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Research Article

THE OPTIMAL RELATIONSHIP AMONG THE MIND, HAND AND THE COMPUTER IN THE ARCHITECTURAL DESIGN PROCESS

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ABSTRACT
One of the designer's tasks is finding the capabilities and effectiveness of different designing tools in order to decide how and when and which tool must be used during the design problem solving process. Nowadays,computers have become one of the main tools used by professionals in the area of architecture and construction.Architectural design,production processes and the tools, ideas, theories, methods and forms have been widely affected by computer and communications technology and also it has caused the designers to neglect the sketching and free hand designing as an effective tool in the crucial stages of ideation and creative development and due to the increasing use and impact of three-dimensional computer systems, wide range of new concepts have appeared so that to a considerable extent the role of computers in decision making is becoming equal with the role of human and these questions are considered: Can computers completely replace manually drawing tools and human mind in all phases of the design process or not? And what is the optimal or efficient relationship among the mind, hand and the computer in the architectural design process? This paper after describing the design process and visual thinking, analyzes the design process conducted before the advent of computers and then illustrates the developments in the design process deals with computer input and by comparing these two trends and analyzing their potentials as a descriptive and analytic research, follows improving the position of the free hand sketching and computer aided design tools in the design process and after analyzing and understanding the functionality of the free hand sketching and computer aided design (CAD) tools ,provides a model based on mutual cooperation of human mind and utilizing of free hand sketching and computer along with the models of the design process, before the advent of CAD and after that in order to use the capabilities of each one to increase the capabilities of the other one.

Keywords: *Sketch, CAD, Design Process, Visual Thinking*

INTRODUCTION
One of the designers' tasks is finding the capabilities and effectiveness of different designing tools in order to decide how and when and which tool must be used during the design problem solving process. The computer and computer software have provided new possibilities for architects. Computer as a design tool to accelerate the expression and presentation enables architects to experience, calculate, display and build any style of architecture (Kashaniju, 2003). Computer-aided design (CAD) software enables designers to draw and present their ideas much easier than in the past. Computers could soon replace traditional methods of drawing and served primarily on two-dimensional and then on three-dimensional drawing as an effective tool for companies.
The development of three-dimensional software caused quickly computer promotion from a drawing tool to an illustrator tool and could bring virtual reality in front of our eyes. These illustrative models make the design judgment easier and provide the ability of much more creative visualization. Three-dimensional modeling software and tools provided detailed pictures of spaces and the interval between virtual reality and physical reality in these images has minimized. This event was a revolution in the presentation of design and Projects and it could have a great impact on the company's organization, required expertise and tools used in the business process (Khabazi, 2012). On the other hand, the entry of computer software is accompanied with the negligent of designers from free-hand sketching that has always a special place as an effective tool in the critical stages of ideation, development and design creativity in the design process and consequently leads to a reduction of their ability in this field and for the increasing use and

impact of three-dimensional computer systems wide range of new concepts have entered into practice, so that to a considerable extent the role of computers in decision making is equal with the role of human and the question that comes to mind is what is the optimal or efficient relationship among the mind, hand and the computer in architecture design process?

This paper aims to answer the questions and to achieve a model to take advantage of the increased capabilities of sketch and computers in the design process and provide a better future in the field of computer aided architectural design for architectural researchers, educators and professionals surveys the stages of the design process before and after the advent of CAD and the disadvantages and advantages of sketch and CAD tools in the design process.

MATERIALS AND METHODS

Materials and methods in this study is the combination of analytic and descriptive research methods. Therefore, using descriptive research methods, design process and visual thinking have defined and clarified and then with descriptive and analytic approach at first, the role of sketch and design process before the advent of computer and then the developments in the design process with the advent of computer is discussed and by comparing them, and the analysis of their potential in order to answer the research question, the combinatorial model to improve the architectural design process through interaction with manual sketch and computer is offered.

Architectural Design Process

Architectural design is an activity related to the creation of designs and proposals that usually changes what already exists to make things better. The architect with researching and his knowledge-based activities links his internal findings to physical findings and reaches the ultimate goal.

Defining the nature of design practice and knowing how the architect deal with the design problem, is the issue that has not been provided clear and definitive answer for it, yet. Each of the theories proposed in this area have examined part of the issue and they have discussed this subject from the specific position. By the time the architect faces with the design problem until he finds the perfect answer to that problem bumpy and vague path is spent and this path for each architect and design problem can be different (Ansari, 2009). Some of the studies based on case studies and empirical evidence suggest that it mostly depends on the characteristics of the individual designers. In early models, had been considered dual process of analysis and synthesis stages for design process (Maver, 1970; Archer, 1969). This simple dual division had extensive capabilities that with more detailed explanation and also adding the stage of "evaluation" to the stages, has led to the engineering design or industrial design.

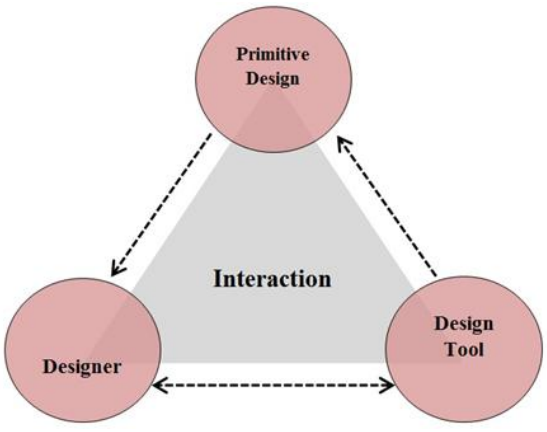

Figure 1: Interaction among designer, design tool and design

Many factors are involved in the design process that the relationship between these factors and the effect of these factors on each other are integral and one of these factors is design tool. Architectural design process has a very complex and ambiguous structure. This process starts from something abstract and

undefined and the architect finds a solution as a primitive design and in this way he uses different methods and tools (Gross and Luen, 2003) (Figure 1).

Architects during the design activity are involved at three levels of activities. These levels are: 1. Skills 2.Knowledge 3.Tools.The architectural design process is mobilizing various tools with knowledge which is controlled by the designer's skill (Hashemnejad *et al.*, 2012). Different tools and media have been used in designing and expression of architectural ideas. Undoubtedly manufacturing all kinds of rulers, the variety of drawing tools and brushes, and drawing tools have affected the design and presentation but from about 1970 onwards using the computer as an expression and drawing means to produce architectural drawings caused significant changes (Khabazi, 2012).

Visual Thinking and Architectural Design

Through humanity's evolution, humans' way of thinking has been influenced by two major developments, these being: Language (verbal) and writing or drawing (visual) in its simplest meaning of communicating our ideas, needs and decisions. In one kind of thinking we are dealing with words and concepts and by putting words and phrases together we think in mind, and it is a form of subjective speech that we do not express sentences with the language .In addition to this way of thinking, is visual thinking that we do not use verbal sentences and phrases for thinking but we have mental images in our mind and helps us to think about the subject. With those two modes of thinking we are able to create more complicated compositions in our minds and be able to reflect on through our hands. This is why language is the beginning of abstract thinking. Writing or drawing enables us to store and re-use these thoughts for a longer time. This is applicable significantly in architectural design.

Mc Kim (1980) separates visual thinking into three behaviors: seeing, imagining and drawing (Figure 2). A designer's words do not describe what is already there on the paper but are parallel to the process by which he/she devises and makes what is there. Therefore, drawing and talking are parallel ways of designing, and together make up the language of designing (Schon, 1991). In other words it is a 'visual language' of graphics that lacks the essential structure of spoken languages, but can nevertheless be used to communicate (Tversky, 2001). We should analyze sketching as an indication of the occurrence of the design conversation.

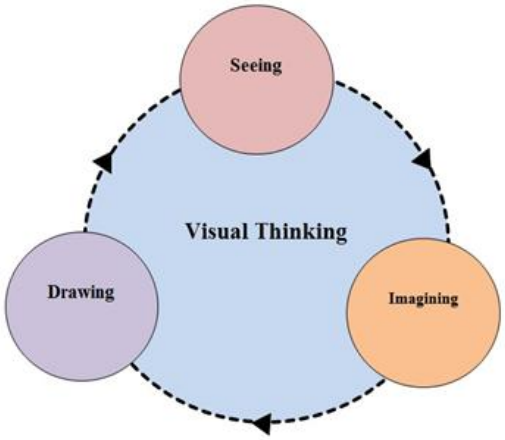

Figure 2: The concept of visual thinking

The Role of Sketching in Visual Thinking and Architectural Design Process

The most common technique to enable designing, is sketching. Sketching is a method of thinking (Schon, 1983). The design process is a visual activity and in this process, ideas should be visually perceived and the relationships between them must be assessed and the graphical presentation of the ideas is essential. Diversity, ambiguity and lack of clarity are the important features of creative processes that have a crucial stage in designing. Designers and architects use sketching for graphical promotion of the ideas and graphical thinking (Hashemnejad *et al.*, 2012).

Designers must work through their visual thinking process and understand that how and why they came to a particular design idea before showing it in a CAD model.

"Before designers had access to CAD, drawing was the foundation of their work and was believed to be necessary "during all the developmental stages of designing" (Ullman, 1990). The reason drawing is thought to be so important in training is because it acts as a tool for problem solving out loud. In other words, "sketching remains a basic tool for speeding up visual problem solving in any engineering field by externalizing and representing design problems" (Contero, 2005). As a result, engineers who were trained with a pen and pencil in hand have a different mindset when they approach a problem compared to engineers who were trained in computerized design technology (Hare, 2004). Lawson believes that architects (designers) can't think without having pen in hand (Feyzi and Khakzand, 2008).

While CAD has the ability to guide the engineer through technical problems such as dimensions and mathematic scaling, it does not have the same ability to let a designer think aloud and present quick visualizations of a potential object the way drawing does. From a creative standpoint, entering data into CAD can be described as a "passionless activity of drawing points, lines, and circles" (Downey, 1998).

Sketching in the early stages of the design process is a key tool and is considered as an essential activity. By sketching, the architect can visually describe the whole concept and identify and modify it and search the details. Designers generally have learned to use paper and pen during the development of the conceptual design and they always think graphically. They draw for the graphically development of the ideas and drawings are used as visual approaches to facilitate thinking and support the idea of instant reflection and help the thinking and short-term memory of the designers (Newell and Simon, 1972) (Figure 3).

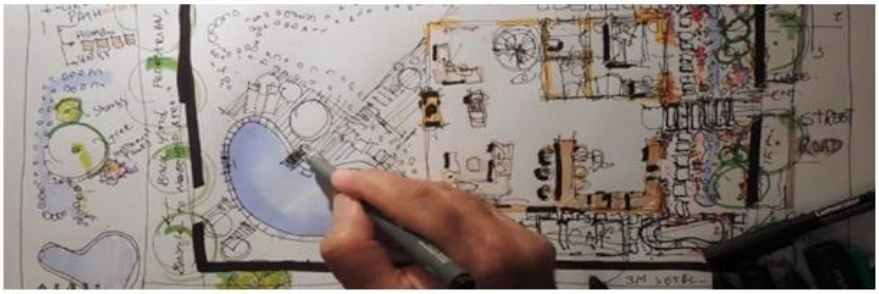

Figure 3: An example of the utilize of sketch in the architectural design process

Features and Benefits of Free-Hand Sketching

Sketching has features and benefits that help the designers to develop and refine the design process. Enhancing the creativity, improving the primitive ideas, reinterpretation of ideas, facilitating the recovery of the former ideas and information are the sketching functions. The lines an unfinished sketch provides peer reviewing of the ideas and this is provided by using the uncertainty and instability in the unfinished sketch. Sketching as a cofactor can help people in creative production and development of forms. Designers use free hand sketching as the main way to communicate their ideas during the conceptual stages (Do *et al.*, 1999). Free hand sketches have facilitated moving from one idea to another idea with a little difference and they avoid premature consolidation and will help to solve the problems and extracting the ideas. Sketches have a set of features that help the mind in translation and transfer of the descriptive proposed information to performance information (Fish and Scrivener, 1990).

The Design Process Model before the Advent of CAD

Drawing thus becomes a "mean[s] of extending and simultaneously transforming our understanding, rather than simply a means to let others know what we think or even ways of revealing to ourselves what we think" (Hare, 2004). Sketching as a tool can be seen as a more dynamic skill. It not only visually achieves a designer's goal of displaying an idea, but it also has the added dimension of representing how a developing designer understands and communicates a concept. Such an approach to design is so deeply ingrained in the pre-CAD generation that it defines how they approach the design process. According to

the discussed materials, the steps of the design process before the advent of CAD can be described by the following model (Figure 4).

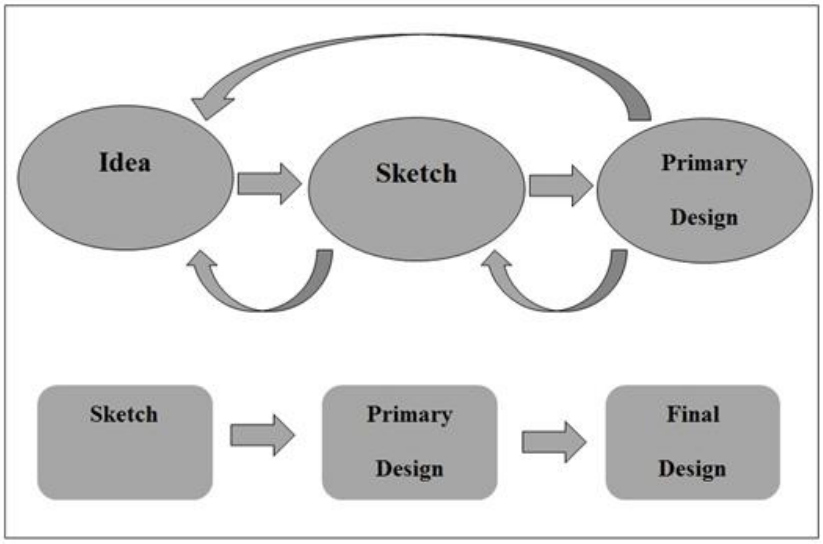

Figure 4: The design process model before the advent of CAD

A significant element of this vision is the dynamic, interchanging nature between the first three stages. The first row signifies the ideation and conceptualization phase where student ideas are in the working stage of being formed and reformed, as they turn the abstract vision they have into a working representation of their final idea. Sticking with this model, if a designer has an idea and sketches it out but cannot quite make sense of one part or gets input from a peer on how to alter the idea, the designer can go back to the ideation stage, sketch up a quick representation of the new idea, and proceed developing it further from there. As scientist and educator Linus Pauling once said, "The best way to get a good idea is to get *a lot* of ideas" (Kelley, 2002), and the ideation and conceptualization phase is where to generate the most ideas possible but with the advent of CAD, the traditional model of design process has changed.

The Role of CAD and Digital Media in the Architectural Design Process

The late 80's and early 90's ushered in a different view of computers in architecture. First, the computer was not seen as a replacement for other things such as draftsmen, hard copy documents and organizations. Second, it became to be considered a "medium" no more no less, and thirdly as a collaborator in the design process in which the computer and the human are the complement of the weaknesses of each other (Akin and Anadol, 1993).

The evolution of computer aided architectural design (CAAD) can be viewed through the generations of CAAD. In the first generation of CAAD, analyzing designing commenced from the view of systems method that divides reality into a small number of subsystems with specific and clear influences. In accordance with the theory of general systems, each system acts in relation to others on the basis of direct and linear coupling within a deterministic approach of association. The assumptions of the General Systems Theory have become the methodological basis for the developed methods of aiding design (Asanowicz, 1999).

The first generation methods had many drawbacks including: deterministic and linear approach of the design process, limited scope to solve functional problems, and a lack of graphical interfaces for communication between users and the computer. The second generation of CAD facilitates designer's communication with the computer whereby software packages were released to enable one to draw on the computer screen without having to know any programming languages. Since then, designers are using computers as a digital board to be an alternative to the conventional drawing board. CAD systems are used to produce technical drawings and 3D computer models. The typical use of CAD systems at subsequent stages of designing can be illustrated as shown in (Figure 5).

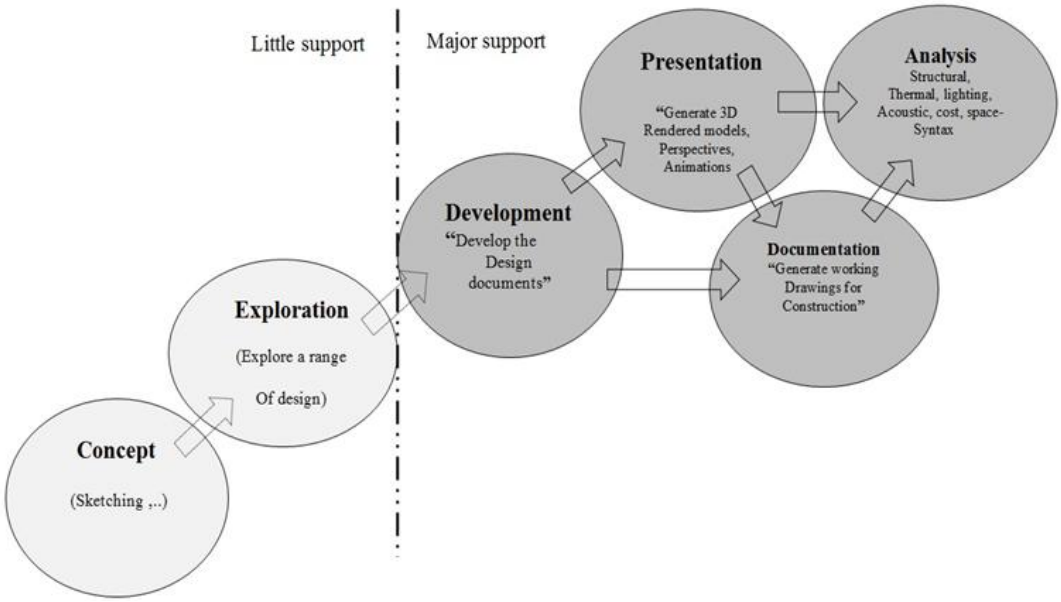

Figure 5: Computer aided support to various stages of the design process in the second generation of CAAD

Little computer support has been provided for both concept and exploration of various useful alternatives. The primary computer aided support is basically for developing design documents, construction and working drawings and generating presentation drawings in 3D and multimedia formats including animations and movies. Extensive computing support has been given to the design analysis including structure, lighting, acoustic, mechanical, space syntax, etc. In the second generation of CAAD systems, there was no real difference that can be identified from the conventional design support apart from replacing the drawing tools of pencil, drawing board and brush with efficient and powerful digital replacements. The computer is transformed into a drafting machine and CAAD meant more Computer Aided Architectural Drafting than Designing. It is arguable that these systems provided the architect with more time to spend on the creative stages of the design process. However, it is not questionable that such systems have enhanced the acceleration and development of the technical documentation of designs and generating architectural free forms that diverted away from the canon of right angles and straight lines (Asanowicz, 1999).

Rivka Oxman proposed new models of digital design based on the extant models of design which have addressed and explicated the differences between the evolving paperless design style and the traditional paper-based process. This was achieved by defining the peculiar and exceptional properties of the emergent designs. The components that models were developed based on them are as following.

1. Representation: Representation as a design component is a constant activity throughout the design process, as every change in the design has to be visually documented and shared with all the participants involved. Sketches, renderings, models, perspective views and photographs are essential modes of representation in the architectural design process. In traditional design methods that involved long periods to draft, representation served only as a communication tool and in no way improved or contributed to the process. With digital media, representational tools could serve as a means of finding form, or manipulating designs. This is greatly aided by the fact that models can be represented in various modes such as wireframe, solid or surface or conceptual modes.

However, digital design environments vary in function, so some may be more suitable to a particular process than the other. Normal CAD models represent curves and surfaces as a series of line segments while geometric modelers such as CATIA, Rhinoceros and Maya use explicit mathematical expressions to define entities (Schodek *et al.*, 2005) (Figure 6).

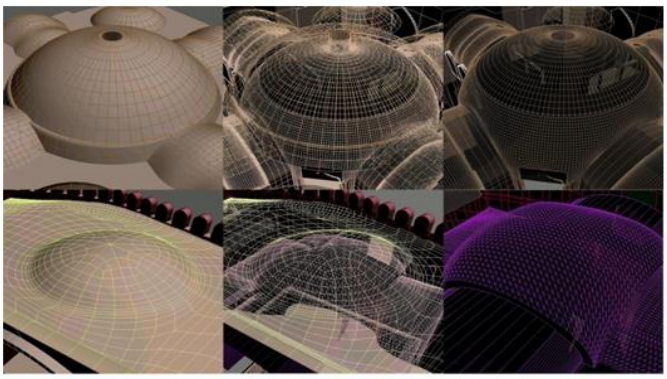

Figure 6: An example of the use of CAD in the architectural design process

Based on the discussed issues, the differences between traditional presentation tools and CAAD tools will be summarized. (Table1).

Table 1: The difference between the presentation with CAAD and traditional tools

CAAD representation	Traditional Presentation
Dynamic reflects on more levels while viewing	Static reflects on the considered level of abstraction
You can see extra visual effects(automated effects: Color, line weight, texture)	You see what you draw
Active and Passive changes	Active in making a change in a representation
Drawing Reuse and pre-drawing reuse	Reuse by tracing over previously drawn-redrawing
Virtuality	Reality
No materiality constraints(unlimited)	materiality constraints(limited)
Storage and display independent	One storage and display dependency

2. Generation: Design has been referred to by renowned Architects such as Otto, and Kalay as a process of search; for problems and solutions. Generation is the process of developing and synthesizing the solutions or ideas discovered from the problem analysis stage. In the paper-based design process this required days, and commitment to the drafting board and tools. Interaction with the generated solution is different with digital media (Oxman, 2006). Although computers have become vital components of contemporary praxis with digital representations utilized in all phases, the conceptual stage is one of the last areas to embrace the computer as free-hand sketches were considered sacred (Smith, 2005). Recent computationally based designs focus on form finding at the conceptual design phase. Emphasis is usually on visualization of sketches and ideas that make up the basic characteristic of the project. "Designers have sought to develop computational environments that in one way or the other actually generate shapes according to pre-specified rule structures or other principles"(Schodek *et al.*, 2005).

Previously, Otto identified the use of computer optimization programs in solution finding as a new form of "Self- Formation Process" (Otto *et al.*, 1995). Design practices have different form derivation approaches attributable to the fact that the techniques and rationales for shape development vary from one program to another. The frequently used tools in form finding are the use and manipulation of digital tools like lines, points, splines, loft and sweeps.

Visually oriented computational tools based on descriptive geometry or other mathematical means of defining lines, curves and surfaces may also be used. Other methods include repetitive algorithms, cellular automata, parametric definitions,«shape grammar» formulations, force density method and relaxation techniques. Some designers however, are considering the incorporation of time into form definition, in which the geometry changes in time based on some prescribed principles or external forces.

While others seek to dissolve the usual barrier between virtual and physical worlds .Digital fabrication is believed to now offer designers the opportunity to design through the production process as against the norm of beginning with form derivation (Gramazio and Kohler, 2011).

2.1. Reverse Engineering: This is a valued and alternative method for conceptualizing and developing design proposals. It employs the use of physical and analog media (Kocaturk, 2008). Firms like Frank Gehry & Associates pioneered the use of reverse engineering as a means of form derivation in Architectural practice. It involves the use of 3D scanning devices to digitally capture the geometry of existing objects or prototypes. The information is then transferred to a geometric modelling environment, where clouds of points are converted to surfaces through interpolation. These surfaces are interactively revised, edited and used to build a new digital model. This model is subsequently used in design development. The geometric software that support reverse engineering include 3D3, 3D Reshaper, Para Cloud, Design works and others.

2.2. Structural Oriented Form-Finding Approaches: Techniques for structural form finding traditionally, were based on accurate, physical models, such as a network of hanging chains or minimal surface experiments with soaps films or stretch fabric. An instance is the continued use of Pneumatic scale models and hanging fabric systems by Heinz Isler to define the geometries of concrete shells. Other examples are found in the hanging models by Gaudi where force diagrams were translated into forms (Kilian, 2006) and in experiments by Frei Otto and Bodo Rasch. The most commonly employed computational techniques based on this approach include the force-density method the dynamic relaxation technique.

3. Evaluation

Evaluation is a direct consequence and derivative of the uncertainty that is inherent to the process of design (Kalay, 2004). It involves the rational and logical evaluation of internal conflicts. This process constitutes the feedback part of the design cycle. Solutions proposed are compared with the goals, constraints and opportunities developed during generation.

From the illustration by Kalay above, it is evident that all questions concerning the created design solutions are assessed during the evaluation process. If the design solutions meet the stated goals and can be modified then it is successful otherwise the goals are redefined and solutions recreated. Evaluation normally occurs in the design development stage and requires more time and effort than the other stated stages. In this stage design intentions are developed and evaluated technically. The modelling at this level is mathematical and very precise, because, the main parameters of the design are defined and assessed. Dimensions and analysis of the model's structural, thermal and material characteristics is carried out in preparation for production of prototypes (Schodek *et al.,* 2005). Design development frequently involves the collaboration between various specialists, thus the need for add-ons such as structural analysis programs. These ensure smooth transitions between digital expression of design ideas and their analytical evaluations. Programs that enable this rigorous activity of development and assessment include: Micro Station, Revit, CATIA, Pro/ENGINEER, Kangaroo Physics, SolidWorks and others.

4. Performance

This is also an evaluative act that examines the context of design and the programmatic orientation of the design (Oman, 2006). Kotnik however, admonishes that functional design strategies could limit architectural thinking to parametric changes only as it tends towards optimizing and being economic (Kotnik, 2010). With digital media designers now have the ability to envisage the future performance of whatever geometric forms generated.

In the generation phase as illustrated above, forms are derived from digital sketches or conceptual models produced by rapid prototyping techniques. Then in the subsequent stage of evaluation, various methods of prototyping are utilized in creating models or drawing that would in turn be assessed and analyzed. Evidently most of the tools are employed during the generation and evaluation phases (Figure 7).

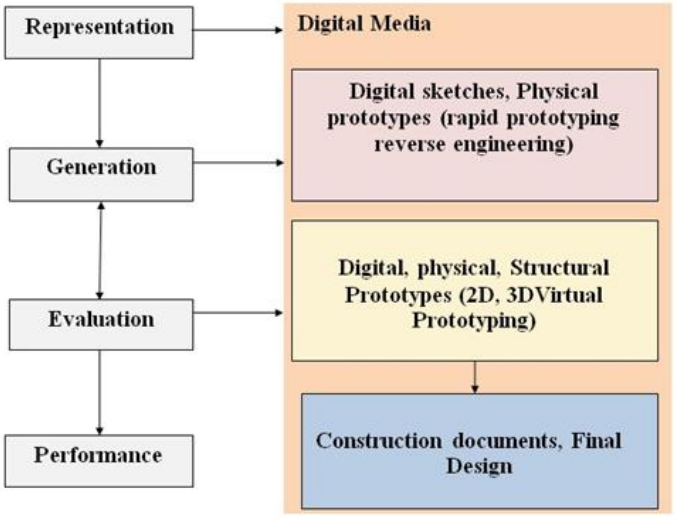

Figure 7: Illustration of the digital media during the design process

The Design Process Model after the Advent of CAD

Designers are visually oriented and are taught to think graphically. Visual presentations vary in order to contain the process of design and to communicate both process and outcome. For this reason, designers convey their ideas mainly in graphical forms with the benefit that these graphical forms are most effective at accurately conveying their conceptual content to themselves and others. CAAD's visualization techniques are the practical methods of encoding data into graphical images to explain a concept via CAAD's medium. Different visual techniques make visual thinking possible and improvable: each concentrate on ways to free the mind from traditional patterns of thought. Interest in CAAD visualization and its effect on the early design stages has increased as students and designers have reached a different level of awareness in terms of computerized working methods and visual appearance. Throughout the development of architectural design mediums, many transitions have occurred, where architects and designers took many years to understand and exploit the new medium potential in conception and the later stages of design evolvement. CAAD as a medium seems to be passing through a similar process of exploiting and understanding (Mc Kim, 1980). As already mentioned, with the advent of CAD, the new generation of designers and engineers changed the traditional model (Figure 8).

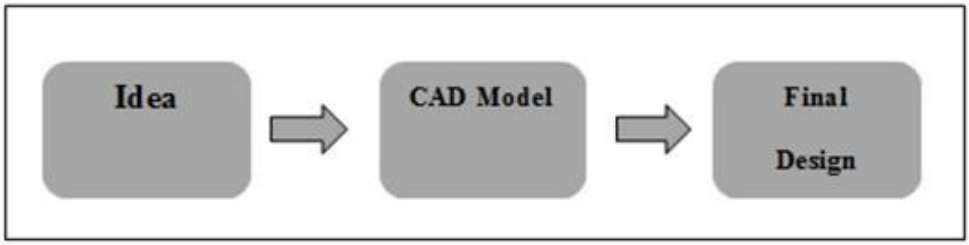

Figure 8: The design process after the introduction of CAD

CAD's role eliminates the stages of sketching and redesigning that are seen in the traditional model and as mentioned in the initial stages of designing largely emphasizes on form finding. If designers use CAD without first working through the conceptual stages, they run the risk of deciding on an idea and spending time on creating the virtual model of something that, in the end, could potentially not be viable for many reasons if a designer jumps into [CAD] too soon and forgets low-fi prototyping, they're losing their ability to innovate." The sketching and rapid prototyping stages allow designers to flush out possible kinks and rethink their concept before committing to model that they'll develop.

RESULTS AND DISCUSSION

Many of the views expressed in the research studies focus on the credit of CAAD programs and complete replacement of the traditional tools by them or simply insist on free-hand sketching and its relationship with the creative thinking and emphasize that CAAD tools are unsuitable for responding to the needs of the primary designs while the expletive potential between the free -hand design and CAAD application as a tool for understanding hasn't been adequately studied. In contrast, this study utilizes the results of previous studies and by considering the capabilities of free-hand sketching and CAAD tools offers a combinatorial model of design process that will be discussed below (Figure 9).

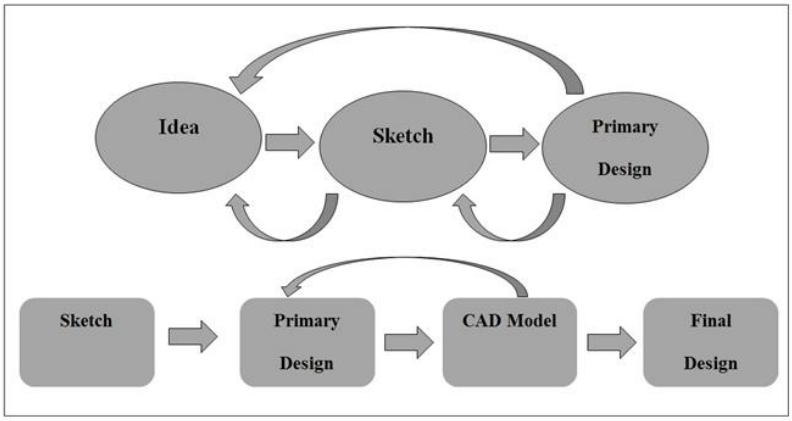

Figure 9: The design process that incorporate both hand drawing tools and CAD

In this model, "the use of CAD technology can deepen the designer's understanding of final form, structure, and performance of the design, for without the initial conceptual stages; the designers do not have access to a simple overview of all the development process traditionally with complimentary range of sketch and appearance models. With all the stages in place, the designers can use CAD as a detailed problem-solving tool to finalize a clean, scaled model that they can then base their modeling on. CAD can allow designers to use more of their energy on creativity.

In fact computer and its logical process can be assumed along the human mind not another model of the mind. As a result for the optimal use of the human mind and computer, instead of replacing the human mind with computer we must think to establish a bilateral cooperation between them and use the capabilities of each one to promote the other's capabilities.

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