APPLICATION OF A CONCEPTUAL STAGES DESIGN PROTOCOL FOR EARLY COLLABORATIVE DESIGN THROUGH COMPUTER BASED MEDIATION

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Abstract. Effective conceptual and collaborative design process in architecture is a prerequisite for efficient overall project development. This can be facilitated by computer mediation methods, including emerging augmented reality technologies and tactile and tangible interfaces. With the current paradigm of conceptual design process being disorganised and quite often overpowered by communication gaps between the different design professionals, collaborative conceptual design is essential to be understood and most importantly effectively managed. Bridging the conceptual design stage with the later detailed design ones by using digital technologies can effectively assist transferring the information and initial ideas between the different design stages and bridge the communication gap between the different stakeholders, like the design professionals i.e. architects, engineers, design managers, etc., as early as possible. This paper is focused on reviewing different design processes and on presenting a predefined Conceptual Design Protocol (CDP) as a descriptive model that illustrates the steps of the design process as sequences of actions that occur during design and eventually manages the conceptual design process. Two studies illustrate the evolution from the current paradigm to the proposed design process and are both briefly presented in the paper. The preliminary study showcases a multidisciplinary conceptual design approach. During the second study, the design process is managed to follow the CPD and the participants utilise a design application developed specifically for the particular study and installed on a tangible user interface (TUI). The nature of design progression and collaboration is recorded and analysed, allowing for a number of conclusions to be drawn regarding the conceptual design process, the role of digital technologies and the application of the CPD.

1. Introduction

Effective collaboration and maximum effort from stakeholders during the feasibility and concept design stages in architecture provide the greatest potential for added value for the overall success of a building project, from the initial design through to construction and operation. Collaborative design is fundamental to solving complex problems and brings together different disciplinary viewpoints. This can enhance understanding and creative insights and prevent drawbacks at later and more advanced design stages.

The focus of the paper is to present a research on testing a predefined design protocol that will include aspects like collaborative design, multidisciplinary team building, design management and certain steps for the early design stages process, which utilises computer mediated collaboration and Tangible User Interfaces (TUIs) in particular. The reason behind the research was to test a design process for a smooth transition from the initial ideas to the actual model and to target effectively the problems occurring during collaborative design. Furthermore, smooth transition can bridge the gap as early as possible between the different stakeholders, like the design professionals i.e. architects, engineers, facilities managers, etc., and can minimize the iterative loops at later and more advanced design stages.

2. Design Problems & Processes

2.1. DESIGN PROBLEMS

In the Architecture, Engineering and Construction (AEC) industry, design problems originate either straight from a client or from someone in-between, like a company, consultancy, contractor etc., and the design problems' requirements and descriptions construct the design brief. Quite often, design problems are considered ill-structured because the brief descriptions are fuzzy with regards to the design prerequisites, the design goals and the methods to be involved (Simon 1973). The design problems can be 'ill-defined' and 'wicked', in a sense that there are no definitive and objective answers (Rittel and Webber 1973), in contrast to 'tame' problems, developed by science that can be exhaustively formulated. The 'wicked' problems cannot be definitively described since there is an infinite inventory of conceivable solutions. What is more, the design problem representation and description is often ill-defined and various stages are required for improved definition and specifications. Heuristics, qualitative and quantitative information, etc. are therefore necessary for describing a problem, leading to a multi-stage, iterative and collaborative process (Chandrasegaran et al. 2013).

The design process identified for ill-defined problems is composed out of well-structured sub problems with a retrieval system that constantly alters the problem space by evoking from long-term memory new constrains, sub goals and generators for design alternatives (Simon 1973). The retrieval system works as a recognition mechanism between the problem solver/ designer and the problem space, which evokes relevant information from memory that feeds into the problem space. During the design process, the information retrieval interrupts the continuity of design flow by importing new data. The reason for these mechanisms is that the serial character of the problem solving processes does not allow for large amount of input over a short period of processing. When the problem space is unchanged then the assimilation of new information from the problem solving mechanisms does not affect the process, since any information is already part of the definition of the problem space. As a result, the new information is about the course of the problem solving process. In the case of a problem space that adapts to the new information, provision should be made for incorporating that information, coming either from the long term memory, the external environment and the sensory channels or the problem's modifications (Figure 1).

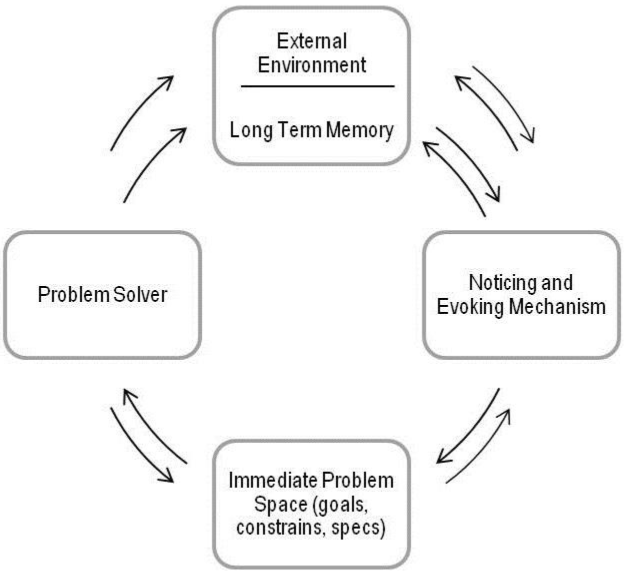

Figure 1. System of ill-structured problems and the connections and feedback from the retrieval mechanism.

2.1. DESIGN PROCESSES

Design processes have been modelled according to different perspectives and theories, either applied from practice based perspectives or from scientific ones. Descriptive models are the ones that illustrate the steps of the design process as sequences of actions that occur during design. They tend to identify the importance of the conceptual stage in the beginning of the process, thus focusing on the solution based approach of the design thinking. The initial concepts are afterwards subjected to analysis, evaluation, refinement and development (Cross 2008). If there are problems within this process, feedback loops lead to the generation of new concepts and the design process starts again. The described design process is heuristic, meaning that it builds on the acquired knowledge and the problem space adapts to new information inputs. Additionally, the design problems are ill-defined by nature; therefore there is no definite solution at the end of the design process.

Schön's theories on reflective practice for design practitioners provide the most basic form of design process, which is the four steps of naming, framing, moving and reflecting (Schön 1991), as illustrated in Figure 2, and they suggest a design focused approach of Herbert's ill-structured problems system (Simon 1973). Further attention should be focused on the structure of the design task and linking the different steps of the process together, allowing for an easier flow between them. Schön mentions that the design processes are driven by a kind of knowing which is inherent in intelligent action (Schön 1991) that again answers to the problem finding mechanisms of ill-structured problems.

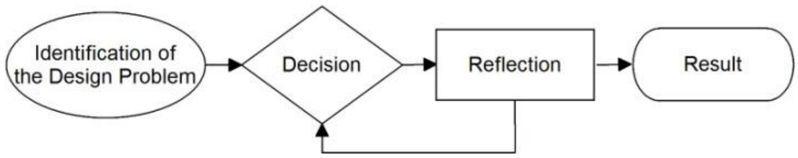

Figure 2. Schön's model on reflective practice and the four stages.

Engineering systems' theory applied within problem solving can be also translated in design steps by dividing the process in fixed stages as described by Pahl and Beitz (Pahl and Beitz 1995). These stages include conceptualising, embodying, detailing, evaluating and deciding. The engineering perspective of the solution finding and design process includes the division into working and decision making steps, thus ensuring the links between objectives, planning, execution and control (Pahl and Beitz 1995), (Krick 1969), (Penny 1970). These links can effectively achieve a generic framework for solutions finding as illustrated in Figure 3. The overall systems are also presented in Table 1.

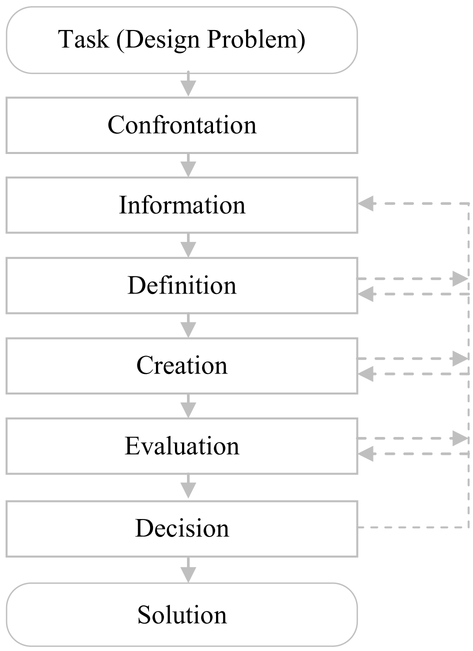

Figure 3. General Process for Solutions' finding, pp.63, (Pahl and Beitz 1995).

	Initial Design Stages								
Schön 1991	Identification of the design Problem			Decision				Reflection	
Cross 1989/ 2008	Clarify objectives	Establish functions		Set Requirements		Determine Characteristics		Generate Alternatives	Evaluate Alternatives
Pahl and Beitz 1988	Design Problem	Clarification of the Task & Goal Setting	System Analysis & Synthesis		Decision		Evaluate System	Decision	Embodiment Design
French 1971	Need	Problem Analysis		Statement of the Problem		Conceptual Design		Selected Schemes	

TABLE 1. Conceptual and Initial Design Processes.

When it comes to practice focused design processes, British Standards (BS) have been actively promoting effective collaboration through key work stages. The focus on effective collaboration initiated by Egan Report (Egan 1998) and continued with the second report, Accelerating Change (Egan 2008). Following these reports, the BS 1192:2007 (BS 1192:2007 January

2008), the successor of BS 1192:1998, is the 'Code of Practice' for Computer Aided Design (CAD) and includes information on Building Information Modelling (BIM) workflows and levels of adoption. The Publicly Available Specification (PAS) 1192-2:2013 on Building Information Management (Project information Management, PIM) provides further details of the key gates and the data management within BIM. Royal Institute of British Architects (RIBA) Plan of Work 2013 re-arranges the work stages similarly to PAS 1192-2:2013 and according to BS 7000-4:1996 on design management. The details of these design processes are briefly presented in Table 2.

	Initial Design Stages			
RIBA Plan of Work 2013	1. Preparation: Project Objectives, Business Case, Feasibility Studies, Assemble Project Team, etc.		2. Concept Design: outline design proposals (structural, services, landscape), preliminary cost planning, Agreement on Project Brief, etc.	
Project Information Model (PIM) 2013	Brief	Concept	Definition	Design
COBie Data Drops 2012	Data Drop 1: Requirements and Constrains	Data Drop 2: Outline Solution	Data Drop 3: Construction Information	
BS 7000: Part 4: 1996, Design Management Systems	Design Brief: Interpretation of the project brief, assigning responsibilities, brief development		Conceptual Design: outline of the design process	

TABLE 2. Conceptual Stages for the Built Environment.

In addition to BIM, there is Construction Operations Building Information Exchange (COBie) and Construction Design and Management (CDM) for sharing information about construction. COBie system aims at organizing and sharing information between the different stakeholders (clients, designers and contractors) and that type of files are utilised for timely delivery of the project's stages and for documenting and grouping buildings components information. Data drops and deliverables are also part of the COBie process with five drops being stated by the regulations, starting from the requirements and constrains, to the outline solution, construction information, operations and maintenance and post-occupancy evaluation (East 2013).

3. Proposed Conceptual Design Protocol and Studies

3.1. PREDEFINED DESIGN PROTOCOL

The proposed predefined design protocol is resulting from the demands of the industry for an organised process when tackling the conceptual design stages. Following the research on the different approaches when searching for a design solution, a division has been identified between systematic approach and the methodology of synthesis. Scientists tend to use a certain strategy and a systematic approach for understanding and identifying the rules that could enable the solution generation by utilising analytical methods, while on the other hand, design professionals focus on initial explorations and then suggest a variety of possible solutions, a methodology of synthesis.

The most common iteration occurring during both design approaches is the process of addressing a design problem by improving the knowledge of it and taking a step back afterwards, for the reason of re-addressing the problem with improved understanding of the project information (Lawson 2005). Based on that knowledge, a predefined design protocol has been developed and tested during a case study. The developed protocol begins with the formation of the design team and the initial introduction to the brief. It continues with the decision making process taking account of the project's constraints and objectives, which is then followed by brainstorming possible design problem solutions and synthesising the information. The protocol is complete when the suggested solutions are evaluated, the design team achieves a consensus and the final design solution is proposed. During this process there are certain decision-making points that act as gates for smooth and continuous solution finding process, (Figure 4).

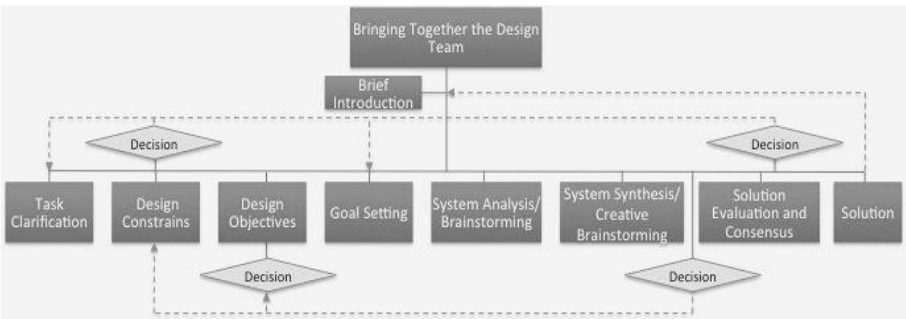

Figure 4. The predefined design protocol for the conceptual design stages.

The Conceptual Design Protocol as a simplified process applied for the built environment initiates with the design brief provided by the client to the AEC professional, which includes information on the client's needs, the budget and other vague specifications deriving from the dialogue between the two stakeholders. The design goals remain incomplete and the relevant AEC professionals evaluate the specifications and derive some specifications from the information provided, like the size of the building. Afterwards, the designer will refer to the list of attributes related to the building's typology, regarding materials, structure, other buildings examples, etc. The actual design process is evolving with the information arriving from memory and from the attributes at any given point and they are the ones that provide the stimuli for the design process to move forward by generating the forthcoming design components. What is more, design alternatives can be generated by triggering the design with new imported information. The whole design begins to acquire structure by being decomposed into smaller problems, thus leading to well-structured smaller problems but ill-structured bigger ones.

3.2. CASE STUDIES

The predefined design protocol was tested in two different case studies with multidisciplinary AEC professionals. The first study did not include the predefined protocol and the team was self-organised while in the second study the team followed the steps of the predefined design protocol (CPD). The teams included different types of designers, i.e. architects, quantity surveyors, structural engineer, mechanical engineer, building surveyor and a project manager. The co-located, multidisciplinary group of participants had a similar range of experience in both studies, which allowed for comparing the results of the studies. A realistic scenario was simulated where the teams were asked to complete a design task in three hours; a design brief was handed in the beginning, informing them about the building specifications and requirements, while afterwards and they were called to complete the conceptual design of the required building.

In both cases the design process was assisted by the M.S. PixelSense (formerly known as M.S. Surface Table or Samsung SUR40), which is a vision based multitouch system and infrared sensing, allowing for 52 concurrent interactions, thus enabling experiments on computer mediated collaboration through visual and tactile user interfaces of multidisciplinary teams of the AEC industry. The M.S. PixelSense was also tested in the first study and from the usability results a new application was developed to adapt to the sketching and drawing needs of the built environment professionals. The developed app was subsequently tested during the second study.

Each group performed the study in two parts; during the first one they were allowed to use any type of conventional means for conceptual design, including tracing paper, markers and commercial design applications through Graphic User Interfaces (GUIs), a laptop in particular, as shown in Figure 5, while during the second part they were called to utilise the M.S. PixelSense (Figure 6). The designers were able to collaborate, discuss their ideas and interact with each other and with the mediums. To assist with the analysis the whole process was video recorded for monitoring the detailed information exchanges. These videos were used for collecting information and analysing collaboration, design and use of the Tangible User Interface (TUI), i.e. the M.S.PixelSense. The study moderator was further guiding the team when necessary during the study process.

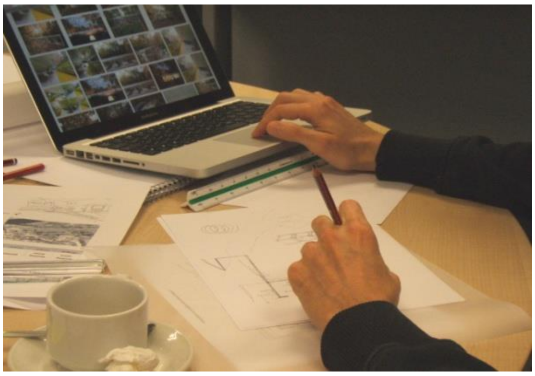

Figure 5. Conceptual design utilising the current paradigm process, pencils and tracing paper layered with maps and internet resources

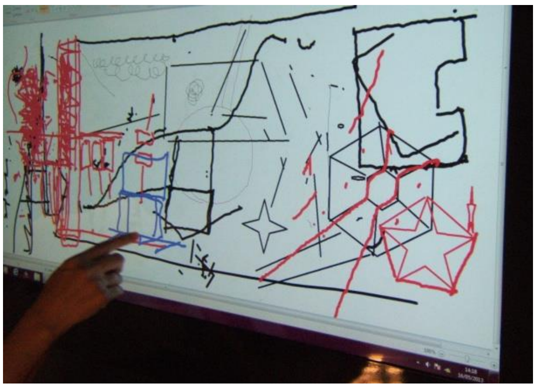

Figure 6. Conceptual design utilising the M.S. PixelSense with commercial software

The initial pilot study aimed at testing both the capabilities of the particular TUI with off-the shelf commercial software and the current paradigm of conceptual design, by allowing the participants to navigate the design process themselves. A usability report, after the completion of the first study (Leon and Laing 2013), informed about the problems and difficulties of the commercial available software, which led to the necessity or the development of a tailor-made software applied for the particular study and for design collaboration purposes. The problems reported at the study were focused on the interface and the difficulties using the commands, the poor quality of lines and the drawbacks with communicating effectively the different geometric shapes. As a result, the development of a tailored application for the particular hardware that complied with certain design aspects was required for the second study.

During the first study, the participants utilised internet resources, images and ideas during both of the stages. The process started with a brainstorming session, with each of the participant reading the design brief, taking personal notes or drawing sketches (Figure 5). Afterwards, a first general discussion about shapes, materials and building' standards took place, followed by a discussion about using the space and their personal perspectives on similar types of space. The main disadvantage during this process was that the team did not reach any final result; they did not finish the conceptual design. Even though the exchange of verbal ideas was vivid and intense, they did not manage to finalise a design; instead they had a collection of drawings and forms. Architects mostly led the design process and the progression of the design was time-consuming, due to the arguments deriving from the multidisciplinary approach. The professional and cultural differences, together with different expectations of the workshop, were substantially slowing the process.

For the second study, key overall principles concluded from the literature review and from the results of the first study influence the development of a tangible conceptual design system. The interface of the developed app was designed to be non-intrusive to allow designers to fully engage on the design problems without any interruptions or problems coming from the interface, and the use of the app is presented in Figure 7. Minimizing the modes and developing a small repository of operations aimed at natural drawing process; the toolbar includes options of actions, like importing pictures, drawing and picking a colour from a colour palette, taking snapshots, etc. All the actions are available with a single touch on the screen allowing for a free-hand drawing surface, a paint tool that allows multiple users to draw at the same time with a selection of palette tools.

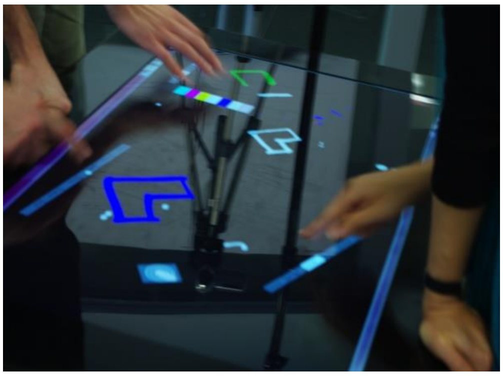

Figure 7. Conceptual design utilising the developed app for M.S. PixelSense

The multidisciplinary approach of the design was positively influenced in this case from the predefined design protocol (CPD). The design activities were substantially more intense than the first study and, as a result, the maturity of the conceptual idea at the end was more advanced than the first study. This was mostly evident on the grounds of achieving a final conceptual design idea that responded to the aims of design question and brief. The perceptual activities were enhanced due to the more effective collaboration among the team members. The reason for that was that the application of a predefined design protocol together with the TUI assisted in having them focused on the different types of relations between the building elements, which reflected on the knowledge of all the participants i.e. budget issues were dealt by the quantity surveyors, space and typology issues from the architects, etc. by drawing users' attention. The efficiency of the design app enthused the participants and they were engaged even more actively on the conceptual design process. What is more, they managed to use the TUI in unpredicted ways, by actively merging the physical and digital worlds when layering tracing paper drawn ideas on top of the interactive surface and moving between them while designing, thus allowing for a seamless exchange between different realms, as shown in Figure 8.

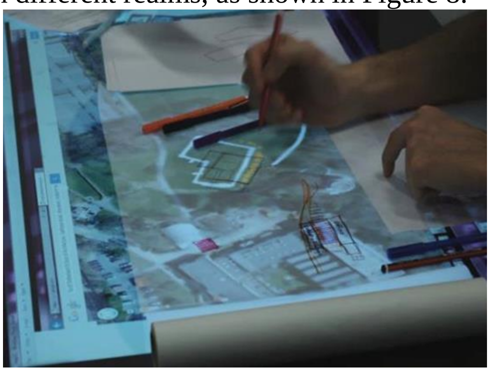

Figure 8. Conceptual design merging physical and digital means

During the first stage of the study, the architects were leading the process followed by the project manager and afterwards the surveyor, while the engineer was participating much less. The second stage was totally different due to the use of the Microsoft Surface Table, which demanded a hand-on approach from all the participants, gathering around the Table. For that particular period most of the participants were actually engaging with the drawings and they were more willing to participate.

Additional observations include the type of professionals engaged with the TUI; the design focus of the interface that is currently restricted to drawing related activities limits its use to design related professionals, like the architects, architectural technologists or structural engineers, not allowing non-design focused professionals to creatively engage with it. This obstacle could be tackled by introducing additional digital means and different types of interfaces especially for the non-designers. An enhanced communication between graphic user interfaces and TUIs could be a possible solution. Furthermore, the protocol analysis suggests that the TUIs enable a smooth design and cognition continuum resulting in enhanced ideas generation by allowing easier ideas externalisation. The users consider the process as a game, thus leading to increased communication, creativity and problem solving activities, even though they are still restricted by the design brief and aims of the design project.

4. Conclusions

The paper presented a review on different types of design protocols and processes, and it also introduced the initial findings of two studies on conceptual design activity utilising TUIs. The conceptual stage was monitored in both studies for the purpose of understanding the design process adopted by the design teams. The first study was exploratory, during which the professionals followed an unstructured conceptual design. The following study applied the design protocol (CPD) during the conceptual stage, making use of a managed facilitation process throughout the design project. The design progression patterns of the two studies were compared and the most important conclusions included the evolution of the design process and the faster progression of the feasibility stage when using the predefined design protocol. Importantly, the creative and unexpected users' interactions with the physical means of exploring ideas, led to a merging of analogue and digital worlds, which further promoted a vibrant collaborative design process with more extensive interactions between the participants.

The research aim is to move collaborative design from being an intuitive interaction for finding solutions to a systematic approach based on protocol methods and supported by rigid methodologies. Enhanced understanding of collaborative design together with standardization of the collaborative design processes through design protocols promote the informed and optimized decision making. Technology also plays an important role within these processes; it shapes and directs them not only because of the new and innovative tools and means but also because it affects the whole sphere of collaboration infrastructures both in face to face and in Cloud-based cases. What is more, the multidisciplinary aspect of collaboration can be endorsed through use of ubiquitous technologies and can encompass both sociological and scientific characteristics since the technology is now at a stage where barriers are mostly social and perceptual rather than technical, as it was demonstrated from the case study. On the whole, this research has the potential to improve the final design solutions for buildings, by making it possible for multidisciplinary teams to work collaboratively and to involve stakeholders more effectively at the early stages of the design process through TUIs. The involved professionals' enthusiasm when utilizing the protocol and the computer mediums might convey the answer to tackle a latent problem in early design stages for multidisciplinary collaborative and computer mediated design.

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