Application of Interactive Surfaces to Support Computer Mediated Collaborative Design Environment

Marianthi Leon[1], Daniel C. Doolan[2], Richard Laing[1], Julian Malins[3], Huda Salman[1]
Scott Sutherland School of Architecture and Built Environment[1], School of Computing Science and Digital Media[2], Gray's School of Art[3]
Robert Gordon University
Aberdeen, UK
m.leon1@rgu.ac.uk

***Abstract*— This paper explores drawing as a design medium for conceptualising ideas within the built environment professionals and its application through computer mediated environments and tangible interfaces in particular. Developments in human-computer interactions' technologies allow the integration of physical and digital realms. Furthermore, advances in multi-touch displays promote the haptic experience, which is substantial for externalising and communicating visual ideas among designers. As a result, an interactive surface is tested in two different studies with a multidisciplinary group of built environment professionals. The aim of the paper is to compare two different design applications, a commercial available one and a tailor-made one, to further analyse the effect of such an environment on the participants' perceptual, conceptual and collaborative actions and, eventually, to propose further research on augmented design platforms.**

Keywords- human-computer interaction; M.S. Pixelsense; built environment; conceptual design

I. Introduction

Effective design collaboration during the early design stages in Architecture, Engineering, and Construction (AEC) industry is a condition for efficient overall design and construction processes. Furthermore, architectural design requires a strong visual approach to communication and means for the purpose of bridging multiple disciplines and different professional viewpoints and creating a shared understanding among all stakeholders. This can be facilitated, supported and promoted through effective visualisation technologies and digital means that are nowadays widely available and tend to take an important role in the design process. Therefore, it is essential to understand and interpret the impact of digital and tangible applications to the cognitive and perceptual activities of the designers, and to achieve a smoother integration of these technologies to the current paradigm of design work. A tangible user interface (TUI), such as the Microsoft Pixelsense (Samsung Surface) in particular [1], is the technological medium used to overcome the research problem of conceptual collaborative design with multiple users. The developed computer medium aims at complementing the human capabilities by offering an augmented design medium focused on conceptual design.

Collaborative design processes and idea generation methods implemented within emerging augmented reality technologies can be the drivers and enablers for a more effective collaboration during the early design stages. A summer studentship, led in collaboration between the School of the Built Environment and Architecture and the School of Computing Science and Digital Media, was focused on developing a prototype application to allow built environment professionals collaborate efficiently and drew upon a wealth of existing material. The particular application was utilised for two user studies on computer-mediated collaboration through visual and tactile user interfaces by multidisciplinary design teams of the AEC industry. Furthermore, the study examined the effectiveness of the system on designers' cognitive activities and design process in co-located multidisciplinary design collaboration experiment.

II. Related Work and Literature Review

A. Sketching as a design medium

Design is a process that builds up a description of an artefact, building, process or instrument to meet certain performance criteria and resource limitations; the product is realizable, and satisfies criteria such as testability, manufacturability, reusability, etc [2]. The essence of design is the communication of information, thus the description of a design solution or artefact in a form that is understandable to those who will build it [3].

Visual communication methods (such as drawings, images, sketches) significantly enhance the quality of information during the design process by providing a representation of the artefact, hence leading to visual engagement of the designers. The design initiates at the conceptual stage during which the initial possibilities of a project are investigated, together with the aims and objectives of the building project, the geometrical characteristics, materials, dimensions, ideas about the form and the use of the artefact/building. The tools that designers use during conceptual design include among others documents, images, maps and sketches. Free-hand drawings and sketches are the medium that allow for greatest flexibility, speed and intuitiveness for communicating ideas due to their consisting of a considerate level of abstraction and of information that can be implemented at later and more advanced design stages. Moreover, ideas verbalisation together with the use of computers for conceptualising can further enhance the ideation process, foster new patterns and relationships therefore allowing for additional ways of perceiving and conceiving design solutions [4].

Sketching and drawing are "spatial and haptic exercises that fuse the external reality of space and matter, and the internal reality of perception, thought and mental imagery into singular and dialectic entities" [5], p. 89. Sketches are being considered the most significant way for design ideation that visually engages the participants and effectively represents the artefact. Free-hand sketches, using pen and paper, together with physical models are the preferable media used by designers [5] [6] [7] [8], while nowadays digital representations are also an additional tool for form generation processes [9], [10]. Designers often find difficult to describe non-verbal processes in words [11] and sketching allows for further communication of ideas.

B. Tangible User Interfaces

Tangible User Interfaces (TUIs) are able to merge the physical environment and digital worlds [12]. TUI is a field within Human Computer Interaction (HCI) that couples digital information to everyday physical objects and environments and they are classified in three different types, Interactive Surfaces, Coupling of Bits and Atoms, and Ambient Media. TUIs have been extensively used for learning purposes, for programming, problem solving and entertainment [13], and they are capable of establishing a greater sense of presence in virtual environments due to the visual, auditory and haptic combination [14]. Integrating information from different sensory modalities results in a richer and more coherent experience that can be applied to co-located collaborative design and as a result, enhance the drawing activities.

Computer Supported Collaborative Design (CSCD) has been developing the last twenty years [15]. It aims in addressing increasingly complex designs that require collaborative team working. When it comes to the built environment in particular, computer supported collaborative working (CSCW) [16] can improve project management and promote the exchange of information across disciplines. TUIs have also the potential to further enhance the cognitive activities by coupling physical artefacts with digital representations, visualisations and information.

C. Applications developed for the built environment

The continuing evolution of technology is managing to bridge the gap between Human- Computer Interactions (HCI) allowing for a seamless and natural exchange between the physical and virtual world. TUIs are situated between real environments and Augmented Reality (AR); they comprise out of physical objects that work as interfaces while the computer disappears into the physical workspace. Design disciplines aim to utilise TUIs to support design processes through tangible interactions. Many different types of applications (apps) have been developed, with most of them based initially on a proof-of-concept approach. The latest apps' prototypes are oriented to provide solutions to more complex design practices, like architectural design, for the reason that tangible environments provide a straight-forward design process by mimicking physical means. However, the impact of TUIs and any AR or Virtual Reality (VR) apps to the cognitive and perceptual activities of the designers has not been fully explored, together with their implementation to the existing ways of working.

The Electronic Cocktail Napkin [17] was a tangible platform that supported synchronous collaboration by utilising digitized pens and papers either for co-located or distant designers. Additional features included trainable recognition, constrain based drawing and pin-up bulletin board. The designers could either share a drawing surface (tablet) or draw simultaneously on different tablets. They could also be located in different physical locations connected through a local area network. Likewise, SKETCHPAD+ was another prototype that was applied on a large design table. It included both pen-based digital input and a computer display where the users could draw with the pen [18]. The sketches were afterwards translated into photorealistic renderings and the system could allow synchronous collaboration by having the prototype viewable on different displays.

Further tangible interfaces for design purposes consisted of the HyperSketch prototype I and II [19] that simulated tracing paper by allowing users to trace previous designs and layer them on a LCD screen. Users could also identify relationships and links between different sketches in order to manage large collections of related sketches. Asynchronous and distant collaboration was supported through the Internet, "by enabling the creation, storage and retrieval of large collections of interrelated sketches from any Internet-enabled computer in the world" [19], p. 295. Additionally, the Luminous Table project combined 2D drawings, physical and digital models by utilising two cameras for space detection and video projection on a table surface [20]. It achieved tangible interactivity by combining simpler technological parts and the design output was utilised for urban planning visualisations.

Platforms supporting asynchronous collaboration and sketching include the PHIDIAS (Procedural Hierarchy of Issues Design Intelligence Augmentation System) hypermedia system [21]. The aim of the platform was to store and retrieve information about design decisions, whether it concerns words and documents or discussions on design projects, without attempting to manage workflow. Sketching processes have also been an extensive research focus, either aimed on rapidly conceptualising and editing simplistic 3D scenes [22], or on transferring free-hand sketches into three dimensional digital models through interpreting gestural and abstracted projections [23]. Augmented Reality based applications for the conceptual stages within a sketch like environment comprise of tools like Hybrid Ideation Space (HIS) [24],that aims at augmenting digital pen and tablet displays with a real-time projection and normal perspective of the designed artefacts.

D. *Applications using Multi-touch displays and M.S. PixelSense*

Multi-touch display environments include proof-of-concept devices' combinations, like a multi-touch display with a Microsoft Kinect camera and two Gametrak devices to track movements above the surface for direct 3D modelling [25]. Within the particular example, a menu provides the option to the users to move from linear to curvilinear extrusions. A division between dominant hand and non-dominant hand of the same user endows with different potential input, i.e. drawing with the dominant hand and option for points snapping or for 3D extrusion with the non-dominant one. The particular setup allows users to sketch directly on a touch screen and extrude on the third dimension by utilising a movement tracking option.

Tangeo is a drawing interface applied on a touch-screen and utilising tangible drawing tools, like rulers and triangles [26]. The aim of that interface is to allow the design of geometric shapes by employing finger design and traditional drawing tools. Users are capable of employing both physical artefacts that are tag-recognised by the PixelSense system. Ink beautification is another important aspect of translating the input into lines, by smoothing shapes and snapping corners.

Flo Tree [27] is a multi-user platform applied on a M.S. PixelSense, for exhibition and learning purposes in a museum. Museum visitors are able to spot a colourful set of lines moving on the screen that represent evolutionary biology. The interaction of the visitors with the PixelSense produces splits in the lines' continuity, conveying the challenges faced by populations, with the end result being the creation of new lines and therefore species. The interface includes a button for restarting the app, information bubbles explaining the exhibit and instructional images.

III. Development and Testing of a Conceptual Design Application

A. *Study Descriptions*

The M.S. PixelSense (formerly known as M.S. Surface Table or Samsung SUR40) is a vision based multitouch system and infrared sensing, allows for 52 concurrent interactions, thus enabling experiments on computer mediated collaboration through visual and tactile user interfaces of multidisciplinary teams of the Architecture, Engineering and Construction (AEC) industry. The M.S. PixelSense was initially tested in a design study with multidisciplinary design participants 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 with a second study and the results and the development are presented in the paper.

Two different multidisciplinary groups of AEC professionals participated in the two studies. The teams included different types of designers, including 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.

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, while during the second part they were called to utilise the M.S. PixelSense. 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 and developing protocols that analyse collaboration, design and use of the TUIs.

The initial pilot study aimed at testing the capabilities of the particular TUI and off-the shelf commercial software was utilised (Drawing application and Autodesk Sketchbook Designer) for completing the design task, as shown in Fig. 1. A usability report, after the completion of the first study [28], informed about the problems and difficulties of the commercial available software, which led to the necessity for 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. The commercial software was not developed with a focus on the particular TUI, rather it is developed for a Microsoft Windows personal computer; therefore, the multi-touch input could not be utilised. Furthermore, the participants had difficulty moving from the design activities to searching for information on the Internet and the importing of pictures from other resources was impossible. 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.

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 is 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 Fig. 2. Minimizing the modes and developing a small repository of operations aims 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. Drawing and sketching are able to provide an easy and flexible externalisation of designers' vague ideas through a cyclic and dialectic process, thus, the ease of visualising and creating is a prerequisite for undisturbed creation. Additionally, working on layers, hence reflecting work with tracing paper, supports combining and restructuring drawings and their relationships, while tracking the design evolution. An image gallery is also integrated within the application, providing visual resources and inspiration. The users can choose the pictures they want, import them on the canvas and take actions on them, like rotation, scaling, drawing over them. Taking snapshots to keep a visual record of the process was also a prerequisite, together with the option to start a new canvas and delete lines and images when required.

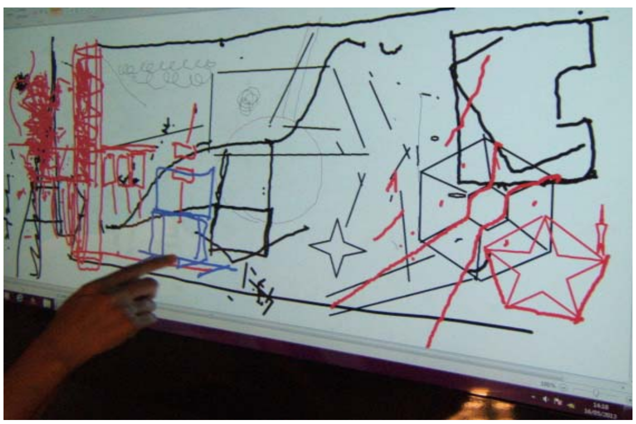

Figure 1. Conceptual design utilizing the M.S. Pixelsense with commercial software.

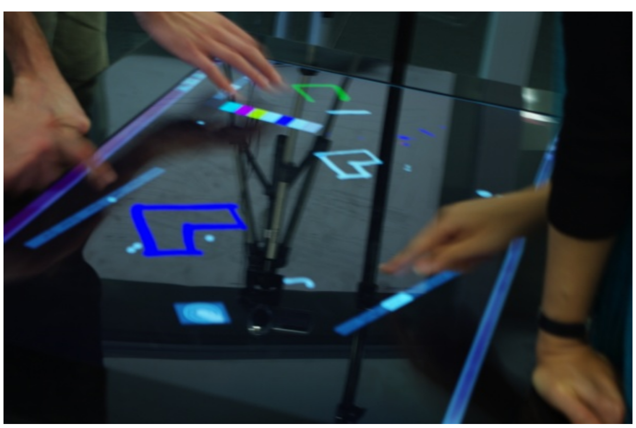

Figure 2. Conceptual design utilising the developed app for M.S. Pixelsense.

B. Results Analysis

Protocol analysis is the preferred method for analysing the video recordings of the users' interactions with the TUI. What is more, the coding scheme is based on identifying the perceptual, cognitive and collaboration activities during the study, while interacting with the TUI. Subsequently, the coding categories answer to questions on the physical act of drawing, the cognitive mechanisms underlying the processes and the collaboration among the participants.

The protocol analysis applied for the TUI mediated conceptual collaborative design stage initiates with the segmentation of the entire video (protocol) into smaller units. Design protocols can be segmented either according to subjects' verbal events like pauses, phrases and intonations [29] or according to subject's intention and to the theme of the content [30]. For this study's design protocols analysis, the latter approach is preferred [31]. Different approaches have also been considered when investigating the suitable types for segmenting the protocol. The current research is influenced from protocols suitable for analysing TUIs and synchronous collaboration [32], protocols on cognitive actions during design processes [31] and protocols on function-behaviour-structure model [33]. The segments' division is case depended and the categories in which they can be divided are determined by the research scope [33].
The segments are divided in four levels with the aim to answer the overall research questions and aims, which are if the TUI enhanced collaboration, the interactions among the participants and with the TUI, if the TUI promoted cognitive activities and the general evolution of the design process through TUI. The levels include the action or physical one, focused on the drawing/sketching on the PixelSense, the collaboration level, with the categories of cognitive synchronisation and ideas clash and the workflow driver, the process level focused on setting goals and making decisions, and the perception level, on perceptual activities when re-examining existing features and relations; this study's coding scheme is presented in Table 1.

TABLE I. CODING SCHEME FOR ANALYSING THE TUI MEDIATED CONCEPTUAL DESIGN

Levels	Categories	
	Code	***Description***
Physical Actions	Sketching/ Drawing	Drawing, importing images, etc.
Perception	Perceptual Activities	Focusing on new or existing features
Concept	Set up Goals Co-Evolution	Goals on new and existing functions Brainstorming
Collaboration	Cognitive synchronisation	Argumentation and negotiation

During the first study, considerable difference was observed between the physical means and the digital ones in the physical actions level; users were experiencing technical problems during the implementation of the M.S. PixelSense and the commercial apps were not intuitive enough to assist a smooth design process in contrast to the ease of physical means, like tracing paper and pens. Interestingly enough, a difference was monitored during the perceptual and collaborative activities between the use of TUI and the physical means, with the most effective communication taking place during the M.S. PixelSense study stage. The participants were more actively engaged when they had to come closer and focus on a tabletop environment, while their attention was also attracted by the interactive medium. The evolution of the ideas occurred again during the PixelSense stage when the participants were creatively engaging on top of the TUI. Despite their collaborative design, the participants did not manage to reach the aim of the study, which was the conceptual design of a small building.

The second study tested the developed conceptual design app for the TUI, during which the use of the TUI was significantly improved compared to the first study. The physical actions during the implementation of the TUI were much smoother and the users managed to successfully integrate analogue and digital means, as shown in Fig. 3, where the participants draw in layers with tracing paper and drawings on PixelSense. 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 TUI assisted in having them focused on the different types of relations between the building elements 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.

Figure 3. Integration on physical means with tangible interface.

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.

IV. Discussion and Further Research

A multi-device configuration for allowing users to interact with different types of information coming from different resources is one of the aspects for further improvement. Examples already show the capacities of connecting multiple devices, like laptops, tablets, mobiles and M.S. PixelSense [34], and the configuration among them can be a cumbersome task. Especially for a designers' collaboration environment, a key aspect is to manage the information coming from different types of software, like pictures, drawings, 3D models, BIM files, and from different types of devices depending on the master device that is the central focus of the user. Furthermore, an addition of an option for importing images from the Internet on the working surface and for working on maps is also an aspect currently under development. The app will be further developed to include Cloud synchronous collaboration and it will be tested in the forthcoming studies according to the described design protocol. Further research could also include integration of human-computer interaction and augmented technologies (i.e. a immersive CAVE virtual environment, tabletop augmented reality environments). The application will be tested in multiple experiments with different types of users and in various design scenarios and adapted accordingly.

The application can improve interactions and provide a sensory richness of meaning through the combination of physical and digital resources. It also adds value for interactions not only during conceptual design but also at more advanced design stages, for improved interaction and augmented communication among the different stakeholders. Nevertheless, still little is known on the influence of the technologies that support tangible interactions on designers' cognition and perception.

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