Informing sustainable building design

The importance of visualizing technical information and quantifying architectural decisions

Mathilde Landgren
Technical University of Denmark, Kongens Lyngby, Denmark
Signe Skovmand Jakobsen and Birthe Wohlenberg
Sweco, Copenhagen, Denmark, and
Lotte Bjerregaard Jensen
Technical University of Denmark, Kongens Lyngby, Denmark

Abstract

Purpose – In recent decades there has been a focus on reducing the overall emissions from the built environment, which increases the complexity of the building design process. More specialized knowledge, a greater common understanding and more cooperation between the stakeholders are required. Interdisciplinary design teams need simple and intuitive means of communication. Architects and engineers are starting to increase their focus on improving interdisciplinary communication, but it is often unclear how to do so. The purpose of this paper is to define the impact of visually communicating engineering knowledge to architects in an interdisciplinary design team and to define how quantifying architectural design decisions have an impact during the early phases of sustainable building design.

Design/methodology/approach – This work is based on a study of extensive project materials consisting of presentations, reports, simulation results and case studies. The material is made available by one of the largest European Engineering Consultancies and by a large architectural office in the field of sustainable architecture in Denmark. The project material is used for mapping communication concepts from practice.

Findings – It is demonstrated that visual communication by engineers increases the level of technical knowledge in the design decisions made by architects. This is essential in order to reach the goal of designing buildings with low environmental impact. Conversely, quantification of architectural quality improved the engineer’s acceptance of the architects’ proposals.

Originality/value – This paper produces new knowledge through the case study processes performed. The main points are presented as clearly as possible; however, it should be stressed that it is only the top of the iceberg. In all, 17 extensive case studies design processes were performed with various design teams by the 3 authors of the paper Mathilde, Birthe and Signe. The companies that provided the framework for the cases are leading in Europe within sustainability in the built environment, and in the case of Sweco also in regards to size (number of employees). Data are thus first hand and developed by the researchers and authors of this paper, with explicit consent from the industry partners involved as well as assoc. Professor Lotte B. Jensen Technical University of Denmark (DTU). This material is in the DTU servers and is in the PhD dissertation by Mathilde Landgren (successful defence was in January 2019). The observations and reflection is presented in selected significant case examples. The methods are described in detail, and if further information on method is required a more in depth description is found in Mathilde Landgrens PhD Dissertation. There is a lack in existing literature of the effect of visualisation in interdisciplinary design teams and though the literature (e.g. guidelines) of integrated design is extensive, there is not much published on this essential part of an integrated design process.

Keywords Case study, Visual communication

Paper type Research paper

1. Introduction

The rapid development of sustainable buildings, which is highly complex, will require more professions to be dependent on the decisions of one another, which will require the further development of interdisciplinary communication (Brunsgaard, 2009; Lewis, 2004;
Svendsen et al., 2007; Zimmerman, 2002). Visual communication is moving to the fore of engineering education because interdisciplinary design teams must co-operate closely to ensure a holistic and uniform final product (Rammer Nielsen, 2003; Svendsen et al., 2007; McGrath and Brown, 2005). In an integrated design process, engineers are expected to be able to proactively influence the early design decisions made by the interdisciplinary design team, but the building industry is uneven in its willingness to alter the traditional roles of consultancy (Luyten, 2010). The fact that traditional consultancy roles linger on influences the design process and constitutes a barrier to the use of interdisciplinary processes in the early phase of a design (Luyten, 2010). However, a number of engineering consultancies are challenging these traditions by focusing on new communication strategies that use visual communication (Jakobsen and Wohlenberg, 2016). Traditionally, visuals are used in schools of architecture in the shape of diagrams, visualizations, renderings, 3D models and sketches (Lawson, 2006; Luyten, 2009). The increased focus on early integration of technical knowledge in design decisions and the increasingly frequent need to achieve sustainability certification of a building require architects to consider how to communicate architectural quality. Quantification of architectural quality is challenging, and some architects would claim that it is not possible, but it could be one way of fulfilling this need (Tanga et al., 2006). Deutche Gesellschaft für Nachhaltiges Bauen (DGNB) is a German sustainability certification system that uses life cycle assessment (LCA) and life cycle costing (LCC) as add-ons to the legal- and regulation-based focus on indoor climate and energy calculations (Birgisdóttir et al., 2013; DK-GBC, 2014). This means that both LCC and LCA must be considered from the earliest design phase, so architects must make quantifiable and knowledge-based design decisions (DK-GBC, 2014; Landgren and Jensen, 2018) in the early design phases. Classical engineering tasks must therefore be addressed and accessed by the architects, who have to take them into account if sustainability certification is the goal. As a result, the architects gain knowledge of the relevant engineering fields (Luyten, 2009). The aim of this research is to define and describe the effect of visual communication of engineering knowledge to architects and other stakeholders in the interdisciplinary design team at the early stages of a building project.

2. Method

2.1 The two case study consultancies

There has been an increasing focus on the importance of early design decisions since research showed that the economic and environmental impact from early design decisions is large. In the last decades, this finding has led to a change in the mind-set and work processes of both architects and engineers, and the necessary processes are now evolving rapidly (Luyten, 2010). In this paper, current attempts to base early design decisions on technical knowledge and the various ways that architects and engineers try to create some common ground were investigated by examining the role of visual communication in a large engineering consultancy and in the quantification of design decisions in a large architectural office. The paper is based on several case studies. However, three were selected for discussion in this paper. They were obtained from two companies in Denmark: a large architectural office with a focus on sustainable buildings, and the Danish part of a large European engineering consultancy of around 1,000 employees. It was organized in special units: planning and design, transport and mobility, and water and environment, this research took its base in the first unit. Each unit had deep specialist knowledge in their field (Sweco, 2017). A selection of these units is shown in the organization diagram in Table I.

The architectural office had around 80 employees and was organized in three main units – city and housing, learning and culture, and business and health – with a range of different specialist knowledge (JJW, 2017). A selection of this knowledge is shown in the organization diagram in Table II.
2.2 Engineering approach – visualizing engineering knowledge

The engineering consultancy had developed their own tool called the “Game Changer,” which was a set of technical guidelines intended to serve as tools to facilitate early phase dialogue, based on a report conducted by a group of anthropologists, who observed the working processes in the engineering consultancy (Jakobsen and Wohlenberg, 2016). They detected three problems in the routines in use at each organizational level that affected how clients experienced their interactions with the engineers. The three organizational levels are the business leader level, the project leader level and the technical specialist level. In the present work, only problems related to the technical specialists were considered. Figure 1 shows the challenges encountered at the technical specialist level. This was the

<table>
<thead>
<tr>
<th>Planning and Design</th>
<th>Structures</th>
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<tr>
<td>Fire safety</td>
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<td>Electricity</td>
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<td>indoor climate</td>
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<td>sustainability</td>
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<td>Light design</td>
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<td>Facility management</td>
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Table I.
Organization diagram showing a selection of the units and some of the related subjects in the engineering consultancy

<table>
<thead>
<tr>
<th>City and housing</th>
<th>Learning and culture</th>
<th>Business and health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public housing</td>
<td>Day care</td>
<td>Hospitals</td>
</tr>
<tr>
<td>Care centers</td>
<td>Schools</td>
<td>Laboratories</td>
</tr>
<tr>
<td>Renovation</td>
<td>Colleges</td>
<td>Business</td>
</tr>
<tr>
<td>Landscape</td>
<td>Universities</td>
<td>Landscape</td>
</tr>
</tbody>
</table>

Table II.
Organization diagram showing a selection of the many subjects at the architectural office

Challenge                  | Behavior | Client experience |
-----------------------------|----------|-------------------|
Running after                |          |                    |
Defensive                    |          |                    |
Front runner                 |          |                    |
Inspiring                    |          |                    |
NO!                          |          | Troubleshooter     |
Alternatives                 |          | Problem solver     |
Analysis in text             |          | Value-added        |
Incomprehensible            |          |                    |
Influence the design         |          |                    |

Figure 1.
The technical specialist level and the three-related challenges

Source: Jakobsen and Wohlenberg (2016)
starting point for the company to understand the relationships between the behavior of their employees and the resulting client experience.

One of the challenges identified by the anthropologists at the technical specialist level was “Analysis in text.” Clients felt that “Analysis in text” is incomprehensible, since they do not share a common medium for the dialogue. Here, visuals may be the right medium for communicating information about the engineering tasks and making expert knowledge more comprehensible; however, this would require a different work strategy (Jakobsen and Wohlenberg, 2016). When changing work strategies, it is not always enough to offer an introductory course and a list of guidelines. The entire routine-based workflow and mind-set of each employee has to be taken into account. Emotional intelligence (EQ) also has considerable impact on how well communication tools are used, so EQ is an important qualification for employees who work within the complex environment of interdisciplinary design teams in the building industry (Riemer, 2007). Once the complexity of the general technical issues in the guidelines has been visualized, they become a qualitative description of design principles instead of quantitative values in a report. This is more easily incorporated into the design process and invites dialogue for an open range of design decisions (Jakobsen and Wohlenberg, 2016). Visuals as a tool for communication are easier to understand and to remember than text, as they engage the imagination and increase creative thinking (Woeppel, 2015).

2.3 Architectural approach – quantification of design decisions

At the architectural office, there was no motivation to make communication more visible since they already work very visually. However, the increased number of interdisciplinary design teams and the demand for sustainability certification of buildings had made it necessary to quantify design decisions.

At the architectural office, the DGNB certification system was being used to define sustainability, which has led to an increased focus on resources, consumption and emissions in relation to LCA, and on the economic aspects of LCC. Internal changes were already taking place at the architectural office, where the entire mind-set of the classical architect had to be modified and an awareness of the benefits of quantification as the background for their design decisions had had to be introduced. The DGNB system mandates this development by requiring ten early phase sustainability concepts to be developed by the interdisciplinary teams, as seen in Figure 2.

2.4 Method of research

Although several case studies were conducted, only two of them were considered to be illustrative of how the initial design phase, prior to actual design, is affected: one at the engineering consultancy Sweco and one at the architectural office JJW Architects. A third case study was used to illustrate the influence of visualization at the schematic design phase in the architectural office. The results of these case studies were compared, categorized and analyzed in terms of the visual communication of engineering knowledge, quantified design decisions and the DGNB certification system. The case studies were

![Figure 2. DGNB, PRO1.3 – new office buildings criteria: the 10 new concepts that were scored](image-url)
conducted using an active research approach in four steps; planning the process, action through involvement in design teams, observing and collecting data and a discussion of the findings (Swann, 2002).

2.5 Case 1

Two researchers with architectural engineering background took part in the first initial meeting of a project, together with the entire design team. The project was confidential and is not further described here; only the process related to the use of visuals is described. The design team consisted of engineers and architects. At the meeting, the engineers presented selected general technical guidelines, which the engineers considered relevant for the given project. The guidelines were presented as visuals to emphasize the scope of possible solutions, from which a dialogue on the potential interdisciplinary benefits could be initiated. After the meeting, the engineers identified which visuals had worked and which had not. The case study was based on Figure 1, “Analysis in text” at the “Technical Specialist Level.” The project had an open beginning, in which the architect had developed the building mass and defined the building geometry. This gave the engineers the possibility of including their knowledge from the very beginning. At the first meeting, all of the specialists brought their most relevant technical guidelines, as illustrated in the Results section, and presented them. They consisted of visualizations of the technical issues and possible benefits that would result from the selected design decision and a list of arguments for and against alternative designs.

2.6 Case 2

One researcher, an engineer employed at an architectural office, participated in the initial design phase of a project to assist the design team with the quantification of their scenarios and project definition. The project is described only briefly to preserve confidentiality. The project started with a request from the project leader to quantify the economic value of two scenarios for an existing building by making LCC calculations. The two scenarios were either to demolish and rebuild the building or to renovate it. For the calculations, a simple tool developed in Denmark called LCCByg was used (Trafik- og Byggestyrelsen | Statens Byggeforskningsinstitut, 2016). The available material for the existing building was rather limited, so the data required in the calculations were derived from old drawings. Included in the calculations were new components, maintenance and operation, supply and cleaning.

To facilitate the LCC calculations on the environmental and social aspects of the two scenarios, a simple tool from the Municipality of Copenhagen called the MBA (Environment in Buildings and Construction) was used (Municipality of Copenhagen, 2016). The project leader requested its use since the project was a public building. Feedback based on the quantified data was obtained from the client for the current case study. The case study was mapped in a large matrix that was developed to align each case in terms of sustainability criteria, technical inputs, technical inputs influence on design decision and level of sustainability. The matrix is shown in Table III.

2.7 Case 3 – depicting the design process as visuals

The third case study was also undertaken at the architectural office, by quantifying design decisions during the design process. The project was confidential and only limited data can be provided here. These data were also collected on the basis of the matrix in Table III. A number of daylight simulations were conducted by the sustainability team and submitted to the design team as reports and presentations. The daylight simulations examined the influence of the type of glazing, solar shading, and depth of balcony overhang, and ceiling surface, upon the resulting daylight conditions in each room and thereby the number of workspaces that it would be possible to create, given requirement for a 2 percent daylight factor (Trafik-, Bygge- og Boligstyrelsen, 2014).
3. Results

3.1 Case 1 – visuals at an engineering consultancy

Figure 3 shows a representative technical guideline illustrating the placement of the installation cores in a multi-story building. It included a list of the advantages and disadvantages of each technical installation.

Planning and action. Addressing the issue of installation core placement in a multi-story building at the first meeting, just as the design process started, was intended to integrate the technical installations in the initial design, hence avoiding future problems with coordinating core placements and finding space for installations.

Observations. Some of the attendees at the meeting found the information useful in the future design process, while others found it banal and restrictive. However, the simple visual and adjacent text made each point precise and clear, and ensured that everyone understood and could use the information.

Reflections. The engineers decided to further develop the visuals, as they proved a useful tool for dialogue. A strategy for timing was also discussed internally on the basis of the reactions and feedback from the architects, e.g., it proved important to restrict the number of visuals presented and to tailor them to the meeting context.

3.2 Case 2 – “quantification” at an architectural office

Planning and action. A visualization was generated using LCCByg, showing the results of the calculations for the two scenarios “demolish/rebuild” or “renovate” as column diagrams.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
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<tbody>
<tr>
<td>JJWs role</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>JJW included design phase(s) (Danish Description of Service)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sustainability focus</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Technical inputs (made by the PhD researcher) Requested by</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Technical inputs (made by the PhD researcher)</td>
<td>–</td>
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<tr>
<td>Technical tools</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Design variations and decisions</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Reason for design decision</td>
<td>–</td>
<td>–</td>
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<td>Level of sustainability</td>
<td>–</td>
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</table>

Table III. Matrix for the case studies at the architectural office

Notes: (a) Suspended ceilings result in increased flexibility in the plan layout; the toilet cores can be placed in various locations; (b) stacked toilet cores on all floors ensure minimal routing for pipes and hence require less space for installations; (c) centralized pipe routings with flexibility in plan layout require less space for installations

Source: Jakobsen and Wohlenberg (2016)
The final sustainability ranking from the MBA (Environment in Buildings and Construction) (Municipality of Copenhagen, 2016) was added as a circle diagram. These diagrams are shown as Figure 4. The results indicate that the most economically advantageous scenario is “demolish and build new” due to the very poor condition of the existing building. The sustainability ranking supports this choice, as it involves the use of environmentally friendly materials, improves the possibilities for maintenance and improves the functionality of the building (since it will better fulfill the needs of the users). The calculations and sustainability ranking ensured a thorough investigation of each scenario and that the final design solution was based on both quantified data and qualitative data.

Observation. The project leader brought the outputs from Figure 4 to a pre-meeting with the clients. The clients stated that they were impressed by the thorough investigation and by the very clear visualized outputs. The analysis convinced the client to follow the architect’s advice to demolish the existing buildings and build new ones due to poor existing quality and the high cost of renovation.

Reflection. As it was a public building with a limited economy, cost was the deciding factor and this was the most crucial aspect for the architects to document in the initial design phase.

3.3 Case 3 – depicting the design process as visuals

Planning and action. The output of the daylight simulations is shown in Figure 5, with the limits of the 2 percent daylight factor marked on the floorplan of the room, for easier communication between design team and client.

Observation. The design loops and design decision parameters were collected in the matrix for each case study. The design team tried to design for the highest possible number of work places in the room, with no additional solar shading needed on the balconies. This was demonstrated to be possible by means of the daylight simulations, but only with a white plane surface as the ceiling. The design team accepted this and included the output from the daylight simulations in the design process to ensure the best possible lighting conditions in the final design.

Reflections. Each iteration of design alternatives was followed by a daylight study to inform the design decisions. Aesthetic considerations guided most of the decisions, but where the daylight simulations could quantify the maximum number of workplaces possible, this was the design decision factor.

Figure 4.
(a) The column diagram shows the costs for each process for the two scenarios from the LCCByg report; (b) the circle diagram illustrates the social, economic and environmental ratings as outputs from the MBA

Notes: The orange represents the new building and the green represents the renovated building
4. Discussion
The need for more sustainable design and the increased use of interdisciplinary design teams led both engineers and architects to alter their means of communication. In the engineering consultancy in Case 1, the engineers focused on simpler and more visual communication strategies that could address typical challenges by influencing how the architects organized the building masses during the early design phases. The architects in Case 2 and 3, in turn, aimed to quantify their design approaches so they could influence decisions that would otherwise be determined by the engineers and by financial considerations. This study illustrates how important it is that each discipline’s individual methods should be supplemented by the methods used in the other discipline, as this promoted knowledge-based design. This was not just a change in methods but an innovative combination of two methods, one that could achieve more than either of them would have done had they been used in isolation.

In Case 1, the engineers succeeded in incorporating their technical knowledge right from the initial design phase with visual communication. One architect commented that the visuals felt restrictive, however, the simplicity of the visualizations actually ensured that all participants had the same interpretation of the topic, so that a dialogue of solutions could start on equal terms. By visualizing a general issue, the technical knowledge shifted from being quantitative values in a report to being qualitative descriptions of design principles.

By being prepared to make quantified design decisions, the architects were able to emphasize their concept and visions and to ensure an open range of solutions, as illustrated by Case 3. This made the design process receptive to engineering knowledge in the early design phases.

These three case studies illustrate how visualizing technical knowledge can facilitate communication between professions and ensure that design decisions are knowledge based in practice. The case studies also show technical knowledge can be visualized and integrated in the design phase whether it is at an overall and general level, such as Case 1, or deals with specific design matters, such as in Case 2 and 3. Additionally, qualitative descriptions of technical design decisions and the quantification of architectural design decisions both lead to more informed design decisions.

The case studies expanded the range of available communication methods and made it easier to achieve the ultimate goal of sustainable buildings with low emissions. A generic space of solutions defined solely in terms of qualitative or quantitative information risks being perceived as restricting in the design process, while a contextual space of solutions with information that has been configured to inform specific design decisions is more likely to be perceived as an enrichment.

Figure 5. The figure shows the daylight simulation of the room, having the green line as the 2 percent daylight factor limit in the room.

Notes: On the right a scale showing the depth of the room in meters from the façade
5. Conclusions
The paper addresses the goal of the building industry to communicate across disciplines to be able to solve the complex matter of sustainable building design.

From this case study research, it can be concluded that simple visuals have great potential as the medium for communicating technical engineering knowledge to architects. Visuals are commonly used by architects as drivers or “tools” in the design process and by adapting the architects’ own tools there is a higher potential for understanding and achieving implementation of technical scientific information in the actual design decisions. Informing early design decisions such as geometry, window/facade ratio, orientation, etc., which are typically in the hands of architects, with technical scientific information is a necessity and a common goal for the interdisciplinary design team. However, the timing and the inclusion of only design decision relevant information is essential, as information overload can delay the design process unless the information is fully integrated into the process itself.

For the architects to underline the value of their design, the case studies indicate the potential of quantification of architectural choices to communicate with engineers. Engineers commonly use quantification and it is possible for architectural offices to use simple digital engineering tools to ensure good communication. The quantification of architectural decisions improved the engineers’ understanding and their acceptance of the work of the architect.

There is potential for further research in the topic by addressing visuals and quantifications as the medium of communication between architects and engineers in a larger range of case studies.

References


**Corresponding author**
Mathilde Landgren can be contacted at: maland@byg.dtu.dk