BuildDigiCraft

New Mindset for High-quality Baukultur in Europe:

Bridging Craft and Digital

Annette Bögle, Emiliya Popova (eds.)

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HafenCity University Hamburg
Henning-Voscherau-Platz 1
20457 Hamburg

Editors: Annette Bögle, Emiliya Popova

Authors and project team members (in alphabetic order)**:**
Justyna Borucka, Gdańsk University of Technology
Annette Bögle, HafenCity University Hamburg
Uģis Bratuškins, Riga Technical University
Günther H. Filz, Aalto Unversity
Anna Kaczorowska, Chalmers University of Technology
Dorota Kamrowska-Załuska, Gdańsk University of Technology
Małgorzata Kostrzewska, Gdańsk University of Technology
Olga Popovic Larsen, Royal Danish Academy: Architecture, Design, Conservation
Roode Liias, Tallinn University of Technology
Bartosz Macikowski, Gdańsk University of Technology
Karl-Gunner Olsson, Chalmers University of Technology
Emiliya Popova, HafenCity University Hamburg
Raido Puust, Tallinn University of Technology
Sandra Treija, Riga Technical University
Lotte Bjerregaard Jensen, Technical University of Denmark

Student assistants:
Benjamin Gellie, HafenCity University Hamburg
David Ehrenreich, HafenCity University Hamburg

Design and layout: Andrea Buonaventura Badia

Proofreading: Tessa Hellbusch

Distribution:
HafenCity University Hamburg
Chair of Design and Analysis of Structures
Prof. Dr.-Ing. Annette Bögle

Project E-Mail: build-digi-craft@hcu-haburg.de
Project Webpage: www.builddigicraft.eu

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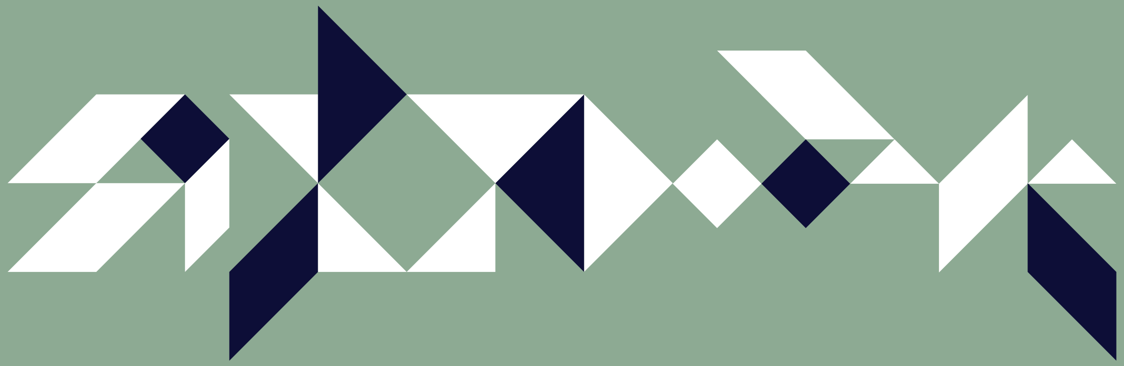
2.5 Material
Intellectual Output 4

The meaning of Material, Materiality and the Digital for Baukultur



Authors
Olga Popovic Larsen, Günther H. Filz

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1.0 Material knowledge and the ancient Master builder

The dome of Florence Cathedral, Italy, represents both a milestone and turning point in the art of design, constructing and building, respectively the history of architecture. Until then, there was no clear separation of professions, such as architects and engineers. In ancient times, the person who worked with specific building materials and mastered building skills was responsible for the entire building process from the early design phase to the final execution and was referred to as the Master Builder. Accumulated knowledge about material, form and proportions of buildings were passed on from predecessors (Larsen and Tyas, 2003) and developed their building skills with "intimate intuitions" from nature (Torroja et al., 1958). Based on centuries-old cycles of trial and error that were the lessons learned from his predecessors, the ancient Master Builder developed material-based building technology from generation to generation and often by leaps and bounds through innovative thinking and building techniques – as was the case when building the dome of Florence Cathedral.

Similar to pottery, material knowledge and shape were inseparably embedded in and dependent on the process of making, which resulted in the final artifact. Today, we speak about these traditions, their processes, but also about the material knowledge as tacit knowledge From the Renaissance onwards the role of the Master Builder separated liberal thinkers and executors (Argan, 1969), so those whose design was based on theoretical and, for example, mathematical considerations, and those who assembled the buildings. While this new approach allowed for the early incorporation of materials and material technology into the design and pre-planned construction process, the earlier feedback loops were broken and the executors lost their involvement in these processes and moreover, their importance and standing in society.

A further division of liberal thinkers into architects and engineers was triggered mainly by the emergence of architectural methodologies and later by the inventions of new building materials, such as cast iron, steel, and glass. The executors became responsible for building construction mainly (Saint, 2007). Consequently, the role of the Master Builder has been fragmented into specialized professions, where the architect's role is limited to conceptualizing the building form, and the structural engineer's role is to rationalize the structure and define the dimensions of the material (Setareh et al., 2015). Later, this fragmentation led to the specialized architect, the structural engineer, the mechanical engineer, the construction manager, etc. Certainly, there are several advantages resulting from the fragmentation into individual specialized professions, especially for complex projects. However, the fragmentation may result in a lack of efficiency due to the difficulty of collaboration between the different professions where different methodologies and different thinking modes are applied. The separation may also result in inefficiencies such as excessive use of material, inappropriate selection of structural form and high costs (Larsen, 2016) as a consequence.

The history of architecture proves that architects have very often invented their own tools in the context of the material. The dome of Santa Maria del Fiore would not have been built the way it was if Brunelleschi in his time had not also thought about the tools and machines to produce the structure. This relationship, however, has changed over the centuries in that it has become somewhat more passive. Historically, it is also interesting to observe how this relationship has evolved in terms of design, planning and implementation. It is perhaps less well known that in the 1940s and 1950s in the aerospace industry, in mechanical engineering and in the automotive industry, the machines used for manufacturing were controlled numerically. These so-called NC machines were controlled by punched cards that guided a specific tool to produce certain components or machine parts. In a later step, these machines became computer-controlled so-called CNC machines. For this purpose, programming languages were developed to feed the machines with appropriate information, while at the time the designs were still made conventionally on paper. This issue then led to the conception of the first CAD programs. The first versions worked with relatively primitive primary shapes and geometries. The conversion of increasingly complex geometries into mathematical formulas enabled their programability. Among the pioneers of the 60s of the 20th century were Citroen and Renault in devising the Bezier and NURBS curves. At the same time, methods were developed for finite element analysis, which nevertheless required a resolution of the geometry as three-dimensional meshes. Especially in the entertainment industry, important advances were made in computer graphics for animation and visualization.

In summary, many of the tools we use in architecture today have their very origins in other industries and disciplines. This in turn means that very often innovations in architecture have been achieved through appropriation of tools from other fields. Although fragmentation into individual specialized professions has several advantages, it can lead to a lack of efficiency in many respects, especially for very complex projects. As a possible way to bridge the gap between architects and civil engineers, the model of the new Master Builder has been mentioned repeatedly in the last decades. Alternative approaches, such as the design-build philosophy (Nicholas and Oak, 2020), architectural or civil engineering as an educational program and profession (Parasonis and Jodko, 2013), the idea of structural arts (Billington, 1985) or the development of robots as modern master builders (Sweet, 2016) have been explored. Few exemplary projects can be found in the recent past (Billington and Garlock, 2004). However, today's technologies offer architecture the opportunity to develop and establish its own systems, tools and processes for both the collaborative and individual discipline.

2.0 Materiality in architecture, engineering, and material sciences

Material understanding and materiality are closely connected to architecture and building design. The history of construction of the pyramids in Egypt shows a great understanding of material properties, load transfer and the art of building. With every "new" material a whole world of development around its properties and performance is developed – one that affects how it is used, applied and constructed with. A common recurrence throughout the history of architecture is that design and construction methods lagged behind the newly discovered/created materials. The Parthenon in Athens built in stone using timber post and beam structural principles or the Iron Bridge in the UK that utilized Dovedale timber-like connections are classic examples of designing and building with the knowledge of the "old" material. This also emphasizes the role of tacit material knowledge, one that was learned by doing – participating in projects, learning through the gained practice experience. This was then transferred further into the trade (of timber construction, glass or any other old or new material technology). However, with each new step in the development of new materials, the design language and the craft of making in the material was lagging behind. With this in mind it is not surprising that the Iron Bridge or the Parthenon were using old material technologies. This is also equally present today. The science of new materials often precedes the design and the crafting language and practice.

At present we live in a time characterized by highly developed scientific methods that enable us to understand and describe materials both old and new on micro and macro scale. It is also fair to state that material understanding has never been more important than today, on the one hand with the great development in material science and engineering leading to an explosion in the development of new materials, and on the other – our performative requirements of materials have become higher and much more specific than ever before. We design buildings with requirements for internal climate, acoustics, energy use, etc. And the materials we choose need to live up to these high requirements. Often in order to live up to the performative requirements, the materials are purpose-developed. Many of these requirements are related to and try to give answers posed by the climate emergency we are facing. More often than not, we wish for low-impact materials that are high-performing, have low maintenance requirements, yet offer longevity to the building and which are biodegradable at their end-of-life.

But what about tacit material knowledge? It is the type of knowledge that connects the "material" with the "maker." In the case of "old" known materials, the knowledge development followed the material. The more we "knew" about the material (its properties, applications, durability, etc.) the more we "knew" about how to work with it, how to craft it (to cut it, or cast and fabricate elements). At present, tacit material knowledge is as important as ever, even more so because the act of making exceeds the physical only, but goes beyond that and into the digital realm, as the **BuildDigiCraft** project has shown. If we go back into history, material understanding both in a physical, performative sense as well as sensual, tactile, and experiential sense has always been very important. Not surprisingly, it continues to shape the design and construction of our buildings, structures, and cities today. Within the realm of building design, one can discuss material and materiality across scales: from nano-scale for material additives and surface treatments, to material understanding affecting element and structural design and all the way to building scale and finally – to urban scale affecting the creation of cities and large complexes across the globe. Understanding material and materiality is as crucial today as it was in the early days of human society.

To define, understand, and model material and materiality, physical modeling has been used as a tool as early as during the construction of the Pyramids in Egypt, throughout the history of architecture, and is still being used today. The book *Physical Modelling for Architecture and Building Design* (Popovic Larsen, 2020) maps the roles physical models have had:

- To **create**: physical models as an exploration and conceptualization tool
- To **see**: physical models enabling visualization, representation, and communication
- To **understand**: physical models aiding understanding through testing and verification
- To **guide**: physical models as a construction definition tool – guiding assembly as sequence of events
- To **link**: physical models linking physical and digital environments

Perhaps the most relevant finding in this book, especially in the context of the **BuildDigiCraft** project, is that physical and digital models are so intertwined and inseparable that they are representation – a model that is neither only physical nor only digital, but often both digital and physical at the same time. And then within this context, when we discuss the notion of material and materiality – it would be difficult to talk about material in a pure and only physical form. Typically, physical material with all its characteristics/performance is described through data that is detailed, complex, and derived and presented in digital form. Whereas the (physical) material possesses the workability and formability that has historically been developed through tacit knowledge and the craft of making, currently, this is supplemented by material as data (data about the material) that facilitates better/more sustainable/higher-quality design, architecture and building design. The two – the physical material and the digital material – are inseparable and without either of them we would not be able to discuss material and materiality.

In the context of architecture, it seems sometimes more appropriate to speak of materiality rather than material. By definition "materiality" means the opposite of "immateriality" and aims at describing the materiality or existence of corporeality. However, materiality incorporates the material with its meaning and effect on people and the environment. Consequently, context and the interactions it contains come into focus: materiality is thus consciously designed and located material. Since materiality simultaneously conveys corporeality and its properties, and thus ultimately seeks to provoke emotions, the duality of the noun – often even in the plural "materialities" – in its use as an attribute seems logical. The material as a natural or artificial raw material enters the material culture through conscious use and design. Through knowledge, processes and technology, it becomes a refined material. Materiality encompasses all material and cultural aspects and meanings. Thus, within materiality, material and immaterial conditions can be seen as having equal value, but since the sensual perception significantly complements the analytical comprehension of materials, the intangibles may ultimately prevail. Therefore, design culture leads to the creation of meaningful work transforming material culture into a holistic effect. Over time, materials change their properties and meanings. Machining processes and use shape, transforming material and environment in a dynamic way and creating new valences. Material thus manifests and stores knowledge and processes. Both industrial and craft processing steps expose their specific potentials and lead to different material qualities.

In the recent past, integrated design concepts have been identified as beneficial for contemporary architectural design (Moe 2008), where material, structure, and architecture (form) and their sequence are essential in the discussion (Oxman & Oxman 2010). Throughout many decades, a "form-structure-material" sequence was adopted. However, different sequences of the three elements are also possible and have been explored and practiced. For example, Oxman (2010a; 2010b) proposed a material-based design concept that computationally links the three elements in a "material-structure-form" order.

This material-first order in integrated design concepts was also practiced by the ancient Master Builder (Ruan et al., 2021). One example shows in the origin of tectonic expression in vernacular architecture where the selection of material informs the expression of form and structure (Oxman 2012). Many of these highly important problems in practical terms are actually of a geometric nature and thus the architectural application attracted the attention of the geometric modeling and geometry processing community. This research area, which is closely connected to digital toolmaking and digital fabrication, is now called Architectural Geometry (Bentley, 2007; Pottmann et al., 2008). Together with the knowledge of material properties, the field of architectural geometry not only links architectural shapes with the making, which means physical realization, but also with the fields of structural mechanics and structural engineering. Material science deals with research on, or techniques for studying, the relationships between the structure, processing, properties and performance of materials. Topics include materials of all sorts and scales such as metals, ceramics, glasses, polymers, electrical, and electronic materials, composite materials, fibers, nano-structured materials, and materials for application in the life sciences. This knowledge of material properties and the development of new materials form the essential basis of structural engineering, where digital and numerical simulation and analysis becomes increasingly important. Latest approaches aim at increasing the complexity of design by overcoming a pure geometric modeling by connecting and exchanging data, by using rule-based processes such as parametric design, by computationally assisted information-based explorations, and by AI approaches that are data-based and in some cases even "unmodeled."

3.0 The Davos Convention and material in the context of Baukultur

An important reference and point of departure for the overall **BuildDigiCraft** project is the Davos Convention, that both defines Baukultur, and also sets the ambitions for creating a new high-quality Baukultur. Material is a crucial element in achieving this.

The Davos Convention describes Baukultur as:

> *"… Baukultur embraces every human activity that changes the built environment. The whole built environment, including every designed and built asset that is embedded in and relates to the natural environment, is to be understood as a single entity. Baukultur encompasses existing buildings, including monuments and other elements of cultural heritage, as well as the design and construction of contemporary buildings, infrastructure, public spaces and landscapes."*
>
> (**Davos Declaration Community**, 2020).

Material is mentioned 57 times in all contexts of the quality criteria defined by The Davos Baukultur Quality System. (Eight criteria for a high-quality Baukultur – the whole story, in 2020.) The eight criteria are Governance, Functionality, Environment, Economy, Diversity, Context, Sense of Place, and Beauty.

Material in the **BuildDigiCraft** project is investigated through the lenses of craft, through the digital and finally Baukultur. In this context, as mentioned earlier, material needs to be understood not only in a physical but also in a digital context, where craft allows addressing the gap between the actual situation of digitalization and its potential. The digital will influence the shape of a building and Baukultur is binding all of the above, based on the quality of space and acceptance through society. Materials are at the heart of innovation and development and have had such an impact that they have defined key eras in the evolution of mankind. Whether it's stone, bronze, iron, the steel of the Industrial Revolution, or the birth of silicon, materials offer the possibility (and threat) of forever changing the way we live. In our built environment, materials are intrinsically linked to technical, constructive, functional and aesthetic aspects and philosophical issues of architecture. Conversely, most will agree that architecturally designed spaces are defined and bounded by materials, but the architecture itself emerges in between, on a meta-level, to achieve what the Davos Baukultur Quality System describes as Sense of Place and Beauty. It is thus stated that *"High-quality Baukultur is more than the absence of defects."* Achieving high-quality Baukultur goes beyond fulfilling the defined technical requirements, like a desired program, volume, or material; it is equally important to reach a consensus about cultural values debated and defined by society. (Davos Declaration Community, 2020).

4.0 BuildDigiCraft: material in the context of process and knowledge

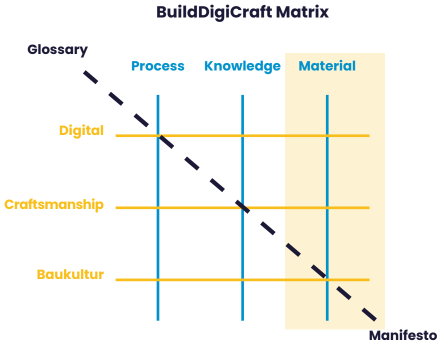
The **BuildDigiCraft** project, as described earlier, establishes a training network for young researchers, teachers, and practitioners that promotes innovative teaching approaches for shaping the built environment in the digital age. With the overall aim of contributing to the development of a high-quality Baukultur, the **BuildDigiCraft** project addresses the potential of digitalization and its effects on the built environment, with new teaching approaches aimed at enabling the introduction of an imminent and highly necessary cultural and organizational change in the planning and building sector in Europe.

The three pillars of the **BuildDigiCraft** project: material, knowledge and process are explored through a number of keynote lectures and ongoing PhD projects from the project network that through specific tasks are further developed, reflected upon, analyzed, and discussed. The **BuildDigiCraft** project reflects the understanding that the shaping of the built environment is a result of complex and diverse processes and includes design, planning, construction, and maintenance. The topics of the PhDs, the given tasks and the keynote lectures all reflect these. The organization of the **BuildDigiCraft** activities is carried out through the four Intensive Training Programs (ISPs) that are all organized around their own specific theme and content:

ISP1: Concepts and Fundamentals
ISP2: Digital Futures
ISP3: Craft and Craftsmanship
ISP4: Rethink Baukultur

The explorations with tasks closely related to the PhDs, Baukultur and the specific theme of the ISPs led to amazingly rich material. Although difficult to separate from each other, with the three perspectives of the **BuildDigiCraft** project Material, Process, and Knowledge that are present in all four ISPs, the ISP3 on Craft and Craftsmanship offers most of the data and results concerning the Material aspects.

5.0 Outcomes relating to material within the BuildDigiCraft project



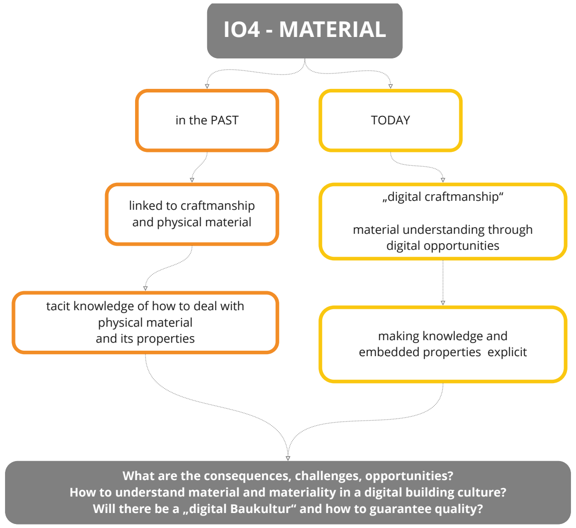
Fig[● 1] The different aspects leading to high-quality Baukultur (from **BuildDigiCraft**).

Returning to the ISPs – when looking at the reflections deriving from all ISPs, on an organizational level one can describe the contents “Knowledge,” “Process,” and “Material” as being influenced by the “craft” and “digital” and leading to new high-quality Baukultur.

Generally speaking, through craft and the digital, (high-quality) Baukultur is influenced by the available knowledge, the processes we utilize and an understanding of materiality. The overall project outputs have been analyzed and developed in taking these perspectives into account.

ISP3, focusing on Craft and Craftsmanship, explored:

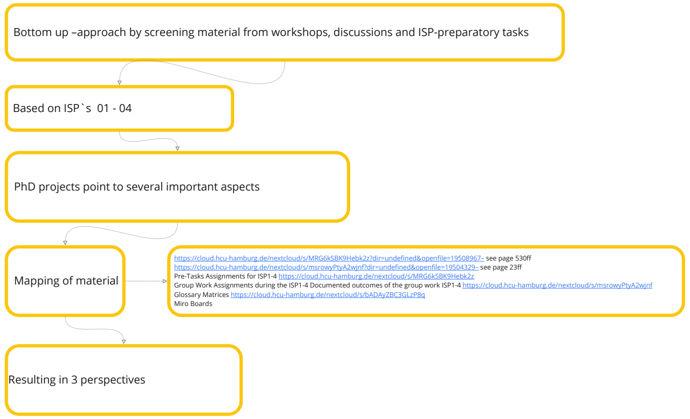
- *What is Baukultur in the digital age?*
- *What is the essence of the digital revolution in respect to the shaping of the built environment?*
- *How do we design, build, and maintain the built environment based on craftsmanship, data and algorithms?*
- *What are the qualities of craftsmanship, what is the essence of craft and craft-based production that we would like to transfer to the future digital shaping of the built environment?*



Fig[● 2] Diagram presenting a summary of outputs IO4 on Material.

The method of analyzing the data that resulted from the ISPs – with greatest input from ISP 3 – was “bottom up,” where the ISP pre-tasks, tasks, PhD presentations and keynote lectures were all mapped according to how they addressed material within the context of their work. This proved to be a good way forward although organizing the data was not always straightforward as a result of overlapping contents, questions and reflections. The mapping of the material (data) is presented in the image below with the links to the files of data from the ISPs.

Clarifying the trends and organizing the data required a long and thorough process. This was because of the richness of the created data, but also because there were more (good) ways of how the data could be read



Bottom up –approach by screening material from workshops, discussions and ISP-preparatory tasks

Based on ISP`s 01 - 04

PhD projects point to several important aspects

Mapping of material

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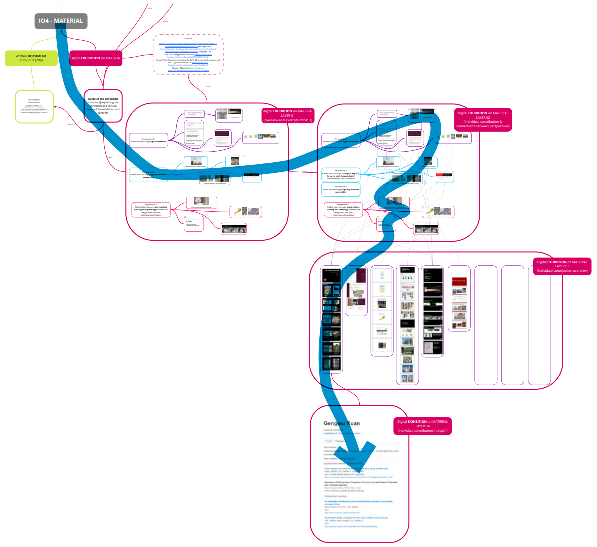
Pre-Tasks Assignments for ISP1-4 https://cloud.hcu-hamburg.de/nextcloud/s/MRG6kSBK9Hebk2z
Group Work Assignments during the ISP1-4 Documented outcomes of the group work ISP1-4 https://cloud.hcu-hamburg.de/nextcloud/s/msrowyPtyA2wjnf
Glossary Matrices https://cloud.hcu-hamburg.de/nextcloud/s/bADAyZBC3GLzP8q
Miro Boards

Resulting in 3 perspectives

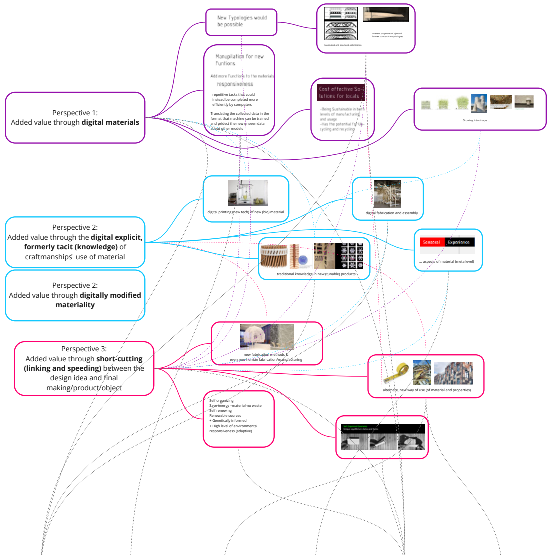
Fig[● 3] Mapping the material (data) relating to material within the overall **BuildDigiCraft** data.

and understood. In this process, it was important to look at trends, rather than search for specific answers. This required many reviews of the data, and also a challenging of the way it was presented, what the main messages were, how these should be understood, and how much the context colored the outcomes. Nevertheless, after several iterations the outcome became clearer and clearer pointing towards three perspectives that were derived by analysis of the data. The pathway through the material data is presented in the screenshot of the interactive whiteboard, with the next one presenting the complexity of the relations and interconnectivity of the ISP material that was studied, mapped, and reflected upon.

Fig[● 4] Screenshot of the interactive whiteboard presenting the mapped data related to material.



Fig[● 5] The data is complex and relates to each other in complex ways. The interconnectivity is on a multitude of scales and levels. Despite the complexity, three clear perspectives can be identified that emerge from the data.



6.0 Three perspectives – findings and discussion

Perspective 1. Added value through digital materials

*Digitally defined/created/optimized/fine-tuned **materials** will have a designed performance. This will embrace both measurable and qualitative Baukultur values.*

Perspective 2. Added value through digitally modified materiality

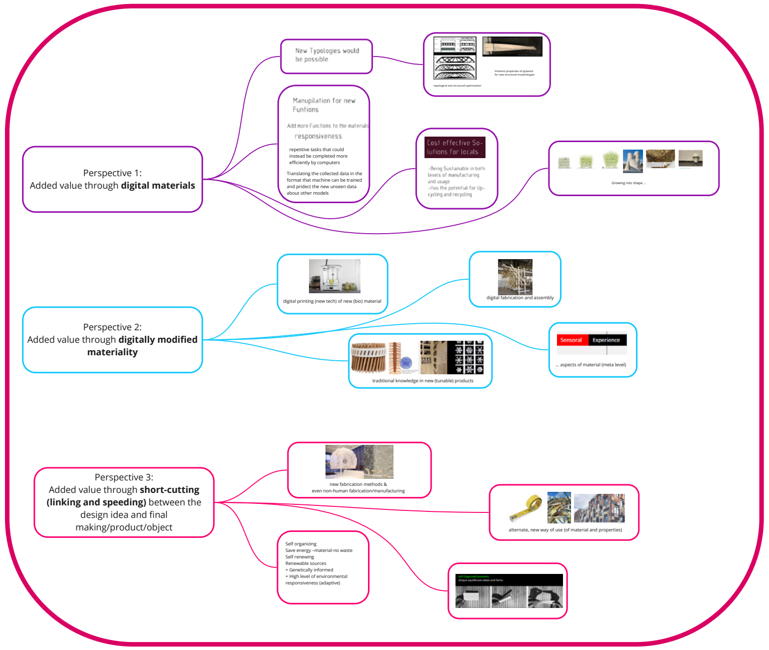
*Building longevity, good indoor climate, resources optimization can be achieved through digitally modified **materiality** – achieving values closely associated with Baukultur.*

Perspective 3. Added value through short-cutting digital workflows

Linking and speeding between the design idea and final making/product/object digital workflows enable real-time simulations and optimizations. Constructing while testing and before designing enables new workflows and opportunities that will secure quality.

The above are the three most important findings – perspectives of all the data related to material. They are organized as shown in the interactive whiteboard diagram below:

Fig[●6] The three perspectives.



Perspective 1. Added value through digital materials

Digitally defined/created/optimized/fine-tuned ***materials*** *will have a designed performance. This will embrace both measurable and qualitative Baukultur values.*

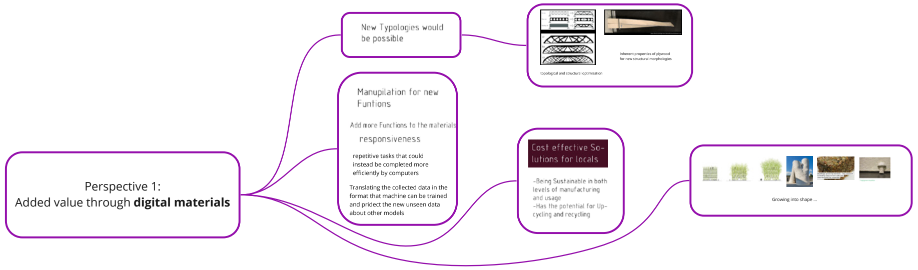
An example of this can be presented through new material technologies where material as data and material as a physical entity cannot be separated. If we look at 3D printing, it enables new, different, complex-built forms to be produced (fabricated and constructed) that are optimized. The 3D printed design of the bridge has an optimized form, performance, and buildability. Furthermore, it is constructed (3D printed) by a robot with a very high level of quality control. The construction workers are no longer exposed and dependent on weather conditions. Instead they work in a laboratory where the robotic constellation does the “physical” work. The processes ensure quality and workers’ safety at the same time.

Fig[●7] Concrete 3D printed bridge design.

Fig[●8] 3D printing of concrete using robotic production methods.

A further advantage is that the materials can be optimized based on performative requirements (as graduated material behaviors) or with the structural elements offering the required performance using an optimized – minimal amount of material. This can contribute to optimizing resources in use and lead to a more sustainable way

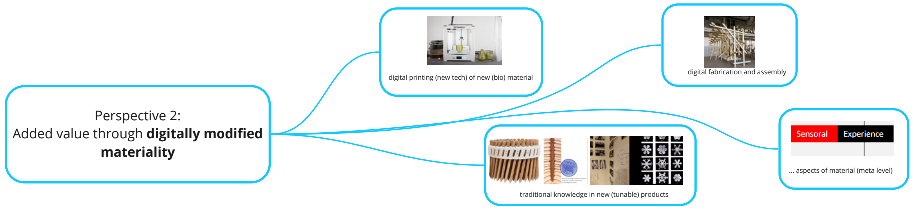
Fig[●9] Perspective 1: added value through digital materials.



of building. One can also argue that through Perspective 1 – Added value through digital materials: digitally defined/ created/optimized/fine-tuned materials will have a designed performance – that we could contribute to a high-quality Baukultur. However, all of these technologies will have to be tested against their social acceptance and time.

Perspective 2. Added value through digitally modified materiality

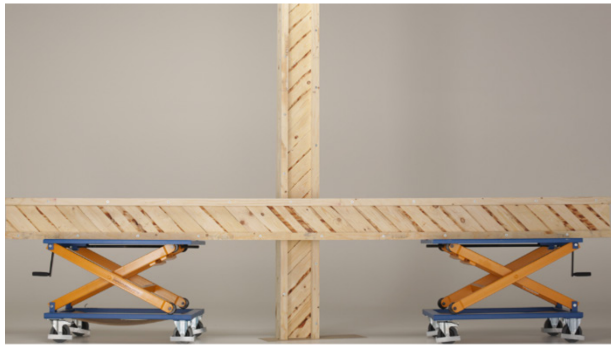
Building longevity, good indoor climate, resources optimization can be achieved through digitally modified ***materiality*** *– achieving values closely associated with Baukultur.*



Fig[●10] Perspective 2: Added value through digitally modified materiality.

This perspective points towards huge opportunities for working with digital technologies and material where we have the possibility to create a digitally modified materiality. An example can be working with materials that are discarded (waste/leftovers) that offer material performances that are reliable. *Material Value(s): Motivating the architectural application of waste wood*, (Browne et al., 2022) investigates the Brusenius-inspired beam topology made out of waste wood, showing performance that is reliable and comparable to a structure made out of new wood.

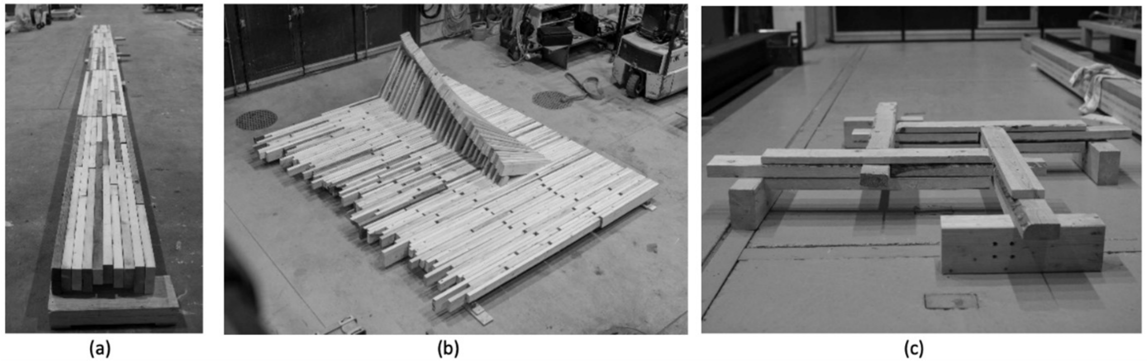
Timber-only structures and architecture: using salvaged timber and wooden nails only by Gengmu Ruan and *Architectural design from upcycled formwork wood: perspectives on new physical and aesthetic qualities of waste wood, computer vision and algorithm-assisted façade design* by Gabrielle Nicolas may provide further examples of how digital technologies and (salvaged) material create a digitally modified materiality. For both projects the aspect of materiality that incorporates the material as well as an effect on people and the environment is essential (Ruan et al., 2022b). The context and the interactions it contains come into focus, and materiality is thus consciously designed and located material.



Fig[●11] Brusenius assembly – post and beam.

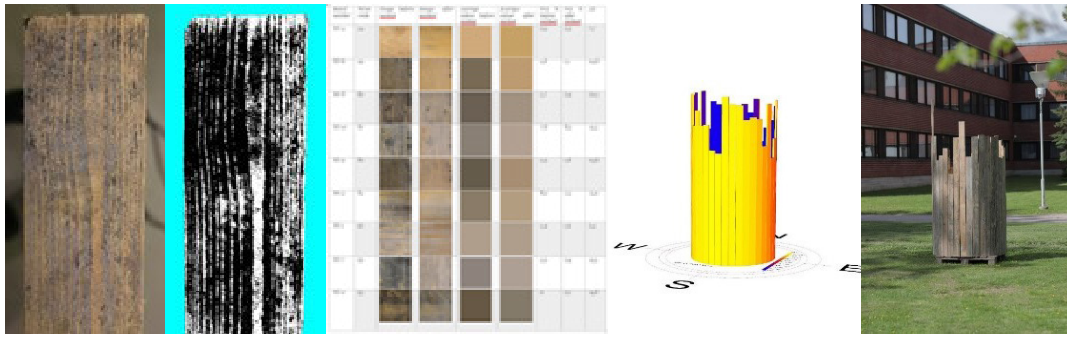
Fig[●12] Brusenius beam made out of reclaimed wood – close up.

Timber-only structures and architecture focuses on integrated sustainable, structural, and architectural design concepts for timber-only structures, more specifically, structures made from salvaged timber and wooden nails only (Fink et al., 2019; Ruan et al., 2021). The key elements discussed in this ongoing PhD research are connection, material, structure, and architectural form. Similar to what is suggested in Oxman and Oxman, 2010, a sequence of "Material and connection first, structure second, architecture third" is applied. Material properties, structural behaviors of possible connections and the entire structure, as well as architectural and structural benefits and limitations are explored by means and design-build-loops (Ruan et al., 2022) of physical (Ruan et al., under review) and digital exploration. Basically, the goal is to introduce salvaged-timber approaches to the field of structures and architecture as an elegant, ecological and efficient option.



Fig[●13] Design showcases: (a) modular elements for Kouvola trail project, (b) a partly curved plaza for Kouvola trail project, and (c) a planar reciprocal frame unit which consists of four beam elements.

“Architectural design from upcycled formwork wood: perspectives on new physical and aesthetic qualities of waste wood, computer vision and algorithm-assisted façade design” explores innovative façade structures from waste wood with the help of machine-learning techniques such as computer vision (Nicolas and Filz, 2022). The hypothesis of this research was driven by the main aspect that concrete remaining on the formwork wood can be considered to be given a new surface treatment/coating instead of turning the wooden boards into waste. Conversely, it can provide the material physical and aesthetic properties not previously considered. Gabrielle Nicolas combined photographic scans, image processing and computer vision, and with UV testing and water absorption tests sought to understand the performance of the new wood material and coating. Quantitative and qualitative results of the UV tests, weathering tests and grade of surface coating are used as input data to create algorithm-assisted customized architectural designs. Combined with actual weather and climate data, Gabrielle presented the showcases of façade designs in two locations – Brussels and Helsinki. In conclusion, this project deals with the opportunity of looking into future scenarios of material performance using machine-learning techniques such as computer vision to simulate and predict technical and visual effects. This takes place after digitally exploring and simulating a full-scale demonstrator of a representative façade design that was built and exhibited at Aalto University.



Fig[●14] Architectural design from upcycled formwork wood, from physical object via computer vision techniques to simulation and real-world application.

WasteWood Canopy, (Larsen, 2022) is a recent project investigating structural application of reclaimed wood, combining crafting methods, tacit material knowledge, and digital (material) data in both physical and digital workflows. The project worked with multi-objective optimization where a number of aspects such as Architecture/Aesthetics, Buildability/Ease of construction and Structural performance were continuously weighed out against each other. The comparisons, relationships, and influence between the factors were optimized so that the outcome – the inhabitable structure in architectural scale (demonstrator) could be designed to achieve a performance that is as high as possible in a holistic way and in all three spheres of influence. It is clear that by achieving a single factor, optimization would give higher results to one factor compared to the multi-objective optimization, which addresses several factors simultaneously (Popovic Larsen and Browne, 2022). However, addressing problems holistically is more beneficial as it mirrors reality in building design practice where it is very rare that we need to optimize one factor only. Furthermore, our current ability to handle complex data combining digital material knowledge with knowledge on physical material offers huge potential opportunities in dealing with the complex challenges that we are facing.

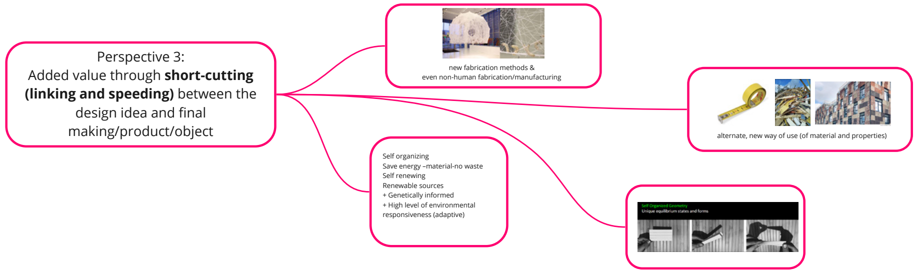
Fig[●15] WasteWood Canopy – exhibition "70% less CO2" at the Royal Danish Academy.

Fig[●16] Examples of façade panels made out of reclaimed wood: Nordic Waste Wood for Good project.

Added value through digitally modified materiality can lead to increasing the building's longevity, securing better indoor climate and if we use resources in an optimized way, it will be a step towards addressing the climate crisis. However, the technical aspects are not the most difficult to deal with. To use and re-use materials that we currently regard as waste, we need to develop a whole new way of approaching design. In addition, a paradigm shift about defining quality needs to happen. A recent project exploring opportunities for re-use of different wood waste streams for façade panels, Nordic Waste Wood For Good, investigated not only the material, design, and detailing aspects, but also tested the social acceptance of the designs (Popovic Larsen and Browne, 2022). If the technical, aesthetic, and social aspects can be handled, this can also contribute to a high-quality Baukultur. However, all of these approaches and technologies will have to be tested against their social acceptance and time.

Perspective 3. Added value through short-cutting digital workflows

Linking and speeding between the design idea and final making/product/object digital workflows enable real-time simulations and optimizations. Constructing while testing and before designing enables new workflows and opportunities that will secure quality.

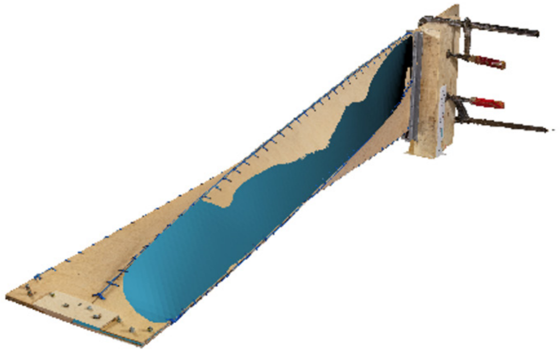


Fig[●17] Perspective 3: added value through short-cutting (linking and speeding).

Building in parallel with designing or building before having the complete design is something digital workflows enable. With this short-cutting, processes results can be optimized, all leading to improved quality and Baukultur for the future that relies on new digital opportunities but celebrates qualities of crafting and tacit knowledge brought into the new millennium.

PhD research by Serenay Elmas, who explores elastic torsion as a design driver for structures and architecture, may serve as a showcase for achieving added value through short-cutting digital workflows (Elmas et al., 2021). The main focus of this research is set on twist and torsion and in more detail on bending-active torsional structures with regard to their geometrical, structural, and architectural potentials, limits, and qualities. It looks into a method of framing a self-organized process by combining bending-active aspects (Lienhard et al., 2013) with torsion, which results in a novel typology of lightweight structures. In particular, this research investigates the advantages of such typologies in conjunction with the geometric stiffening, the generation and control of geometry itself, possible bi-stable equilibrium states through the introduction of torsion during the process of form-generation as well as fields of real-world application. The methodology for this study includes both computational and physical approaches. Multi-disciplinarity and parametric design thinking have a crucial role in addressing and solving the questions. Since this particular way of using elastic torsion results in large deformations and non-Euclidean geometries, geometric non-linearities have to be considered. However, after a phase of exploration of material properties and material parameters, the principle findings of material behavior were compared with results from the digital exploration by physics engines. Geometrical observations were evaluated and verified by photogrammetrically generated point-clouds (Filz et al., 2022). A similar procedure has been applied to the structural aspects – physical testing verifying the computational simulation and results – linking and bi-directional bridging between disciplines (Filz et al., 2021). After only a few cycles a purely digital workflow can be established, which not only takes geometrical aspects and structural performance of the single member into account, but also the process of assembly (Elmas et al.) and change of geometry, i.e., the large deformation of the material during this process. Since the exact deformed geometry is known, a wide variety of configurations of the elements can be explored in further steps and in a purely virtual environment and evaluated from different points of view. As a real-world implementation, as part of a larger architectural structure and together with other parameters such as user-structure interaction, a fully digital prototype can be designed, explored, and investigated as firstly demonstrated in the kinematic research pavilion “Zero Gravity” (Filz et al., 2019) realized by the team of ASA (Aalto University Structures and Architecture) in 2019 (Markou et al., 2021).

Fig[●18] Photogrammetric reconstruction of the beam element compared with the mesh from the computational simulation and Zero Gravity research pavilion at Väre building, Aalto University, October 2019, image credit: Lassi Savola.



7.0 Discussion

Within IO4 of the **BuildDigiCraft** project, we discussed Material and its role within the changing digital opportunities of current building research and design practice. The discussion took place on the basis of mapping the data created through the keynote lectures, pre-tasks, PhD projects, tasks and discussions. The rich data was organized, analyzed, discussed, reflected upon. The data suggested the three perspectives presented here.

Digital tools and material practice

The digitization of manufacturing tools has radically changed production. Where computers and numerically controlled machinery have introduced a high level of precision consistency and quality as well as considerable time-efficiency and the ability to deal with high levels of complexity and variance, this approach has also introduced a new category of tools that has profoundly changed the way we understand and perform not only manufacturing but also data collection, transformation, use, and application. Most of the works presented within the framework of the **BuildDigiCraft** project (**BuildDigiCraft**, 2022) have shown one or several of these aspects. This paper may refer to ISP3 (ISP3: Craft and Craftsmanship – **BuildDigiCraft**, 2022), which can be found on the **BuildDigiCraft** web page as well as in its exhibition section (Exhibition – **BuildDigiCraft**, 2022). There is also a recognizable introduction of shared digital platforms creating new interfaces between design, performance, analysis, and fabrication. The increased focus on digitally defined work processes has enabled highly precise and complex design investigations and also the linkage to production with file-to-factory technologies. Here information is directly passed from the design to the fabrication – beginning with data that is used as material, which then undergoes a process and manifests itself in physical artifacts. The used digital tools – often self-programmed – allow architects, designers, engineers, and researchers to reconsider theoretical concepts as well as material practices. Programming is used as a design tool, a new computer logic and a new source of creativity for designers, architects and engineers. In many cases, programming goes along with ready-made, digital tools, and software that is often borrowed from other disciplines and applications.

Material thinking as a design driver

The use of digital tools, digital processes, and digital technology in general shift virtual and digital material thinking into the core of design. This way, new structural, material and tectonic potentials can be explored pushing the boundaries of the disciplines. These approaches – observed within the **BuildDigiCraft** project and from the work of its contributors – can to a certain extent be understood as digital crafting (ISP2: Digital Futures – **BuildDigiCraft**, 2022). Digital crafting shifts manufacturing from a practice-based knowledge residing with the craftsman as tacit knowledge to an integrated practice that also connects with other disciplines during the design and implementation phases.

The concept of material performance

Digital fabrication necessitates a good understanding of crafts traditions and their processes. Designing within and for digital processes and fabrication means understanding the highly developed traditions of material handling, tectonics and their meaning for the design and application space. Together this leads to an enhanced interest in the material and its performance (ISP1: Concepts and Fundamentals – **BuildDigiCraft**, 2022). The creation of new digital material and possibly tuned material suggest new active material understanding also allowing them to provide feedback on the design processes. Finally, digital processes and fabrication allow the exploration of the potential of material thinking, which enables the designers to engage directly with material rather than understanding standardized, prefabricated, and out-of-the-shelf building materials. This opens up new perspectives of highly specified and customized material descriptions, manipulations and therefore material performance. These approaches can be achieved by tuning and creating new material, and by introducing these new concepts, graded material and variations thereof in direct response to their contextual and programmatic aims for a new material culture that can be highly connected to industrialization and which is at the same time questioned on a fundamental level.

The opportunities – but also challenges – in the data analysis for IO4 Material were that the:

- data was very rich – this was both an opportunity, but also a challenge as it was not easy to handle
- data could be understood, handled and analyzed in more than one (good) way, which required many iterations
- iterations gave clearer suggestions of the trends, presented through the three perspectives

By analyzing the material (data) for IO4 – Material, one should point out that the outcome and conclusions are as rich as the data that was studied. The three perspectives suggest three possible ways of how high-quality Baukultur can be achieved. It is interesting to witness whether they will prove to be on point or not. The test of time and social acceptance as well as further research will provide more answers in the future.

8.0 Conclusion

In conclusion, the **BuildDigiCraft** project reflects upon several crucial questions in relation to material:

1. *Material vs. data = material vs. immaterial?*

The digital (data) is the new material. In the last few decades an entirely new conception of the material world has emerged, as unlike physical components, this material is invisible and intangible. What is known as Industry 4.0 also has implications on our future Baukultur and refers to the intelligent networking of machines and processes with the help of information and communication technology. The possibilities include flexible production and manufacturing, convertible, and modular production lines, customer-oriented and customized solutions, optimized logistics, combined and analyzed use of data, resource-efficiency, and circular economy. Besides information and data-driven tuning, designing, and composing of new materials, the flow of data and the used technology is stored as an aesthetic feature and trace in the final artefact. This phenomenon is for example most visible in CNC-milled components or the surfaces of 3D-printed objects. The physical and digital are closely connected. They are actually inseparable: they flow between and are closely linked supporting each other's existence. They are truly "one."
The data is the material and any material can be described as or by data. That clearly offers opportunities but also challenges.

2. *Material and sustainability?*

With new digital material an understanding of material's behavior and performative qualities can be tuned, customized and optimized, which may lead to the development of new materials with specifically designed or bespoke performance. Furthermore, building with what we currently consider as waste becomes possible and offers new potential of resource optimization as well as a rise to a new aesthetic paradigm based on material agency.

3. *Where are we in terms of digitalization?*

Currently, we are able to handle huge and complex forms of data. If, however, we look at the history of digitalization, it is very short in comparison to history of our civilization. The development in digital workflows, processes, and tools is extremely fast. Systems of a few years ago that at the time were presenting the height of human achievement in the field are not only obsolete, but also impossible to use. The data we use is short-lived if supporting digital systems are outdated and thus, not there any longer. A relevant challenge to address is how to store, manage, and in some cases restore data in future as systems and software are subject to constant change.

If we, on the other hand, look at buildings that we celebrate as high-quality Baukultur, they are built to last for hundreds of years. It is essential that digital systems, tools, and flows should have the in-built robustness and adaptability throughout the buildings' lifecycles and beyond. The question of how to guarantee the longevity of data, the associated data accessibility, the synchronization of data and the realized artifacts, which are based on this data, remains open.

Another important aspect related to data is that we need to understand the data and its potential impact on more qualitative values. Also, we need to connect material knowledge better with design and construction. How to store, manage, and in some cases restore data in future as systems and software change? In this context, tacit knowledge, if unused, is just as at risk of being lost as digital data is.

If we look at the craftsmen of the past, they passed the data on physical material through tacit knowledge. The "new" digital form of material data is very rich but still detached from the tacit craftsmanship process and knowledge. The symbiosis of material, design and construction knowledge, and (digital) data is very powerful.

4. *Material and a "new beauty"? What is the level and amount of data to guarantee beautiful structures/spaces?*

Baukultur as we know it epitomizes building quality, beauty, embraces aesthetics and human/use values where materials are crafted to a level that ensures the quality that Baukultur stands for. Many of the architectural masterpieces of the past were created before the emergence of digital opportunities. Digital workflows enable us to handle complexities of building projects at present. Matching data levels/requirements for achieving the quality of a new Baukultur is essential.

A final comment that arises from the **BuildDigiCraft** project relating to material is that digital materials/data will not replace the physical realm. For a high-quality Baukultur, the physical and digital realms are becoming increasingly inseparable and have the potential to inspire each other. Therefore, the crafting qualities, tacit knowledge, the qualitative-unmeasurable qualities have to be interlaced in new meaningful ways with the digital, quantifiable and data-driven ones. This will result in future high-quality Baukultur as it is envisaged in many of the **BuildDigiCraft** project's examples. For achieving high-quality Baukultur, it is essential to establish the connections between data, material, design, and construction knowledge – making the tacit explicit.

9.0 References

ARGAN, G. C. (1969) *«The Renaissance City(Planning and cities)»*, New York: G. Braziller.

BENTLEY, D. (ED) (2007) *«Architectural Geometry»*, Exton, Pa., Bentley Inst. Press.

BILLINGTON, D. P. (1985) *«The Tower and the Bridge: The New Art of Structural Engineering»*, Princeton, N.J., Princeton Univ. Press.

BILLINGTON, D. P. AND GARLOCK, M. M. (2004) *«Thin shell concrete structures: The master builders»*, Journal of the International Association for Shell and Spatial Structures, vol. 45, no. 146, pp. 147–155.

BROWNE, X., LARSEN, O. P., FRIIS, N. C. AND KÜHN, M. S. (2022) *«Material Value(s): Motivating the architectural application of waste wood»*, Architecture, Structures and Construction.

BUILDDIGICRAFT (2022) [Online]. Available at https://www.builddigicraft.eu/ (Accessed October 9, 2022).

DAVOS DECLARATION COMMUNITY (2020) *«The Davos Baukultur Quality System: eight criteria for a high-quality Baukultur – the whole story»* [Online]. Available at https://davosdeclaration2018.ch/media/DBQS-the-whole-story-en.pdf (Accessed June 27, 2022).

ELMAS, S., FILZ, G. H. AND MARKOU, A. A. (2022) *«An ephemeral, kinematic pavilion in the light of assembly/disassembly and material use/reuse»*, in Architectural Research in Finland 2022.

ELMAS, S., FILZ, G. H., MARKOU, A. A. AND ROMANOFF, J. (2021) *«Zero Gravity: a novel cantilever beam utilizing elastic torsion for structures and architecture»*, Proceedings of IASS Annual Symposia [Online]. Available at https://research.aalto.fi/en/publications/zero-gravity-a-novel-cantilever-beam-utilizing-elastic-torsion-fo.

EXHIBITION – BUILDDIGICRAFT (2022) [Online]. Available at https://www.builddigicraft.eu/exhibition/ (Accessed October 13, 2022).

FILZ, G. H., ELMAS, S. AND MARKOU, A. (2019) *«Zero Gravity 2.0 Exhibition | Aalto University»* [Online]. Available at https://www.aalto.fi/en/research-art/zero-gravity-20-exhibition (Accessed May 11, 2022).

FILZ, G. H., ELMAS, S. AND MARKOU, A. A. (2022) *«The structural geometry of a beam element from 4 torqued strips»*, in Cruz, P. J. and Hvejsel, M. F. (eds) Structures and Architecture A Viable Urban Perspective?, London, CRC Press, pp. 150–158.

FILZ, G. H., ELMAS, S., MARKOU, A. A., HÖLTTÄ-OTTO, K. AND DEO, S. (2021) *«Zero Gravity: radical creativity by multidisciplinary collaboration»*, Inspiring the Next Generation. Guildford, UK, August 23–27, 2021, IASS - International Association for Shell and Spatial Structures, (full paper accepted).

FINK, G., RUAN, G. AND FILZ, G. H. (2019) *«Sustainable design concepts for short span, timber-only structures»* [Online], IASS, Annual Symposium of the International Association for Shell and Spatial Structures. Available at http://congress.cimne.com/Formandforce2019/frontal/default.asp and https://www.ingentaconnect.com/content/iass/piass.

ISP1: CONCEPTS AND FUNDAMENTALS – BUILDDIGICRAFT (2022) [Online]. Available at https://www.builddigicraft.eu/isp1_concepts_and_fundamentals/ (Accessed October 13, 2022).

ISP2: DIGITAL FUTURES – BUILDDIGICRAFT (2022) [Online]. Available at https://www.builddigicraft.eu/isp2-digital-futures/ (Accessed October 13, 2022).

ISP3: CRAFT AND CRAFTSMANSHIP – BUILDDIGICRAFT (2022) [Online]. Available at https://www.builddigicraft.eu/isp3-craft-and-craftsmanship/ (Accessed October 13, 2022).

LARSEN, O. P. (2016) *«Conceptual structural design: Bridging the gap between architects and engineers»*, ICE Publishing.

LARSEN, O. P. AND TYAS, A. (2003) *«Conceptual Structural Design: Bridging the gap between architects and engineers»*, Thomas Telford Publishing.

LIENHARD, J., ALPERMANN, H., GENGNAGEL, C. AND KNIPPERS, J. (2013) *«Active Bending, a Review on Structures where Bending is Used as a Self-Formation Process»*, International Journal of Space Structures, vol. 28, 3–4, pp. 187–196.

MARKOU, A. A., ELMAS, S. AND FILZ, G. H. (2021) *«Revisiting Stewart–Gough platform applications: A kinematic pavilion»*, Engineering Structures, vol. 249, p. 113304 [Online]. DOI: 10.1016/j.engstruct.2021.113304.

NICHOLAS, C. AND OAK, A. (2020) *«Make and break details: The architecture of design-build education»*, Design studies, vol. 66, pp. 35–53.

NICOLAS, G. AND FILZ, G. H. (2022) *«Architectural Design from Upcycled Formwork Wood: Perspectives on New Physical and Aesthetic Qualities of Waste Wood, Computer Vision and Algorithm-Assisted Façade Design»*, in Architectural Research in Finland.

OXMAN, R. AND OXMAN, R. (2010) *«New Structuralism: Design, Engineering and Architectural Technologies»*, Architectural design, vol. 80, no. 4, pp. 14–23.

PARASONIS, J. AND JODKO, A. (2013) *«Architectural engineering as a profession: Report on research leading to a curriculum revision»*, Journal of Civil Engineering and Management, vol. 19, pp. 738–748.

POPOVIC LARSEN, O. AND BROWNE, X. (2022) *«Nordic Waste Wood for Good»* [Online], Royal Danish Academy.

POPOVIČ LARSEN, O. (2020) *«Physical modelling for urban design and architecture: A design practice tool»*, London, ICE Publishing.

POTTMANN, H., KILIAN, A. AND HOFER, M. (2008) *«Advances in Architectural Geometry Conference Proceedings 2008»*.

RUAN, G., FILZ, G. H. AND FINK, G. (2022) *«Master Builders revisited - the importance of feedback loops: a case study using salvaged timber and wooden nails only»*, in Architectural Research in Finland.

RUAN, G., FILZ, G. H. AND FINK, G. (UNDER REVIEW) *«Shear capacity OF timber-to-timber connections using wooden nails»*, Wood Material Science & Engineering.

RUAN, G., FILZ, G. H. AND FINK, G. (2021) *«An integrated architectural and structural design concept by using local, salvaged timber»*, IASS Annual Symposium 2020/21 & the 7th International Conference on Spatial Structures: Inspiring the Next Generation At: Guildford, UK [Online]. Available at https://research.aalto.fi/en/publications/an-integrated-architectural-and-structural-design-concept-by-usin.

RUAN, G., FILZ, G. H. AND FINK, G. (2022b) *«SALVAƏƎ – sustainable use of salvaged wood»* [Online], Aalto University Aalto. Available at https://www.aalto.fi/en/events/salvage-sustainable-use-of-salvaged-wood (Accessed June 9, 2022).

SAINT, A. (2007) *«Architect and engineer: A Study in Sibling Rivalry»*, New Haven [u.a.], Yale University Press.

SETAREH, M., JONES, B., MA, L., BACIM, F. AND POLYS, N. (2015) *«Application and Evaluation of Double-Layer Grid Spatial Structures for the Engineering Education of Architects»*, Journal of Architectural Engineering, vol. 21, no. 3.

SWEET, K. (2016) *«Resurrecting the master builder: A pedagogical strategy for robotic construction»*, Automation in Construction, vol. 72, pp. 33–38.

TORROJA, E., POLIVKA, J. J. AND POLIVKA, M. (1958) *«Philosophy of Structures»*, University of California Press.