# Improvement of Digital Design Processes with the use of Tangible User Interfaces

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***Abstract*— from the time when Computer Aided Design (CAD) has been introduced into design disciplines, decades have passed, however client communication is still in its rudimentary state. Designers and architects still use hand drawings and physical models at conceptual design stage, which are then being input into the computer, printed again, sketched over and transformed back into digital. This process is repeated multiple times, what creates a time and material consuming loop. Furthermore Graphical User Interface (GUI) disables users from cognitive perception of the space, making them concentrate on less relevant details, rather than on the bigger picture like spatial relationship between elements of the design. On top of that clients mostly possess verbal abilities that make communication with designer very limited. This is where tangible user interfaces (TUI) come in place. The theory behind TUI promises to turn a space and familiar objects around the user into the media for producing sophisticated digital designs. This paper is looking at different tangible tools that allow that, compares those tools and briefly looks at feasibility of tangibles.**

***Index Terms*—CAD, Computer Aided Design, Architecture, Tangible User Interface, Augmented Reality**

## I. Introduction

It can be seen that many contemporary designers realize the rapidly increasing distance, that digital design tools create between the creator and designed object. Although very contributive, designing physical objects through digital tools is becoming less and less natural, especially using procedures involving parametric modeling and design through scripting. In those cases the designer creates space and form of the object by inputting parameters that are later transformed into the actual object by the computer [1]. With all these pressing technologies it is getting harder for a senior designer to expose oneself to new software, which is being released and updated every half of the year [17]. If trained professionals find it hard to keep up with design tools, then it is hard to imagine what clients have to go through to be able to comprehend anything that designer produces. That is where one of the most important dilemmas lies and along with that contemporary architecture is loosing its nature and creativity. It becomes a mild version of computer science, pointed much more to knowledge of software, rather than to thinking and developing processes.

Furthermore physical representation is still perceived better by clients that do not necessary have skills to interact with digital designs, therefore it is still the most important aspect of communication between both parties.

Digital design may eventually be printed onto paper or made into model by using CNC routers or through other means like 3D printing. However, due to the dynamicity of the design flow, the 3D models require constant reprinting or be dynamic themselves. On top of that this printing process does not assist in communication at the initial design stage and adds significant cost that not many companies can afford. Communication error, at any stage of the design, may cause significant client disappointment in the final product. While most of the designers can still rely on free-hand sketches and physical models, there is nothing that clients can do to express themselves and explain their requirements to the designer [2][8]. Therefore conceptual stage of the design is unaffected by the might of computers and is still immature.

Due to the fact that TUI improves spatial understanding and spatial perception [2] [5], it seems that they could open the gate to the ideal world, where physical is digital and vice versa; the world where designer does not have to leap over the giant trench to get closer to its creation without loosing the performance and all the intelligent abilities that digital world provides. Would it be beneficial and feasible if artifacts were invented with the ability to be manipulated by a person, without specific education, to define the space in real world and convert into digital? How hard it is to produce such artifacts?

## II. Understanding of architectural design process

Since Computer Aided Design (CAD) has been introduced, the architectural design process has become significantly more sophisticated. The way the process is initialized depends entirely on the designer; however it always starts with either scribbles on the paper or a draft physical model that then is modified, analyzed and transformed in more precise computer drawings or models [2][8]. It does not end here though – after each little step is made in digital form, it has to be printed. Printed form allows a better understanding of scale, as scale visible on a screen is different to what it will be after design is printed. It further allows for printed media to be brainstormed over and marked up in more efficient way than doing it digitally. All the physical changes have to reflect on the digital world, hence the marked up data is being input back into the computer.

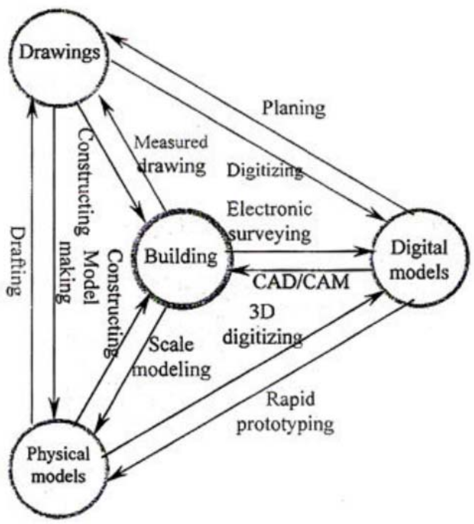


Fig1. Relationship between different design demonstration techniques (Drawn after William J. Mitchell)

Most of the actual design is still done with use of standard tools and only when the draft design is complete it is being converted into digital world. From now on, it is mostly about making the design more precise. This process is also important when it comes to client presentation, therefore the entire process goes from real to digital and backwards multiple times until the final set of fabrication information is produced and presented to the client in the printed form [3]. Unfortunately there is very little client interaction up to this stage, what always causes some degree of miscommunication.

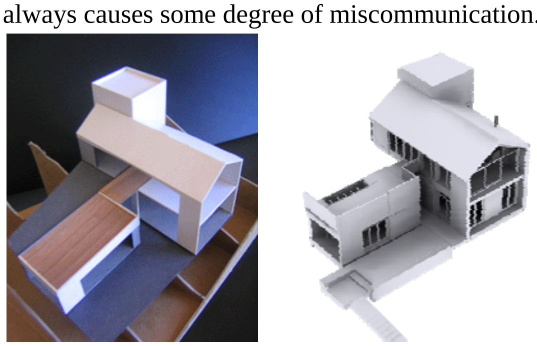

Fig 2. From left to right: Physical model #5 used for initial design concept communication between client and architect; reconstructed digital model. (used with permission of MOTM Architects LTD)

## III. Benefits of tangibles in design fabrication

Research shows that TUI allows users to pay attention to design problems rather than concentrating on least important details. In [5] the research states that designers in the GUI environment, place objects without noticing problems in relation to other elements of design, while users in TUI environment perceive the spatial relationship between elements of design much better. Being able to constantly relate different elements of the design is utmost important ability. Incorrect placement of, for instance, bathroom in relation to the kitchen and dining room may result in long trips, for inhabitants, to wash their hands before having food. Secondly it converts the familiar, to any user, objects and the space around the users into interface, what potentially creates a possibility for anyone to prototype naturally without additional knowledge of hardware/software [14][18]. Thirdly designers using TUI perform cognitive actions in a shorter time. Furthermore it is a promising tool for collaborative design and education [11].

The described above are not all the positives that tangibles can bring, but, in my opinion, are the most valuable for the design industry. Looking closer at selected examples should confirm or argue these advantages.

## IV. Current tangible approaches to digital fabrication

### A. *Physical tangible artifacts.*

The first and most logical step is to offer a more natural alternative to keyboard and mouse interaction [4]. Tangible blocks (TangiCAD) that are used for onscreen manipulation were created with a hope of using natural human ability to manipulate 3D objects. While it all offers a new way of interaction, this system, unfortunately, represents no more than a substitute to mouse and keyboard, which, in my opinion, still performs pure virtual manipulation and requires training. The “Replacing the mouse and keyboard” technique at this stage does not seem to be reducing the distance between user and design significantly, as according to the authors it still hits similar walls that need to be overcome in the future. In addition to that TangiCAD does not improve client–designer relationship and adds further complication to design process. According to authors the resulting model is not accurate enough to use it as a final model and interface is too complex to use it for rapid prototyping, so, at the current state, there is no need and no place for this process to be integrated into. Nevertheless TangiCAD is still offering perceptional benefits and to take a step further, it is necessary to start treating tangibles as objects that are part of the design and are being manipulated rather than objects that are used for manipulation [4].

In [6] two approaches to recognizing tangible input were made: 1) self describing blocks that recognize position relatively to each other and interpret the structure they are formed into; 2) system that performs a volumetric scan of the object and create a digital replica on a fly. First system that reminds a Lego like structure is proving useful and could potentially work well for the representation of entire building as well as interior spaces. Unfortunately it is still not accurate enough for a conceptual design as well as it has a very rigid structure that does not allow quick modifications to be done to it. It is also not the best example of visual quality representation either. In addition to that forming blocks into structure is a very time consuming modeling process that will not suit as a design environment no matter how simple it is. Even so the evident benefit is the ability of a computer to interpret a simple, not suitable for presentation, model, which remotely reminds of a building, into the presentable house and all of that in a matter of a few moments. This capability is a possible time savior in fabrication process in the future.

The second tested system that is discussed in [6] - volumetric scan, is currently one of the most widespread methods of recognizing 3D geometry. Unfortunately it does not work well for architectural models as most of the buildings are blocky, rigid and not as amorphous as clay objects, therefore the complexity of digital artifact produced by 3D scanner is rather unnecessary in this case. Moreover it is hard to scan miniature model with the sheltered or secluded spaces.

Although 3D scan is possible to achieve, at a present time it is still a time consuming process that comes with a great expense for all but the simplest cases [7]. This, however, leads to opportunity of representing each and different element of design as a separate object. For example, user can design interior space with a use of dollhouse furniture, which then is converted into digital world and manipulated further by the designer. This will allow for clients to quickly explain their requirements without having more professional education than a child, giving designers a chance to correct client's expectations or suggest a better solution.

Why does this environment have to be a tangible and what is the digital part of this environment for? First of all digitally recorded prototype of a model is a time saving basis for final design. Even a simple model can be immediately transformed into something complex by letting the computer to perform tedious calculations [6]. Then the digital model can be used for preliminary simulations and analysis in real time. For example, if the client wants to see the amount of sun the rooms of the designed building will get in summer, the draft model can be utilized by many of computer programs and tools, like Autodesk Ecotect [12] that can perform various calculations on a digital model and project it back in real time. By borrowing technologies from other tangible interfaces like illuminated clay [13] such projection is possible within a second after the data is analyzed on the computer. Basic concept of illuminating clay consist of reading 3D data of the 3D surface, analyzing it and relaying the analyzed information back onto clay model. It is again using 3D scanning technologies but this time it involves infrared or laser scanners. Of course, due to many reasons, these calculations cannot be called precise; however there is enough accuracy to engage discussion and further calculations.

Alas each and every design is different and it is quite hard to create an object that will work universally for all designs. For instance, there are different wall thicknesses, different forms of chairs and different window heights. Because of the reason that 3D printing has become affordable only recently there was no possibility for rapid production of tangible artifacts. On top of that, looking at the above described tangibles [6] in addition to [7] it is noticeable that creating a simple physical artifact poses no difficulty; alas making it tangible, intelligent and recognizable by the computer is a momentous challenge. For that Augmented Reality (AR) tangibles were used. Virtual objects replace physical artifacts, while keeping the same functionality. There is little difference between AR and physical artifacts and the only major complication is that virtual tangibles have to be manipulated through AR interface. Therefore by analyzing data provided by such tangibles it is possible to make assumptions on what fully physical system of tangibles will have to offer.

### B. *Tangible augmented reality.*

As expected in [11] [14] [15] [16] [19] AR tangibles do exactly what artifacts, mentioned earlier, do - improve cognitive perception, while adding a degree of entertainment to help engage a user into the process. Every one of above systems associates markers with virtual objects for real-time registration. Each marker has a pattern that later is being recognized and overlaid by virtual object it is associated with. The difference however is in AR approaches. Some of the systems require user to move markers and arrange them in real world [11] [14] [15], while the more unique approach allows virtual movement of virtual objects by the use of Magic Paddle, without interacting physically with the markers [16]. Magic Paddle itself is a marker, which has slightly different properties, allowing it to be a tool that performs augmented manipulation in virtual environment. Overall there is no significant difference between each of the above approaches from the tangible perspective – the only difference is in the AR component.

Casting AR component aside and looking at how it can be contributive in design communication it is not hard to notice that, even according to authors, these types of artifacts offer exactly the same benefits as physical tangibles – a better spatial understanding and improvement in cognitive operations. On the other hand, it offers a wide range of problems, associated mostly with augmented side, which potentially could confuse the user. For instance artifact manipulation is happening through gesture recognition, which is not proving accurate (90% success rate) [16] and requires a significant amount of computation and patience. It also seems that the main complaint about such tangibles is that the processing time of geometric operations is too slow. On top of that it feels unnatural and has all sorts of issues related to delay in visual representation of AR artifacts and detection of the markers (i.e. obscurity of the marker by hand) [14] [15]. Some of the above weak features can be improved by having a better computing power which has evolved significantly since the day AR tangibles were invented, however these types of artifacts will never feel more natural than physical ones.

AR Tangible artifacts show some advantages, which, in my opinion, are arguable, over standard method of urban design education. Normally students are required to arrange wooden blocks, representing buildings, on a map to improve the urban situation [11]. Wooden blocks are replaced, in the case of presented TUI, by markers that are associated with pre-fabricated buildings. According to the author the main advantages are:

*1)* Mobility – It does not require having a large number of physical objects other than markers, which are very light and flexible. It is arguable however, as the mobility of the AR equipment, which does all the magic cannot be forgotten.

*2)* Better quality visualization especially in texture and detail area (which is possible but harder to achieve with physical tangible objects).

## V. COMPARISON AND FURTHER ANALYSIS.

It is transparent that both AR and physical artifacts do not differ from each other much in terms of benefits that they have got to offer. However while both present the same positives, the negatives are different. With a growth of current 3D printing and recognition technologies, rapid prototyping with the use of tangible interfaces seems to be more and more possible [8] [9] [10], however is still an expensive alternative to AR tangibles. At the same time none of the described tangible 3D modeling systems proved to be fully working and currently none have gone beyond the prototype stage. Most of the investigated papers do not provide the exact outcomes, indirectly indicating that tangibles are still not very well accepted. Moreover fabrication of the object does not require too much effort even without 3D printing [10], but all papers suggest that turning the printed object into tangible seems to be a nightmare at this stage. There are many ways of artifact recognition as described in (IV), including ways adopted from augmented reality (ex. marker pattern recognition), but none of them seem to be without a fault. Other technologies like signal broadcast (wired or wireless) would require relatively complicated technologies to be integrated into each and single artifact, what makes rapid fabrication of tangibles too luxurious.

Judging by what has been achieved so far, tangible augmented reality, at this time, is possibly adding unnecessary convolution to design and communication, and also hasn't fully found its way into the industry. However the amount of research that is being conducted in that area indicates that there is a demand for it. The dilemma associated with fabrication and recognition of physical tangibles is removed by the use of AR. The possibility of connecting tangible AR with online model databases, which contain, literally, millions of digital models, in my opinion, can provide unimaginable results. Unfortunately these types of TUI, as stated before, do not feel natural to humans [19], call for training and obviously require a significant amount of investment into related technologies.

## VI. CONCLUSION

Since the day of the invention of tangible user interfaces over two decades have passed however there is still no successful tangible UI for the use in design and architecture. One would expect that with the current development of technologies there would be an integration of similar systems into computer aided design. The research indicates that attempts were made with little success and that none of the prototypes made its way successfully into the industry.

Nevertheless all prototypes make few things definite. Tangible user interfaces do provide designers with a means of getting a better spatial design. Furthermore the process, preformed by the computer, of interpretation of incomplete and very conceptual model into something more presentable can potentially decrease the time required to complete the full set of fabrication material. Finally TUI would not require significant amount of specialized knowledge to be able to design, therefore would find application not only in preliminary fabrication, but in education and communication between designer and the client.

## VII. FUTURE DIRECTION

Obtaining the experimental data from the researchers directly is crucial for development of this report. Regrettably the research papers do not provide investigational data in full scale and it almost seems that shortcomings of those experiments were never published. Therefore it can only be obtained from the authors of the papers through collaboration. After that further research is needed to be acquired around the possible methods of recognition of tangible artifacts. It might be achievable to apply one of general "object in space" recognition methods to tangibles. This should allow to access the necessity and possibilities for tangibles in design industries.

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