MR. SAP: AN ASSISTANT CO-WORKING WITH ARCHITECTS IN A TANGIBLE-MODEL-BASED DESIGN PROCESS

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Abstract. To avoid interruption on architects’ tangible-object-based design process, MR.SAP is being developed to co-work with architects as a cost-acceptable personal solution with tangible user interface, which can scan the tangible object, analyze its digital counterpart, and prompt visualized suggestions upon it through a portable projector in real time. It extends the user’s capabilities of form perception, real time calculation, and operational positioning upon tangible objects, which can better serve his subjective aesthetic taste and design aims.

Keywords. Mixed reality; projector and camera system; manual craft; co-working.

1. Introduction

In the researches of design methods, the user interface of any design tool is always an important issue having impacts on the design process and even the result. Traditionally, architects use a manual user interface consisting of sketches and mockups. It provides very high fluency in design thinking (Arnheim 1971). With the development of digital technologies in computer modelling software and numerically controlled machines, architects use more digital tools to extend their accuracy in design thinking and counter-part building, which makes computer-based architectural applications, such as digital fabrication, very popular (Yuan 2012). However, most of the applications work with a Graphic User Interfaces (GUI), which interrupts the users’ fluent design thinking when he repeats to build linkage between a piece of digital information and its tangible counterpart in real world (Ishii et al. 2008). Thus, Tangible User Interface (TUI) is raised for the designers to take the both above benefits (Ullmer and Ishii 1997).

In this study, a project called MR.SAP is introduced as a cost-acceptable solution based on TUI concept for individual front-line designers. It tries to provide real-time form-related visual information upon tangible objects to raise the designer’s accuracy in perception and operation, when he simultaneously enjoys the fluent design thinking upon tangible objects in real world. As an initial achievement in this project, main modules of the system are depicted and a design process concerning Gross Floor Area (GFA) is demonstrated in the following paper.
2. Literature Review

2.1. TRADITIONAL DESIGN PROCESSES WITH A MANUAL USER INTERFACE

In a traditional design process with a manual user interface, a designer improves his ideas by successively drawing sketches or making mockups, and visually evaluating them. A number of these cycles make up the whole design process, which is so-called “visual thinking” (Arnheim 1971), and depicted as the prototypical creative cycle of perception and presentation (Buxton 2006) shown in Figure 1. It is widely adopted by architects before the digital technologies are involved, in which designers have the most efficient cognition on what they are deliberating. When the manual user interface makes the design process a non-interruptive cycle, designers would acquire more inspiration benefiting from the direct feedbacks through the tangible interface.

While there is a limitation of manual user interface: when operating with an architectural model with only naked eyes, designers would have difficulty figuring out the model's properties accurately in real time, such as the GFA, sunlight condition, etc., especially when the form of model is irregular. Digital technology could make up for the deficiency.

![Figure 1. The creative cycle of perception and presentation (qt.Buxton 2006).](image)

2.2. DIGITAL ARCHITECTURAL APPLICATIONS WITH GUI AND TUI

Once digital technologies are widely applied in computer-based architectural applications such as digital fabrication, architects are able to establish precise sketch models or even full size building parts rapidly through a robotic making process. Digital technologies play the role of robotic craftsmen in all these projects, such as ICD/ITKE RESEARCH PAVILION (Fleischmann and Menges 2011), Wind Tunnel and Environment Performance Morphologies (Yuan and Xiao 2014), either in the process of design or fabrication. The technologies turn digital models into tangible counter-parts in the interaction with architects through Graphic User Interfaces (GUI) as shown in Figure 2. However they work as independent function modules interrupting the architects’ visual thinking process.
While, Tangible User Interface (TUI) opens up another possibility of the role digital technologies playing in design process. TUI provides physical form with digital information and computation, facilitating the direct manipulation of bits. It aims to empower collaboration, learning, and design by using digital technology. And at the same time, TUI takes advantage of human abilities to grasp and manipulate physical objects and materials. Three feedback loops are involved in TUI: A feedback of immediate tactile, a feedback through digital processing and a feedback with computational actuation (Ishii et al. 2008).

In this study, focusing on the second feedback loop of TUI, the new role of digital technologies applied in the process of design or fabrication is explored. It mimics a design assistant by offering visualized information and reasonable suggestions for architects during the visual thinking process in Figure 3. In this way, architects can receive more feedbacks or even inspiration from tangible interactions than they can from a process involving only a robotic craftsman.

2.3. PROJECTOR-CAMERA SYSTEM AS A LOW-COST SOLUTION OF TUI

“Projector-Camera System” (PCS) is a powerful but low-cost solution of TUI. The application of PCS is common in digital entertainment industries, which reads data from real world through cameras, and outputs feedback through projectors. In the field of architecture, the PCS appears in several well-known projects, such as Figure 4, Collaborative Design Platform (CDP) (Schubert et al. 2011, 2012, 2015), offering visualized information on models to urban designers around a table. The information such as irradiance levels, wind speed, accessibility of buildings, etc. is offered in real time, when the designers operate the volumetric models...
on the table. Another project, named Smart Drafting Table (SDT) is developed by Precision Planning Lab (PPL) of Tongji University in Figure 5. In the field of geographic education, AR Sandbox, is another well-known system developed by KeckCAVES of UC devis in Figure 6, in which an augment reality sandbox provides an interactive study platform for the students and teachers (Reed et al. 2014). All of these projects work on a 2.5d mode through a depth sensor from a top view to perceive the tangible objects (Dalsgaard and Halskov 2013), which limits their application for true 3D architectural forms. Meanwhile, due to their requirements on spacious room, good budget, it is almost impossible for the front-line designers to use them as personal tools.

![Figure 4. Collaborative Design Platform (qt. Schubert et al. 2011).](image1)

![Figure 5. Smart Drafting Table (May 2016).](image2)
3. Methods

3.1. MR.SAP

Based on the notion of the visual thinking, the Tangible User Interface, the solution of PCS, algorithms in computer vision and mixed reality, a prototype system, namely “MR. SAP” is being developed (Figure 7), which can perceive tangible models in architect’s hands and offer real-time prompts according to customized algorithms in Grasshopper. MR.SAP works in a desk scale and faces with an individual person like a design assistant. Thus, MR.SAP is another robotic system consisting of physical entity scanner as eyes, analysis algorithms as a brain, and image projector as pointing fingers on the tangible models. Essentially, MR.SAP exhibits another role of the digital technologies in computer-based architectural applications.

The project of MR.SAP started in mid-2016 inspired greatly from Schubert’s CDP project. While MR.SAP features itself as a visual think tool for personal usage with true 3D capability. By June 2017, the second prototype is published, which can work through the full cycle consisting of scanning, analyzing, and prompting. In December 2017 (Sun et al. 2017), a new version is prepared with more progress, including an algorithm simplifying meshes and an algorithm optimizing the calibration accuracy.
MR. SAP is designed as an assistant co-working with an architect following his visual thinking process mentioned above without interruption from a robotic craftsman. It means that the architect is still operating the tangible model continuously, while in real time the computer assistant offers visualized suggestions as images projected on these models, which actually expands the architect’s ability in real-time perception and calculation. Compared with those PCS projects mentioned above, MR.SAP is proposed to satisfy a more customized using experience, instead of being a public platform. In both hardware operation and software function, MR.SAP provides more flexibility. Since the positions of the camera and projector are adjustable, they give better viewing experience for different persons and tasks. The analyzing module working between the camera and the projector is connected to Grasshopper, one of the most common scripting tools used by architects, allowing users to customize the analyzing function by themselves. Furthermore, to serve as a personal tool, MR.SAP is designed with low-cost hardware. On one hand, MR.SAP’s contribution to fluent visual thinking makes it most suitable for the preliminary stage of architectural design, which has plenty of modification possibilities and repeats many cycles of visual thinking process. On the other hand, the precise requirement of preliminary stage is relatively low, thus even with low-cost hardware, MR.SAP can still reach acceptable accuracy when reacting to designer’s deliberation.

3.2. HARDWARE

The system has a Microsoft Kinect2 as its “eye”, a PC as its “brain”, and a portable projector as its “fingers”. Two types of 3d sensors (structured light and TOF) (Butkiewicz 2015) are used widely. After Kinect 1, Kinect 2, and RealSense are evaluated, Kinect 2 (300$) is selected for its acceptable accuracy and huge development community. A portable projector (Philips ppx4010) (300$) is used to prompt information on the surface of foam models for its portable size and big tolerance of focus distance.

In the selection of materials of tangible models, several kinds of foams are compared with each other. Their IR reflection ratios, prices and fabrication tools are evaluated. Finally, normal white EPS foam, popular in design studios is selected as the working material.
Additionally, a turning plat decorated with AR markers is used to host the foam model, which can greatly reduce the calculation time for point clouds registration. Therefore, real-time performance is improved and cost of PC is reduced. Except for the PC, the hardware cost of MR.SAP adds up to 600$ approximately.

3.3. SOFTWARE
In this stage, MR. SAP is designed to work with Grasshopper (Figure 8), which means:

1. The tangible model is perceived as a mesh parameter component in Grasshopper at a fixed refresh rate;
2. The analysis process can be highly customized with algorithms available in Grasshopper;
3. A customized output component in Grasshopper casts the calculated suggestions onto the foam model as distorted color points through the projector.

Thus, the start and the end components in Grasshopper are developed through the C Sharp interface. Several SDKs are used, such as RealSense SDK, OpenCV 2.4.11, AR Toolkit 5.1, PCL 1.7.2.

4. Demonstrations
As an initial exploration to apply the MR.SAP, a GFA involved design process for a building is demonstrated here. There are two samples in the demonstration.

The first sample illustrated in Figure 9 shows how MR.SAP works out the GFA of a tangible model. In this scene, the foam model represents a high-rise building, cut by the user manually. When the user modifies the shape of the model, MR.SAP, as an assistant, collects the model’s data in a prescribed scale and provides the GFA of the building to the user on the screen in real time.
The second sample illustrated in Figure 10 shows how MR.SAP suggests where to cut on the foam model through paths lit by its projector to satisfy the user’s GFA reduction requirements. In this scene, the user tries to cut the model to adjust the GFA to 20000 square meters by changing the inclination of the top surface of the shape, which is a tough task without digital assistance. MR.SAP helps work out the exact cutting boundary and projects it on the tangible model. Therefore, the user can follow the prompts given by MR.SAP and cut the model to reach the GFA requirements manually.

However, MR.SAP’s real-time performance still needs to be improved. When working on a PC with Core i7 2.60GHz, the two samples need 5-7 seconds to rebuild the image projected on the form when dealing with different scanning views.

![Scan foam model](image1.png)
![Evaluate model GFA](image2.png)
![Modify model shape](image3.png)
![Update GFA of the modified model](image4.png)

Figure 9. Sample 1.
5. Conclusions

Based on concept of TUI and the framework of PCS, MR.SAP is built offering a Tangible User Interface. It prevents visual thinking from being interrupted, during which digital technologies serve as an assistant instead of a robotic craftsman. And the illustrated demonstration shows that MR. SAP is a feasible assistant to co-work with the designer and to provide performance information and operation suggestions. This reveals another huge potential of digital technology in architecture field, namely “a robotic design assistant”.

Obviously, there are still two main problems in the current stage. One is the non-linear scan deviation. In order to increase the accuracy of MR.SAP, there should be an engineering method to calibrate the irregular scan deviation. The other is real-time performance in projection. The refresh rate of MR.SAP is still very low. Specific optimization algorism is needed and parallel computing with GPUs is planned.

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