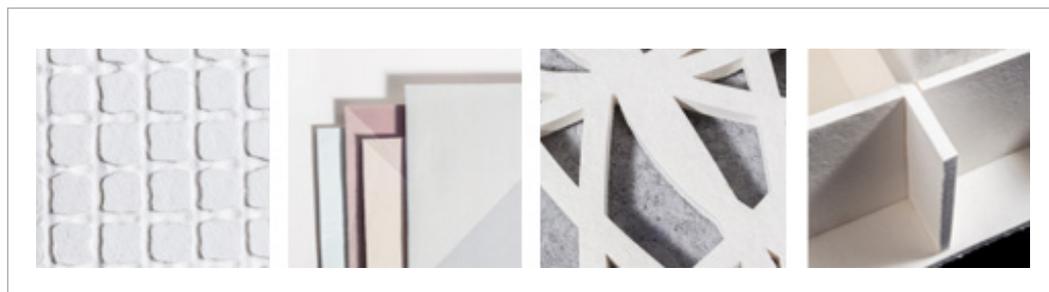


Fig. 1

Foamed Material on the right: patterned foam, printed foam, water jet-cut foam, and foam utilised as a structural material.

Photos Eeva Suorlahti

Foamed Material, 2017-2018

Team: Heidi Turunen Aalto, Jani Lehmonen VTT

Soft cellulose foam has been pressed to make stiff boards. The density of the boards is adjustable. The bending stiffness of the material has been tested to be 2.95 ± 0.43 MPa, which turned out to be better than commercial peeled plaster board. The bending stiffness of the plaster board was 1.13 ± 0.13 MPa. In addition, when comparing the maximum deflection of foamed material to peeled plaster board, the measure of the foamed material was 14.45 ± 0.38 mm, and plaster board just 0.5 ± 0.1 mm. The foamed material boards can be post-processed in various ways. In this research, patterns have been pressed on the foam. A commercial printer has been tested to print thin lines. The aim of the printing was generating knowledge how ink spreads on top of the board. The printing quality was superior. In addition, the material was tested on water jet cutter. The quality of the cutting edge was sharp, and material did not absorb water. A 1:1 scale sample was made to present an early phase sketch, if the foamed material could be considered to replace gypsum boards. Future application areas for foamed materials could be in indoors, where stiff boards are required in vertical or horizontal applications, and where it is desirable for the material to be recyclable, reusable and bio-based.

Review Process

In the chart, all 40 aspects were tested to fit cellulosic research. In this preliminary study, the foamed material was observed from raw material towards products, meaning that the end use of the material was not defined. Due to this, the scope of the future application areas was wider than if reviewed the other way round. The results presented in this paper were limited to cover A. *Technical aspects* from the horizontal thematic area, and 1. *Raw Material* to 8. *Re-used Raw Material*.

Results of Testing

The knowledge is possible to assort with help of the assistance of 40 different viewpoints. The chart follows four phase paths (Table 3). In the case of the foam material, only selected aspects are shown, the journey of the material from a technical point of view. In this article, the first round of questions is presented using simplified concepts marked in the table (Table 4).

An example of a simplified concept is; available technical information (A3) and the question; what are the available technical information of the foamed material (see also Table 3). After that, in the third phase, the answers are created according to the questions. The answers were, for example, the high air permeability of the material. The fourth and final phase is aimed at collecting information on how the research can proceed further. This means gathering information on what kinds of knowledge, tests, or processes might be beneficial to serve the research. In the fourth phase,

Table 4

In the chart, it is possible to select certain aspects or utilise the whole chart for knowledge generation

A. Technology	
1. Raw Material	<ul style="list-style-type: none"> • Production • Obstacles • Harmful particles • Complicated methods
2. Material R & D	<ul style="list-style-type: none"> • Handling • Processing • Machining
3. Product / Produced Material	<ul style="list-style-type: none"> • Technical abilities vs. design • Main technical aspects • Reaction to water • Reaction to stresses • Combining to other materials • Available technical information • Coating possibilities • Colouring method • Available colour charts • Measures of the material • Material strengths, applicability • Customisation • Fire classification • UV resistance • Chemical resistance • Weathering • Surface sensitivity
4. Commercialisation	<ul style="list-style-type: none"> • Application areas • Technical data sheets / recommended use • Brand of the reseller / reliability • Obstacles
5. Use	<ul style="list-style-type: none"> • How material works • Construction details • Relation to other materials (technical) • Technical usability, water tolerance • Slipperiness • Accumulation of dirt • Air permeability • Effect on indoor air • Reaction to air humidity • Emission classifications • Indoor / outdoor climate tolerance • Release of harmful chemicals
6. Maintenance	<ul style="list-style-type: none"> • Release of harmful chemicals • Methods for maintenance • Repair • Replacements if damaged • Cleaning • Renovation • Maintenance interval • Ease of maintenance • Difficulty of maintenance
7. End-use	<ul style="list-style-type: none"> • Reusability • Steps for re-using • Material separation • Detachability • Replacement with other material • Removal • Biodegradability
8. Re-used Raw Material	<ul style="list-style-type: none"> • Re-use possibilities • Processability • Remaining / perishing properties

more knowledge was generated utilising more specific questions, notions, and comments. The second round of questions is not necessary if the first phase managed to generate enough information regarding the material. In the case of foam material, the second question round can be related to map specific technical methods how to obtain information, such as defining next steps when measuring air permeability.

In the case of the foam material, the first round answers have been analysed, and the condensed information has been summarised below briefly in written form to provide an impression of the type of gathered information.

Foamed material

A. Technical Aspects: 1. Raw Material to 8. Re-used Raw Material

Technical aspects: When evaluating the foamed material with the help of the chart, it is worth noting that the production processes of the *Raw Material* (A1) can be relatively simple and well known, but the limitative aspects need to be mapped from the viewpoint of architecture. These can include aspects, such as the quality of the product as well as amounts of the potential production volumes. These considerations as to whether the material is wise to use from the standpoint of material properties are important to recognise at an early phase. For example, there is a notion in foam material that cellulose tends to get wet easily. On a practical level, the foamed material in this case has been analysed from the viewpoint of processing possibilities. These processes were water jet cutting, printing, pressing patterns, and constructing three-dimensional structures. When analysing the cases with the help of the chart, it was clear that more testing of the processing of the material is required. In addition, identifying the limitations and studying, for instance, the customisation potentials of the material would be beneficial to comprehend the potential end uses. In the *Product* phase (A3), it is possible to identify the technical properties of the material. In the foam material case, these can include water tolerance, fire resistance, UV-resistance, surface sensitivity, chemical resistance, and the potential external dimensions of the material.

In this phase, it is possible to generate preliminary information of the tests, which are required to ascertain the potentials of the material on a technical level. In addition, it might be valuable at this phase to consider how the variations of the customisation possibilities might serve various end-products. When materials are aimed at commercialisation, various aspects must be clarified prior to that. Information for that phase can be generated with the help of the frame *Commercialization* (A4). The mapped data can increase the reliability of the material, when evaluating suitable end uses. In the case of the foam materials, the potential information for the technical datasheets or design principles may help guide the research and development phase to comprehend the material potentials. In the *Use* phase (A5), information of a certain scenario can be generated as to how the material is expected to be utilised, allowing researchers to feed the resulting information into the research phase. The scenarios regarding how to use the foam material may lead researchers to consider aspects, such as the potential accumulation of dirt and dust on top of the relatively soft and fibrous material. In this phase, it might be wise to consider if unwanted additives or chemicals may be released during the use of the material. The gathered information can be fed into the research and development phase, where improvements and testing can be performed in anticipation of these concerns. Feedback from the *Maintenance* phase (A6) to the research and development phase would include knowledge generation of cleaning possibilities and the limitations, which the material sets for the maintenance customs. In the case of foamed material, cleaning with a wet cloth is not practical and requires consideration in the research and development phase if cleaning is desired in the maintenance phase. Similarly, replacing broken or worn material can be considered in this phase. The consideration here is related to the repair methods or the possibilities for affixing a replacement. In the *End Use* phase (A7), the consistency of the material can be considered from the viewpoint of potential re-use, and this information can be fed into the research and development phase. The aspects considered in the case of foamed material may be concentrated on noting the potential additives or chemicals planned for inclusion in the material. Additives or chemicals might prevent or complicate re-use or recycling of the material. This is due to the fact that separating the ingredients in the material may be difficult, if materials are merged together, for example chemically. In addition, additives or chemicals may disrupt the biodegradability. In the early phase of the material development, the notion that the foamed material may be recycled among newspaper waste was considered from the viewpoint of additives. The last observed phase, *Re-used Raw Material* (A8) generates knowledge as to where and how the material can be re-used, and what must be considered when returning the material back into the material loop. In the case of the foamed material, re-use among composites might be a valuable aspect to consider.

Different material research and development cases can vary significantly due to the researched materials, processing methods, facilities, end applications, and customs in the materials research and development phase. However, tools have been developed to steer the process in the desired direction. The tools are often related to understanding and analysing material impacts from the viewpoint of environmental issues and sustainability. In architecture, the design processes tend to be complex due to unique outcome of the buildings in a living environment and the different demands of the users. In addition, the aspects are bound to cultures and practices. The nature of the designed outcomes is often one-off or even experimental. In human-related aspects, the interpretation is dependent on a designer, user, or experienter. Contemplating the previously mentioned aspects, gathering precise information might not be a clear process to filter the information back to the phases of materials research and development.

Thus, the objective of this paper is to generate a tool to facilitate materials research and development. The tool is observed from the viewpoint of architecture, but it is not designed to make the role of an architect unnecessary. Understanding the aspects included in architectural design is a

Discussion

long learning process, where architects reflect their personal history, experiences, and learnings from previous design tasks. Due to this, it cannot be assumed that all valuable information could be filtered to serve materials research and development solely with the help of this review method. Instead, the focus is to open the mindset of the participants to versatile approaches, where architecture and materials can merge, and to facilitate effortless interactions with the participants of the research. Otherwise, the use of the chart might be a superficial shortcut, lacking in depth.

The primary assumption of the chart is that the materials would come back into use in a loop. This can be taken into account in the material design phase. While the materials involved in architecture might not return to serve only architectural applications later on, they can be utilised in other product fields as a new raw materials. Due to this, it might be wise to survey other potential re-use possibilities at an early stage of the material research and development, not just those which are related to architecture or the construction industry.

Conclusion

In recent years, material selection has broadened in architecture, resulting in the inclusion of various disciplines in the research and development process. Given these developments, this paper focusses on a tool for recognising aspects, which might be beneficial when researching and developing materials for use in architecture. The focus of the study has been aimed especially at projects in which various disciplines are included. In terms of the role of the architect, the focus has been on which aspects an architect emphasis when performing a design task or when defining materials or products for use. The result is a systematic tool for knowledge generation to facilitate discussion during materials research and development. The principles of the tool mirror the aspects, which architects focus on and favour when evaluating suitable choices during the construction process or prior to that, and it simultaneously identifies what kind of information is valuable to notice. The aim of the tool has been to return the information back into the materials research or development phase. With the help of the chart, it is possible for all to comprehend different viewpoints related to the materials life cycle.

The chart consists of 40 viewpoints related to how materials research or development can be approached. These viewpoints are generated from the horizontal aspects, which are considered vital in architecture. Based on Alvar Aalto's notions, these horizontal aspects include the categories of technical, human, psychological, social, or economic aspects. In contrast, the vertical aspects focus on the life cycle of the materials. The vertical viewpoints are different stages of the life cycle: raw material, material research and development, product, commercialisation, use, maintenance, end use, and re-used raw material. The chart has been tested with an early stage material research project, where the case material is foamed and pressed cellulose.

The practical application of the chart presented in this paper is to facilitate knowledge generation for material research and development when developing new or recycled materials for architecture. In other words, the researched material might contain great potential, but the view is narrow, or the product exists, but a suitable material is not yet available. In both cases, knowledge generation allows for a more comprehensive comprehension of the demands before the start of the research and development phase. In addition, the chart can assist researchers in comprehending aspects-related materials research and development. This utilisation is similar to how a building specification document facilitates architectural design. As well, the chart can be utilised as a flexible tool to reveal the necessities of a certain material from different viewpoints. The chart can also be employed as a checklist to survey valuable aspects to facilitate research and development. Further studies related to the topic could concentrate on the 40 frames. These considerations may be related to how valuable and meaningful information can be revealed more accurately. In particular, when there is demand to adapt various end uses, properties, or qualities of materials for the practical work of research and development.

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