Socio-technical Challenges in the Digital Gap between Building Information Modeling and Industry 4.0

Peter de Lange[1], Boris Bähre[2], Christiane Finetti-Imhof[3], Ralf Klamma[1], Andreas Koch[4], Leif Oppermann[5]

[1 2 4]RWTH Aachen University, 52074 Aachen, Germany
[3]TFI-Institut für Bodensysteme an der RWTH Aachen e.V., 52068 Aachen, Germany
[5]Fraunhofer FIT, Birlinghoven Castle, 53757 Sankt Augustin, Germany
[1]{lange, klamma}@dbis.rwth-aachen.de,
[2]baehre@caad.arch.rwth-aachen.de,
[3]c.finetti@tfi-online.de,
[4]andreas.koch@ita.rwth-aachen.de,
[5]leif.oppermann@fit.fraunhofer.de

Abstract. Building Information Modeling (BIM) and Industry 4.0 are complex application domains. Doing interdisciplinary research with architects, engineers and computer scientists at the intersection of the domains is both challenging and promising, since many relevant research problems need multi-perspective views and cooperatively designed solution strategies. In this paper, we envision a socio-technical solution strategy, based on the common understanding that communication and cooperation is mission-critical for the overall success of the deployed information system, the design process and the final result of the mission, the building. To that end, we sketch the challenges and discuss a running construction project as a real application scenario. Our solution includes the use of serious gaming strategies, near real-time collaboration and mixed reality. The results show that despite the tough cost and time restrictions, innovative and relevant research in interdisciplinary research and development teams is feasible.

Keywords: Socio-Technical Approaches, Building Information Modeling, Industry 4.0

1 A Digital Gap: BIM and Industry 4.0

Building Information Modeling (BIM) describes a methodology of generating a digital representation of all aspects of a building. This includes not just a 3D model, but an integrative building process that takes the whole life-cycle of construction and fabrication (from idea to planning, construction, operation, facility management, reuse and even demolition) into account [3]. Introduced at the beginning of this century in the US, BIM slowly spread around the globe. It already landed in a lot of industries under different names, examples are the aircraft industry (*Integrated Modular Avionics*, IMA), or the car- (*Integrated Product Development*, IPD) and boat manufacturing (*Integrated Ship Design*, ISD). With the high-stretched goal of integrating and supporting the whole building life-cycle, it is hard to determine a common definition of what BIM is – and what it is not. Looking at the worldwide market, there are almost as many different definitions as users of BIM [3]. Reasons to introduce BIM are mainly internationalization, economic crises, new technologies, complexity and competition. Logically emerging from the development of technology and the new possibilities of current building industries (e.g. scanning, printing and digital fabrication), BIM is no standard introduced by a specific group of people, but a necessary adaption of the building industry to modern market requirements.

In order to exchange the information on building product performance and assembly situation, the capability of digital, industrial manufacturing strategies, namely *Industry 4.0*, can be exploited. The term stands for connecting and enriching industrial production processes with modern information and communication techniques, such as *Internet of Things* (IoT) or *Cloud Computing* technologies. Key elements of this strategy are connection and integration, meaning that all manufacturing and logistic processes are expected to be networked across companies in the future, in order to optimize the material flow, to recognize any possible mistakes at an early stage and to adapt quickly to changing market conditions [2]: starting with development, via manufacturing, operation and maintenance, up to recycling.

Despite all recent advances in the two domains BIM and Industry 4.0, there still exists a *Digital Gap* between the design of buildings, their construction and the building life-cycle. Within the development chain, from building design up to the building life-cycle, the construction process itself is an *Analogue Bottleneck* [1]. To eliminate this bottleneck and to close the existing digital gap, digitalization of the building sector (*BIM*) and digitalization of industrial production (*Industry 4.0*) should be linked to each other as shown in Fig. 1.

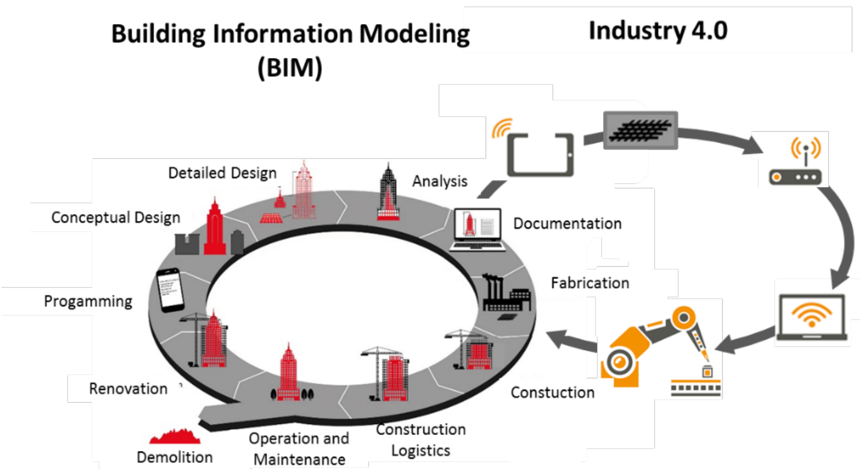

Fig. 1. Linking digitalization in the building sector (BIM [5]) with digitalization in the production sector (Industry 4.0 (own supplement))

Together, these two areas, BIM in the domain of planning and Industry 4.0 in the domain of production, will have a sustained impact on future building processes. Especially the rising need of *Mass Customization*, large-scale manufacturing of building parts, each tailored to special customer needs, will profit from the improved digital support (*digital-first* approaches) and automation the two areas of BIM and Industry 4.0 introduce to the construction domain. Here, knowledge and information exchange play a central role.

The cooperation between architecture, engineering and computer science has to be encouraged to link digital design processes with reality, thereby creating a new building culture of the future [1]. Complex networking of all involved stakeholders (architects, engineers, owner etc.) at an early stage, a close relationship and the intensive exchange of information will lead to a new construction process based on partnership [3], [4]. The potential of an integral digitization of building will be fully exploited when BIM and Industry 4.0 are linked to each other. But the development of an interface between these digitalization strategies calls for a new cooperation approach. In this paper, we propose a socio-technical approach to achieve the linkage of the two domains. We start by pointing out the current challenges (Chapter 2) before introducing our approach how to deal with these challenges (Chapter 3). We finish by describing a demonstration case (Chapter 4), in which we want to apply our approach in the near future.

2 Closing the Gap: Challenges on the Way

Looking at companies, institutions (i.e. building departments) and education reveals that we are at the beginning of an enormous change process in both the building- and construction industry – far more complex than just introducing the usage of new tools and technology. The transition from *Computer Aided Design* (CAD) to BIM is not comparable to the digitalization that happened during the shift from paper sketches to CAD in the 1980s. This is due to BIM being a methodology rather than (just) new tool support. To introduce an integrative approach like this, it needs commitment at a high level (top-down) to fundamentally change the whole process from planning to construction and fabrication. The same holds also for the digital transformation to Industry 4.0. Next to buyable technology and knowledge, a change of habits and mindset is needed to fulfill the integrative demands of both concepts [3]. In Germany, this fundamental shift in perspective is hindered by the economic boost bubble we are currently experiencing. Looking at worldwide developments, it becomes clear that the introduction of BIM is often connected to an economic crisis which made it necessary to rethink and optimize the processes in order to still be able to build or fabricate in a competitive manner. Changing a process requires people to leave their comfort zone. People situated in a booming market do not see the need for change. Therefore, telling people to change the process as an investment into the future is a recommendation that is difficult to communicate. In addition to these rather high-level factors, there are several further challenges we want to present here, categorized by the four domains process, policy, technology and people.

2.1 Change in Processes

Both BIM and Industry 4.0 represent a paradigm shift in building industries and industrial production. Rigid production structures with a hierarchical-inflexible control of production aggregate should be replaced by flexible structures with active, autonomous, self-controlling or self-organizing production units [9], [10], [11]. New business models and new models for cooperation constitute the real added value of Industry 4.0. However, this is not always apparent. Space for creativity needs to be established. This is a challenge for senior management: exploiting the new, innovative business opportunities offered by Industry 4.0 is not always easy while running a business on a day-to-day basis. To answer the questions how companies can learn and how change can be managed are of key importance here [12]. For BIM, the major challenge regarding change in processes will be to understand and practice “frontloading”. The management has to understand and accept, that using BIM in the first phases produces significantly more effort and costs than traditional construction approaches. Much more time is used to introduce parallel processes, where constructing complex models goes alongside extensive communication among all involved stakeholders, before the actual building process starts.

2.2 Changing Policies

Whilst the new planning and manufacturing processes and horizontal business networks found in Industry 4.0 will need to comply with the law, existing legislation will also need to adapt to take new innovations into account. The challenges include the protection of corporate data, liability issues, handling of personal data and trade restrictions. This will require not only legislation but also other types of action on behalf of businesses. An extensive range of suitable instruments exists, including guidelines, model contracts, company agreements or self-regulation initiatives, such as audits [14]. For Industry 4.0, the “Internet of Things, Services, Data and People” also opens up new avenues for data theft, industrial espionage and attacks by hackers. Cyber-attacks and viruses can have a devastating impact on Industry 4.0, potentially bringing networked and smart production systems to a standstill at substantial costs [12], making safety and security both critical to the success of smart manufacturing systems. It is important to ensure that production facilities and the products themselves do not pose a danger either to people or to the environment. At the same time, both production facilities and products – and in particular the data and information they contain – need to be protected against misuse and unauthorized access. This will require, for example, the deployment of integrated safety and security architectures and unique identifiers, together with the relevant enhancements to training and continuing professional development content [14]. Almost the same holds for the BIM domain. Countries, companies and institutions already committed to BIM and Industry 4.0 intensely experienced the necessity to develop execution standards, so-called *Execution Protocols*, to be able to work together on a trustful and reliable basis, introduced and kept by these common agreements. Execution protocols are templates, adjustable by the participants to specific project needs. They exist worldwide under different names and versions. Amongst others, the most important topics they specify are common project information, tools to be used across the different phases, roles and responsibilities, ways of how specific working steps need to be handled and fulfilled, information and data exchange and quality management. Both BIM and Industry 4.0 involve networking and integration of several different companies through value networks. This collaborative partnership will only be possible if a single set of common standards is developed. A reference architecture will be needed to provide a technical description of these standards and facilitate their implementation [14]. As already mentioned, there exist some approaches to form standards. Most prominently, in the BIM domain the *Industry Foundation Classes* (IFC) standard has to be mentioned here. But still, integration of these standards is not complete and many commercial applications rely on their own proprietary standards.

2.3 Technological Changes

The major challenge of BIM in terms of technology changes is that it takes into account objects over time, instead of focusing on elements on levels, like traditional CAD does. This shift from 2D/3D to n-D, where domains like time and money have to be modeled as additional dimensions, requires new modeling techniques and data formats. Since a BIM model represents a “digital twin” of the building process, including all construction steps and all decisions made during planning and construction, it changes over time and has to be adapted constantly. This shift from “passive to active data” needs to be coped with by new technology. Both BIM and Industry 4.0 generate enormous quantities of data. Gathering, analyzing and processing big data generate new insights, support decision-making and can create a competitive advantage. But the major challenge here is managing these large quantities of data, for example, by analyzing production data and coordinating the findings with customer information systems. Companies need to develop new specialist skills in the areas of analytics and efficient data management, and put new business processes in place on the basis of the insights that this analysis reveals [12]. Another important aspect is the exchange of data. New technological ways of collaboration on shared data are needed to achieve successful collaboration, also in distributed settings. There exists a need for standardized interfaces, so that machines in smart factories are able to communicate with each other and share data seamlessly with other smart infrastructures to achieve smart mobility, a smart grid, smart logistics and smart homes and buildings [12]. A range of systems in differing business segments, such as research and development, procurement and purchasing, production, warehousing and logistics, marketing, sales and services, needs to be taken into consideration with regard to networking [12]. Overcoming missing continuous networking, caused by missing uniform data standards, missing translation programs for different data standards and missing secure and simple ways for data transmission, is still a major challenge [8]. Finally, both BIM and Industry 4.0 rely on a broadband Internet infrastructure in the Gigabit range to allow for real-time data exchange between different distributed stakeholders, which can only be realized by a comprehensively available fiber network [13].

2.4 Working Style Changes – People's Adaption

Although often perceived the other way around, the social impact on organizations is mostly more important than the technology behind it. This is also known as the "90/10 rule" (see Fig. 2) that shifts the focus to the sociology involved in technological impacts, justifying socio-technical approaches.

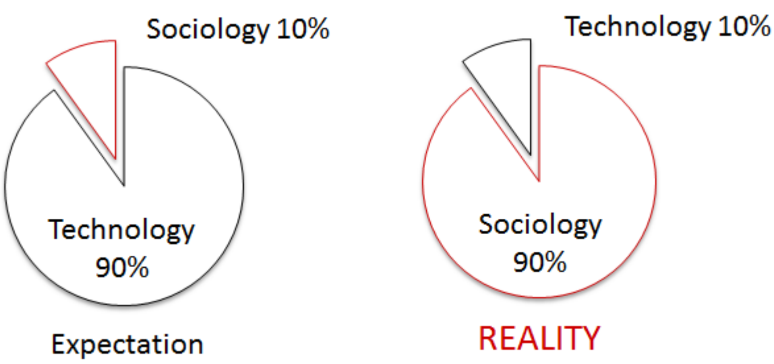

Fig. 2. 90/10 rule: perception vs. reality [19]

Digitalization processes increase the importance of adapting new technical skills, in Industry 4.0 notably in the case of operating activities and mechanical working processes in production, purchasing, warehousing and logistics. For BIM, the increased complexity of the building industry made it necessary for higher-level stakeholders to think and run processes in the role of a conductor: one does not need to know all the details of a certain aspect, but has to know the specialists that can help realize it.

Fig. 3. left (age 20): picks up processes and new technology fast
middle (age 40): finished with traditional education and asked to study again
right (age 60): experienced, knows how to build, needed if able to team up

New, process-dependent systems that make greater use of technology may prove to be a major challenge for existing employees. In some cases, employees require retraining or further training in operating these new applications if they want to make full use of them [12]. It is essential that long-term employees are continuously further qualified and trained in order to be able to keep pace with future developments [8]. This is especially important for mid-aged employees, who do not possess the high-level overview of older employees (who often have higher-ranked jobs that do not require tool adaption), but also in comparison to younger employees finished their traditional education a long time ago and are now asked to study new methodologies and tools (see also Fig. 3). An important aspect here is the needed change in "error culture". The attitude towards errors, both against own errors as well as against others', has to change in a way that errors are again seen as something to learn from, instead of being something only to be ashamed of. Industry 4.0 will radically transform workers' job and competence profiles. It will therefore be necessary to implement appropriate training strategies and to organize work, such that it fosters and enables lifelong learning [14].

3 A Socio-Technical Approach

3.1 Four Pillars of Integration

As already indicated by the challenges we described in the previous section, integrative approaches such as BIM and Industry 4.0 are methods based on the four pillars *Process*, *Policy*, *Technology* and *People* (see Fig. 4). The transition from classical planning methods (based on thinking in levels and single elements) to an integrative and process changing method (based on thinking in time and objects) needs to focus on the connections between these four pillars. To focus on just one of those pillars is possible, but would contradict the desired integrative approach. By taking all four pillars into account, all information within an integrative approach needs to be communicated multidirectional. Our proposal is to see communication as the "glue" that holds the whole process together – without strongly improved communication, integrative construction is not possible. Previously made BIM experiences in other countries support this idea [3]. Among existing developments, there is almost no focus on the social aspects of BIM or Industry 4.0.

Current BIM use is mostly driven by a demand of the market to use new technology and its possibilities. Process management, policy knowledge and education of building professionals seem not to be developed "at the same eye level". Our idea is to ask and examine the question, whether it should be mandatory within integrative approaches to develop and use socio-technical tools to support better processing within BIM and Industry 4.0, and therefore develop better projects and products. The palette of examples regarding planning mistakes, such as those made during the construction of projects like "BER", "Stuttgart 21" or "Elbphilharmonie" is long enough to rethink existing approaches. We claim that by taking the socio-technical aspect more strongly into account, the complete building and production processes of BIM and Industry 4.0 can be improved.

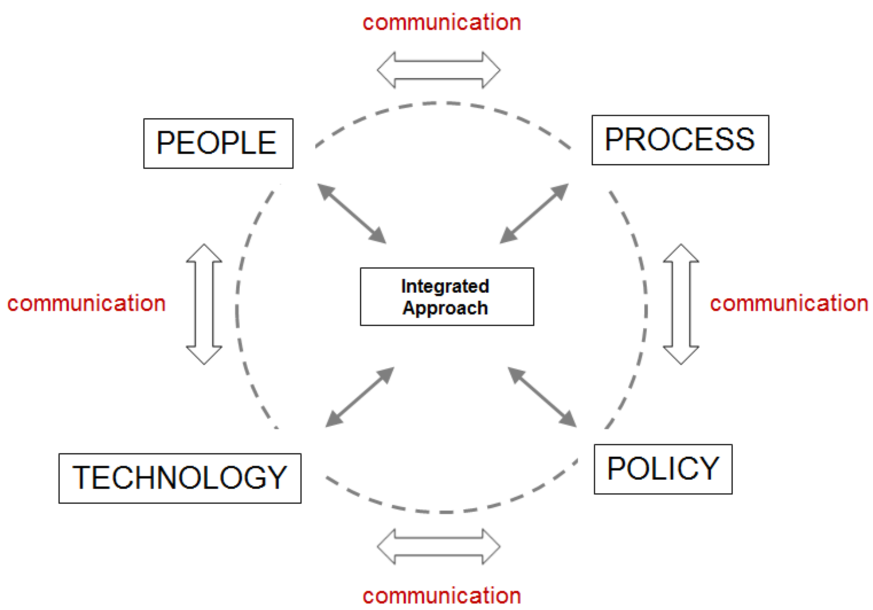

Fig. 4. Process, policy, technology and people, tied together by communication [19]

3.2 Tool Support

To enforce this socio-technical approach, we have a set of tools available that support communication and collaboration between all stakeholders of a BIM and Industry 4.0 project. We estimate two main approaches as key factors for the success of our socio-technical approach. The first is near real-time communication technology and *Mixed Reality* (MR) tool support, that build the technological underpinning for successful collaboration. The second trains the people's communication and collaboration skills by using team building workshops and serious gaming methods to raise the awareness for the changing requirements of this new way of building construction.

In most current projects, all stakeholders working locally in the same room or office is a rare phenomenon. This raises the need for technology that enables working collaboratively at the same time on the same documents without the need to actually be at the same place. Near real-time collaboration technology enables this by using the Web to propagate changes done by a collaborator to all others currently working on the document in (near) real-time. A prominent example for this technology is collaborative editing (Google Docs), but recent near real-time collaboration tools go beyond simple editing tasks. SyncMeta [7] is a framework for near real-time collaborative (meta-)modeling on the Web. The framework enables the definition of conceptual and visual aspects of a modeling language and allows generating model editors for these metamodels. The diagram editors used for modeling and metamodeling support synchronous, near real-time collaborative creation of models. The tool is fully open source (https://github.com/rwth-acis/syncmeta) and has been enhanced with support for collaborative definition of views and view-based collaborative modeling.

Using mobile devices, MR tool support brings the digital information for the current use context to physical locations, be it remote or on-site. Typical mobile devices in this sense are smartphones, tablets, smart glasses, and other wearables, but also traditional computers with projectors, head-mounted displays, and other more sophisticated setups that aid communication. In construction, architects and other stakeholders like to discuss over miniature models, which are traditionally made from wood or Styrofoam. Alternatively, computer generated images and videos are used for communication. While these all serve a particular purpose, they are often expensive, inflexible (when changes occur or variations need to be shown), and difficult and slow to transport in case of the physical models. They also generally do not allow for changing perspectives on the model from exocentric to egocentric, or for other views. Using MR technology, it is possible to carry an unlimited number of virtual models and variations in one's pocket, or connect to them over the Web, to display them in a variety of ways. Example applications to be build using this technology are not only limited to pure visualization, but can also aid communication and workflow, e.g. through issue-tracking to support ordering, installation, and approval of work on-site, or to aid maintenance. In the scope of our approach, we plan to use and adapt these technologies to the BIM and Industry 4.0 domain, since we are convinced that collaboration is one of the key factors for a socio-technical approach. Near real-time technology, used in modeling scenarios and combined with MR visualizations resembles a more natural way of peoples' communication, adapted to a distributed setting by using the Web as the transportation medium.

The second tool we consider important to introduce BIM and Industry 4.0 from a socio-technical perspective is the use of serious gaming [15]. Among a number of serious games available, we put our focus on a game using LEGO bricks to introduce different stakeholders into the domain of BIM. In team building workshops, participants are divided in groups of about five to ten persons and placed around a table. The group is told to build a certain (easy) LEGO structure. Each participant then receives an individual role which she is not allowed to tell anyone else of the group. Examples for these roles are that she is only allowed to build on a certain layer of the structure, or that it has to be ensured that only red stones are used for a certain element of the structure. During the following ten-minute building phase, participants are not allowed to speak to each other. After that, participants are invited to guess certain roles of other people and we show the linking to the BIM process. This "silent" building phase confronts the participants with their own ability to work in different roles of the BIM process, indirectly outlining the participants' strength and weaknesses.

3.3 Merging BIM and Industry 4.0

The linkage between BIM and Industry 4.0 enables a totally new and much closer connection between the participants of the planning process (e.g. architects) and the production companies (see Fig. 5). The task of designing new building products will no longer belong to the production companies, it will be part of the BIM process itself. This shift can only be realized, if the BIM-actors have the knowledge of the technical production opportunities of the specific companies. Furthermore, the production capabilities can also be linked to the BIM process and can be a part of the new "online" tender procedure. These challenges have to be mastered in the next years to achieve the next step of an integral planning process. The linkage of BIM and Industry 4.0 plays a major role to increase the efficiency of the construction process regarding time and cost aspects.

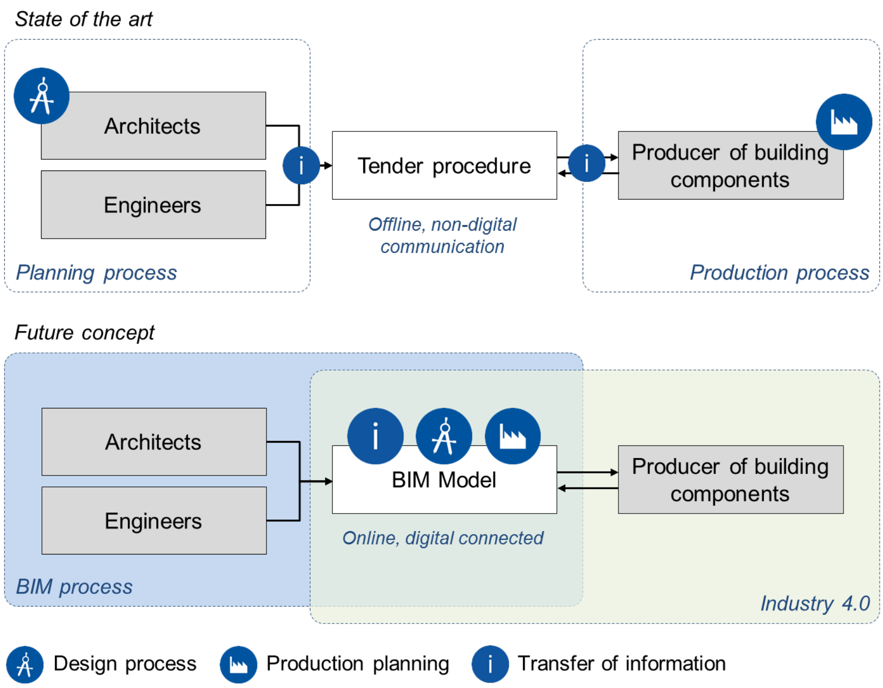

Fig. 5. Restructured, digital communication between the participants

4 Demonstration Case

To test the necessity of the socio-technical approach within BIM and Industry 4.0 we propose to conduct a construction project as test case. We found a real-case renovation project within the Birlinghoven castle building (Fraunhofer FIT campus), where we have the possibility to test the above-mentioned aspects of our socio-technical approach. The goal is to realize two connecting pathway structures between existing office buildings. By introducing the above-mentioned tool support into the planning process, in combination with newly developed material or new material use (i.e. supporting structure, facade material or architecture surfaces), we aim to show that there will be a significant change towards a better process flow, more accurate cost prediction, and avoidance of delay in project completion time. Up to now, we want to sketch here the following socio-technical tools to be used in the different project phases (see Table 1).

Building Phases	Socio-Technical Aspects	Proposed Tools
Project set-up	interviewing possible project partners team communication (all) selecting suitable project partners	human resources workshop serious gaming workshop human resources workshop
Planning	team communication (all) simulating, optimizing and adjusting presentation skills looping & evaluation knowledge documentation knowledge	serious gaming workshop MR visualization & communication public relation workshop process workshop administrative workshop
Construction	team communication (all) simulating building methods simulating construction simulation time & costs	serious gaming workshop remote communication support MR communication, issue tracking human resources workshop
Fabrication	team communication (all) simulating digital fabrication	serious gaming workshop mixed reality machine operation, remote maintenance & quality control
Operation/FM	team communication (user & planner) operate & service building parts	serious gaming workshop MR tools, e.g. remote maintenance
Reuse/Demolition	team communication (constructor & planner) disassemble building parts (objects)	serious gaming workshop MR communication decision support tools

Table 1. Proposed tools for different socio-technical aspects of our real-case evaluation project

Within the demonstration project the linkage of BIM and Industry 4.0 will be evaluated. Specifically, *Textile Reinforced Concrete* (TRC) facade panels representing the building envelope, and a floor covering representing interior fitting, will be used as the elements of our case study. TRC facade panels are currently produced precast and can easily be scaled and designed. Precast building components generally offer a good opportunity for the realization of a digital connection between BIM and Industry 4.0, because of the clearly defined production processes and material properties of the building element. Manufacturer of the textile reinforcements currently work with software tools (e.g. ProCad warpknit 3D®) for a virtual development of new textile structures. Some companies have already implemented the usage of these data formats directly on their production machines (which acts also as a good example for an implemented Industry 4.0 process). A digital linkage between the construction planning and building design (*BIM*) and the production process of the textile reinforcements (*Industry 4.0*) will open a next level of designing and producing textile reinforced concrete components. Material requirements can directly be defined within the BIM model and transferred to the digital development process of textile reinforced concrete components (*Industry 4.0*).

Designing of the textile structure as an independent process step can be transferred to the integral planning process, which is a part of the generated BIM model. The production companies are no longer responsible for the textile design, saving them efforts and costs due to the fact, that the design of the textile reinforcements will be developed externally as part of the BIM modeling.

BIM modeling will also lead to effort and cost savings with regard to interior fitting. The cooperative working methodology of BIM, as well as the consideration of the whole building life cycle, will ensure knowledge and information exchange concerning each individual building product. The manufacturer will receive extensive information on the specific assembly situation, architects as well as engineers will be informed about products' performances comprehensively. Interaction between different building products for interior fitting and the synchronization of their technical requirements can be taken into account, due to the complex networking of architects, engineers and manufacturers. To give a specific example for this, consider a suspended ceiling, which requires other acoustic absorption measures than a non-suspended one. The mutual influence of the ceiling system and the flooring system have to be considered while specifying the measures to increase the acoustic comfort (see Fig. 6).

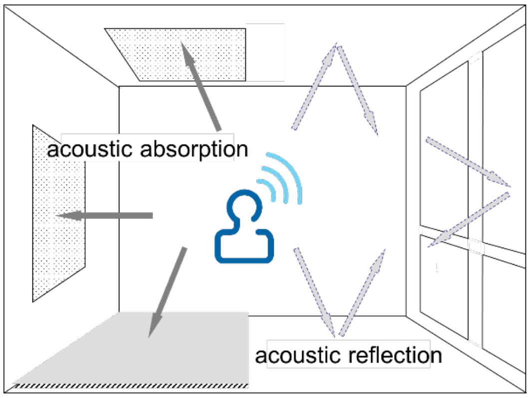

Fig. 6. Different measures to increase the acoustic comfort [16]

Thanks to BIM, individual measures are going to be ordered chronologically. This will enhance resource and cost-efficiency. The required flooring system profile should be determined first before the ceiling construction is designed. This will lead to a more resource and cost-efficient solution, in comparison to the traditional approach, starting with a complex isolation of the ceiling construction, followed by the requirement definition for the flooring system [17]. BIM will allow to check for inconsistencies and modify, if necessary. All in all, we consider the following three challenges to be the most important ones during the realization of the case study.

- Development of a new data standard, which can be used for the data exchange between the planning processes (*BIM*) and the production of the building components (*Industry 4.0*).
- Ensuring an information transfer between the production companies and the BIM participants. The BIM-engineers need general information about the production opportunities and capabilities.
- Civil engineers with competences of designing TRC-components have to be involved in the BIM-process of the demonstration case.

5 Conclusion and Future Work

We are convinced that the future will show that the worlds of planning, fabrication, operation, and reuse need to be connected by far better communication. Using a real-case building project (at the Birlinghoven castle) we will design, test, redesign and document the communication tools proposed. With a successful realization of the linkage between BIM and Industry 4.0, we will evaluate how our socio-technical approach can help overcome the challenges we described in this paper and create a new intelligent building production process.

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