BIM BASED COLLABORATIVE DESIGN TECHNOLOGY FOR COLLECTIVE SELF-ORGANISED HOUSING

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Abstract *This paper refers to the ongoing EU FP7 project PROFICIENT. The paper concentrates on the development of innovative Collaborative Design Technology (CDT) solutions. A CSO housing process inserts the client at all stages of design and implementation, not just at initial briefing stages. In this paper we evaluated the potential of Building Information Model (BIM) based Collaborative Design Technologies (CDT) for supporting the CSO housing design process. Based on the evaluation, the paper introduces the architecture for a platform with an accompanying business model that can guide a group of homeowners through the entire design project. In conclusion, the paper shows that architectural housing design can be meaningfully supported by a purposeful combination of BIM based techniques.*

1. INTRODUCTION

This paper refers to the ongoing research and intended follow-up of the EU collaborative project titled PROFICIENT that deals with the development and validation of new processes and business models for energy-efficient Collective Self-Organised (CSO) residential buildings and neighbourhood projects. The research addresses the emerging and rapidly increasing trend of CSO housing in Europe.

Despite this market growth, a number of barriers and constraints to successful implementation of CSOs exist. From the demand perspective, the CSO housing process needs to provide meaningful possibilities to integrate the client – as a non-professional - at all stages of design and implementation, not just at initial briefing stages. A further complicating factor is the collective nature of CSO communities and the need for joint decision making between members of a group that may include different members at different stages of the process, as new members join and others leave.

BIM based CDT technologies can overcome some of the struggles outlined above, little however is known so far about how to support the specific design process on CSO projects. To address this challenge the paper proposes a Collaborative Design Technology (CDT) model that prescribes a comprehensive process based on a systematic evaluation of Building Information Modelling (BIM) tools and their potential to support CSO projects.

2. ARCHITECTURAL DESIGN IN THE CSO CONTEXT

Traditionally, architects have a commercial perspective on their role in the process. Many of these businesses are not used to working for collective groups of clients, with the participatory design approach this entails. For contractors, suppliers and consultants it is often more complex and it demands more explanation compared to regular cases where one deals with professional stakeholders. As end-users keep on changing their wishes up to the end of the project, and a contractor prefers to have things decided upon as early as possible, this is a great challenge. Many end-users have started the CSO housing process for several reasons, such as ideology, better living quality, social cohesion, environmental reasons etc. Almost all have had an unrealistically positive image of the process [1].

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Architectural design can be described as reflective conversation between the individual designer and the design situation. According to this concept, designers operate by labelling the parameters of the situation, framing the design problem in a specific way, making observable moves towards the solution, and evaluate these moves.

Recent studies have shown that each of the tasks within the formalized design processes can be supported by the targeted application of building information models [2]. Many studies have, for example, provided evidence that BIM based visualizations can support communication tasks of designers and can help to develop design knowledge together. Additionally, the parametric possibilities of state-of-the-art BIM software allows for the quick development and evaluation of design alternatives and for the possibilities to run advanced simulations. However, supporting the exchange of information from one frame to another frame still poses significant problems. Integration of design tasks and their frame require better process guidelines for BIM based information exchange.

Despite the rising popularity of CSO housing design, no process framework exists to support this emerging practice. To overcome this gap this paper sets out to provide a comprehensive evaluation of the possibility to support CSO housing projects with BIM technology. The following section describes how we conducted this evaluation.

3. RESEARCH METHOD

We conducted the evaluation and consecutive platform architecture building effort within the context of the European Union funded PROFICIENT project. This evaluation and platform building effort forms the first step in the PROFICIENT project that in the end aims at developing a networked business model to bring the knowledge and tools developed to the target group of European architects and other stakeholders.

Our exploration of existing CDT tools for the support of CSO project followed the steps below:

- First, we selected the most promising, market-ready ICT frameworks that allow for the development of CDT solutions to support CSO housing process. The selection procedure focused on available software, preferably open-source, which can minimize development costs and, in turn, the required investment costs by users while establishing a connection with their existing software tools and platforms.
- Second, an open technology infrastructure for the development of CDT solutions was established, including an e-marketplace based on the selected ICT framework. This structure will allow technology providers to develop interoperable and aspect-oriented CDT solutions according to the evolving needs of architects.
- Third, the potential, advantages and benefits of the CDT solutions as support of the creative process is presented along with the assessed quality of the design products in use cases for new building and refurbishment projects. To this end, we will select a number of existing architectural design support technologies and make them available on the e-marketplace as initial products [3].
- Finally, the impact of applying CDT solutions in living lab sessions is demonstrated. This session involves end-users and other stakeholders, as a simulation of the working process of collaborative design.

In the next section of this paper, the state-of-the-art of CDT will be described. Within this section the various elements of CDT will be described with the emphasis on applied research for the purpose of CSO housing.

4. DEVELOPMENT AND ADOPTION OF COLLABORATIVE DESIGN TECHNOLOGY (CDT) SOLUTIONS

4.1. The essence of CDT

Architectural design is different from most creative industries, in that it is highly constrained by external social and technical factors. To develop feasible design solutions, architects need to have deep insights into the structural mechanics of buildings, building production techniques, energy performance, functionality of utility systems, organizational processes of building users, construction and exploitation cost, environmental aspects and life span considerations. As a result, architectural design can only be successful if the architect is collaborating intensively with civil engineers, building contractors, component suppliers and most important the client/end-user. To support this collaboration, architects increasingly need the technological support that emerging CDT solutions offer.

CDT solutions can enhance the development of participatory and concurrent architectural design processes. Here, participatory design (PD) refers to a design approach, which entails an active involvement of end-users through decision-making processes in the whole design process. During PD processes, CDT solutions allow end-users to focus on the functional and spatial performance of specific architectural design alternatives. Complementary to participatory design, concurrent design (CD) refers to a direct collaboration between professionals in collective design activities to increase possibilities for specialized knowledge sharing and development. Both processes, if organized adequately, can reduce the transaction costs of architectural design processes.

CDT solutions support knowledge generation and exchange through an increased inter-firm interaction, focusing on the technical aspects, and related to the feasibility of the building process. The underlying ICT-technologies (semantic BIM, parametric design, Concept Modelling Ontology (CMO), Virtual and Augmented Reality (VR/AR), and BIM-linked end-user solutions) are described in the following.

4.2. Building Information Modelling (BIM) within the CSO context

With BIM, a new way of modelling for the Building & Construction industry has been introduced. BIM consists of shared knowledge resources to support decision-making about the building from earliest conceptual stages, through design and construction, through its operational life till demolition. BIM is as such a basic condition for collaborative design and construction.

BIM’s object oriented and semantic approach provides a better understanding of what is actually modelled compared to traditional CAD-systems. Communication between applications and disciplines is strongly improved. BIM is essential interfacing the design with all kinds of innovative user applications, such as energy performance assessment tools, lifecycle cost calculations, facility management tools, virtual and augmented reality, and geographic and indoor positioning systems. The current BIM content is mostly exchanged via the open standard IFC (ISO 16739:2013). Some important drawbacks of this standard are solved via Semantic Web technology form W3C.

The implementation of BIM at an earlier stage of a project can benefit architects engaged in CSO developments in the following ways:

- BIM will shorten the time needed to explore and validate multiple design alternatives;
- BIM allows for the visualization of design solutions on a higher level compared to traditional 2D/3D solutions offering extra competitiveness;
- BIM will make it possible for architects to integrate information from other disciplines to create a design that can show the feasibility of meeting the multiple performance demands of a client within the design process (e.g. energy performance predictions compared to quantified cost estimations can be offered), which is a milestone of raised competitiveness;
- BIM will reduce potential failure cost by reducing design iterations and more important building defects;
- Facility Management software applications can be interfaced with BIM, providing two way data exchange. These end-user tools are dealing with optimisation of the exploitation and management of real estate.

4.3. Parametric design technology within the CSO context

Parametric design technology allows the generation of design content from a family of initial parameters and the design of the formal relations they keep with each other. Using these variables to generate a hierarchy of mathematical, semantic, and geometric relations, this allows the exploration of a whole range of possible solutions by varying the values of the initial parameters.

Within the CSO context architects can benefit from implementing the parametric design technology in the following ways:

- Reuse of models and data in previous projects becomes possible via building up libraries of Parametric Models. Each project is different, but many of the previously used components will share the same concepts.
- Many complex designs are only possible with the support of parametric design, hence opening up complete new areas for architectural design creativity.
- Consistency between parts of a design is covered better when using parametric design. Especially in the early design stages, initial ideas can change and designs and assumptions have to be reconsidered in turn. Parametric design can help by keeping designs and requirements consistent throughout the iterative design process.
- Parametric design will allow architects to generate more alternatives by structurally exploring the design space.
- Parametric design will allow for the inclusion of different technical and social constraints within the process of systematically generating alternatives. This will support the creative design process as architects will not need to worry about developing unfeasible solutions.
- Parametric design will allow architects to evaluate alternatives according to multiple criteria for which indicators can be quickly calculated according to specific parameter settings of a generated alternative.

4.4. Concept Modelling Ontology (CMO) within the CSO context

CMO is a standard based in Semantic Web and inheriting its benefits. CMO with Extensions is an extension of CMO that also supports storing and exchanging parametric design. CMO-technology connects the parametric design tool to BIM. Using semantic BIM and CMO within parametric design tools can allow architects to overcome the limitations of the traditionally purely geometric parametric modellers. Architects will be able to generate and evaluate alternatives throughout each stage of the design process using intuitive natural language interfaces. This will substantially increase the amount of design alternatives that can be generated and evaluated.

CMO is a reusable, generic ontology that enables semantic parametric design modelling capabilities. Semantic Web (W3C) technology, building on the W3C OWL language, is the perfect medium for developing large-scale, web-based, multi-stakeholder information structures and ontologies. These structures and ontologies can be used for knowledge management and/or data exchange.

Some essential modelling capabilities (ingredients) are modelled once only in CMO and then can be reused every time needed. CMO is imported in all CMO/OWL2-compliant end-user ontologies. CMO is a fully open standard that can be freely reused without any constraints.

Architects can benefit from implementing CMO in the following ways:

- CMO enables reuse of parametric design and libraries in several software packages
- CMO is an open standard and vendor independent. Hence, using CMO will allow cooperation between partners that work with software from different vendors. Especially SMEs will benefit from such vendor independence enabling them to work more flexibly on different projects.
- As SMEs do not have the power to influence large software vendors, vendor dependency is an important issue. Becoming vendor independent by using CMO is a very important stepping stone for increasing the competitive advantage of European architects.

4.5. Virtual and Augmented Reality (VR/AR) within the CSO context

Graham et. al [4] explain augmented reality (AR) as the material/virtual nexus mediated through technology, information and code, and enacted in specific and individualised space/time configurations, that is the physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data. By contrast, virtual reality replaces the real world with a simulated one. With the help of advanced AR technology (e.g. adding computer vision and object recognition) the information about the surrounding real world of the user becomes interactive and digitally manipulative. Artificial information about the environment and its objects can be overlaid on the real world.

The development of custom VR/AR interfaces upon BIM allow for the seamless representation of parametrically generated design solutions to all important stakeholders at a specific stage of the design. Transaction and opportunity costs of design content and planning meetings can thus be drastically reduced.

Virtual and Augmented Reality technologies tie together the semantic and parametric design technologies and make them intuitively and seamlessly available within participatory (PD) and collaborative (CD) process. Virtual reality will support the clear representation of the many design solutions that can be generated by parametric modelling applications. To this end, VR can provide detailed representations of technical details for very specific design activities, as well as holistic representations of design alternatives for communication tasks with stakeholders within the value chain. Contributing to the possibilities of VR/AR will allow moving design activities to the field to seamlessly integrate the existing conditions of the urban fabric that poses the main constraints to architectural creativity. AR will allow for the integration of information about existing constraints, but also for directly developing design solutions while creatively interacting with these constraints.

Architects may benefit from implementing VR/AR in the following ways:

- VR/AR enhance the quality of communication by replacing the typically used 2D drawing print outs that are not easy to handle and only provide a limited information density. The enhanced quality of communication VR/AR offers will speed up the decision making processes and allow for deep understanding of the expected result by experts and clients.
- VR/AR allow for design adjustments before they create extra planning costs and investments costs for double work of other experts involved, such as, for example, structural engineers who regularly follow the workflow of the architect.
- VR allow architects to visually evaluate different parametrically created alternatives according to both, aesthetic and technical objectives.
- VR allow the inclusion of a wide variety of specialist and non-specialist stakeholders in the design process.
- AR bring the design process to the field providing architects and their stakeholders improved possibilities for including the construction site and existing building condition within their design activities.

4.6. Network business model to provide architects with innovative Collaborative Design Technology (CDT) solutions

Along with customizing, configuring and demonstrating emerging CDT solutions for CSO housing development, PROFICIENT proposes a business model to bring the knowledge and tools developed to the target group of European architects. The business model focuses on the development of a comprehensive and easy to handle platform (web portal) for provision, learning and exchanging state-of-the-art CDT solutions. An e-marketplace will be part of the platform, to allow technology providers to develop and market innovative CDT solutions based upon a combination of BIM, semantic and parametric modelling, as well ask advanced (mobile) AR/VR user interfaces. The e-marketplace will allow for a quick and easy uptake of CDT solutions by architects. Bringing innovative technology providers and architects together will fully allow architects to leverage the potential CDT solutions offered in order to widen creative possibilities and improve efficiency.

As design activities in the built environment become technically complex (for example due to increasing requirements for energy life-cycle behaviour) and socially complex (due to the development of a more and more pluralistic society), architects need to deliver creative design solutions that include integrated performance requirements, which is a difficult task without the possibility of using advanced CDT solutions. The intended PROFICIENT e-marketplace will foster exchanges between architects and providers of innovative CDT solutions and will become a catalyst for collaboration opportunities, flexible partnerships and joint business models between the architectural design SMEs, construction partners and CDT solution providers.

At the e-marketplace ICT-suppliers offer their commercial CDT solutions and architects/ ICT-clients can communicate their specific questions, requests and requirements. Clear communication will allow shaping flexible partnerships and joint business models between the architectural design SMEs, construction stakeholders and CDT solution providers. The e-marketplace will be used to implement new ways of collaboration based on project collaboration (ICT-supply just for specific projects), SaaS-contracts (Software as a Service, preventing large investments in software and hardware infrastructure), shared investments (ICT-investments shared by the building consortium) and partnerships between architects and ICT-providers based on a jointly adapted business model.

The PROFICIENT business model for the leveraging of CDT solutions to European architects consists of the following elements:

- An e-marketplace where commercial ICT-suppliers offer their products and services to the target group.
- Demonstrations of the potential of emerging CDT solutions for architects by way of impact case studies.
- Free downloads of open standard basic software developed in previous EC-supported research projects (IFC toolboxes/CMO tools/Open Source BIM Server).
- Commercial software applications and end-user tools that are highly customizable and flexible adjustable.
- E-learning material to be used for self-instruction and CPD (Continuing Professional Development) and in university curricula.
- Creative business strategies to accommodate the limited investment resources of architecture SMEs based on smart partnerships between architects and ICT-suppliers.

Architects who are engaged in the CSO housing projects can take the following advantages from the PROFICIENT business model:

- Direct, fast and unambiguous communication with all stakeholders, which enables the architect to better direct the design efforts towards societal and organizational needs of clients.

- Direct and fast access and use of various sources of knowledge, solutions, ideas and innovations for full and holistic architectural and design integration as early in the process as possible. This allows for the fast but accurate exploration and (re)setting of design parameters together with all stakeholders through ‘many-to-many’ (visual) communication.
- Digital information exchange enabling international collaboration between different designers and streamlined communication between the architects’ offices and building sites. These possibilities for digital information exchange will increase the international competiveness of European architects.
- Quick and accurate feedback on the performance of design alternatives. Such feedback will significantly increase building performance by improving the design process for a single building and by providing advanced possibilities for learning across a number of building design projects.
- State-of-the-art stylish and highly visual company, portfolio and design presentations.
- Delivery of end-user tools, connected to design and BIM, enabling post construction services extended to the exploitation phase that can be offered by architects.

5. CONCLUSIONS

This paper has introduced a method and process framework that incorporates CDT, BIM and AR/VR modelling to support the design of CSO housing projects. The presented approach allows for an iterative and integrated process to support architectural design of CSO housing. CDT solutions and the proposed business model can extend the reflective conversation beyond the individual designer and the design situation, to incorporate collective inputs into the design in CSO housing communities. The architectural design process can be supported by the application of BIM. BIM can aid communication between client and architect, which is especially important in a CSO design process, given the need to communicate and co-design within a group, rather than individual clients. The paper shows how the exchange of information at different stages of the design between clients and architects around EeB requirements can be supported, how the value base of client groups can be incorporated, and how end users can become increasingly participative within the design process.

The parametric possibilities of the use of BIM software allow for the rapid improvement of designs based on the ongoing evaluations made by client groups. The possibility of providing clients with advanced models and simulations offers a common visual language to both clients and architects, while allowing for the consideration of constraints related to existing regulations and planning frameworks. Considering the value-base of many CSO communities, the model also allows client limitations, such as for communal and shared facilities, EeB design and green infrastructure, to be built into the design process. In conclusion, the CDT/BIM approach as presented in this paper brings a new solution for co-design in this emerging field of residential housing.

We expect that the incorporation of online implementations of the presented technologies into the participatory design process can provide an effective tool for the implementation of streamlined co-design between architects, other contractors and CSO communities.

Nevertheless, the CDT solution should be subject to continuous improvements and further research should illustrate the applicability-of the solution in-practice. This research, in particular, needs to quantify the advantages the solutions can offer within the architectural design process using clear metrics. Additionally, further case studies need to qualitatively illustrate the efficiency gains for architects and client groups empirically through real world case studies. The willingness of architectural practices to engage with the tools and the networked business model that PROFICIENT offers should also be explored.

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