# THE IMPACT OF COMPUTER ON THE DESIGN CAPABILITIES OF ARCHITECTS: A COMPARATIVE STUDY OF DIFFERENT TRENDS

**by**

**WAEL A. ABDELHAMEED**

**B. Sc., Architectural Engineering, Assiut University, 1988**
**M. Sc., Architectural Engineering, Assiut University, 1995**

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**Department of Architecture**
**University of Assiut**
**Assiut, Egypt**

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**Supervised by:**

**Mahmoud A. Abdellatif**
Prof. of Urban & Regional Planning, University of Assiut.

**Filiz Ozel**
Prof. of Architecture, Arizona State University, Tempe, U.S.A.

**Mohamed Ayman A. Daef**
Associate. Prof. of Urban & Regional Planning, University of Assiut.

**Examined by:**

**Mahmoud A. ElEkiaby**
Prof. of Architecture, University of Monofyia.

**Mustafa A. Baghdadi**
Prof. of Architcture, AlAzhar University.

**Mahmoud A. Abdellatif**
Prof. of Urban & Regional Planning, University of Assiut.

**Mohamed Ayman A. Daef**
Associate. Prof. of Urban & Regional Planning, University of Assiut.

IN THE NAME OF ALLAH, THE COMPASSIONATE, THE MERCIFUL

**DEDICATION**

I would like to dedicate this research to:

- My family; to the soul of my father, to my mother, to my wife, and to my children “Omar and Allyia”,
- All those who are interested in architectural education in our virtual age.

## ACKNOWLEDGMENTS

All the thanks to ALLAH who guides us all the way in this life. May ALLAH put this effort in my good deeds.

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# ABSTRACT

## تأثير الحاسب الآلى "الوسائط الإلكترونية الرقمية" على القدرات التصميمية للمهندس المعماري: دراسة مقارنة للإتجاهات الفكرية المختلفة

يعتبر التطور الواضح المستمر فى استخدام الحاسب الآلي والأجهزة المصاحبة فى مهنة العمارة، بل والاعتماد المتزايد على هذا الاستخدام خلال السنوات الحديثة، أمراً جلياً ولا يحتاج إلى برهان. حيث أن استخدام الحاسب الآلي فى مجال العمارة قد تحول مؤخراً من كونه وسيلة للرسم والإظهار يستعملها المعماريون فى المراحل الأخيرة لعملية التصميم المعمارى، إلى كونه وسيلة مساعدة للتصميم توظف منذ بداية العملية التصميمية. وقد أصبح استخدام مصطلح الحاسب الآلي يعبر عن جميع الأجهزة والاستعمالات والنظريات المختلفة المصاحبة للحاسب الآلي أو بمعنى أخر استخدام الوسائط الإلكترونية الرقمية كما تسميه الأبحاث الحديثة الإصدار ويعتقد أن هذا الاستعمال سيؤدى ليس فقط إلى تحولات فى أساليب ممارسة مهنة العمارة ولكن أيضاً إلى التأثير بشكل أو بأخر على القدرات التصميمية للمعماريين.

**تهدف هذه الدراسة إلى ثلاثة أهداف رئيسية:**

- تعريف القدرات التصميمية للمعماريين ووضع مفهوم للعلاقة بين هذه القدرات، وذلك عن طريق دراسة المجالات الآتية: الأنشطة المستخدمة لحل المشكلات التصميمية، والفكر التصميمى المحرك لهذه الأنشطة، وطرق نشأة الأفكار التصميمية، وأخيراً طبيعة وخصائص عملية التصميم المعمارى.
- تقسيم الاتجاهات والأفكار المختلفة الخاصة باستعمال الوسائط الإلكترونية الرقمية داخل المراحل الأولية لعملية التصميم المعماري، بهدف دراسة ما يقدمه كل اتجاه إلى عملية التصميم المعمارى.
- التعرف على التأثيرات الإيجابية والسلبية للاتجاهات المختلفة الخاصة باستعمال الوسائط الإلكترونية الرقمية على القدرات التصميمية للمعماريين.

وإعتماداً على أساليب منهجية نظرية ودراسة أدبيات الموضوع بالإضافة إلى أساليب منهجية ميدانية "استبيان رأى عالمى"، أظهرت الدراسة نتائج تفصيلية يؤمل أن تسهم فى بناء أفضل للاتجاه المتنامى نحو أتمته فعاليات عملية التصميم من خلال الوسائط الإلكترونية الرقمية وما لذلك من تأثيرات على القدرات التصميمية للمعماريين.

**ويتكون البحث من سبعة فصول:**

- **الفصل الأول "مقدمة عامة":** يحتوى على خلفية البحث، وعرض المشكلة البحثية، وأسئلة البحث، وفرضيات البحث، وأهداف البحث، ومنهج وطريقة البحث، والمنطق والفكر المحرك للبحث، والإطار المحدد للموضوعات قيد البحث، وهيكل البحث، وأخيراً ملخص النتائج.

- **الفصل الثانى "التفكير التصميمى":** يتضمن دراسة الموضوعات الآتية: حل المشكلات التصميمية والتفكير التصميمى، بهدف التعرف على الطرق التى من خلالها يقوم المعماريون بحل المشكلات التصميمية.

- **الفصل الثالث "العملية التصميمية":** يهدف هذا الجزء من البحث إلى تعريف خصائص وطبيعة عملية التصميم المعمارى، والعلاقة بين المراحل المختلفة لهذه العملية، وأخيراً وصف حلقات التفكير التصميمى أثناء عملية التصميم المعمارى.

- **الفصل الرابع "القدرات التصميمية للمعماريين":** يدرس هذا الفصل العلاقة بين القدرات التصميمية المختلفة وتعريف تفصيلى لهذه القدرات والمجالات المتعلقة بها. وتقسم القدرات التصميمية للمعماريين إلى خمس قدرات تصميميه وهى: قدرة وضع المفاهيم التصميمية للمشكلات المعمارية، وقدرة تكوين الأشكال المعمارية، وقدرة الإظهار المعمارى من خلال الرسومات والمجسمات ثلاثية الأبعاد، وقدرة اتخاذ القرارات التصميمية، وأخيراً قدرة بناء وتكوين الخبرة والمعلومات المعمارية واستعمالهما فى المواقف التصميمية المختلفة.

- **الفصل الخامس "الوسائط الإلكترونية الرقمية":** يقسم هذا الجزء من البحث استعمال الوسائط الإلكترونية الرقمية فى المراحل الأولية لعملية التصميم المعمارى طبقاً للمفاهيم المحركة لهذا الاستعمال، وتقسم اتجاهات استعمال الوسائط الإلكترونية الرقمية إلى ثلاثة اتجاهات وهى: تفاعل الوسائط التقليدية والإلكترونية الرقمية، والتصميم وتكوين الشكل المعمارى عن طريق الوسائط الإلكترونية الرقمية، وأخيراً استخدام الوسائط الإلكترونية الرقمية فى البحث عن المعلومات والرسومات الممكن استعمالها فى حل المشكلات المختلفة التى يتناولها المعماريون.

- **الفصل السادس "القدرات التصميمية للمعماريين والوسائط الإلكترونية الرقمية":** يستعرض هذا الفصل تأثير استعمال الوسائط الإلكترونية الرقمية على القدرات التصميمية للمعماريين، وذلك من خلال طريقتين منهجيتين بحثيتين: استخلاص هذا التأثير من الأبحاث السابقة القريبة الارتباط من موضوع البحث، والاعتماد على تحليل نتائج استبيان الرأى العالمى الذى تم إجراءه.

- **الفصل السابع "الخلاصة والتوصيات":** يستعرض هذا الفصل خلاصة النتائج التى توصل إليها البحث مع عرض التوصيات المختلفة التى توصى بها الدراسة من أجل إدماج تطبيقات استعمال الوسائط الإلكترونية الرقمية فى عملية التصميم المعمارى والاستفادة بإمكاناتها فى تحسين القدرات التصميمية للمعماريين.

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# Chapter 1 Introduction

## 1-1 Research Premises

In the past, manual preparation of drawings and presentations took much effort, time, and attention from architects. Being dazzling and colorful, drawings and presentations were a priority for architects, to the extent that an architect may not be differentiated from an artist. By the Renaissance era, exact perspective drawing emphasizing the third dimension had appeared and become important in the design exploration and presentation process. It was not enough, in order to explore design ideas, for designs to be evaluated and seen in two dimensions only. Making models emphasizing the third dimension, was another method used in design exploration and presentation during the design process. In Classical and neoclassical architectural design, the architects exclusively concentrated on facadism and proportional dynamics within the two dimensional methods of design. By the beginning of the 20th Century, from Mendelsohn's Einstein Tower 1921, through Frank Gehry's museum at Bilbao 1997 Figure (1-1), to Frank Gehry's Experience Music Project building 2000 Figure (1-2), architecture has become more three dimensional in design process and in presentation.

To explore and illustrate their design ideas, architects used to use the traditional paper and pencil media. At the beginning of utilizing the computer[1] within the design process, its initial use was limited to pragmatically resolve technical issues, such as presentation tasks, after the design was completed, in order to produce drawings with qualities that cannot be obtained through manual media[2]. With the accelerated development of computer software and hardware, the use of computers has

[1] The term computer is used in this research in its broadest sense to include all forms of digital design tools and approaches.

[2] Also termed analog, hand-made, material or physical

changed and evolved from being just a tool for drawing to a medium through and by which the design process is performed and solutions are generated. Since the computer is now used in the design process as a medium, digital media[3] are introducing new tools and techniques, which lead to noticeable achievements in helping architects to be more creative during the architectural design process. In the field of architecture, "media can be defined as a tool for selecting, gathering, sorting, and conveying knowledge in representational forms. Media enable ideas to be externalized and evaluated and hence become a highly influential factor in the design process"[4]. Both the way and the form of interactions, between digital and analog media during the design process, have influenced not only the design process itself, but also the architectural design capabilities of architects.

**Figure 1-1 Guggenheim Museum at Bilbao, Spain by Frank Gehry**

a- Side view b- Close up of masses c- Main entrance
From [http://www.greatbuildings.com/]

[3] Also called electronic, computer aided, virtual, etc.

[4] Atman, O. and J. Bermudez, 1999.

The transition, from the traditional tools and techniques in the design process to the novel tools and techniques offered by digital media, is generating a controversy in the architectural community. On the one side, there are those who favor the intensive use of digital media from the initial phases of the design process. Marx (1998), for instance, maintains that designing "on screen" must be learned by students, initially without hand sketching[5]. On the other side, there are those who favor the use of traditional tools within the initial phases of the design process. For instance, Do and Gross (1995) maintain that drawing-thinking with a pencil remains an essential design skill[6], and Kellett (1996) maintains that prior media are never 'unlearned' and are rarely displaced, but incrementally adapted or redefined to a more appropriate and effective role in the repertoire (he means the design media repertoire –capabilities- of architects)[7].

In addition, the view that the digital will not displace the analog, but instead will help in clarifying its different strengths and in forcing specialization and complementation, is shared by many researchers, such as: Herbert, 1995; Kellett, 1995, 1996; Neiman, 1994; Sumlevich, 1997[8], on the one hand. On the other hand, there are those who believe that fully digital –paperless- practices produce architecture that could have been developed without computers[9]. Those disputes of digital versus analog may last for some time in the future till digital media become completely common-place.

The design capabilities of architects are believed to be affected by the increasingly growing role of the digital media. As an example of the role of

[5] Marx, J., 1998, p. 58-73.
[6] Do, Ellen and M. Gross 1995.
[7] Kellett, R., 1996, p. 31-42.
[8] Bermudez, J. and K. King, 1998, p. 6-26.
[9] Marx, J., 1998.

digital media use, Frank Gehry (2000) says about his Experience Music Project building, "this building wouldn't be possible without computers. It's too complicated…we were able for the first time to go from models to construction"[10], Figure (1-2). Digital media are powerful and influential tools that will inevitably become the mainstream in design practice. The new methods and technologies eventually find their own place and role, displacing the existing processes and practices no longer as necessary or as effective[11]. In order to benefit from and cope with these revolutionary tools and techniques, it is important to take up the challenge to explore arenas that acknowledge their uses and impacts.

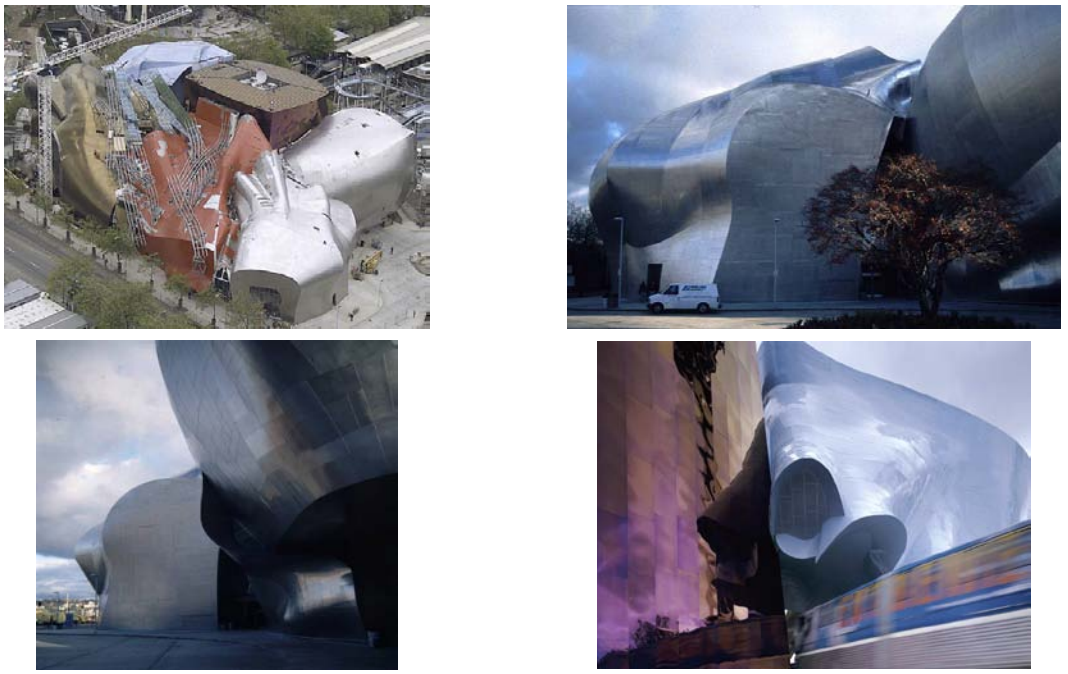


**Figure 1-2 Experience Music Project at Seattle, Washington by Frank Gehry**

a- Aerial view b- Side view
c- curvaceous walls d- Close up of two masses connection
From [http://www.greatbuildings.com/]

## 1-2 Research Problem

[10] See http://seattlepi.nwsource.com/visualart/emp16.shtml. An Article in 'Seattle Post-Intelligencer', by Regina Hackett, May, 2000, citing Gehry, Frank O., 2000.

[11] Kellett, R., 1996.

The overall impact of digital media use is often investigated by researchers in many forms. For example, its impact on changing work and teaching places, on altering ways of teaching, on pursuing the design process, and on influencing architecture. Marx (1998) maintains that computers have the potential to radically change the process of architectural design. He argues that the instruction of architectural design teaching should be 'creatively based' rather than 'skill based', as it is the case with the conventional architectural design concepts applied and employed[12]. Architecture schools are considered to be in need of elaborate pedagogy and theory to deal with both media[13]. Kellett (1996) describes the combination of the use of the traditional tools and techniques as well as the novel ones as the 'messy mix'[14]. It may be stated that there is an insufficiency in the elaborate methodologies that guide digital media use in the teaching and practicing of architectural design.

These influences of digital media should be deliberately evaluated and clarified. Many questions have to be searched. For example, what are the changes generated by digital media use in architecture (i.e. building form), in the tools and techniques used in design, and in the design capabilities of architects themselves? Consequently, how should architects be educated and prepared to practice design?

The changes of fields, such as work and teaching places, ways of teaching, design process, architecture itself, and even architects themselves, have to be fully explored. The aim of this exploration is not only to identify the contributions made by the fundamental approaches of the current use of digital media, but also to have a better understanding of thoughts and

[12] Marx, J., 1998.

[13] Bermudez, J. and K. King, 1998.

[14] Kellett, R., 1996.

practices that keep up with the continuous development of the trends in digital media use in the design process.

The research problem is basically concerned with the field of the design capabilities of architects and the impact of digital media use on them.

## 1-3 Research Questions

The previous introduction of the research problem raises major questions, which could be stated as follows:

- Do architects employ certain capabilities through and by which the architectural design problems at hand are solved? If that is true, what are these capabilities?
- Do architects use certain types of digital media throughout the design process? If they do, what are these types?
- Is there any impact for digital media on the design capabilities of architects? If there is any, what is the nature of this impact?

## 1-4 Research Hypotheses

Tentative answers to the above mentioned questions lead to the postulation of the three research hypotheses. These hypotheses could be stated accordingly as follows:

1) Architects employ certain capabilities through and by which the architectural design problems at hand are solved.
2) Architects use certain types of digital media along the design process.
3) The nature of the impact of digital media on the design capabilities of architects varies according to the design capability and the type of media use.

## 1-5 Research Objectives

The research, dealing with the influential role of digital media, aims to achieve three main objectives:

1) Testing the first hypothesis, and defining a framework for the design capabilities of architects.
2) Testing the second hypothesis, and articulating the various approaches and trends of digital media used along the design process.
3) Testing the third hypothesis, and exploring the impact of digital media on the design capabilities of architects.

## 1-6 Research Methodology

In order to verify the previously stated hypotheses, and to achieve the research objectives, different methodological tools will be applied in data collection, analysis, and synthesis.

### 1-6-1 Data Collection

Data collection is classified according to data type (secondary data and primary data), as follows:

1) Secondary data has been collected through intensive consultation of previous research work (books, journals, conferences, etc.) in the research subject matter. Synthesizing the theories of previous research work introduces outlines, which help achieve the research objectives. Searching the areas of problem solving and design thinking will be an initial step. This search will help explore the nature and the characteristics of the design process and the correlation between its phases. Consequently, a framework for the capabilities which architects employ during design is defined. In order to shed light on the impact

made by various uses of digital media on the architectural design capabilities, defining these capabilities will be followed by an exploration of the trends in the use of digital media throughout the design process.

2) Primary data has been gathered from a questionnaire[15] extracting the views of a sample of respondents (faculty members and professional architects) exposed to various digital/manual media settings. The main issues of questionnaire design, sending the questionnaire, characteristics of the respondents, and the difficulties of conducting the questionnaire, are illustrated as follows:

- A questionnaire is designed to assess the impact of various digital and manual media settings. Figure (1-3) shows a conceptual scale of these media settings. The questions and definitions of the questionnaire are designed to be direct and simple, in terms the respondents to have the clarity of meaning and purpose. The respondents are asked to include their comments for the questions of Design Capabilities.

  The questionnaire is in three sections. The first section is a cover letter, which contains introducing the researcher, an introduction to the study, and directions of how to fill the questionnaire. The definitions of terms used in the inquiry are in the second section; these definitions include the design capabilities of architects and various media settings. The third section has the questions which are divided in two parts: General Background Questions, and Questions and Comments of Design Capabilities. Also, there is a definition above each main question (of the design-capabilities questions) in the

[15] See Appendix 1.

second part of the third section; this definition is concerned with the illustration of each architectural design capability.

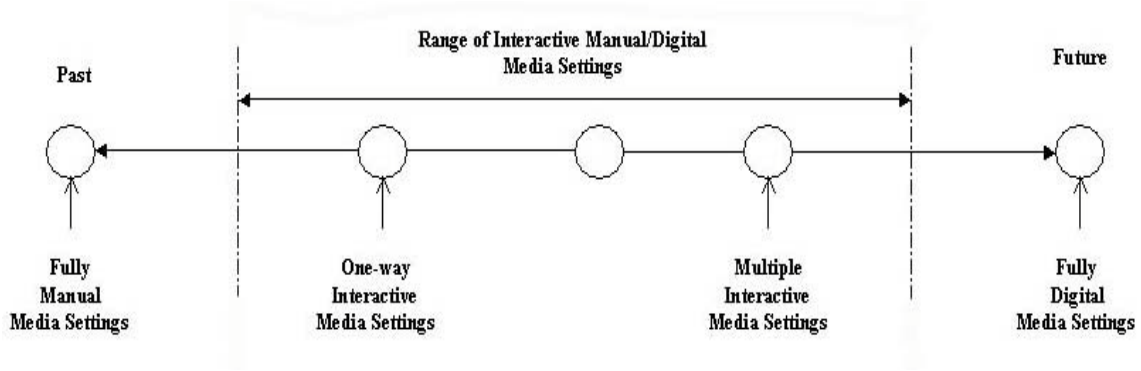



**Figure 1-3 A Conceptual Scale of Various Media Settings**

The figure is prepared by the researcher, with acknowledgment to a meeting with Abdellatif

- An invitation for participation is electronically sent to the members of the global conferences specialized in the research subject matter. The conferences which are received an invitation for participation in the questionnaire are: the Association for Computer-Aided Design in Architecture (ACADIA of North America), the Conference on Computer Aided Architectural Design Research in Asia (CAADRIA of Asia), the Conference on Education in Computer Aided Architectural Design in Europe (eCAADe of Europe), and the Ibero-American Society of Digital Graphics (SIGraDi of South America) Table (1-1). To submit the questionnaire, a participant has to visit a web site[16] that has the questionnaire in "Front Page" format.

**Table 1-1 Conferences which have received an Invitation to Participate in the Questionnaire**

| Title of the Conference | Abbreviation of the Conference's Title | Location |
|---|---|---|

[16] This website was a part from the researcher's personal space in the server of Arizona State University. The URL address of the questionnaire was "http://public.asu.edu/wabdelh/questionnnaire".

| | | |
|---|---|---|
| The Association for Computer-Aided Design in Architecture | ACADIA | North America |
| The Conference on Computer Aided Architectural Design Research in Asia | CAADRIA | Asia |
| The Conference on Education in Computer Aided Architectural Design in Europe | eCAADe | Europe |
| The Ibero-American Society of Digital Graphics | SIGraDi | South America |

- In addition, an invitation is sent via Email to: a) the architecture professors and the architecture students of M.Sc. and Ph.D. in Arizona State University "USA" and University of Sydney "Australia", and b) the architecture professors and the architects who are members of ASCAAD "The Arabic Society of Computer Aided Architectural Design". To submit the questionnaire, a participant has to return the sent file as an attachment in "Word doc" format via Email.

- The total number of replies is 56. Few respondents preferred not to assess all various uses on different design capabilities, concentrating only on what they have been using[17].

- The sample represents both the practical and theoretical views of those who are practicing, teaching, and researching in the subject matter, as follows: 35.72% of the respondents are architects who are pursuing either Master's or Doctoral degrees in architecture; 16.07% of the respondents are professional architects (CAD managers, etc.); 48.21% of the respondents are faculty members who are involving in teaching and research (Lecturers, Associate Professors, and Professors) Table (1-2).

[17] Appendix 2 shows tables of the numbers of respondents for each design capability per various media settings.

**Table 1-2 Characteristic of Respondents: Position**

| Position | Number of Respondents on each Position | Percentage of Respondents |
|---|---|---|
| **Architects who are pursuing either Master's or Doctoral degrees in architecture** | 20 | 35.72% |
| **Professional architects, CAD managers, etc.** | 9 | 16.07% |
| **Faculty members who are involving in teaching and research (Lecturers, Associate Professors, and Professors)** | 27 | 48.21% |

- Other important characteristics of respondents to the questionnaire, such as the period of computer use and self-assessment of computer use, are summarized in Table (1-3).

- The major difficulties that have been faced in conducting the inquiry are as follows: a) the number of respondents was lower than the researcher's expectation, which required that personal requests were resent via Email to many experts and architects asking them for their help, b) some respondents did not include comments in their replies, although it is mentioned in the questionnaire that this step is highly appreciated, and c) there are not mail lists of the conferences of CAAD Futures, and ACSA[18] "the Association of Collegiate Schools of Architecture", which required that invitations were individually sent via Email.

**Table 1-3 Characteristics of Respondents: Period and Self-Assessment of Computer Use**

| Characteristics of Respondents | Number of Respondents | Percentage of Respondents |
|---|---|---|

[18] These two conferences and the four participating conferences present all the global conferences that are specialized in the field of computer use in architecture.

| | | | |
|---|---|---|---|
| **Number of Years of Computer Use** | **Less than 5 years** | 17 | 30.36% |
| | **5-10 years** | 11 | 19.64% |
| | **10-15 years** | 16 | 28.57% |
| | **15-20 years** | 5 | 8.93% |
| | **More than 20 years** | 7 | 12.5% |
| **Self Assessment of Computer Use** | **Low User** | 1 | 1.79% |
| | **Below Average User** | 4 | 7.14% |
| | **Average User** | 0 | 0% |
| | **Above Average User** | 32 | 57.14% |
| | **Intensive User** | 19 | 33.93% |

### 1-6-2 Data Analysis

Data has been analyzed using various descriptive, analytical, and comparative techniques and methods. Among these methods, one may mention the following: Conceptual Diagrams, Conceptual Scales, Statistical Charts, Verbal Presentations, Graphs, and Tables.

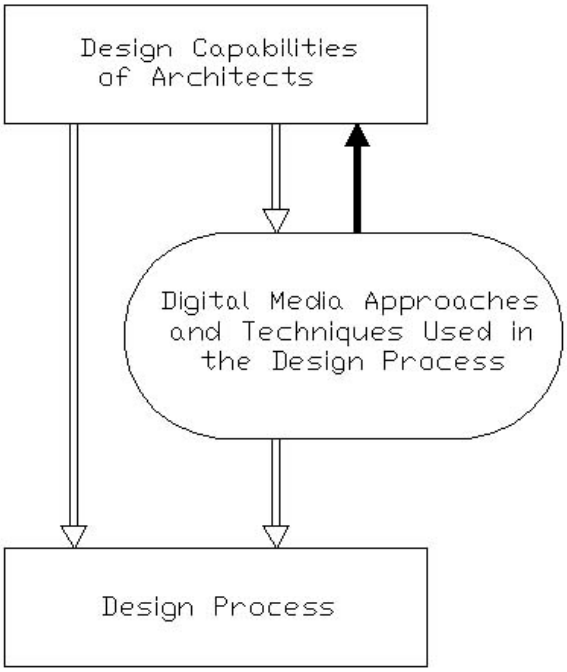
### 1-6-3 Data Synthesis

Data has been synthesized with different tools, in order to verify the research hypotheses and to conclude the research objectives. These tools can be described as follows: Conceptual Frameworks, Verbal Presentations, Graphs, and Tables.

## 1-7 Research Logic and Rationale

The logic and rationale behind this research can be stated as follows:

- First, architects use their design capabilities to conduct the process of design through analog and digital media.
- Second, there are correlations between the realms of the research concern, which are the design process, the design capabilities of architects, and the use of digital media, as illustrated in Figure (1-3).




The Arrows Refer to the Various Impacts Between the Design Capabilities, Digital Media, and the Design Process

**The bold arrow refers to the concern of the research**

**Figure 1-4 The Research Logic and Rationale**

The figure is prepared by the researcher

- Third, there is a reciprocal impact between the design capabilities of architects, and the digital media used in the design process, as it is evident that:

    - The representational environments –media-, which the architect chooses to design, affect what the architect can conceive and perceive through them.
    - The design capabilities of each architect influence the potential of a single type of media employed in design (in terms of the output and use.)

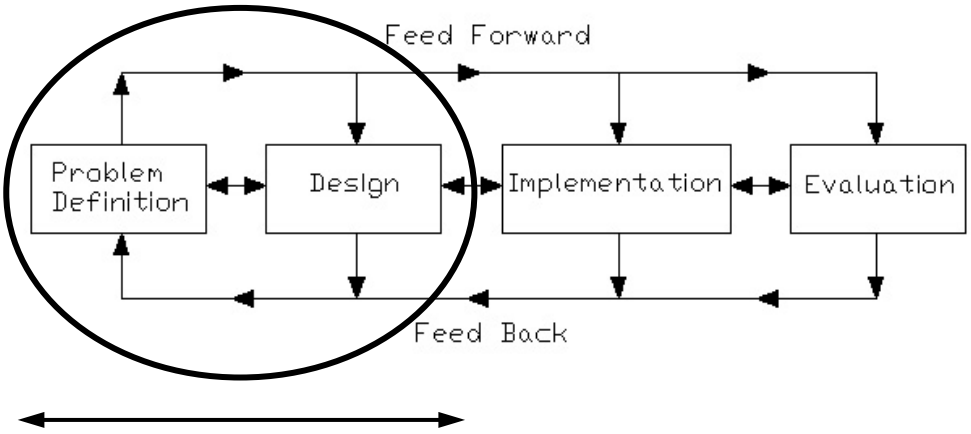
  The research is concerned only with the impact of digital media on the design capabilities of architects. This impact is represented by the bold arrow in Figure (1-3).

- Forth, the nature of media employed by architects affects the design process and the formal aspects of the designed artifact. When the architect employs a particular technique of media use, the design process phases will be developed according to the rules and the potential of this chosen technique. For example, within using programs of the Artificial Intelligence, the architect may have shapes and forms without executing the representation tasks of the design process. This case shapes the design process phases in a particular model.

## 1-8 Research Scope

The scope of this research is classified according to the bases of geography, time span, and subject, as follows:

- The geographical scope of the research is universal in nature, where it covers the secondary and the primary data from expertise around the world (Arab Countries, Asia, Australia, Europe, North America, and South America).
- The time span of conducting this research extends to four years and nine months (from March, 1999 to December, 2003).
- In terms of the subject basis, the research scope is illustrated as follows:
    - The range of the design process, as investigated by this research, covers the tasks and activities of the initial phases, which begin with problem definition, continue through concept articulation to design development, to evaluation, and end with the final architectural design representation in the form of drawings or models Figure (1-5).




The Range of the Initial phases of the Design Process
(on a Model of the Design Process Phases from Abdellatif 1985)

**Figure 1-5 The Range of the Design Process as Investigated by the Research**

The figure is prepared by the researcher

- There are factors that would mainly affect the architectural design process and its final product. This research deals only with the procedural aspects of the architectural design process, not including issues such as the size or function of the design, environmental factors, aspects of practice, aesthetic qualities, construction technology, etc.
- The framework of the architectural design capabilities, as investigated by the research, encompasses capabilities by which design solutions are generated, completed, and represented as architectural drawings or models.
- The research is concerned with the concepts, rather than techniques, of digital media use, because the variety of techniques results from many issues, such as the creativity of architects, the available software and hardware of media, the skill in using a particular type or technique of media, etc.

- The research is not concerned with the performance and proficiency level of architects, such as capability to design, fluency in using a particular type or technique of media, design experience, etc. The differences in the design capabilities from an architect to another will not be investigated either.

## 1-9 Research Skeleton

The dissertation is organized as follows:

1- Introduction: Research Premise, Research Problem, Research Questions, Research Hypotheses, Research Objectives, Research Methodology, Research Logic and rationale, Research Scope, Research Skeleton.

2- Design Thinking: The chapter explores the areas of problem solving and design thinking, in order to identify ways through and by which architectural design problems are solved. Thus, this chapter consists of Problem Solving and Design Thinking, Architectural Design Thinking, and Derivation of Design Ideas in Architectural Design Thinking.

3- Design Process: This chapter is concerned with the relation between the phases of the design process, the nature and the characteristics of the design process, and the description of cycles of the design process.

4- Architectural Design Capabilities: The theoretical background of the previous two chapters gives the research a basis to identify Tasks of the Architectural Design Process, and the Architectural Design Capabilities: Conceptualization Capability, Form Giving Capability, Representation Capability, Decision-Making Capability, and Knowledge Building and Retrieving Capability.

5- Digital Media: This chapter includes Media Repertoire, and the Trends and Approaches of Digital Media Use along the Design Process: Media

Interaction, Digitally-Based Media, and Digital Knowledge through Technical Information and Visual Drawings.

6- Digital Media and Architectural Design Capabilities: Exploring Digital Media Impact on the Architectural Design Capabilities is achieved through: synthesizing of the Theoretical Analysis from previous research, and the Results and Analysis of the Questionnaire.

7- Conclusion: The chapter consists of the findings from the fields of: Design Thinking, the Design process, Architectural Design capabilities, Digital Media, and the Impact of Digital Media on the Design Capabilities of architects, in addition to the Future Research Work.

# Chapter 2 DESIGN THINKING

## 2-1 Introduction

Design is a practical art (Niels Diffrient) just as a designer is a problem solver[1] (Henry Wolf)[2]. However, the designer is in essence an artist (George Nelson), hence, the impact of the aesthetic qualities of a design does not occur in a space alone but in people's interactions with these qualities over time[3]. Creativeness plays an important role in the way design is created and completed, as working in the three dimensional forms demands the architect to be more than just a problem solver. In other words, designing is problem solving in a creative way.

Problem solving, design thinking, and architectural design thinking should be studied, in order to understand the approaches, methods, procedures, and capabilities by which architects design. Design thinking is a conscious exploration activity, rather than an inspiration or illumination, in terms of achieving creativity in design-problem solving that may generate from design-problem context, for example. Moreover, the media used by the designer/architect plays a critical role in this exploration process.

## 2-2 Problem Solving and Design Thinking

As design is in essence a problem solving activity, understanding the nature of the thinking utilized to reach the solution of a problem can reveal the characters of design thinking and the tasks of design process. The bounded rationality that is a characteristic of design, refers to the concept that designers are rarely in a position to identify all possible solutions to a given

[1] Some might maintain design is much more than mere problem solving, however, this depends on the definition of the word of problem. "To paraphrase Thorndike's venerable definition, a problem can be said to exist if an organism wants something but the actions necessary to obtain it are not immediately obvious. It is hard to imagine circumstances under which the impetus for design is not covered by this definition" [Rowe, 1987, p. 39, citing Thorndike, 1931]. In addition, creativity plays a prominent role in solving a design problem.

[2] Mitchell, C. Thomas, 1996, p. xv.

[3] Ibid.

problem; rather, they settle for what seems to relate to the required properties designers see at the time. Generally, problem solvers make decisions that might be seen as satisfactory; according to Simon (1979) this process is called “satisficing”[4].

### 2-2-1 Problem Solving Theories

Without venturing too much into either the explanation of problem solving or its history, by the end of the nineteenth century two main themes were already distinguished to develop theories about problem-solving activity. The first theme[5] was a mechanistic type of doctrine that sought to explain problem-solving behavior through the use of the irreducible law of the relationships deemed to govern the mental process. The other theme used more behavioral and nonmentalistic terms during problem-solving analysis[6].

Further explorations led to significant contributions that are pertinent to design. During the late 1950s and the 1960s, a number of attempts were made to describe the creative problem-solving process of design, in order to understand the logical structure of overt activities that appeared to take place. Design was regarded as a series of stages characterized by dominant forms of activity, such as analysis, synthesis, evaluation, and so on. The impact of logical decision-making process (i.e. analysis, evaluation, etc.) along the process of design-problem solving appeared to replace other concepts that tried to elaborate this process, such as the behaviorism that depended on behavior in illustrating design generation, etc.

### 2-2-2 Problem Solving Models

[4] Simon, H. A., 1979, p. 3; and Simon, H. A., 1969, p. 64-67.
[5] See Appendix 3.
[6] Rowe, P., 1987, p. 41-46.

From a number of theories that Rowe presented in his book "Design Thinking", the following two models will serve to introduce the main development of the theoretical contributions in explaining the process of problem solving:

1) Bruce Archer proposed a model of design which is represented in a simplified form by Figure (2-1). The process can be described in a general form, irrespective of particular circumstances. Feedback loops, or relationships between activities, are more in evidence than in preceding theories. The staging of activities is perhaps less discretely defined. With the enumeration of three interrelated realms for the process, namely, external representation, process of activities, and the problem solver, a distinction begins to be made between overt behavior and the cognitive realm[7].

With Bruce Archer's model, the role of external representation in the process of design-problem solving began to appear for the first time, as the preceding theories did not include this role. The external representation can be illustrated as how the designer/architect represents the ambit of a problem at hand, and the ideas of the solutions that are in mind. As what an architect can conceive and comprehend depends on what this architect can perceive through the media used. Consequently, it can be stated that the role of media (such as: drawing, modeling, etc.) is identified in the process of design, even before this process is completely defined, and its phases and tasks are totally explored, in the form that we know today.

[7] Rowe, P., 1987, p. 48-50.

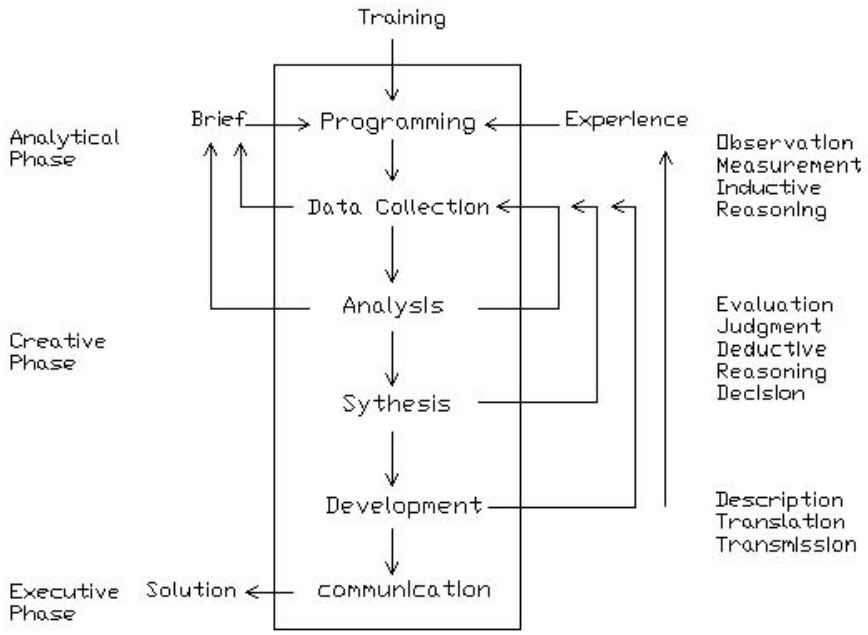



**Figure 2-1 Archer's Model of Design Process**

From [Rowe, 1987, pp. 50]

2) As a result of accumulated experimental evidences from about 1930s onward, behaviorism, according to Hunt (1982), was found to be increasingly difficult to use in explaining the process of problem solving, especially with the awareness of cognitive role[8]. These evidences seem to divert the attitude from one that is based purely on behavior to one that is cognitively based. The postulates which emerged from the early work of Newell, Shaw, and Simon, became the base of the information of processing position[9].

These postulates were:

- First, there is a problem space that has knowledge states[10] as elements. Solutions can originate from specific components resulted from a design-problem space. Therefore, the definition of a design problem has a

[8] Hunt, Morton, 1982.

[9] Newell, Alan; Shaw, J. C.; and Herbert A. Simon, 1967, p. 63-75; and Hayes, John R., 1978.

[10] Knowledge states can be defined as what can be perceived and conceived from the given problem space.

significant role in forming the feasible solutions. Furthermore, the media used in the external representations of a design-problem context have an important part in reaching the design-problem solution.

- Second, there are one or more generative processes or operations, that allow one to take knowledge states as input, or as starting positions, and produce new knowledge states as output. In a sense, the problem space, composed of knowledge states, is being transformed during the course of problem-solving events. This transformation of a problem space affects problem definition. Therefore, the definition process of a design problem is an ongoing process. Along with problem-solving process, the definition of a design problem depends on the input of knowledge states, which is highly affected by the nature of the media used.

- Third, one or more test procedures allow the problem solver to compare those knowledge states. Knowledge states are presumed to incorporate solution properties with a specification of the solution state. Test procedures are also assumed to exist for comparing parts of knowledge states to detect differences among them. External representations play an important role in shaping the way, in which the knowledge states, derived from the ambit of a design problem, are conceived. Consequently, while choosing between tentative solutions, evaluating or comparing knowledge states, according to the required needs and objectives, depends on how these knowledge states are represented (in: textual, drawing, modeling, etc.). In other words, media play an important role not only in the solution-generating process but also in the solution-evaluating process. It is, also, evident that the evaluation process is an ongoing process during the design process.

- Forth, there are further processes enabling a problem solver to decide which generative processes and which test procedures to employ, based on the information contained in available knowledge states. By this postulate, the role of concepts which guides the process of design-problem solving appeared. This appearance is represented in forming the standards for the tested solutions. The role of decision-making process is, also, evident during the repetitive evaluation processes along the design-problem solving.

To elaborate the concepts of problem space, evaluation process, decision route, backtracking process, and media impact, we may represent a simplified example which is a part of an architectural design problem. The problem space and the decision tree of this example will serve to make the decision process more tractable. Figure (2-2) describes a problem space and the structure of a decision tree, which is represented by nodes for decision points and by branches for the courses of action. While contemplating to make a rough budget to a design, derived from the cost of building materials and land, there are various choices and criteria involved, such as: First, we may decide whether or not to build on the whole area of the available land. Second, what is the number of floors? Third, what is the timing of construction? Forth, the structural system that we may decide to use depends on a variety of factors, such as availability of the used materials, the relative cost, and the time of construction. Finally, within the means available to us, we may choose a certain route. The comparative advantages for every possible decision of action could be computed in order to select the one which meets our priorities. The architect employs the available media used in external representation to explore what is in mind and to evaluate the tentative solutions. This process reveals the ongoing role of representation along the design process. In actual practice, the architect chooses the

combinations which serve her/his criteria. In most cases, these combinations of the criteria may be changed according to the repetitive evaluation process. As a result, a backtracking movement to an earlier point in the decision route of the problem space may occur. From that point, a new decision route is chosen according to the new combinations of the criteria.

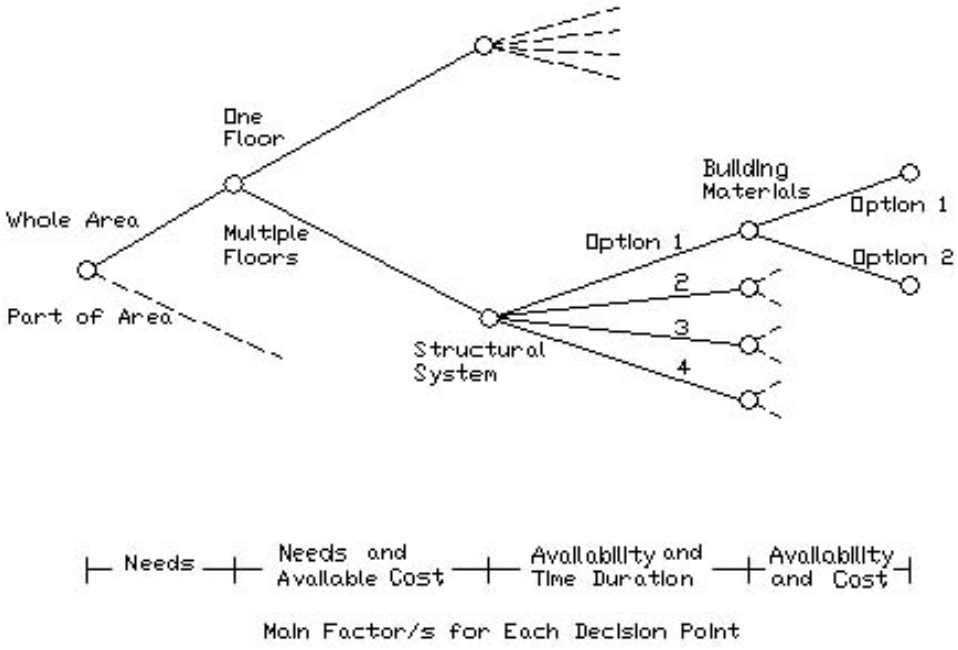



**Figure 2-2 Problem Space and Decision tree**

From [Newell, Shaw, and Simon, 1967; Rowe, 1987], with modifications made by the researcher

### 2-2-3 Classification of Design Problems

The categories of design problems can be identified according to their defined level. There are, according to Churchman (1967), well-defined problems, ill-defined problems, and wicked problems[11].

1) Well-defined problems are those for which the goals are already prescribed and apparent; their solution requires the provision of

[11] Churchman, C. West, 1967, p. B 141-142.

appropriate means[12]. In architecture and urban design, this class would include the space-planning problem, in which a set of building spaces is prescribed, together with a site in which they are to be assembled and some expression of adjacency requirements among spaces[13].

2) Ill-defined problems are those for which the ends or the means of solution are unknown at the outset of the problem-solving exercise, at least in their entirety[14]. Most architecture and urban design problems come under this classification, as a large step of the problem solving is to define and redefine the problem itself. For an example of this class in architecture and urban design, noticeable time and effort are usually spent in terms of clarifying what is required although the objectives and thrusts of the problem may be clear.

3) Wicked problems are so ill-defined problems[15].

The last two categories that are most pertinent to architectural design problems have the following characteristics[16]:

1) There is no definitive formulation or possibility of being fully defined. They are problems with continually possible reformulation. The definition process is highly affected not only with the way of representation (the nature of media used), but also with the evaluation process in conjunction with this representation process.

2) As a corollary to this first characteristic, there are no explicit bases for the end of problem-solving activity. The proposed solution that generates on

[12] Newell, Alan; Shaw J. C.; and Herbert A. Simon, 1967, p. 70.
[13] Rowe, P., 1987.
[14] Newell, Alan; Shaw J. C.; and Herbert A. Simon, 1967, p. 71; and Bazjanac, Vladimir, 1974, p. 8.
[15] Churchman, C. West, 1967.
[16] Bazjanac, Vladimir, 1974, p. 9-10.

any time can be developed still further more, at least to some significant extent. It can be stated, therefore, that the back-forth movement between tentative solutions and the ambit of a design problem in the form of evaluation process, is also a continuous process. Moreover, the satisfactory solution can be changed because of further courses of evaluation, or of media use.

3) Differing formulations of these problems imply differing solutions, and vice versa. In other words, problem formulation depends on a preconception which, in turn, refers to a definite direction toward a problem solution. Consequently, the personal prejudice towards problem interpretation has a prominent part in problem definition and in solution generation. Thus, the relation between these areas clarifies the realm of the personal style of design thinking, for different styles of design thinking lead to different solutions of the same design-problem. In addition, the solutions of different design problems, conducted by single design thinking, may have some similar characteristics.

4) Solutions that are proposed are not necessarily correct or incorrect. Plausible alternative solutions can always be provided. Reformulation can take place beyond the realm of considerations within which the original proposals were made, thereby opening up avenues of an approach to other solutions. Reformulating and remodeling design-problem ambit through a different use of media from what was used before, can introduce avenues of new solutions.

The next part of the research aims to explore how architectural design-problem can be solved, and from what sources architectural design-solution can be generated.

## 2-3 Architectural Design Thinking

In order to comprehend the architectural design thinking of architects while they are in action, it is important to explore how architects perform design tasks. There are many tasks and activities that are simultaneously performed within the architectural design process, which elaborates the unique nature of this process. The architectural design process has no ideal algorithmic pattern. Furthermore, performing architectural design tasks manifests common characteristics of different individual styles of decision-making and design making. The similarity of these characteristics is derived from differentiable streams that architects employ to solve the design problem.

There is a distinctly episodic structure of the design process, that is, the consolidation of problem constraints may cause backtracking. Within this episodic structure, blinding moments followed by backtracking periods take place, where blinding refers to the condition in which obvious connections between various considerations of importance go unrecognized by an architect[17].

Many researchers introduce the idea of streams for partial solutions of design problems, by which the designer/architect utilizes assistance during the design process, and from which complete solutions can be derived, for example 'patterns' of Alexander (1977), 'elements' of Krier (1988) and Thiis-Evensen (1991), 'heuristics'[18] of Rowe (1987), 'enabling prejudices' of Schon (1988), and 'visual chunks' of Akin (1986)[19].

## 2-4 Derivation of Design Ideas in Architectural Design Thinking

[17] Newell, Alan; Shaw J. C.; and Herbert A. Simon, 1967, p. 106-107.

[18] A heuristic is any procedure that contributes to reduction in the search for a satisfactory solution [Simon, 1969, p.80].

[19] Johnson, Scott. , 1997, p. 5-15.

In many cases, the designer/architect utilizes streams and references to have a derivation of a design idea or a partial solution. Although creativity has an important role in this episode, rules and principles are necessarily invoked while the architect is pursuing the tasks of design process and problem solving. Invoking such appropriate rules, for relating the results from an evaluation of potential solutions to further courses of action reveals the meaning and the use of the term of heuristic reasoning[20].

The design ideas can be derived from design-problem context, outside of design-problem ambit, subjective or objective interpretation of design-problem aura, personal prejudice of design thinking, or use of media. The heuristics (the process of design-idea derivation from streams) which architects utilize can be distinguished with reference to the types of information that they provide[21]. According to Rowe (1987), the heuristics of architectural design thinking are classified into five types[22], and the researcher maintains that there are two more types: use of media and personal prejudice of design thinking, as follows:

**1- Anthropometrical analogies:** This analogy-use involves employing a mental construct that describes man's physical occupancy of a given space. It may be described, also, as the corresponding between the dimensions of a space and the function that man performs in this space. In some cases[23], the body and anthropometrical qualities may be more central to architectural thought, within certain desired impression made by the architect in order for users to

[20] Heuristic reasoning refers to a problem solving process in which it is unknown beforehand whether a particular sequence of steps will yield a solution or not. Heuristic reasoning is part and parcel of most solution generation strategies and guides the overall organization of search through a problem space, however; it is an area in which no general theory seems to exist [Rowe, 1987, p. 75].

[21] Rowe, P., 1987, p. 74-79.

[22] Rowe, P., 1987, p. 80-91.

[23] The non-body-centered architecture gives understanding spatial feeling in our experience of buildings [Rowe, P., 1987, citing Bloomer and More, 1977].

comprehend. For example, in Figure (2-3), “a” gives a spatial feeling of power and control, while “b” represents elegance.

a- Petersburg Palace, Dvortsovaya Square

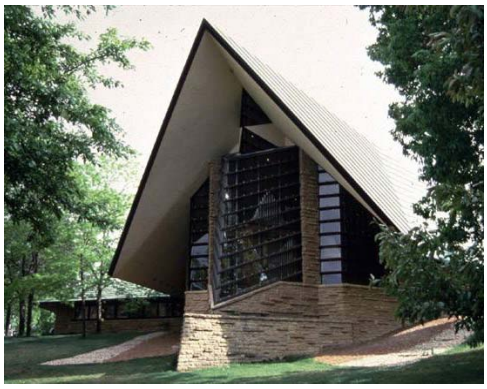
b- Palace in Istanbul, staircase

**Figure 2-3 Anthropometrical Qualities and Spatial Feeling**

“a” from [http://petersburgcity.com/city/photos/history/squares/palaces/index.phtml?page=3]
“b” from [http://www.exploreistanbul.com/showarticle.asp?parented=15]

**2- Literal analogies:** In this category of design-idea derivation, architects borrow known forms as a point of departure in terms of reaching a partial solution of an architectural design-problem. For example, the shell of a crab for the roof of Le Corbusier’s Ronchamp Chapel, hands folded in an attitude of prayer for Frank Lloyd Wright’s Unitarian meeting house, and sails for Utzon’s Sydney Opera House, Figure (2-4).

a- Le Corbusier's Ronchamp Chapel



b- Frank Lloyd Wright's Unitarian Church

c- Jorn Utzon's Sydney Opera House

**Figure 2-4 Literal Analogies of Natural World**

"a" from [http://www.tu-harburg.de/b/kuehn/lec5.html]
"b" from [http://www.planetware.com/photos/US/WI016.HTM]
"c" from [http://www.greatbuildings.com/cgi-bin/gbi.cgi/Sydney_Opera.html/TR004388.gbi]

Other kinds of analogies[24] generate from proportional systems or formal geometric properties. Configurations such as Cartesian grids or Platonic solids have quite a venerable history in the shaping of design problems, Figure (2-5).

**3- Environmental relation:** The proper relations between man and the components of building fabric itself on the one hand, and the environment on the other hand, generate a set of principles for this kind of heuristics.

[24] According to Broadbent, there are two kinds of these analogies: Iconic analogies and Canonic analogies. Iconic analogies are derived from: 1) the natural world, 2) imagery from scene, painterly conception, or narrative account of real or imagined circumstances, and 3) artifacts and elements from more squarely within the realm of architectural experiences. Canonic analogies are usually manifested as somewhat abstract geometrical patterns or shapes [Broadbent, G., 1973].

Environmental factors are climate, physiography, and resource availability (e.g. engineering factors that affect the structure and material used).

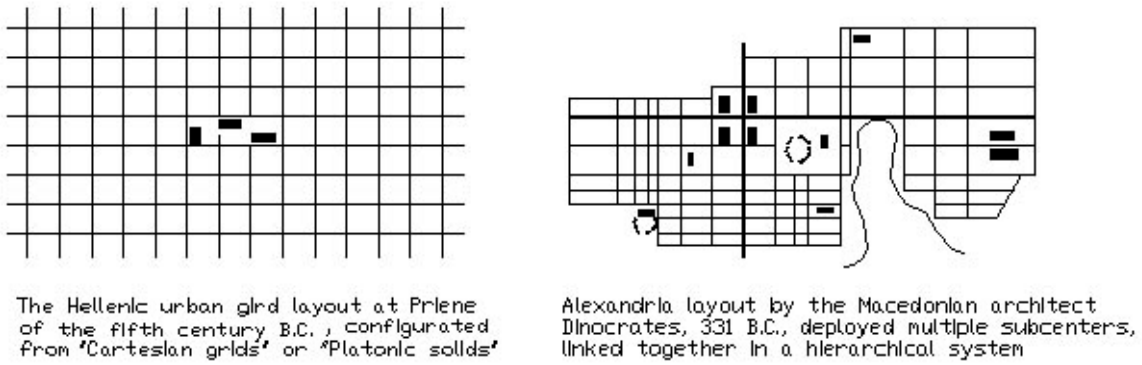



**Figure 2-5 Literal Analogies of Formal Geometric Properties**

From [Rowe, 1987, p. 85]

**4- Typologies:** In this class of design-idea derivation, architects apply knowledge about past solutions to the related architectural problems. These typologies may be divided into three subclasses: 1) Building types as models which introduce worthy characters to emulate, and provide for the perceived needs, requirements, and uses found in the design situation in hand, for example courtyard house or courtyard building. 2) Organizational typologies which are used for solving problems concerning the spatial distribution and conformation of functional elements. 3) Elemental types which are prototypes for solving general classes of design problems, for example that of resolving the needs for both a sense of community and a sense of privacy in a building[25].

**5- Patterns and Formal languages:** These kinds serve as languages where they possess guiding structures, or as rules where they direct decision-making about the accuracy and appropriateness of both the functioning and ordering

[25] Rowe, P., 1987, p. 87, citing Vilder, 1977.

of formal design elements. Other streams of design-idea derivation, especially typologies and environmental relations, generate generalizations of information which construct these patterns and formal languages. For example, treatises on the "classical languages" provide a repertoire of architectonic elements and rules for their composition which undoubtedly incorporate fundamental aspects of relevant typologies but go beyond the realm of particular types in both scope and generality[26].

**6- Use of Media:** The role of this class of design-idea derivation can be identified as exploring and developing what is in the architect's mind through the media used, where design ideas need a representational environment (such as: sketching, two/three-dimensional drawing, modeling, etc.) to be explored and developed to further courses of action in design-problem solving. Each way of media use has its own characters that architects employ to benefit, to modify, or to reform the design ideas in a certain way. For example, two-dimensional drawing is different from three-dimensional drawing in the kinds of information which are not only used as input but which are also are perceived and conceived as output.

**7- Personal Prejudice of Design Thinking:** Each of the preceding heuristics may result in introducing different solutions, even for a single design problem, according to the design thinking that conducts the design process. For the design thinking of one architect is unique and different from the design thinking of others, even when confronting of the same context of a design problem, or when using the same type of media. This is evident in the behavior adopted to invoke appropriate references and rules, resulting from the technique or type of media which is used by or provided to the architect. In other words, one architect may choose drawing to develop a design idea,

[26] Alexander, Christopher, 1977; and Rowe, P., 1987.

while another may choose modeling to develop the same design idea. Moreover, even if two architects choose to explore and develop the same design idea through the same medium “sketching only, for example”, the outputs will not be the same.

## 2-5 Conclusion of the Chapter

1- By the late 1950s and the 1960s, the impact of cognitive realm and logical decision-making process (i.e. analysis, evaluation, etc.), along the process of design -problem solving, appeared to replace other concepts which had tried to elaborate this process.

2- From Bruce Archer’s model of problem solving, it can be concluded that:

a) The interrelated impact derived from the realms of external representation, the process of activities, and the problem solver, was introduced inside problem solving process.

b) The role of media (external representation), such as drawing, modeling, etc. was identified in the design process, even before this process has been completely defined.

3- From the work of Simon, and Newell, Shaw, and Simon, it can be extracted that:

a) Along with problem-solving process, problem space may be transformed, leading to redefine the problem. Therefore, the processes of definition and evaluation are ongoing processes during the design process.

b) Choosing between tentative solutions depends on evaluating the required needs and objectives, and how the knowledge of these two realms is represented. Consequently, media play an important role

not only in the solution-generation process but also in the solution-evaluation process.

c) The role of concepts which guides the process of design-problem solving was appeared.

4- Design thinking is a conscious exploration activity, rather than an inspiration or illumination, in terms of achieving creativity in design-problem solving.

5- From Rowe's work, it can be extracted that:

a) The strategies of solution generation and the overall organization of search through a problem space, is an area in which no general theory seems to exist.

b) The back-forth movement between tentative solutions and the ambit of a design problem in the form of evaluation process, is a continuous process during the design process.

c) Different styles of design thinking lead to different solutions of the same design-problem. In addition, the solutions of different design problems, conducted by single design thinking, may have some similar characteristics.

6- Many researchers introduce the idea of streams for the partial solutions of design problems by which the designer/architect uses assistance during the design process.

7- The design ideas can be generated from: 1) design-problem context, 2) outside of design-problem ambit, 3) subjective or objective interpretation of design-problem aura, 4) use of media, or 5) personal prejudice of design thinking.

8- Each way of media use has its own characters that architects employ to benefit, to modify, or to reform the design ideas. The output derived from a certain use of media may defer from one architect to another, according to the personal style of design thinking and of media use, because what an architect can conceive and comprehend depends on what this architect can perceive through the media used.

After this illustration of design-problem solving, design thinking, and solution generation of architectural design, the next chapter of the research is concerned with exploring phases and activities of the design process, in order to define a conceptual framework of the design capabilities of architects.

# Chapter 3 DESIGN PROCESS

## 3-1 Introduction

After exploring the fields of design-problem solving, and architectural-design thinking and its heuristics and characteristics, this chapter of the research attempts to describe the design process in three parts. The first provides an overview of the main stages of the design process, while the second discusses its nature and characteristics. The third one describes cycles of the design process.

The design process has no ideal step-by-step technique; "rather, there are many different styles of decision-making, each with individual quirks as well as manifestations of common characteristics"[1]. The architectural design process is comprised and linked series of visual thinking cycles[2].

Media Repertoire is the whole stock of what an architect utilizes to perform design (e.g. design capability, fluency of the way of media use, and other skills and aptitudes related to design). Designers employ their media repertoire in a sequence or series against the many tasks of the design process[3]. As shown in Figure (3-1), "each large loop represents a design process phase (concept formation, for example) within which are focused media studies that mark or characterize a design decision-making cycle within that phase (how might this building be shaped or sited, for example), with acknowledgment to Faruque, 1984 and Zeisel, 1981"[4].

The impact of different ways of using media during the architectural design process is alluded to in Figure (3-1) in a much summarized way, by referring to how to test various criteria within a detailed cycle of the linked cycles of

[1] Rowe, P., 1987, p. 2.
[2] Kellett, R., 1996, citing Zeisel, 1981, and Abdellatif, Mahmoud, 1985.
[3] Kellett, R., 1996.
[4] Ibid.

visual thinking. This reveals the continuing role of media along the progression of the design process.

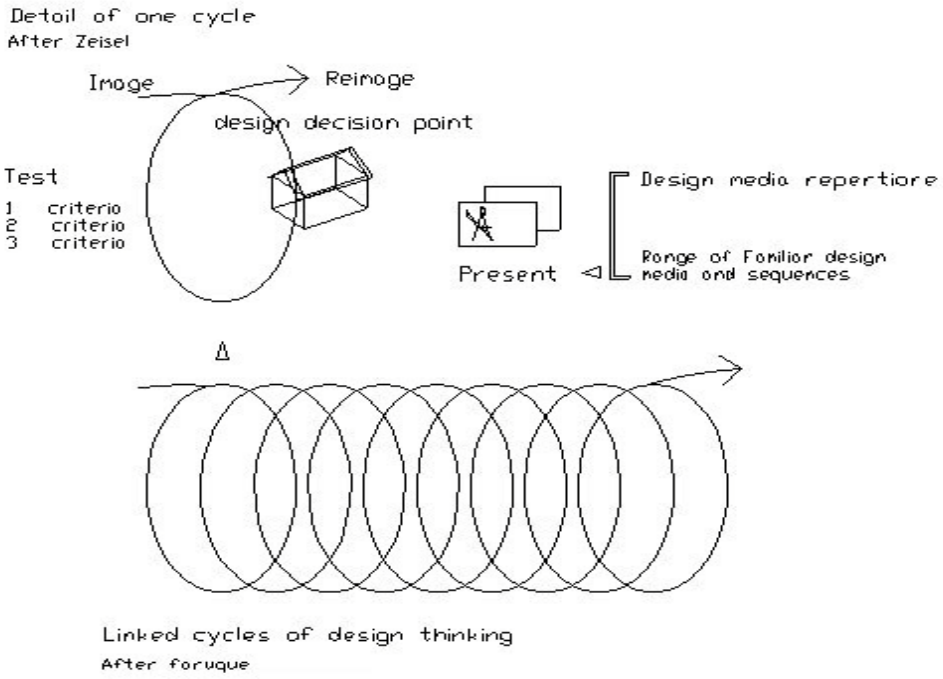



**Figure 3-1 Cycles of Design Thinking and Media use in Design Process**

From [Kellett, 1996, p. 32]

## 3-2 Phases of the Design Process

The design process can be classified into four main phases: Problem Definition, Design, Problem Implementation and Problem Evaluation, Figure (3-2). The scope of this research covers the tasks and activities of the design process, which include: problem definition, concept articulation, form giving, design development, representation and evaluation, Figure (3-3).

Each phase's activities may merge into the activities of other phases. This appears through the activities of the evaluation process which are performed with the activities of all other phases in the shaded area of Figure (3-3), where the continuous evaluation is needed during the progression of both the individual phases, and the whole design process.

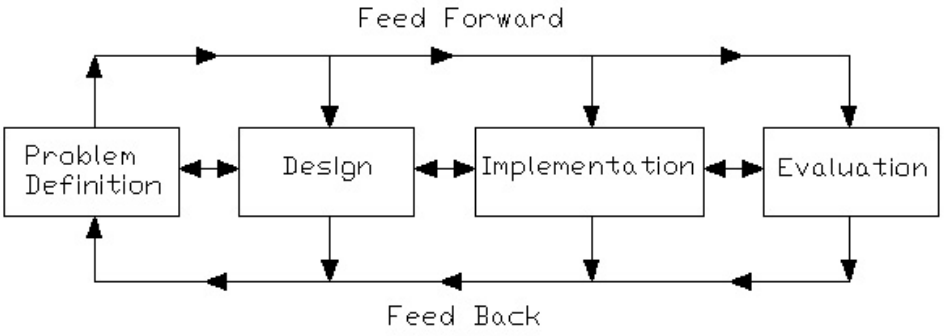



**Figure 3-2 The Phases of the Design Process**

From [Abdellatif, 1985]

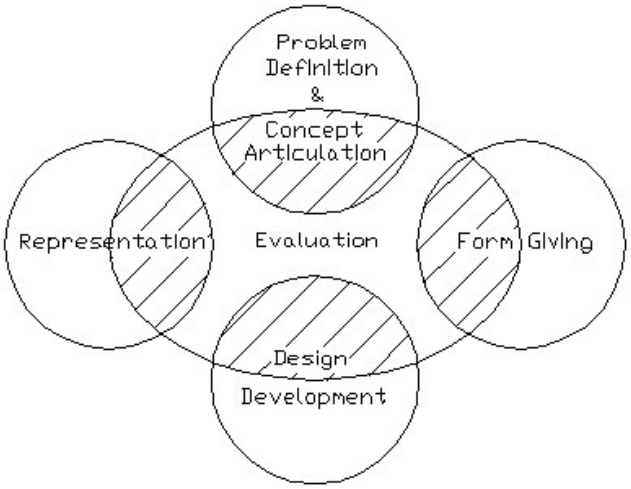



**Figure 3-3 The Interactive Connection between the Design Process Phases**

The figure is prepared by the researcher

The tasks of the design-process phases (e.g. problem definition, representation, etc.) are simultaneously conducted without any particular paradigm. For example, during the problem-definition phase or the concept-articulation phase, architects may employ representation activities in order to have more exploration and evaluation. In other words, inside any phase, the tasks and activities of other phases may be involved.

The tasks of the various phases overlap at certain times along the design process. We may refer to these times as evaluation points/periods that repeatedly occur during the progression of the design process. Evaluation tasks are basically the links which connect the other tasks of the different phases. Of the many evaluation points/periods of the design process, Figure (3-4) describes a single evaluation point/period and the connection between the tasks of the phases (or the sub-phases), which are concurrently performed along this evaluation period[5].

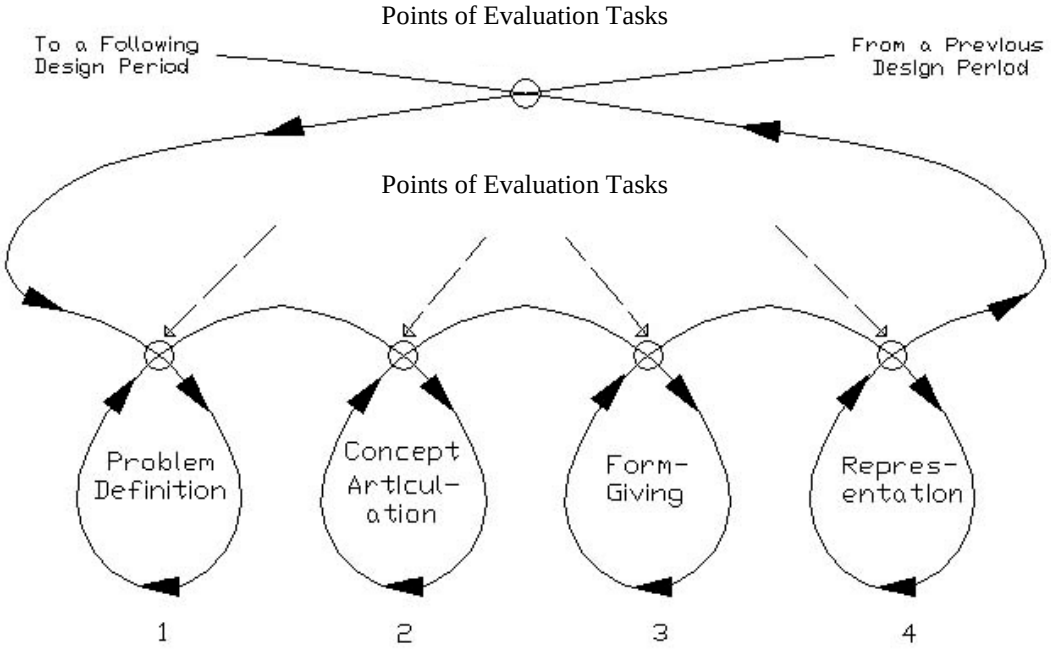



**Figure 3-4 Evaluation Points and Overlapping of Design Phases**

From [Abdellatif, 1989], with modifications made by the researcher

These evaluation points may lead the courses of action to: 1) backtracking to a more promising point of departure, 2) switching between organizational concepts/principles, or 3) further developing of an avenue of argument that the architect has employed. The role of media used during these repeated evaluation points/periods can be summarized as helping architects evaluate

[5] Abdellatif, Mahmoud, 1989.

what they have been accomplishing, according to what they have conceptualized earlier.

## 3-3 Nature and Characteristics of the Design Process

As a result of the discussion above in this chapter, the design process phases, influenced by different individual styles of visual design thinking, interrelate and overlap with no ideal algorithmic model or pattern. There are many characteristics in terms of the nature of the design process to be described; however, six of them are basically serviceable in investigating the research objectives within its rationale and logic. These six characteristics, which are developed by the researcher, draw the general portrait of the nature of the design process, namely:

1) **Numerous Models:** The unique nature of the design process manifests itself in the numerous numbers of models that can be identified. The variation of these models is derived from two main streams: a) the architect: her/his creativity, way of media use, and style of design thinking, and b) the design problem at hand and its ambit.

   For example, one architect may form concepts during problem definition exploration, and then these conceptual frameworks guide the evaluation of the whole design process. While in another case (maybe by the same architect), the personal prejudice of the architect towards a particular type of problem, which is similar to the one at hand, may lead to constructing concept/concepts even before any investigation of the problem's circumstances and conditions is undertaken.

2) **Organizing and Dominating Concepts:** The concept articulation phase encompasses episodic exploration of organizing concepts and principles which originate from the architect's vision and evaluation of the context

of the problem at hand. In general, after concept generation, the concepts, in conjunction with evaluation, play a major role in the validation and the organization of design development. Even when other organizational concepts are generated at a later stage, the earlier concepts, which have initially formed the problem space, have the priority of influence[6]. In other words, the earlier concepts are more dominating than the later ones.

**3) Continuous Refinement and Enhancement:** The methods used in the evaluation and the modification of designs can vary from an architect to another. Within the progression of the design process tasks, there is evidence that refinement and enhancement of design is a continuous process which is related to the evaluation process. For example, during the design development phase, the necessity to revaluate the design may appear, or the need for modifying the initial concepts may become essential.

**4) Nonlinear Nature of Design Phases:** The tasks of the design process phases can be performed together with other phases' tasks and activities, because there is no obvious end at which the execution of the design-process phases stops. In other words, design is a nonlinear process. Thus, it can be stated that the tasks of these phases dynamically overlap according to the architect's vision and perception of the design problem at hand.

**5) Correlation with Visual Design Thinking:** The processes of refinement, adjustment, and embellishment happen during the progression of the design process, according to the linked cycles of the design thinking of the architect. If we may describe the progression of the design process as a number of plans, Figure (3-5), where each plan describes a model of the

[6] Simon, Herbert A., 1979; and Rowe, P., 1987.

overlap of the phases, these plans will be developed parallel to the visual design thinking that conducts the process. In other words, design exploration and design development are related to the visual design thinking of the architect.

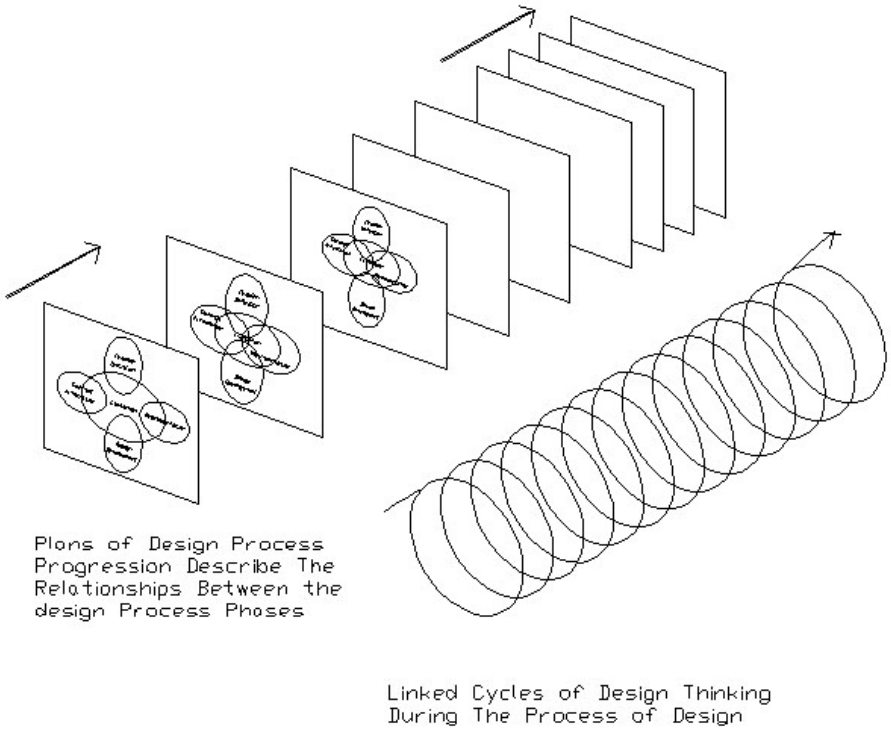



**Figure 3-5 The Progression of the Design Process and the Linked Cycles of Visual Design Thinking**

The figure is prepared by the researcher

**6) Progression in Representational Environments:** The tasks of the design process need a representational medium to be performed and conducted, such as sketching, two-dimensional/three-dimensional drawing, modeling, etc. Designers/Architects utilize representational environments to explore what is in mind and to develop designs. In other words, different media assist in design representation and in design evaluation at different stages of the design process.

Indeed, the examples of the relationships between the architectural design process phases mentioned above do not cover all possible models of the process of design. Nevertheless, they do provide a sufficient material and variation to clarify the dynamic connection and overlap of the phases of the design process.

## 3-4 Cycles of the Design Process

The dynamic overlap of the design process phases lead to conceiving this process as tasks and activities, rather than phases, because of the nonlinear nature of the design process. Thus, tasks and activities of the design process can be represented as a repeated cycle of decision-making and evaluation. Each single cycle may result in modifying: 1) the problem definition and the concepts, or 2) the design and form. Figure (3-6) describes a detailed cycle of the design process. The output of one single cycle is the input of the next one. This cyclical process of design stops when reaching a satisfactory solution for the design problem.

The use of analog and digital media may help architects in the design process through two major contributions: emerging new ideas or new forms, as illustrated in Figure (3-6).

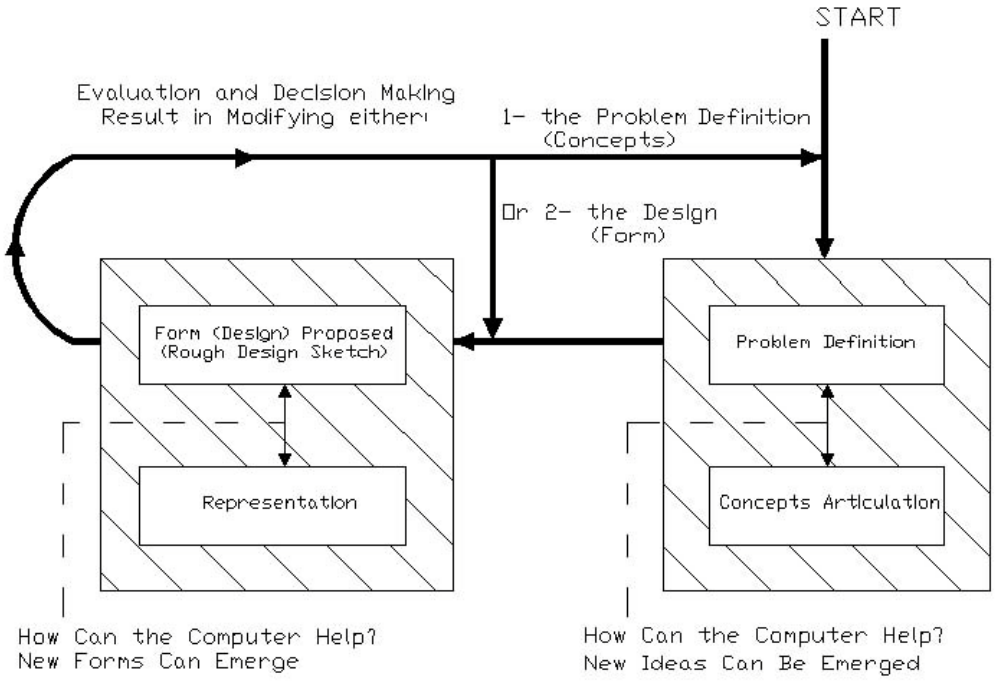



**Figure 3-6 A Detailed Cycle of the Design Process**

The figure is prepared by the researcher, with acknowledgement to meeting with Ozel

## 3-5 Conclusion of the Chapter

1- The tasks of the design-process phases (e.g. problem definition, representation, etc.) are simultaneously conducted without any algorithmic paradigm.

2- Along the design process, the overlaps of the phases dynamically move from one model to another, according to the architect's vision and perception of the design problem at hand.

3- There are many characteristics in terms of the nature of the design process to be described; however, six of them basically serve in investigating the research objectives within its rationale and logic. These characteristics, which are developed by the researcher, are as follows:

- Numerous Models: The unique nature of the design process manifests itself in the numerous numbers of models that can be identified. The

variation of these models is derived from two main streams: 1) the creativity, the way of media use, and the design thinking, of each architect, and 2) each design problem and its ambit.

- Organizing and Dominating Concepts: The concepts, in conjunction with evaluation, play a major role in the validation and the organization of design development. The earlier concepts are more dominating than the later ones.
- Continuous Refinement and Enhancement: Within the progression of the design process tasks, there is evidence that refinement and enhancement of design is a continuous process which is related to the evaluation process.
- Nonlinear Nature of Design Phases: The tasks of the design process phases can be performed together with other phases' tasks and activities, because there is no obvious end at which the execution of the design-process phases stops. In other words, design is a nonlinear process.
- Correlation with Visual design Thinking: The processes of refinement, adjustment, and embellishment happen during the progression of the design process, according to the linked cycles of the design thinking of the architect.
- Progression in Representation Environments: The tasks of the design process need a representational medium to be performed and conducted, such as sketching, two-dimensional/three-dimensional drawing, modeling, etc.

4- Tasks and activities of the design process can be represented as a repeated cycle of decision-making and evaluation. Each single cycle may result in

modifying either the problem definition and the concepts or the design and form. The output of one single cycle is the input of the next one. This cyclical process stops when reaching a satisfactory solution for the design problem. The impact of analog and digital media use on the design process may be generally summarized in two major contributions: new ideas and new forms.

The illustration of the nature and the main characteristics of the design process gives the research the basis to classify and to define a conceptual framework of the design capabilities of architects, which will be the concern of the next chapter.

# Chapter 4 Architectural Design Capabilities

## 4-1 Introduction

Within the context of this study, design capabilities are not seen as indigenous ones. Rather, they are seen as those which can develop and improve through knowledge, and what may accumulate in architects' minds and hands during the study and practice of architectural design. Architects utilize these capabilities to perform various tasks in the design process, beginning with problem definition tasks, such as drawing out design implications from the information (words, numbers and images) of the program and site, through concept articulation tasks which are summarized in analyzing, finding and extracting design concepts, and ending with form generation tasks which explore the creative leap from concept to form and its schematic development.

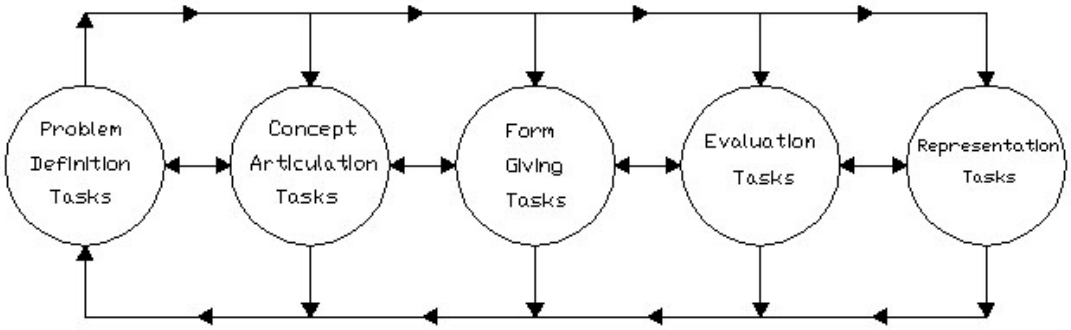
This chapter is concerned with: 1) testing the first hypothesis (architects employ certain capabilities through and by which the architectural design problems at hand are solved), and 2) achieving the first objective (defining a framework for the design capabilities of architects).

## 4-2 Tasks of the Architectural Design Process

Tasks of the architectural design process can be identified according to information input, information output, and method by which they are performed. Therefore, these tasks can be categorized in types/classes, such as Conceptualization tasks, Representation tasks, Evaluation tasks, etc. Each category generally needs certain capabilities different from what are required in the other categories. In the tasks of problem definition and conceptualization categories (the tasks of the early design phases), much imagination, conceptualization and interpretation are employed. During

evaluation tasks, however, criticism, analysis, background knowledge and decision-making are more required and employed.

Architects execute all the tasks or a number of them along different periods of the design process, as the design situation demands, Figure (4-1). Evaluation tasks and Representation tasks are continually performed in conjunction with the other tasks along the whole process of design, because both tasks are related to evaluation process which is a continuous process.




Arrow Movements Refer to the Continually Changing Connection between the Tasks of the Architectural Design Process

**Figure 4-1 The Dynamic Connection between Tasks of the Architectural Design Process**

The Figure is prepared by the researcher, with acknowledgment to Abdellatif

## 4-3 Architectural Design Capabilities

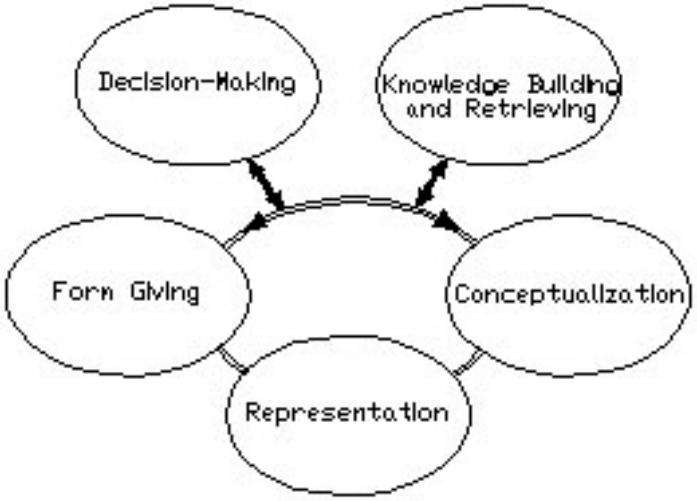
The design capabilities of architects can be classified according to the tasks which are related to these capabilities. Thus, the architectural design capabilities can be defined and classified into five types: Conceptualization Capability, Form Giving Capability, Representation Capability, Decision-Making Capability, and Knowledge Building and Retrieving Capability.

Although there is no arrangement or order of how architects use these capabilities during various tasks of the architectural design process, the

features of a generalized portrait can be discovered. Within this portrait of the conceptual framework which is developed by the researcher, architects move back forth inside a loop of reciprocal influences which connects Conceptualization, Form Giving, and Representation capabilities. Although these three capabilities may be performed simultaneously, the Conceptualization capability has the main role in leading this loop. Meanwhile, architects use a mixture of both Decision-Making and Knowledge Building and Retrieving capabilities in order to guide the foregoing mental loop in evaluating and choosing between the tentative proposals they have in mind for solving the given problem as a whole or in parts, Figure (4-2). The mixture of both Decision-Making and Knowledge Building and Retrieving capabilities are utilized in evaluation tasks. In other words, the synergistic impact of these two capabilities can be identified within the evaluation tasks of the design process.

The back forth movement the capabilities' loop can be identified within various episodic moments of exploration, like the moments of exploring particular organizational principles, which are usually followed by evaluation the validation and appropriateness of these principles. During the evaluation periods which act as a formal composition for the design theme, architects use the Decision-Making capability and the Knowledge Building and Retrieving capability as a compositional guide for other capabilities' results and outputs.

This foregoing description of the design-capabilities portrait can be distinguished at any point inside the design process.




The Loop of Reciprocal Influences of the Design Capabilities

The Effects of the Decision-Making Capability and the Knowledge Building and Retrieving Capability on the Influence Loop of the Design Capability

**Figure 4-2 The Relation between Design Capabilities of Architects**

The Figure is prepared by the researcher

### 4-3-1 Conceptualization Capability

Conceptualization capability of architects can be described as the capability to set concepts and conceptual frameworks which will guide the design process towards its final product, and which emerge through the ambit of the given problem and through the interpretation of the architect. These concepts construct the interpretation of the design problem and vice versa. Architects move back and forth, within evaluation periods, between the problem as given and its definition process, on the one hand, and the tentative proposals they explore and develop in mind, on the other hand. Continually influenced by the constraints derived from the problem context, and by the evaluation resulting from Decision-Making and Knowledge Building and Retrieving

capabilities, the chosen creative concepts lead the design process from the earlier proposals to the final delineation.

Hardly does one concept, if any, lead the process of architectural design, as one concept or organizational principle rarely suffices to provide all that is required to solve a design problem. One concept, in some cases, may have a main role among the roles of the other concepts. However, the conjoint influences of all concepts, in most cases, develop the architectural design. In other words, different concepts do not have the same degree of impact. The variation of the concepts' impact depends on the design problem's constraints and architect's evaluation of these constraints.

In general, initial concepts play the main role of the validation and appropriateness of ideas during design development, and draw the outlines to guide the design process. Therefore, the modified and subsequent concepts in later stages do not have this influential impact[1].

Concepts derived from the initial design ideas, which are appropriated from outside the immediate context of a given design problem, are often more highly influential in the making of design proposals than the ones generated from the aura of the design problem are. For Example, a design scheme may be developed from few well-chosen concepts that are more an architect's interpretation of what the project might be like than being pragmatic responses to prevailing site conditions and program. In other words, some organizational principles which are originated from the outside of problem space, may have the main impact on the process of design.

[1] Simon, Herbert A., 1979.

Exploring the two fields of how concepts emerge, and what their roles and tasks are, gives us a sufficient definition of this capability and how architects utilize it in the design process.

#### 4-3-1-1 Bases of Concept Emergence

Having temporarily[2] explored the design problem into a well-defined one, architects proceed to organize various ways, which generate an initial sense of problem, and formalize concepts and conceptual frameworks. The design thinking priority of this phase is to collect and sort through information related to the program. Much of this information comes in the form of data (e.g. words, and numbers), and a little comes in the form of documents (e.g. images, planes and maps). All results of this process are edited to create the content of design concepts, which represents the base to form and shape concepts and conceptual framework.

The tasks of concept articulation can be identified according to the streams of this concepts' emergence[3]. These streams can be classified into four classes: Context of Design Problem, Individual Interpretation of Design Problem, A Prior Use of a Similar Design Problem Model, and Multiple Sources.

**a) Context of Design Problem**

The concepts can emerge from the immediate context of the design problem, prevailing site circumstances, program conditions and building purposes. The initial exploration and modification of the design problem which form constraints, strongly affect the unfolding of the design. Modifications may

[2] More exploration of concepts, forms, and proposed solutions leads to a further definition of the design problem at hand, and consequently to more modification in the design problem.

[3] According to Gero, emergence is the process of making implicit features explicit [Gero J. and R. Saunders, 2002, citing Gero J., 1992].

arise through the attempts to extend the strategy of expressing various design problem constraints.

In other words, the design problem context leads to generating the guiding principles which may form concepts. These kinds of concepts, during problem solving, are basically affected by the context of design problem.

**b) Individual Interpretation of Design Problem**

The concepts may originate from the individual interpretation of the given design problem, such as specific style of a problem type, the spatial feeling of a desired impression, functional expression, modes of fabrication technology, etc. These personal attitudes may construct the guiding principles that participate in adapting and in adopting concepts. Architects utilize presuppositions and hunches about architecture as a departure point to form concepts, at least as much as these concepts depend on information furnished during orderly confrontation with the constraints found in a given design problem[4]. For instance, this is evident in adopting a symmetrical form of a plan or an elevation, or an implied axial arrangement that may have no relationship to the design problem context.

**c) Prior Use of a Similar Design Problem Model**

The concepts may be dominated by a prior use of an organizational principle or a model for resolving the same particular problem. The reference-principle or reference-model may be of a functional type, historical type, classical type, building type, etc. In a creative endeavor such as an architectural design, an attempt is made to overcome the situation's novelty by seeking any similarity in this situation or its components to a prior design model/principle. For

[4] Rowe, P., 1987, p. 3.

example, an architect may employ, in a design scheme, the use of a particular style of building, which is related to the function of a given design problem.

These references, utilized by architects to form concepts, may be objectively derived from well-known models and principles, or may be quite subjectively evolved from a prior individual experience of usage.

**d- Multiple Sources**

Concepts and conceptual frameworks are generated from the array encompassing design problem's constraints and architect's interpretations. It is evident in some cases that one prominent concept may generate from multiple sources.

In most cases more than one concept act as conspicuous features to dominate the process of design, as one concept or organizational principle rarely suffices for all that is required to solve a design problem.

#### 4-3-1-2 Roles and Tasks of Conceptualization

A large step in design-problem solving is to define the problem itself. Exploring and defining the given design-problem is the first task of the Conceptualization capability. In addition, the formulation of design problem depends on a preconception which, in turn, refers to a definite direction toward the solution of design problem. In other words, there are reciprocal dialogues which take place in the architect's mind between the tasks of exploring and defining the design-problem on the one side, and the tasks of forming concepts and conceptual frameworks on the other side.

Different ways of media used affect these reciprocal dialogues. Media, therefore, have an influential part in defining a design problem and in constructing concepts and conceptual frameworks.

The formed concepts or conceptual frameworks, as variably evolving from the previous streams, could have conflicting influences and/or complementary effects on the design scheme. The impacts of concepts, in some cases, are supplemental towards one direction of solving the whole design problem or solving one of its sub problems. In other cases, these impacts are confrontational to form the direction of solution. For example, it is evident that concepts derived from the economy factor, represented in the availability of resources, have conflicting influences with the ones obtained from another factor, such as man needs, program requirements, etc.

The concepts or conceptual frameworks (in other words, guidelines or rules) are established to help the architect propose solutions, and to prepare for subsequent exploration and for further evaluation. The results from this evaluation give shape to a more definitive organization for the design scheme.

The role of the Conceptualization capability may affect not only the manner in which a problem is represented and explored, but also the processes in which solutions are evaluated. The role of concepts may be summarized in these tasks:

- Continually defining, exploring, and redefining the design problem along the process of design.
- Constructing the guidelines and organizational rules that lead design development.
- Exploring the potential of each decision route to solve the sub-problem classes.
- Evaluating the proposed solutions of the whole design scheme.

### 4-3-2 Form Giving Capability

Form giving capability of architects can be described as the capability to transfer and convey their conceptual frameworks into architectural forms. In other words, it is the capability that enables architects to express their concepts and conceptual frameworks into architectural formal propositions and compositions, in order to develop a design scheme from prevailing program conditions and site circumstances, through the early form proposals to the final delineation.

Investigating the definition of this capability is achieved by identifying the both fields of Form Giving emergence and tasks of Form Giving capability within the process of architectural design. The illustrations of these two areas draw a satisfactory image of utilizing Form Giving capability and its role.

#### 4-3-2-1 Bases of Form Giving Emergence

Creativity, indeed, plays a conspicuous part in this episode, achieving the creative leap from concepts to forms within the given problem context. Points of thinking departure, however, might be used to generate this leap. These departure points are construed from two main fields which are literal analogies, and typologies. Therefore, the basis of Form Giving emergence can be classified into three classes: Creativity, Literal Analogies, and Typologies.

**a) Creativity**

Two main fields, the context of design problem and the individual interpretation of design problem, have several distinct lines of creativity origination:

- ***Context of Design Problem:*** It is evident that a design-problem solution, affected by the design-problem context and its constraints, may be derived

from creativity. Analyzing an architectural design case, Rowe (1987) states that both the systematic evaluation of the site and its environs, followed by contextual studies, generated two themes: "one was the creation of a landmark at the point of symmetry (of the site plan)… the other was the development of a scheme in the form of a linear system of buildings and interstitial spaces". The sequent programmatic evaluation revealed both the insufficient provided building facilities and the inefficient arrangement of the linear structure; the need for vertical extension in the form of a tower emerged to play an important role with the two themes. Designing the building in a tower shape was the result of the previous evaluation and the solution of combining the two themes[5].

- ***Individual Interpretation of Design Problem:*** Architects may adopt and adapt a formalistic, symmetrical, classical, or neoclassical conformation for the building they design, throughout the made explorations. These guiding principles that construct and shape creative form result from architects' interpretation and vision. For example, the section of Performing Art Center at Fort Wayne, Indiana, by Louis Kahn has the form of a violin in its case. The architect's interpretation of the need for acoustic symbol in a concert hall played the basic role in suggesting the form of design[6].

**b) Literal Analogies**

Architects' minds have the quality to adopt and adapt reference-image of any resource (be it artificial or natural form); borrowing forms associated with design concepts is a main feature of this capability. Architects utilize various references to observe and store, and to use and employ. Architectural design

[5] Rowe, R., 1987, p. 20-22.

[6] Do, Ellen and M. Gross, 1995, citing Brownlee and Long, 1991.

primers (e.g. [Laseau, 1980]), stories of masters (e.g. [Guiton, 1987]), and studies of the design process (e.g. [Broadbent, 1973]), all these research works discuss the use of references of visual analogs and metaphors and their important role in shaping formalization[7]. Gero and Maher (1991) suggest using reasoning by analogy to bring in innovative solutions[8], and Navinchandra (1991) supports the same approach[9].

**c) Typologies**

As a departure point to construct and shape form, architects utilize typologies derived from: 1) building types as models, 2) organizational typologies, such as functional or historical references, and 3) elemental types, such as that of using particular methods or procedures to solve a functional sub-problem of a building component.

This class, as well as literal analogies, indeed, is strongly related to the underlying design-scope of architects, and their Knowledge Building and Retrieving capabilities, as architects utilize their architectural background in trying to overcome the novelty of design problems.

### 4-3-2-2 Tasks of Form Giving

The tasks of Form Giving capability can be classified into two classes: two-dimensional type and three-dimensional type. In spite of this classification, architects utilize the tasks of both classes without any particular paradigm. In some cases, several distinct lines of reasoning for the two-dimensional type of form are the start that leads to the three-dimensional type of form. In other cases, the opposite path of thinking is evident. Nevertheless, architects

[7] Do, Ellen and M. Gross, 1995.
[8] Gero, J. and M. Maher, 1991, p. 241-249.
[9] Navinchandra, D., 1991.

simultaneously explore the both types of one form, and do not separately deal with only one type.

There are mutual effects between the two types of tentative forms while exploring and constructing, in order to generate a final form. For example, undertaking a massing study, or building a physical model at the early stage of the process, the architect cannot proceed further without seeking organizational rules originated from the inner elements and components of the building masses and their relationship in plan (the two-dimensional type). These organizational rules identify major aspects of the design in the three dimensions, such as the dimensions of the building mass which are related to the number of floors, and to the areas of the elements of each floor and their relationships.

***In two dimensions:*** The two dimensional part of Form Giving capability manifests its self in: 1) solving space-planning by prescribing the rules with which building spaces are assembled through expressing adjacency requirements, and 2) organizing architectural plan composition, where the architect tries to combine various diagrams (such as a structural diagram, a functional diagram, a circulation diagram, etc.) in terms of having a plan that expresses the evaluation of all program requirements. For example, in some cases of design, an architect may introduce particular organizational principles, such as utilizing several lines in plan at 45 degrees in order to better relate parts of the project or elements of the plan.

***In three dimensions:*** the organization of facades and external form of the design is pursued somehow later in the process, although to some extent these investigations are performed concurrently with the studies of structure and circulation. For example, façades of a building may be

composed from a proportional grid that is an outgrowth of the references employed earlier in the process.

Different methods of media use affect the form exploration and form giving process. The feedback one gets from one type of media may generate formal ideas that are not accessible by the other types of media. Media, therefore, have an influential role in exploring and shaping forms generated during the design process.

### 4-3-3 Representation Capability

Representation capability of architects can be described as the capability to compose their thoughts in representative ways through lines, areas, volumes, colors, etc. Tasks of this capability, performed in conjunction with other capabilities' tasks, are used by architects for presentation, exploration, and evaluation of what occur in their minds during the design process.

This capability encompasses two and three dimensional drawing, physical modeling, and coloring capabilities, regardless of the type of media (be it analog or digital) which is used during these activities. All the analog activities of Representation capability, including drawing, are learned processes, not an in-born talent, achieved through confidence and knowledge building, motivation, practice, and application.

Architects draw to explore problem definition or to construct concepts, as drawing is a versatile language[10], which not only connects various design activities, but is also utilized inside these activities.

[10] Kasprinsin, Ron and J. Pettinari, 1995, p. xiii.

### 4-3-3-1 Act of Drawing and Sketching

Drawing is eminent in the activity array of the Representation capability. Drawing is not only a versatile language but a spatial thinking also, as architects explore and reveal their schemes with the aid of sketches and other drawings (be it two-dimensional or three-dimensional). While representing their ideas through sketches and drawings, architects organize and construct these ideas. The act of drawing is important as a vehicle for communication; it actually helps designers see and understand the forms they work with[11]. As Mitchell (1990) points out, the ambiguity of drawings plays an important role in using these drawings to construct representations, in response to goals and experiences during designing[12].

Drawing, therefore, is used as a cognitive process. Through its act, spatial relationships emerge and are formed, and opportunities and implications of forms are assessed. In addition, sketching is an experimental system to explore the potential of various shapes and forms[13].

It is hard to have an idea which is used in solving a design-problem, without using drawing in its germination or its evaluation. The basic act of drawing, which associates the process of design, can be summarized in:

**a) Visual Design Thinking:** There is an inevitable reciprocity between the act of drawing and the thinking associated with it. “The hand moves, the mind becomes engaged, and vice versa”[14]. Two points in visual design thinking have established a fundamental base for the use of drawing in the exploration of complex urban patterns: “1- (cognitive operations of called

[11] Do, Ellen and M. Gross, 1995, citing Edward, 1979.
[12] Mitchell, William J., 1990.
[13] Gero J. S. and R. Saunders, 2000, p. 215-224.
[14] Graves, Michael, 1977, p. 384-394.

thinking are not the privilege of mental processes above and beyond perception but the essential ingredients of perception itself … active exploration, selection, grasping of essentials, simplification, abstraction, analysis and synthesis, completion, correction, comparison, problem solving, … combining, separating, and putting in context), and 2- (shapes are concepts … what matters is that an object at which someone is looking can be said to be truly perceived only to the extent to which it is fitted to some organized shape)"[15].

b) **Germination of Design Ideas:** While defining, exploring, and redefining the design problem, architects construct, evaluate, and form their design ideas and concepts by utilizing different types of drawings, such as static standard projections (such as plans, elevations and sections), axonometric drawings, and perspective drawings.

**c) Development of Design:** The foregoing role of drawing plays a major part in forming ideas, so that it acts as the basic part in shaping decisions and developing designs. "Recent books on the functions of drawing in architecture (e.g. Fraser and Henmi, 1994; Herbert, 1993; Lawson, 1994; Robbins, 1994) remind us that though CAD/CAM[16] is used for making and editing mechanical working drawings and for producing renderings and animations for clients, drawing – researchers mean manual drawing - is still the medium of choice for creative design and design development"[17].

#### 4-3-3-2 Representation Tasks

[15] Kasprinsin, Ron and J. Pettinari, 1995, citing Arnheim, Rudolph, 1969.

[16] The phrases CAD –Computer Aided Design- and CAM –Computer Aided Manufacturing- are used in their broadest sense to include all forms of digital design tools and approaches.

[17] Do, Ellen and M. Gross, 1995.

Three stages of Representation tasks can be identified inside the process of design, according to their outputs and the tasks that are interdependent with:

A) Early episodic investigations of initial ideas, through two/three dimensional drawing and modeling, help in defining the design problem and in constructing concepts. Drawing is "the making of concepts and conceptual developments"[18]. "Sketching is basic to conceptual design…it may be that CAD software is too structured for conceptual design thinking, which uses freehand sketching as its primary mode of development "[19]. When digital media are not solely used, analog media dominate in performing this episode, even with the associated use of quite sophisticated software of digital media. For example, Gehry starts design by directly building physical models before using digital media.

b) Later drawing and modeling subsequently revoke refinement and adjustment for the compositional principles of fitting forms and structures, for the formal configuration of circulation and use, and for the three-dimensional conformed consequences. During these episodes, various computer based drawings and three-dimensional modeling programs provide a large aid for architects. Using representational techniques introduced by digital media during design-development process has altered what we can represent, see, and therefore understand and imagine.

c) Finalized by the architect with all the required details, the representation of final drawings suits more the nature of computing CAD as an algorithmic process, in order to produce a more accurately, rapidly, flexibly and effortlessly documented version.

[18] Rowe, P., 1987, p. 98.

[19] Do, Ellen and M. Gross, 1995.

### 4-3-4 Decision-Making Capability

Decision-Making capability allows architects during the design process to understand, specify, evaluate, and decide how the designed forms and shapes are suitable and apt for the required functions and needs, regardless of the forms generated and the media used. In a sense, this capability helps architects determine what fits or does not fit architecturally, in response to the appropriateness of both functioning and ordering of designed elements. It causes the occurrence of both the abandonment of some decision routes previously chosen, and the change of particular organizational principles. It encompasses many activities such as logical thinking, mental organization, criticism, evaluation, and selection capabilities. In other words, one decision can be decomposed into various activities and tasks.

Architects use this capability to facilitate evaluation and assessment of various steps within which design scheme crystallizes into a more definitive form. For example, in the evaluation periods of the design process, it may be distinguished that an organizational rule/principle is selected and applied under conditions of constancy of appreciation. A solution is proposed, and then the information derived from the evaluation, in the light of known solution properties, may form the basis by which another rule/principle is selected. Consequently, the switching process of rules and constraints may happen.

There is a network of constraints and requirements to shape a decision route or to solve each sub-problem of design. In most cases, the architect’s mind is not occupied by one constraint at a time to take a decision route, but a combination of different constraints shapes a given route of decision. This happens in the direction of decision sequence for solving the whole design-problem. For example, the dimensions of building form are specified upon the program requirements, functional elements, layout conditions,

architectural codes, and aesthetic proportions of masses and facades; also this can be judged on the levels of environmental factors, such as economic factor, climate factor (macro, micro, and indoor), etc.

The philosophy of design-problem solving methodologies that are established, relies on abstracting the activities of the design process into Decision-Making activities, as the final objective of design is to reach decisions which would be apt for particular situations and circumstances of design-problem aura[20]. The important part of the Decision-Making capability, performed during the process of design, manifests itself in these characteristics and roles:

1) **Influencing Early Structure of Design:** Early organizational rules that architects utilize in defining, exploring, and solving the design-problem, have long lasting influences on the process of design. The initial structure of a design-problem is the basis on which the solution of this design-problem is constructed. Thus, this structure is the starting point from which paths towards design solution are sought and evaluated. Experimental evidence suggests that the guidance provided by the early ordering of a problem space is relatively difficult to abandon[21].

2) **Selection of Organizational Principles:** Architects adopt and adapt what seems to be a promising direction to solve the design problem or its sub problems. Therefore, architects utilize this capability to proceed towards further courses of action, to reach a satisfying design-solution.

4) **Evaluation of Organizational Principles:** The evaluation of the selections that architects adopt reveals this role of the Decision Making

[20] Abdellatif, Mahmoud, 1985.

[21] Rowe, P., 1987, p. 108, citing Simon, Herbert A., 1970.

Capability. A shift may occur in the type of an organizational principle, from a preoccupation with formal composition derived from a model type, for example, to a concern with another guiding principle, for example a geometrical type. This shift, resulting from evaluation periods, is caused by the decisions that architects may make.

5) **Choice of Decision Routes:** In analyzing the generation of a new decision route during the process of design, architects throughout periods of evaluation may abandon a line of argument because of a lack of confidence in the outcome portrayed by immediate information. When difficulties are encountered within the use of one organizational principle in making a composition, the change to another organizational principle leads the process of design through another decision route. Through evaluation conducted by the architect, decisions are prominent: 1) in determining the promising point of progress towards design solution, 2) in adopting new information, 3) in choosing another decision route, and 4) in formalizing the directions of design-process development.

The different scales and levels of conception affect the different qualities of solutions, and influence design development in general. Therefore, media influence this capability by helping architects increase this conception level.

### 4-3-5 Knowledge Building and Retrieving Capability

Knowledge Building and Retrieving capability of architects is the ability to accumulate and retrieve knowledge based on architectural design experience, i.e. the use of architectural shapes and forms, different types of media, building materials, and structural systems. This capability helps architects make decisions, employ all their design process capabilities, and implement their own style within the design process.

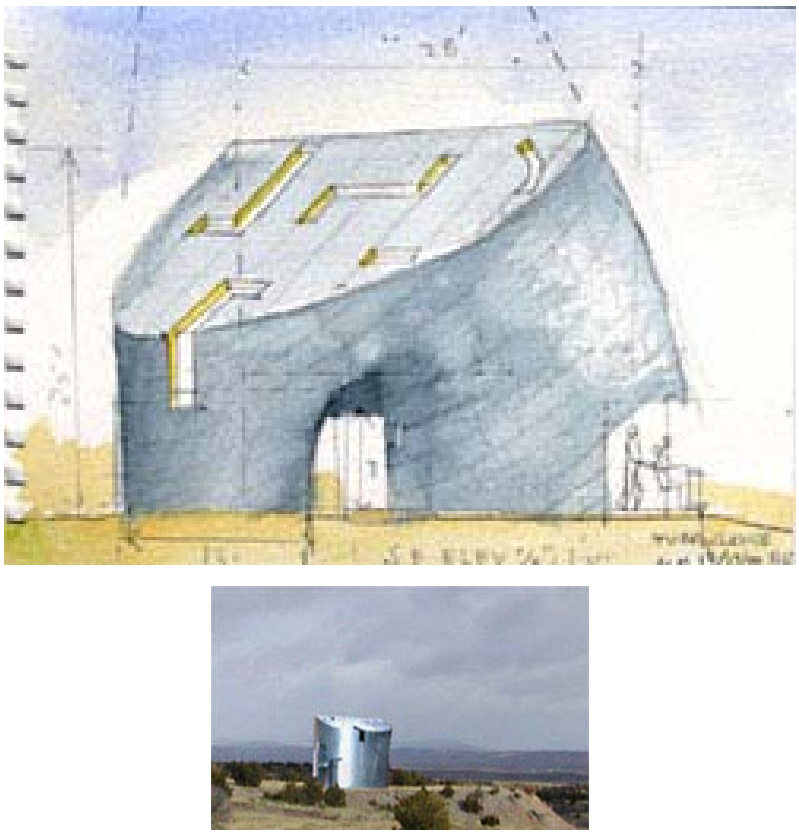
Moreover, this capability encompasses having good understanding of the factors affect design, such as culture, tradition, weather, etc., and reflecting these factors in the final artifact. The Knowledge Building and Retrieving capability plays an important role in making the design sound, in response to the fulfillment of the interactions between man and architecture on the one side, and man's environment on the other side. In essence, some architectural ideas that may come from the effect of non-architectural sources (such as environment, culture, etc.), may lead to solutions. The role of the architect in this episode is not to present his environment but rather to represent it[22] by having man's need fulfilled through the design.

Furthermore, it takes years of experience for an architect to understand how the drawings could be presented in reality, as design ideas need to be developed according to program requirements, construction practices, and field conditions. For example, how to specify the dimensions of a corridor in a building, in order to accurately achieve its functional objective and fulfill the needs of users. Gaining this knowledge and experience is a qualitative component in the Knowledge Building and Retrieving capability.

In design-problem solving, formalizing proper decisions requires clarity of the information which is derived from design-problem context and architect's vision. This capability helps architects construct this information. Therefore, the advanced background an architect has proceeds and elevates the position within and by which decisions are formed and made. This illustrates how the combination of the Decision-Making capability and the Knowledge Building and Retrieving capability affects the design process, and the other design capabilities.

[22] Bermudez, J. and K. Kevin, 1999, p. 321-325.

Some styles of architectural design thinking require quite effective use of manual media (emphasized in hand sketching and manual drawing) in order to reach the same results that are offered through digital media use. And this use can be only achieved through the high level of the Knowledge Building and Retrieving capability in manual representation, Figure (4-3).



A picture and drawing of Turbulence house, courtesy Steven Holl architects

**Figure 4-3 Turbulence house, New Mexico, by Steven Holl**

From [http://www.designboom.com/portrait/holl_mexico.html]

Some distinguished architects in our virtual age, still prefer this style of Le Corbusier of using manual media in architectural design thinking, through developing the kinesthetic aspect of the architectural promenade in a design by relying on drawing by hand to sketch the experiential quality of moving

through a building. For example, Steven Holl[23], who is the most highly published architect today, seems not to be interested in the computer to promote the sensory characteristic of his designs; his devotion concentrates on drawing as the embodiment of an authentic thought[24], Figure (4-4).

Simmons hall at the MIT (Massachusetts institute of technology) the facade of the new dormitory as inspired, in part, by a bathroom sponge. Courtesy Steven Holl architects

**Figure 4-4 Simmons hall at the MIT, by Steven Holl**

From [http://www.designboom.com/portrait/holl_simmonshall.html]

The important role of the Knowledge Building and Retrieving capability, which is performed during the process of design, can be identified in these two characteristics:

1- **Personal Style and Subjective Point of View**: The main feature of this capability is the personal designing styles that may distinguish one architect from another. It is the subjective point of view of architects in terms of solving any given problem. Moreover, the designer has

[23] The success of Steven Holl's architecture derives from his sculptural shapes, his interest in the poetics of space, color, and material, as well as his fascination with scientific phenomena. His work refers to urban history and the potentials of modern science [http://www.designboom.com/portrait/holl_simmonshall.html].

[24] Gruzdys, Sophia, 2002.

heuristics, evolved from prior personal experiences, which serve the designer's purposes for more than a single project and thus become incorporated as a central part of that individual's design thinking[25]. Rowe (1987) defines it as the habitual way of doing things or of solving problems, and illustrates it as "a fluency in a particular way of designing, and the consistency that comes with it"[26]. This is evident in styles of famous architects where each one has certain patterns of design thinking, media use, and design process performing, which affect the output of the design process. Therefore, buildings belong to well-known architects can be differentiated, according to the style performed, media used, and form designed.

2- **Background of Decisions**: The synergistic influence of using the Decision-Making capability and the Knowledge Building and Retrieving capability can be identified in how decisions can vary from one architect to another even in the same design situation, according to the background of the architect. Represented in architectural experience, the Knowledge Building and Retrieving capability has the basis of constructing decisions. In addition, what seems promising about solving a design-problem comes to mind via this capability. For example, choosing between different routes in solving design-problem relies on the knowledge about these avenues provided to and acquired by the architect, because an architect cannot think of utilizing a specified constructional system or using a certain way of media unless s/he already knows all the main features of it.

[25] Vickers, Sir G. 1983; and Rowe, P., 1987, citing Schön, Donald A., 1984.
[26] Rowe, P., 1987, p. 110.

Media help architects increase the Knowledge Building and Retrieving capability by offering the required data and information during design, in digital or analog format.

## 4-4 Conclusion of the Chapter

1- The chapter has: 1) verified the first hypothesis, that is architects employ certain capabilities through and by which the architectural design problems at hand are solved, and 2) achieved the first objective, that is defining a framework for the design capabilities of architects.

2- The design capabilities of architects can be classified into five types: Conceptualization capability, Form Giving capability, Representation capability, Decision-Making capability, and Knowledge Building and Retrieving capability.

3- Within the conceptual model, which is developed by the researcher, architects move back and forth inside a loop of reciprocal influences which connects Conceptualization, Form Giving, and Representation capabilities. Although these three capabilities may be performed simultaneously, the Conceptualization capability has the main role in leading this loop. Meanwhile architects use a mixture of both Decision-Making, and Knowledge Building and Retrieving capabilities in order to guide the foregoing mental loop in evaluating and choosing between the tentative proposals they have in mind for solving the given problem as a whole or in parts.

4- **Conceptualization Capability** is the capability to set concepts and conceptual frameworks that will guide the design process towards its final product, evolved by the ambit of the given problem, and by the interpretation of the architect.

* The streams of concepts' emergence can be classified into four classes: Context of Design Problem, Individual Interpretation of Design Problem, A Prior Use of a Similar Design Problem Model, and Multiple Sources.

* The role of the Conceptualization capability may affect not only the manner in which a problem is represented and explored, but also the processes in which solutions are evaluated. The role of concepts may be summarized in these tasks:

  - Continually defining, exploring, and redefining the design problem along the design process.

  - Constructing the guidelines and organizational rules that lead design development.

  - Exploring the potential of each decision route to solve the sub-problem classes.

  - Evaluating the proposed solutions of the whole design scheme.

* Different ways of media used affect both defining the design-problem and forming concepts. Media, therefore, have an influential role in defining the design problem and in constructing concepts and conceptual frameworks.

5- **Form Giving Capability** enables architects to express their concepts and conceptual frameworks into architectural formal propositions and compositions.

* The basis of Form Giving emergence can be classified into three classes: Creativity, Literal Analogies, and Typologies.

* The tasks of the Form Giving capability can be classified into two classes: two-dimensional type and three-dimensional type.

* Different methods of media use affect the form exploration and form giving process. The feedback one gets from one type of media may generate formal ideas that are not accessible by the other types of media. Media, therefore, have an influential role in exploring and shaping forms generated during the design process.

6- **Representation capability** of architects is the capability to compose thoughts in representative ways through lines, areas, volumes, colors, etc. This capability encompasses two and three dimensional drawing, physical modeling, and coloring capabilities, regardless of the type of media (be it analog or digital) which is used during these activities.

* The basic act of drawing that associates the process of design, can be summarized in: visual design thinking, germination of design ideas, and development of design.

* Three stages of Representation tasks can be identified inside the design process:

  - Early episodic investigations of initial ideas help in defining the design problem and in constructing concepts.

  - Later drawing and modeling subsequently revoke refinement and adjustment for the compositional principles of fitting forms and structures. During these episodes, various computer based drawings and three-dimensional modeling programs provide a large aid for architects.

  - Finalized by the architect with all the required details, the representation of final drawings suits more the nature of computing CAD as an algorithmic process.

7- **Decision-Making Capability** allows architects during the design process to understand, specify, evaluate, and decide how the designed forms are suitable for the required functions, regardless of the forms generated and the media used.

* The important part of the Decision-Making capability performed during the process of design, manifests itself in these characteristics and roles: Influencing Early Design Structure, Selection of Organizational Principles, Evaluation of Organizational Principles, and Choice of Decision Routes.

* The different scales and levels of conception affect the different qualities of solutions, and influence design development in general. Therefore, media influence this capability by helping architects increase this conception level.

8- **Knowledge Building and Retrieving Capability** of architects is the ability to accumulate and retrieve knowledge based on architectural design experience, i.e. the use of architectural shapes and forms, different types of media, building materials, and structural systems.

* The advanced background an architect has proceeds and elevates the position within and by which decisions are formed and made. This illustrates how the combination of the Decision-Making capability and the Knowledge Building and Retrieving capability affects the design process, and the other design capabilities.

* The important role of the Knowledge Building and Retrieving capability can be identified in these two characteristics: Personal Style and Subjective Point of View, and Background of Decisions.

* Media help architects increase this capability by offering the required data and information during design.

After this discussion of the conceptual framework of the architectural design capabilities, exploring and classifying the use of digital media in the design process will be the concern of the next chapter.

# Chapter 5 Digital Media

## 5-1 Introduction

This chapter, through the captious exploration of digital media used in the design process, attempts to: 1) verify the second hypothesis (architects use certain types of digital media along the design process), and 2) achieve the second objective (articulating the various approaches and trends of digital media used along the design process).

The computer use of two-dimensional drafting tools, and three-dimensional display of objects as wire-frames was the first pattern of digital media use in the design process, which was followed in later stages by raster displays. The capability to display a shaded image, along with developments in geometric modeling[1], allowed designers/architects to visualize objects on the screen as "real". They were able to concentrate on decisions about objects rather than about drawings. This changes computer use from a tool for Aided Drafting to a medium for Aided Design. Using the computer as a tool to represent final drawings restricts its potential to the limitation of our imagining[2]. To benefit from computers and associated devices and concepts (i.e. Information Technology) is achieved by utilizing computers as media. In this way, the computer is assumed to play a role in creating an environment within which it is associated with design, by amplifying architects' capabilities and by offering unexpected results and forms.

Thus, CAD/CAM representations have gradually been moving closer to being a 'Knowledge Representation' that includes all aspects of knowledge about the designed object, for example "suitable additions would be precise part-whole relations [Winston et al, 1987], the representation of function

[1] Brown, David C., 1998, citing Mantyla, 1988.

[2] Glanville, Ranulph, 1995.

[Umeda & Tomiyama, 1997], and design rationale [Lee, 1997]"[3]. It can be stated that digital media used in the architectural design process, has switched to being rather questioning or suggesting than confirming. Their role is exploration of what is being made, rather than illustration of what has already been made.

There are many applications and techniques of using CAD/CAM in the design process which introduce remarkable contributions which could not be achieved without the use of this type of media. For example:

- **Three-Dimensional Scanning**[4]**:** Architects are enabled to scan a three-dimensional physical model to a computer model, which achieves many advantages besides saving time and effort, such as:

1- *Calculations*: complex area and volume of a physical model with unusual geometries can be calculated from a computer model. In addition, calculating surface to area ratios can determine stresses within a given material. For an example of this use, Frank Gehry's office studies his architectural forms with various skin materials until one matches Gehry's aesthetics and the engineer's approval. After capturing the study models, the information is converted into a software program called CATIA which creates a surface model for studying structural curvature[5]. In the Guggenheim Museum in Bilbao, Gehry used a titanium skin in part because it was capable of being formed to his architectural shapes and at the same time act as sheer

[3] Brown, David C., 1998.
[4] See Appendix 4.
[5] Entous, Marc, 1998, p. 212-220.

plates between steel framing behind it[6], Figure (5-1). This process would have been very difficult without using such technology.

2- *Environmental Studies of Light and Shadow*: daylight concern and shadow casting can be effectively implemented with a physical model of a complex geometry, through transferring this model to the computer. Manipulating a computer model can show what surfaces need to be reshaped in order to satisfy such environmental studies.

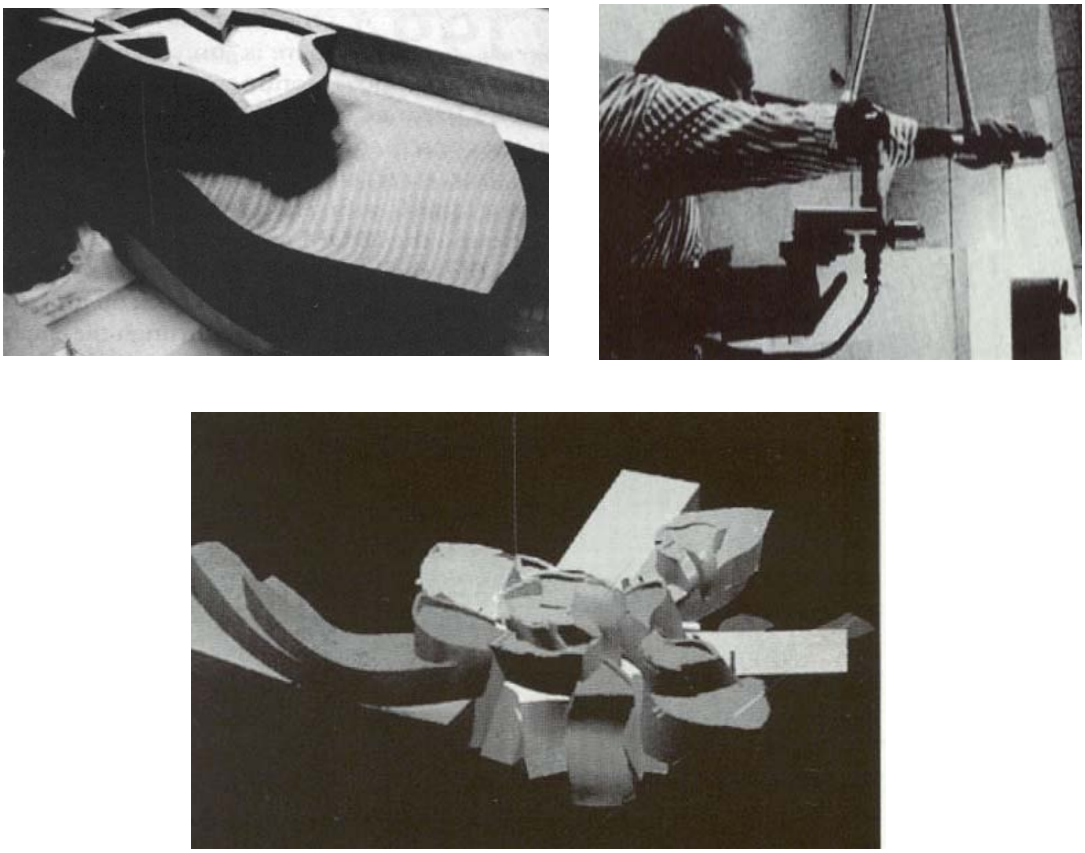


**Figure 5-1 Frank O. Gehry Associates Use Digitizer to Scan a Physical Model into a Computer Model**

a- Physical Model b- Stylus Digitizer c- Computer Model

From [Entous, 1998, p. 216-217]

[6] Stein, K. D., 1997, p. 75-87.

3- *Visualization and Morphing*: three-dimensional scanning can, also, be used in capturing an element to be used as a metaphorical geometry base for design, or in combining a series of elements into one design using morphing techniques, such as taking two or more study models and morphing the ideas together. These techniques seem to be so simple. However, the resulting idea could originate unexpected design schemes. For example[7], architect Benjamin Wood of Wood and Zapata currently uses this technique with two-dimensional images. He shows clients the transformation of an old and final design of a project, through converting two or more images and animating the transformation. This software has a very low cost compared to Gehry's software.

- **Virtual Reality:** the conventional use of VR within the design process limits its potential to be just a tool for producing such visually real images. Employing VR to perform tasks like walking through walls inside the buildings, or creating senses of texture, smell, etc., is an endeavor to simulate reality. According to William Bricken, the research director of the Human Interface Technology Lab in Seattle, this use to check out a synthesized simulacrum of reality restricts the productivity of virtual reality, instead of allowing its power to introduce realities that are not bent to make concessions to the consensus of the familiar reality[8]. The carefully guided animations by virtual reality would be more suitable for marketing, whereas the full three-dimensional models are more suitable for architects to study and develop[9], Figure (5-2). Many researchers find

[7] Entous, Marc, 1998, citing Sullivan, 1997.
[8] Glanville, R., 1995.
[9] Cheng, N., 1995.

the generation of hyper-realistic rendering-simulations usually misguided during the process of design[10].

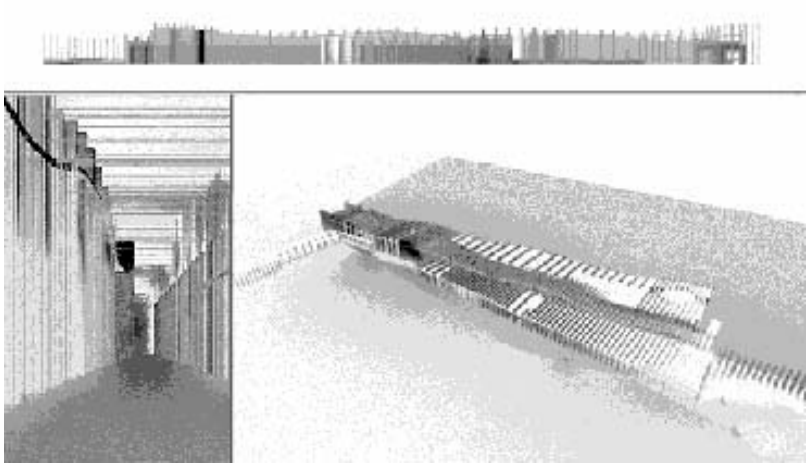


**Figure 5-2 Digital Images from Virtual Design Studio by a Student of Cheng "University of Hong Kong"**

From [Cheng, 1995 b, p.8]

To sum up, researchers have concentrated on the characteristics of each media, separated or combined together, and the techniques of interactions between analog and digital media, without much illustration of how the impact introduced by digital medium/media use affects the design capabilities of architects. As an initial step to illustrate the subject of digital media use, this chapter is concerned with the exploration and classification of the concepts and approaches of digital media used.

## 5-2 Media Repertoire

In the design process, media are the representational environments of the architects' design ideas. Media play an effective role in the process of architectural design. Moreover, the methods of media use which architects employ have an important impact not only on the way of design practice, but also on the output of design process.

[10] Bermudez, J., 1997 b, p. 57-63.

While leading the design process, the cycles of visual design thinking, previously illustrated in Figure (3-1), are characterized and marked by particular media types and sequences[11]. The various methods of representation during the design process are environments wherein architects' minds and hands fully engage in order to explore the issues of architecture. Media go beyond being just tools and techniques to compose architectural thoughts and making[12]. Using different types of media, even by one architect, affects the final product of the architectural design process. This results from the different paths that each technique/approach of media introduces.

Each medium in/by which the architect designs, has its own characteristics and idiosyncrasies. Media and thoughts, therefore, are inextricably related, as certain ideas only emerge with specific tools[13] and from individual uses.

Design is by nature a science and technology of innovation and change[14], therefore, the methods and approaches of digital media used have a direct and essential impact on the way architecture is conceived, developed, and communicated[15]. As a result, this leads to improve architects' repertoires (palettes of tools and techniques). These repertoires continually grow, develop, and evolve as architects increasingly learn by practicing design and conservatively gain experiences of media use during the process of design[16].

It can be stated that, for the design-exploration process, three-dimensional modeling is the essence of computer media while sketching is the essence of manual media. In addition, the effective use of digital media in the

[11] Kellett, R, 1996, citing Faruque, 1984; and Herbert, Daniel M., 1995, p. 21-35.

[12] DeLaura, Louis P., 1997, p. 76; McCullough, Malcolm, 1996, p. 62-64; Smulevich, Gerard, p. 148, 1997; and Bermudez J. and K. King, 1998.

[13] Cheng, Nancy, 1995 b.

[14] Bermudez, J., 1999.

[15] Bermudez J. and K. King, 1998, citing Ataman, O. 1997.

[16] Kellett, R., 1996.

architectural design process, which highly contributes to this process, results from the concepts and approaches behind this use. Thus, this part of the research is concerned with these concepts and approaches of digital media use, rather than, with the techniques of the use, although some techniques are illustrated in a summarized way, as examples for these approaches.

## 5-3 Trends and Approaches of Digital Media Use

Studies and research work should be employed, especially in the early phases of the design process, to observe and measure to what extent each innovation of digital media affects the design capabilities of architects. Such studies need cumulative, detailed, and massive efforts.

Each tool and technique, which digital media continually offer to design practice has a powerful impact on the design process and on the mental process that architects use to solve a design problem. However, the theory behind the use is the most important objective of this research. In other words, the main concern of this part of the research is to classify the different approaches and trends behind these techniques, in order to explore what are introduced to the design process, and to the design capabilities of architects.

These trends can be classified into three major classes (the two last classifications were made by the researcher): first, Media Interaction (One-Way Interactions, and Multiple Interactions); second, Digitally-Based Media (Digitally-Based Design, and Digitally-Based Form “Knowledge Based and Form-Parameter Based”); and third, Digital Knowledge through Technical Information and Visual Drawings.

### 5-3-1 Media Interaction

Employing digital media within the design process enriches the output of the process, as using both types of media: analog and digital enhances this process by benefiting from the advantages and contributions of each medium.

The use of both media is introduced through a massive array of techniques and methods, according to the fluency and creativity of the architect in utilizing each medium, and in organizing the interaction.

Many scholars of different perspectives mentioned the interaction approach of both analog and digital media being used in the design process, and emphasized its importance. According to Kellett (1996), analog and digital media will go side by side for some time to come. More explicit theoretical ideas and practices are needed for more links between them[17]. Bermudez and King (1998) believe that schools find themselves today in the odd situation of having a hybrid productive environment with little or no elaborated theory to deal with it. They add that students are generally left alone to figure out the connections between manual and digital media. This situation often produces superficial, wasteful, and frustrating use and understanding of what otherwise could be a powerful productive environment[18]. Cheng (1995) maintains that working with more than one medium allows not only the enrichment of the translating process but also the insight into the interplay of both method and content[19]. This kind of interaction acts as an extension of the architect's design thinking, not as a product of thinking[20].

The transition from analog to digital or vice versa can be simple in some cases, or complex in others as planning how to organize a computer model from a sketch design. In addition on the one side, there are low cost techniques with simple technology that are available and affordable for most architects, for example: scanners of two-dimensional images. On the other

[17] Kellett, R., 1996.

[18] Bermudez, J. and K. King, 1998.

[19] Cheng, Nancy, 1995 b.

[20] McCullough, M., 1996; Atman, Osman and Bruce Lonnman, 1996, p. 3-9; and Neiman, Bennett and J. Bermudez, 1997, p. 131-137.

side, there are high cost techniques applying sophisticated technology which is available for few architects, for example: laser scanners[21] which can scan an existing three-dimensional object or building. Cheng (1995) states that while gliding fluidly fosters spontaneity, changing between media in a more laborious way which can improve the design by encouraging reassessment[22]. When the transition is not seamless and automatic, it requires consideration of essentials. For example, this is evident in understanding structural properties, particularly instability and member sizing, of the design that developed through a digital medium.

The manipulation of representations through media interactions is more in the direction of analog to digital, not the opposite direction, i.e. scanned analog sketches, videotaped physical models, etc., whereas the other direction (an analog manipulation of digital representations) has limitations of:

- The economical inaccessibility of technology, to export electronic information out into the analog format, i.e. three-dimensional printing[23], the two-dimensional printing is excluded from this limitation[24].
- The reasonably accurate and priced three-dimensional scanning and printing with CAD/CAM based on physical models manufacturing[25].

[21] CYRA technologies of Berkeley, California has developed a laser scanner that is capable of scanning anything in its field up to 80 meters away. It creates a vector-triangulated base computer model within its own software program and can export in any of the very common file formats [Entous, 1998].

[22] Cheng, Nancy, 1995 b.

[23] Cheng, Nancy, 1995 b; and Scott, Andrew and William Michell, 1997, p. 152-153.

[24] Bermudez J. and K. King, 1998.

[25] Streich, Bernd, 1996, p. 183-190; and Bermudez J. and K. King, 1998.

In respect of the interactive applications of digital and analog media use, two major types of interaction can be identified: One-Way and Multiple Interactions.

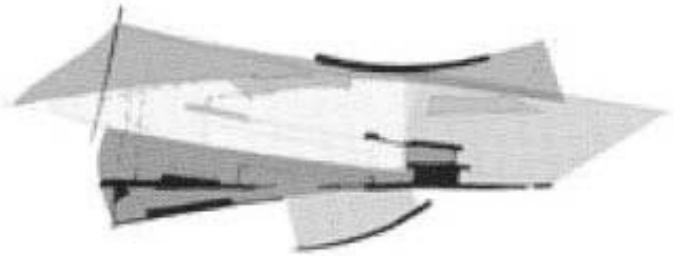
#### 5-3-1-1 One-Way Interactions

One-way interactions between analog and digital media mean that these interactions (in which the designer/architect shifts some substantial part of the design process from an analog to a digital medium, or vice versa[26]) are simple and single. For example, a shift in one direction would be at the end of the conceptual stage when a designer/architect might copy handmade conceptual sketches into a CAD program for detailed development, Figure (5-3). It could occur, also, as a shift in the opposite direction. After making three-dimensional massing studies with a computer-modeling program, a designer/architect might generate an underlay perspective print for final rendering by hand[27]. In such a case, one-time-one-way shifts close out a unit of work altogether from one medium and open it up altogether into the other[28].

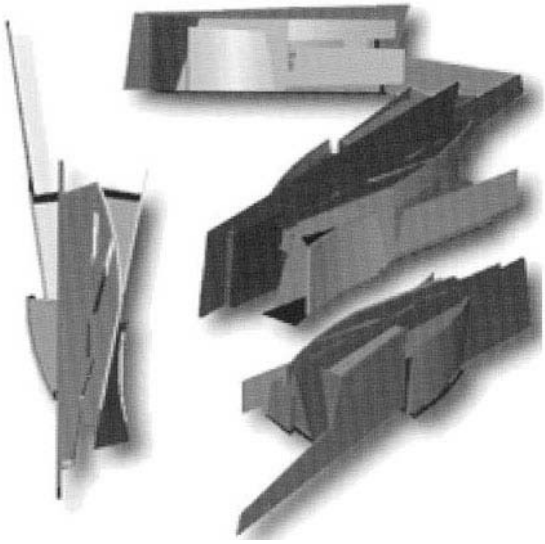
In addition, there are many other techniques emphasizing the same approach. For example:

- Scanning a freehand perspective sketch, in order to develop elevations through image editing programs,
- Digitally extruding a scanned manual sketch,
- Reforming a plan in digital media done from a video-captured (plan-view) of a three-dimensional physical model,
- Manipulating a three-dimensional image of a physical model, etc.

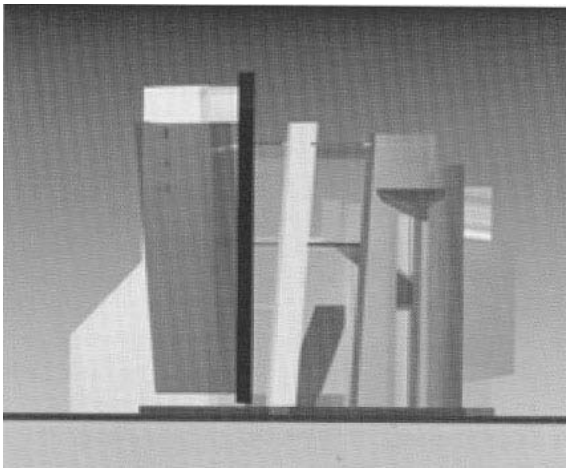
[26] Herbert, Daniel, 1995, citing Fargas, 1993 and McLeod, 1995.
[27] Herbert, Daniel, 1995, citing Danhy, 1989.
[28] Herbert, Daniel, 1995.



A Developed Plan from Free Hand Sketching



3D Digital Plans



Digital model

**Figure 5-3 A Design Developed within One Way Interaction, by Students of Bermudez.**

From [Bermudez and King, 1998, p. 21]

First step was: beginning with free hand sketching, where concepts and relationships related to lines and planes are manually synthesized. Second was: scanning the plans. Third was: importing and developing the scanned plans in CAD.

Each medium has a unique way of limiting our choices; and its influence is probably just as marked in the reciprocity between a designer and a drawing[29]. Translating a design idea from one medium to another allows the architect to reinterpret and reformulate what is in mind. This translation process leads to enhancing the potential of this particular idea in a way that could not be achieved with the use of one medium. In other words, the

[29] Frampton, Kenneth, 1980, p. 297.

process of reinterpretation and reformulation introduces new avenues obtained from the original design idea, from which the architect can develop the design scheme.

Cheng (1995) gives an example of a design developed through one-way interactions of media made by a student of hers. The design was adapted and modeled into a sculptural three-dimensional truss element. Then by digital media use, the geometry was manipulated to create a new-paired rhythm, Figure (5-4). This manipulation was made by extending the arcs of the ends of the paired trusses. The image editing programs helped in finding a new form that would have been very difficult to shape accurately in a physical model of card or wood[30]. As mentioned before, this kind of transformation requires an understanding of the structural properties (e.g. instability and member sizing) of the design. In addition, carving and gluing forms are analogous to Boolean operations, thus, working in a second medium can anchor new conventions.

Consequently, each medium (be it analog or digital) has its own praxes that another medium, even in the same category, cannot introduce to the designer/architect. For example, this is evident in the differences between three-dimensional sketching and physical modeling in analog media, or between scanning and digital captioning in digital media. Moreover, digital depictions are vivid when architects create parallels in familiar media[31].

[30] Cheng, Nancy, 1995 b.
[31] Ibid.

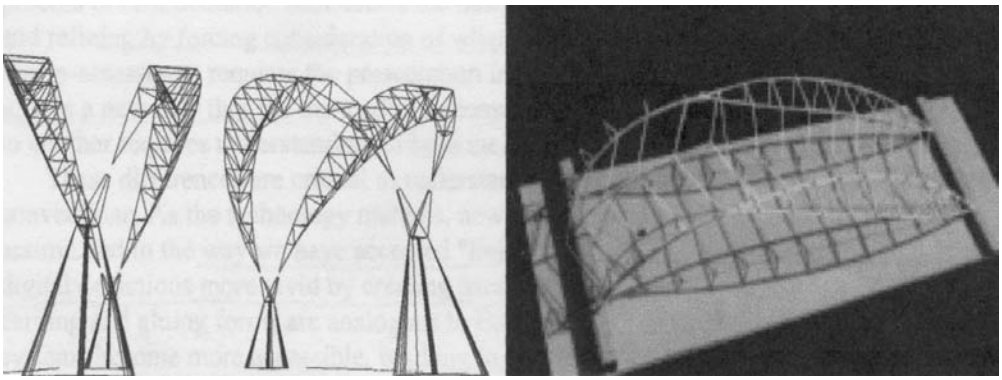


**Figure 5-4 A Design Developed within One Way Interaction, by a Student of Cheng**

From [Cheng, 1995 b, p.3]

A Digital Model "left" Was Created through a Computer Use by Manipulation of a Physical Model "right" that Was Adapted from Waterloo International Terminal

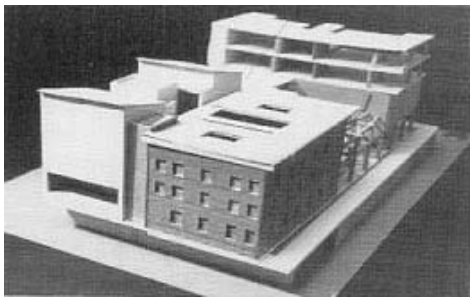
### 5-3-1-2 Multiple Interactions

The interactions of this category, between analog and digital media, are multiple, and the changes are two directional in which the architect shifts some substantial part of the design process from an analog to a digital medium and vice versa. Within this class, the computer introduces an important help in the design process, in terms of the design to be explored or imagined.

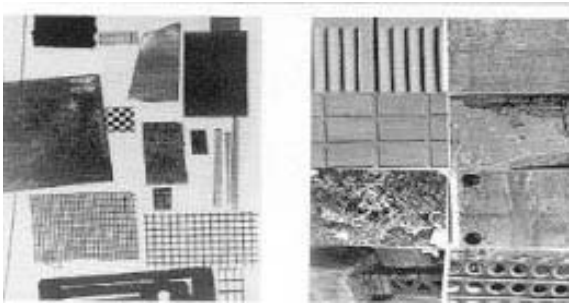
Drawing on paper or shaping physical models does not introduce the immediate feedback that comes from manipulating two- dimensional or three-dimensional drawings by a digital medium, through transformation, scaling, rotation, etc. Digital drawings allow architects to project and manipulate complex geometry in ways that would not occur if these drawings were in paper format.

Herbert (1995) considers that multiple interactions provide a supplementary approach that is qualitatively different from the foregoing shifts (one-way interactions)[32], Figure (5-5).

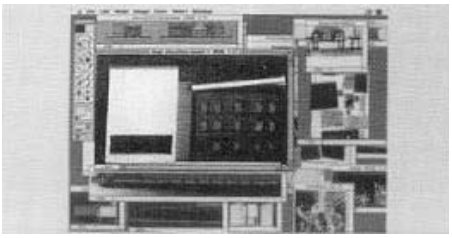
[32] Herbert, Daniel, 1995.



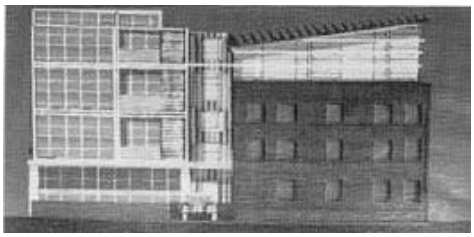
Physical Study Model



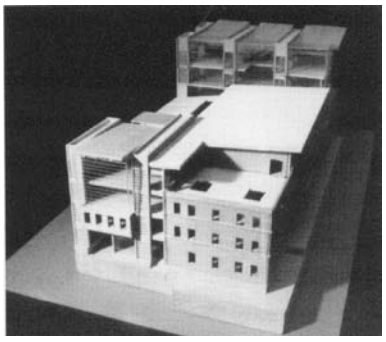
Palettes of Scanned Materials



Computer Screen with Scanned Materials



Completed Draft of Elevation by manipulation



Complete Physical Model

**Figure 5-5 Some Stages of a Design Developed within Multiple Interactions, by a Student of Herbert**

From [Herbert, 1995]

The Beginning Was a Physical Study Model. This Stage Was Followed by Scanning Palettes of Materials by Which Was the Manipulation of Facades in Digital Media. Final Step Was Making a Complete Physical Model

Herbert (1995) adds that if the study and the analysis of designers' work on projects confirm that the transitions between two dimensions and three dimensions, and vice versa (through multiple interactions), are especially creative moments within the design process, then some of the basic assumptions about computer-aided design are subject to challenge. For example, one assumption is that because buildings exist in three dimensions, the designer's work will be most effective if it is also in three dimensions.

Another assumption is that when the designer does work in two dimensions, translations into three dimensions can be best done by the computer rather than by the designer. Both assumptions may cause us to neglect important creative links in the working process[33].

New techniques of digital media, indeed, are added to and integrated with existing ones (analog and digital), where and when they add values to the design process. This would happen exactly as in the case of "facile designers cultivating an ability to switch seamlessly back and forth (in parallel, or in series) among as many techniques and media as needed, and as situations and opportunities demand"[34].

Rearticulating the design through media iterations accelerates the cycle of creation in the design process, as both reassessing and refining occur through forcing the consideration of what is essential and what is vestigial[35]. The concept of initializing ideas through drawing by hand, and then using sophisticated computer technology in later phases of the design process to promote a further understanding of the design and the form, is adapted by a number of contemporary architects whom are known as very inventive[36].

The designs of Frank Gehry and Benjamin Wood are examples of the use of the Media Interaction approach. The first uses very sophisticated software and hardware, and the second uses a simple technique. Both start the design "conceptualization and formulization phases" within analog media, and then use digital media to manipulate and explore form, in order to complete the design and to have the finial form.

[33] Herbert, Daniel, 1995.

[34] Kellett, R., 1996, p. 32.

[35] Cheng, Nancy, 1995 b.

[36] For example, Frank Gehry moves from the sketching and physical modeling at the beginning of the process to the CATIA software [Gruzdys, Sophia, 2002, p. 65-67].

### 5-3-2 Digitally-Based Media

Within this classification, the computer helps the architect by introducing a design environment wherein the design process is digitally performed. This design environment is considered more apt and powerful for exploring what is in mind. The help of this design environment, in some cases of the use, exceeds exploration to create arrays of forms and shapes from which architects develop and proceed according to design-problem context.

The concept of this category evolves from that the computational speed in creating, exploring, or manipulating three-dimensional forms suggests that architects' concerns for cumbersome manual drawing operations are no longer valid. According to Gardner (1998), these manual operations now are replaceable by interests that pursue more productive and efficacious design processes, while the computer mechanizes routine drawing tasks. Although intuition inherent in manual drawing is not a computable talent, the computing environment can substantially facilitate the intuitive database through generation and suggestion of alternatives[37].

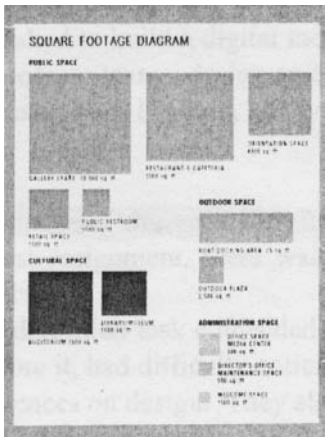
Concerning the applications and practices of the Digitally-Based Media concept during the design process, there are many approaches which can be classified into two major classifications, namely: Digitally-Based Design and Digitally-Based Form.

#### 5-3-2-1 Digitally-Based Design

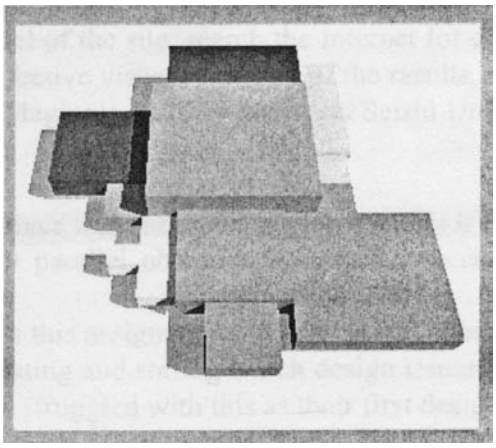
In this classification, the design is totally created in a digital environment, and basically emerges in a three-dimensional level; design ideas are germinated within the digital environment. However, conductibility of the design process, embodied in shaping concepts and forms, is within the creativeness of the architect.

[37] Gardner, Brain, 1998, p. 222-237.

The decisions architects make in Digitally-Based Design class are screen-based (on computer monitor), and without paper sketching. The design evolves from the earliest possible stage in the three-dimensional digital format and remains digital throughout the design process, Figure (5-6).




Size and Proximity



Volume and Mass

**Figure 5-6 A Design Emerged and Developed in Digital Environment, by a student of Kellett**

From [Kellett, 1996]

Spatial Requirements of Components of the Design Were Excreted from Names and Numbers of the Program "left". And then an Initial Design Was Made by Assembling the Volumes and Masses "right"

According to Marx (1998), architectural students must learn to design in digital media initially without hand sketching, as computers match more closely the formal aspirations of contemporary designers. Screen-based design gives architects the ability to design in a highly effective simulated three-dimensional environment. In formal level, the created shapes can be much more complex and dynamic[38], Figure (5-7).

[38] Marx, J., 1998.

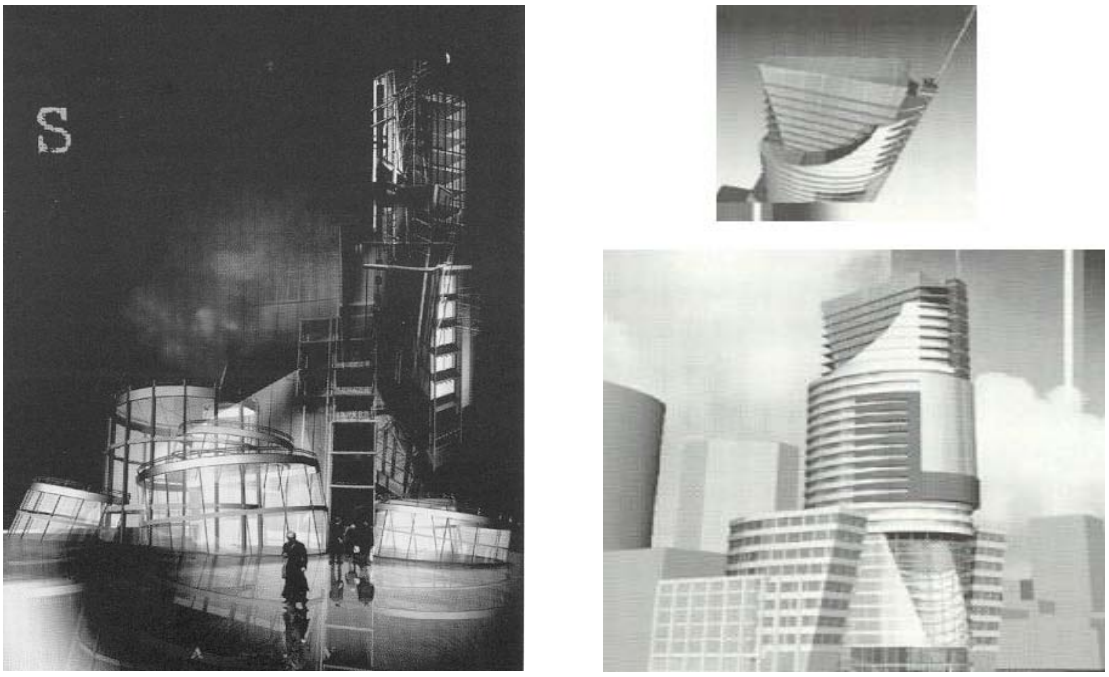


**Figure 5-7 Two Screen-Based Projects – Digitally-Based Design - by Students, Design Studio of Marx, University of California, Berkeley**

[Marx, 1998, pp. 70, 71]

The ability to predict and present a formal idea, according to the scholars who maintain the effectiveness of this class' approach, is enhanced by a Digitally-Based process because in most cases this process is quicker and more accurate than a traditional one –paper based.

## Theories Derived from the Digitally-Based Design Approach

Within the Digitally-Based Design approach, the sole use of digital media, from as early a point as possible in the design process, has resulted in the emergence of many theories that would not have been implemented without the available digital environment and its software. These theories form both of the design process and the architectural design thinking into particular paradigms. Greg Lynn (1999) puts the idea behind these theories into simple words, "it is always more interesting to begin with an inventory of what

machines want to do to us before we start asking what we desire from the machines"[39].

There are many theories developed within the Digitally-Based Design approach: the Animate Form, the Top-Down approach of design development, etc. The research illustrates the Animate Form as an example of these theories.

**1- Animate Form:** Within the Animate Form[40] of Greg Lynn[41], an object defined as a vector whose trajectory is relative to other objects, forces, fields and flows, defines form within an active space of force and motion. Entities are given vectorial properties and they are released in a space of forces, collisions and boundaries where they move in a continuum. Architectural form is conventionally conceived in a dimensional space of idealized stasis, defined by Cartesian fixed-point coordinates. The shift from a passive space of static coordinates to an active space of interactions refers a move from autonomous purity to contextual specificity. Contemporary animation and special-effects software are just now being introduced as tools for design rather than as devices for rendering, visualization and imaging.

[39] Lynn, Greg, 1999.

[40] Animation is a term that differs from, but is often confused with, motion. Where motion implies movement and action, animation suggests animalism, animism, evolution, growth, actuation, vitality and virtuality. The term virtual has recently been so debased that it often simply refers to the digital space of computer-aided design. It is often used interchangeably with the term simulation. Simulation, unlike virtuality, is not intended as a diagram for a future possible concrete assemblage but is instead a visual substitute. "Virtual reality" might describe architectural design but as it is used to describe a simulated environment it would be better replaced by "simulated reality" or "substitute reality." Thus, use of the term virtual here refers to an abstract scheme that has the possibility of becoming actualized, often in a variety of possible configurations [Lynn, 1999, p. 10-12].

[41] His research activities deal with the use of advanced Computer software for the design and documentation of buildings and with the use of Computer Numerically Controlled machines for the fabrication of building components and architectural models [http://www.verw.ethz.ch/cgi-win/whoShow.exe/ws7?ID=1033&lang=engl].

**Terms and Concepts of Animate Form:**

- Virtuality is a term used to describe the possession of force or power. Design becomes virtual when it begins to model form in association with force. As well as being defined by digital information, animation techniques model form within a virtual space of force and motion.
- The primary difference between the cinema[42] and animation paradigm is like the difference between an ideal virtuality of inertia and a vital virtuality of force. Contemporary animation uses interacting forces and vectors within an open temporal sequence rather than a sequence of key frames or cells[43]. According to Lynn (1999), "The difference between virtual movement and actual movement is critical, as the two imply very different consequences and both conceptual and methodological problems arise when these two concepts of time and force are casually exchanged… Both the processional and the sequential models of movement are instances of virtual rather than literal timing…The initial elimination of force and motion from form along with the reintroduction of motion to a sequence of static frames is the basis of both the processional and the sequential models"[44].
- "The forms of a dynamically conceived architecture may be shaped in association with virtual motion and force, Actual movement often involves a mechanical paradigm of multiple discrete positions, whereas

[42] In the cinema industry there is presently a shift occurring from a paradigm of motion pictures to special effects through animation. The virtual space of cinema is inert where the virtual space of animation is vital. Motion of animation is defined by interacting vectors that unfold in time perpetually and openly. Animation becomes the interaction and inflection of those vectors in a creative field rather than in a regimented linear sequence [Greg Lynn, 1999].

[43] Lynn, Greg, 1999, p. 10-12.

[44] Ibid.

virtual movement allows form to occupy a multiplicity of possible positions continuously with the same form”[45].

The following example Figure (5-8) will explain the foregoing concepts of the Animate Form. In a recent design of a roadside structure in Austria, in which vector-based animation software is utilized, to develop its architecture, by Greg Lynn of FORM, Michael McInturf Architects, and Martin Treberspurg, the architects began with the commissioner’s logo (a triangular symbol), which they made dimensional by projecting its "depth." Already the choice to begin with a two-dimensional representation of corporate embodiment inverts the conventional trajectory of identity architecture where the building becomes a corporate symbol (e.g., the Transamerica building in San Francisco). Within another phase of the process these forms are projected as a skeletal system anticipating its sitting along a highway. Here, the motion of the passing automobile becomes a force in the development of the structure’s rhythmic sequential intervals. These structures are then wrapped with surfaces and subjected to a de-formation process. In this project, multiple segments of like but differentiated shape are held within the continuity of an unfolding, animated sequence. Architectural form is derived within a fluid and temporal digital medium and anticipates its animated and dynamic life in physical form.

[45] Ibid.

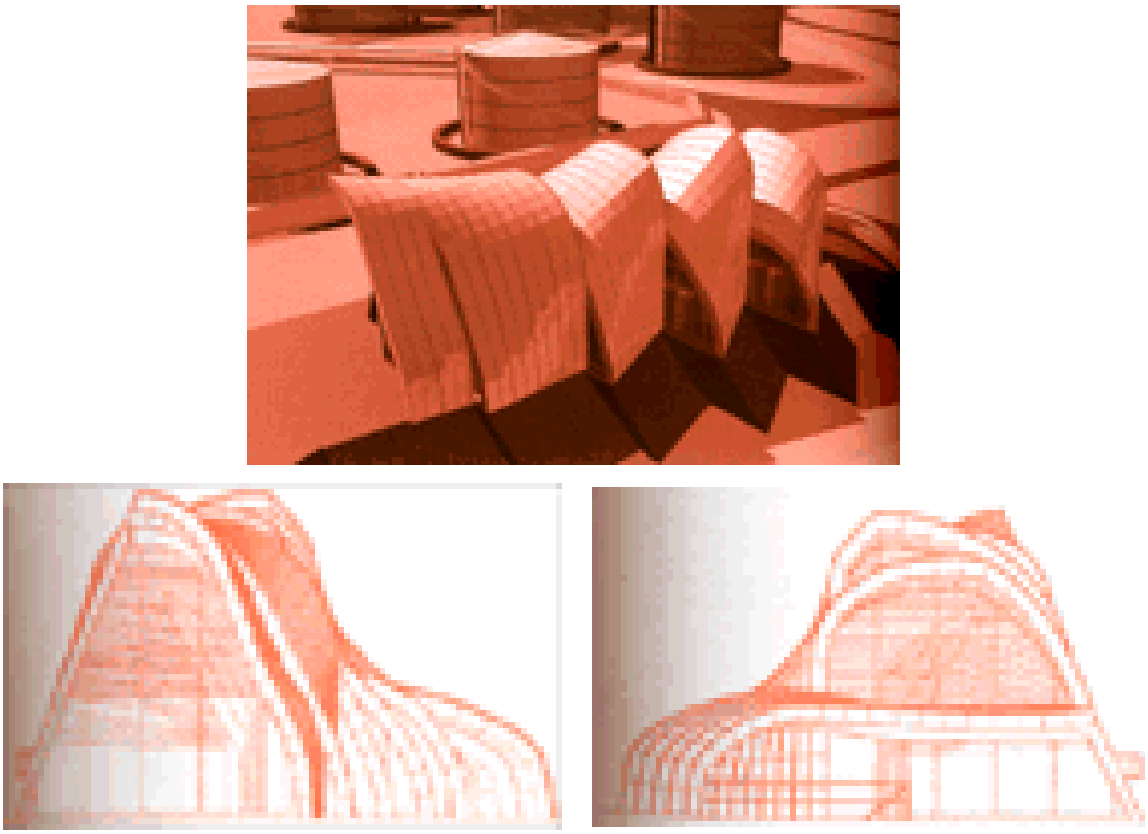
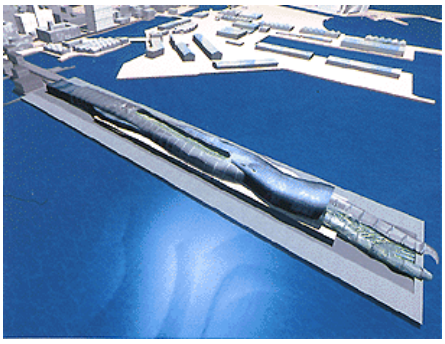


**Figure 5-8 H2 House, Schwechat, Austria. By Greg Lynn FORM, Michael McInturf Architects, and Martin Treberspurg**

From [http://www.walkerart.org/salons/shockoftheview/space/sv_space_r.html]

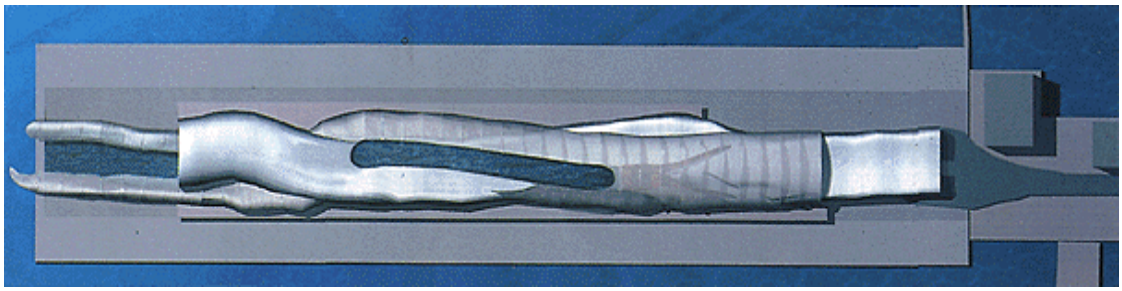
In summary, the main concept of the Animate Form approach can be described as: instead of a neutral abstract space for design, the context for design becomes an active abstract space that directs form within a current of forces that can be stored as information in the shape of the form, Figure (5-9) and Figure (5-10).

In addition to the special effects and animation industries, many other disciplines, such as aeronautical design, naval design, and automobile design, employ this animate approach to modeling form in a space that is a medium of movement and force.



a- Aerial Perspective

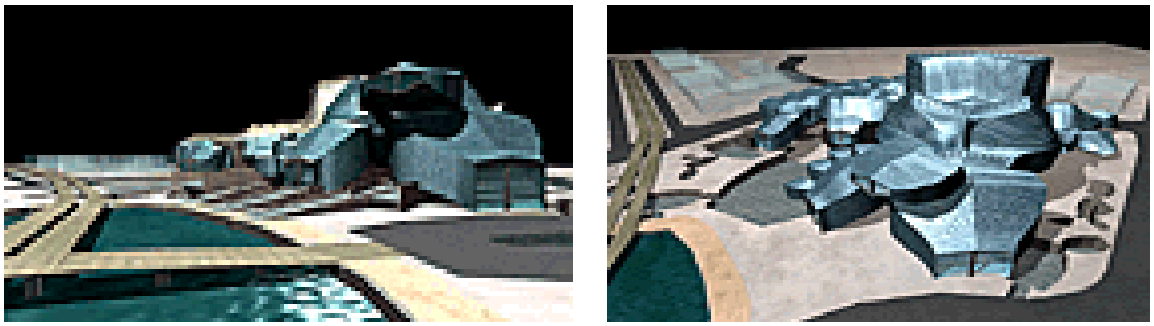
b- Longitudinal Elevation



c- Roof Plan

**Figure 5-9 Yokohama Port Project, by Greg Lynn**

From [http://www.archforum.com/main/korea/architect/n_go/5/1greg.html]



A Digital Model of the Site of the Welsh National Opera House on the Inner Harbor of Cardiff Bay

**Figure 5-10 Cardiff Bay Opera House, by Greg Lynn**

From [http://www.basilisk.com/C/CARDIFF_608.html]

2- **Top-Down Design:** Within this concept, design starts with a complete form, and then breaks down into smaller and smaller components. Top-Down Design is a method of design in which the designer solves a problem by assuming that some sub-problems have been solved, as a common way of problem solving is to break the problem down into conceptually simpler sub-problems (and so on). Eventually the sub-problems are so small that they can be solved. Designing the form, within this concept, is like sculpturing. The designer begins with the whole form, and then goes into smaller details, by adding or subtracting components to/from this form. Digital media and image editing programs help architects employ such method of the architectural design.

In principle, Top-Down Design involves starting at the uppermost components in the hierarchy and working down the hierarchy level by level. In practice, architectural design is never truly top-down, as some components are designed before others. Designers reuse experience (and sometimes components) during this paradigm of the design process.

As a result of the powerful use of digital media and the available software, architects utilize the foregoing concepts in the design process which are derived from computer programming science. Conceptualization and formulization used in the Digitally-Based Design approach would be very difficult to implement without the technology used in digital media. Although concepts and forms are initially shaped by architects, forms have more importance, and their developments are derived within the powerful use of digital media. This gives formulization the priority over many important issues that architecture should be concerned with, such as environmental, social, economic, etc.

### 5-3-2-2 Digitally-Based Form

The use of the software of digital media within this class creates forms and shapes according to the ambit of design problem, in terms of some constraints to be satisfied. From an array of the created forms and shapes, either the architect selects to develop and proceed on the process of design, or computation excites this episode instead of the architect. Through formalization provided by the software, the digital environment initializes the first step of design. Consequently, after executing formalization, germinating design ideas and constructing concepts come, after allowing formalization to basically play the influential part in shaping the design, because the influence of the first arrangement of the design problem solution is usually long lasting and has high effectiveness.

The concept of this class is derived from the fact that the ability to generate and present a form is enhanced by computation, and as a result, formalization should be translated to be performed by the computer. Computer is used, within this class, to generate forms and shapes through many approaches, such as: Artificial Intelligence, Genetic Algorithms, Shape Grammar, Algorithmic Design, and Generative System. The generative processes of these approaches and their techniques lead to the generation of forms, where architects have no control over the development of these forms. By using procedures - not necessarily precise, and possibly as complex in their interaction as to be, in principle, undeterminable - computers (metaphorically) propose architectures of their own[46].

[46] Glanville, R., 1995.

## Theories Derived from the Digitally-Based Form Approach

There are two main concepts and theories of the Digitally-Based Form approach, within which form generation is computationally pursued through a diverse set of techniques. These concepts are Knowledge Based and Form-Parameter Based:

### 1- Knowledge Based

Simulations of value reasoning may reveal the suitability of designs; this is the inherent implication in systems derived from the Knowledge Based concept. Form generators force the outputs of the formal production algorithms to be strictly result-based solutions, through conforming the chosen parameters emphasized by the software that leads processing. There are many challenging issues fraught with contentious and subjective questions. These issues evolve from emphasizing form suggestiveness in immaterial areas, such as social perception, creative content, etc.[47]

#### Implementation of the Knowledge Based Concept

Artificial Intelligence applications basically represent examples of the Knowledge Based concept. In Artificial Intelligence[48], algorithms and software computationally produce a model of designing using situated processes in order to simulate what occur of consequential actions of design during the design process. Many researchers maintain the computational capability of performing this kind of processes: computational processes already exist for the perception of figures and gestalts[49], the appreciation of qualities[50], and the capability of recognizing

[47] McLaughlin, S., 1993; and Gardner, B., 1998, citing Schön and Wiggins, 1992.

[48] See Appendix 5.

[49] Gero, J. and M. Yan, 1994.

[50] Soufi, Bassel and Ernest Edmonds, 1995; and Reffat, R. and J. Gero, 1998.

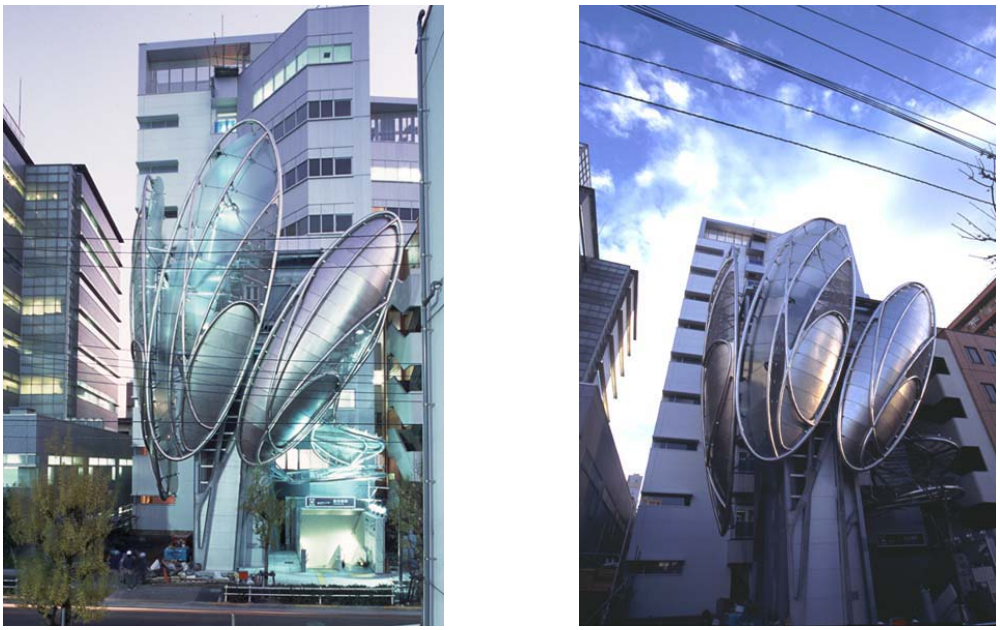
unintended consequences of actions[51]. For example, Gero and Saunders present a computational model of designing using situated processes that construct representations[52].

As another example is the Induction Design of Watanabe[53] where computer programs generate architecture and proposals by solving conditions. The purpose is not to discover form, but rather to discover ways of making architecture that provide better solutions to design problems while at the same time offering greater freedom to the imagination. In this sense, artificial life, genetic algorithms, and neural network programs can also contribute, so that it could be called Induction Design, Generative Design, since it is born from conditions, or evolutionary Design, since it has the characteristic that results improve over generations. The Complexity science has discovered simple principles hidden within what appears to be utter disorder[54]; this is a generator of this concept of Induction Design, Figure (5-11).

In spite of what has been accomplished in the areas of human mental simulation, research still partially (not completely) introduce steps for the simulation of human mental processing during designing. The full simulation of human mental processing, especially in immaterial areas, requires underlying algorithms of very high level of complexity to be implemented. The use of AI to handle large design problems has been criticized as being too computationally expensive, and as not being a good model of human thought, in spite of research attempting to address this by

[51] Gero J. and R. Saunders, 2000, p. 215-224.
[52] Ibid.
[53] Watanabe, M., 2002, p. 5-10.
[54] Watanabe, M., 2002.

grouping constraints and by organizing them hierarchically[55]. It can be stated that logical processes of computation that portend to facilitate conceptual design process can never replicate the designer's experiential world[56], without major limitations (e.g. in complexity level, in cost, etc).



Instead of Joining pillars and forms, the material extends, separates, rejoins, and forms a single overall frame without distinctions between verticals and horizontals

**Figure 5-11 Lidabahi Subway Station, wing, Tokyo by Makoto Watanabe**

From [http://www.makoto-architect.com/subway/syb_e.htm]

## 2- Form-Parameter Based

The implication of this concept is worked within the context of the more generalized, but formally explicit, shape grammars (emanations of architectural form). Contrary to the systems of the Knowledge Based concept, the systems of the Form-Parameter Based concept leave issues such as content, interpretation, resolution, and form suggestiveness, for architects to perform, as computation does not try to implement them. In some

[55] Brown, D., 1998.

[56] Gardner, B., 1998.

techniques (systems) derived from this concept, one or more contextual parameter specified by the architect/programmer may be used to produce the output paradigm which can be repeated responding to other chosen parameters. These suppositional paradigms find their definition in various prototypical visual design precepts of geometry, such as scale, proportion, order, adjacency and rhythm.

**a- Implementation of the Form-Parameter Based Concept**

Genetic Algorithms, Shape Grammar, Algorithmic Design, and Generative System are implementations of the Form-Parameter Based concept.

- Genetic Algorithms[57] allow artificial variety of form generation and its consequent space. Some of the procedures introduce media in such a way that allows the architect to interact with a form-growing algorithm in real time, through the application of developing rules[58].
- In Shape Grammar[59], rules set the conceptual foundation for constructing the software of form generating algorithms. Growth algorithms implement parametric production rules which control the operations of generating intermediate and final forms[60].
- Generative System[61] can be represented by a state-action graph in which each vertex represents a potential state of the system and each edge is an operation that changes the state of the system. Mitchell (1977) gives a simple example of a generative system, which is the design of a window consisting of five essential elements. Each element

[57] See Appendix 6.
[58] Glanville, R., 1995.
[59] See Appendix 7.
[60] Gardner, B., 1998.
[61] See Appendix 8.

of the design has several valid alternatives. A potential design is generated by drawing a line through one alternative in each row[62].

- In Algorithmic Design, the aim is to create and define algorithmic procedures which will generate building solutions to well-defined problems which satisfy the creator of the algorithms as being acceptable architectural responses, even as being solutions of these procedures[63].

**b- Techniques of the Form-Parameter Based Concept**

There are many techniques which demonstrate the software designed as a strictly formalistic tool to suggest arrays of form in design, by which the role of computer is accentuated as a form generator. The research gives an example of these techniques, the Grid Sketcher of Gardner:

- Within the Grid Sketcher, the computer, under the influence of certain contextual parameters, can introduce an array of forms that respond through algorithmics to the architect's creative intents. The following describe the algorithmic processes of Grid Sketcher: 1) shape grammars concept, formal production algorithms, 2) grids as fundamental space organizing schemata, 3) the distributive influence of randomization, 4) layering as combinatorial processes, and 5) the five formal production, or growth, algorithms; each of these algorithms (edges, corners, faces, stacks, and slopes composite) responds uniquely to the system's random variable. Avoiding Knowledge Based activities and leaving contextual evaluations to the architect, the Grid Sketcher intends to mimic the processes associated with pencil and sketch paper the architect uses in early design explorations. The Grid Sketcher uses the power environment of

[62] Mitchell, William J., 1977.
[63] Glanville, R., 1995.

AutoCAD. Using a complete set of production rules, the algorithm iteratively constructs a composite form by invoking the rules, one for each growth unit, in sequence until the formal composition is complete[64], Figure (5-11).

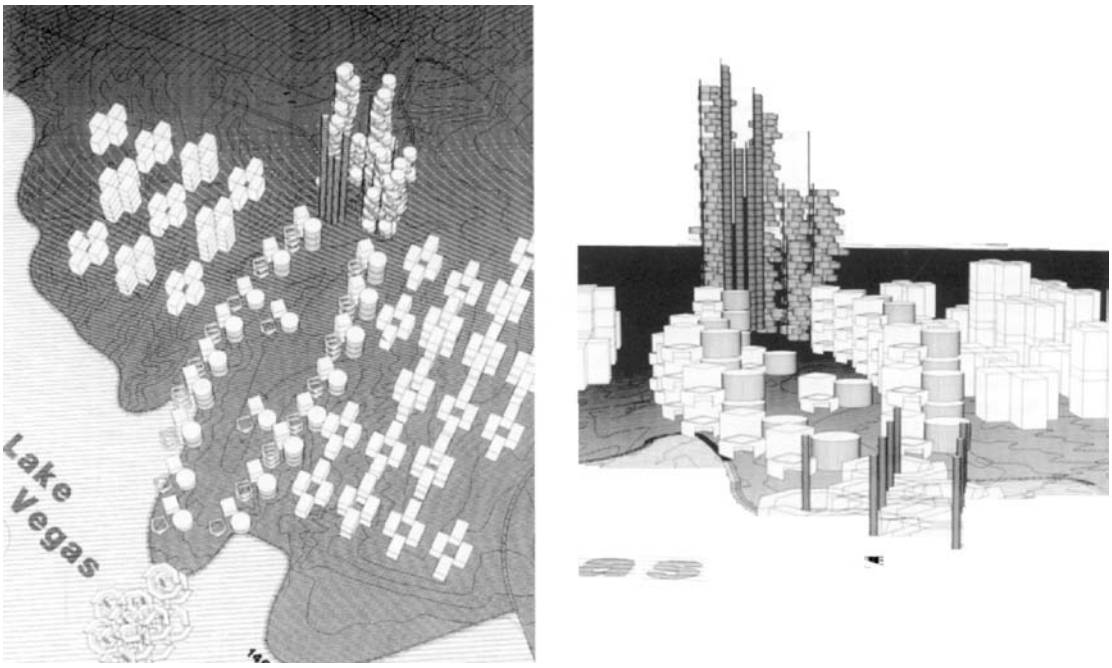



**Figure 5-12 Formal Composition through the Algorithms of Grid Sketcher, Imported to AutoCAD by Gardner**

From [Gardner, B., 1998, p. 235]

Shaping form as an initial step of solving a design problem gives formulization the priority over many important issues that architecture should be concerned with, such as environmental, social, economic, etc. This concept shapes the design process in a certain paradigm, as the role of the Conceptualization capability is not a source of form generation, but rather a scale of form suggestiveness.

### 5-3-3 Digital Knowledge through Technical Information and Visual Drawings

[64] Gardner, B., 1998.

The role of computer in this class is an indirect assistance to the architect through introducing a wide stream of database from which the architect utilizes what relates to the design. This assistance comes in two different types: 1) Technical Information, through the exposure to knowledge, e. g. in some cases of designing a novel type or model, the architect does not know the detailed data about it or its components. The architect obtains the related information about this particular case of design from digital references. 2) Visual Drawings, through the exposure to the drawings of design precedents, e.g. in some cases, the architect partially extracts concepts and forms from the drawings of previous designs that are related to the design problem at hand.

Accounts of creative architectural design often mention natural and artificial objects as sources of architectural form. For example, Le Corbusier wrote, "the shell of a crab picked up on Long Island in 1946 is lying on my drawing board. It will become the roof of the chapel"[65]. Moreover, studies of design method and process often identify visual analogy, metaphor, and visual reference as important activities in creative designing[66].

Although the two types of use, the technical information and visual drawings, are related and introduced together, the role of computer is more prominent in the visual drawings one, through the massive move that is achieved when digital references are employed in such use. Common references like books still play a part in this episode of the design process, especially in the use of technical information. However, research concentrated on connecting digital database to architecture, introduces conspicuous help to architects, i.e. on-line libraries of architectural drawings.

[65] Do, Ellen and M. Gross, 1995, citing Le Corbusier, 1957.

[66] Broadbent, G., 1973; Lawson, B., 1980; and Antoniades, A. C., 1990.

Within this class, the use of computer in a broad sense is as a tool for researching in specialty areas which architects are concerned with during the design process (such as: environmental issues, history, etc.). According to Ozel (1997), the use of design knowledge through the use of computers is revolutionizing the way architects access and use information (in both technical information and visual drawings). Furthermore, the use of design knowledge can be greatly affected by how this knowledge is represented, modeled, and presented to the architect[67]. The databases of Digital Knowledge can be indexed, in image or text format, according to specific information, such as architect, date, place, and function or type of design.

This class has not fully crystallized for architects' use yet, as massive work still has to be done in order to digitalize all the technical information and visual drawings that may be used in the architectural design process. Prominent examples of this class' use have been developed for teaching in architecture:

- ArchWAIS, a Multimedia Based Architectural Information System for Teaching and Learning History and Theory, by Choi, J. W.;
- Architectural Courseware, a Network Based Multimedia System for Design Education, by Tector, J. and Thornhill, C.;
- DOORS, Design Oriented On-line Resource System, by Sklar, H.;
- SPIRO, Slide Library Image Database at UC Berkeley, http://www.mip.berkely.edu;
- Buildings Collection, http://www.greatbuildings.com/.

The classifications of these databases, which use keywords in queries, are via hard coded links, e.g. classifying a building with others by the same architect,

[67] Ozel, Filiz, 1997, p. 37-49.

or a plan of a building with photographs and other drawings[68]. This enables architects to search using queries formed by keyword contents.

Research work in such field is going further than this stage, as Do and Gross, by their Drawing Analogies technique, maintain that these queries can be posed including a sketch or diagram instead of keywords[69]; and Ozel, by DesignRep, introduces a computer assisted learning system model which uses abstraction and analogies to analyze a design precedent (i.e. past cases). The aim is to build a problem or sub-problem hierarchy of this precedent's problem solving stages, to be used in a similar design-problem. This is done by identifying goals, constraints and solutions for each level of precedent hierarchy[70].

## 5-4 Conclusion of the Chapter

1- The chapter has: 1) verified the second hypothesis, that is architects use certain types of digital media along the design process, and 2) achieved the second objective, that is articulating the various approaches and trends of digital media used along the design process.

2- Computer use has been changed from a tool for Aided Drafting to a medium for Aided Design. Digital media use in the architectural design process, has been switched to be questioning or suggesting, not confirming. Their role is exploration of what is being made, rather than illustration of what has been already made.

3- Media and visual design thinking are inextricably related, for certain ideas only emerge with specific tools and from individual uses. It can be stated that, for the design-exploration process, three-dimensional modeling is the

[68] Do, Ellen and M. Gross, 1995.
[69] Ibid.
[70] Ozel, Filiz, 1997.

essence of computer media while sketching is the essence of manual media.

4- According to the fluency and creativity of the architect in utilizing each medium, and in organizing the interaction of media, the interactive use of analog and digital media introduces a massive array of techniques and methods.

5- The trends and concepts behind the use of digital media in the architectural design process can be classified into three major classes (the last two were classified by the researcher): first, Media Interaction (One-Way Interactions, and Multiple Interactions); second, Digitally-Based Media (Digitally-Based Design, and Digitally-Based Form "Knowledge Based and Form-Parameter Based"); and third, Digital Knowledge through Technical Information and Visual Drawings.

**a- Media Interaction** (One-Way Interactions and Multiple Interactions):

- The transition from analog to digital, or vice versa, results in generating new ideas and unexpected forms, which would have been very difficult to project and manipulate if they were in paper format.
- The manipulation of representations through media interactions is more in the direction of analog to digital, whereas the other direction has limitations.
- The designs of Frank Gehry and Benjamin Wood are examples of the use of the Media Interaction approach. The first uses very sophisticated software and hardware which is unaffordable for many architects, and the second uses a simple technique that is more available for most architects. Both start the design "conceptualization and formulization" within analog media, and

then use digital media to manipulate and explore form, in order to complete the design and to have the finial form.

**b- Digitally-Based Media** (Digitally-Based Design, and Digitally-Based Form): Within this concept, the computer introduces a design environment wherein the design process is digitally performed. The help of this design environment, in some cases of the use, exceeds exploration to create arrays of forms and shapes from which architects develop and proceed with the design.

* **Digitally-Based Design**, the design evolves from the earliest possible stage in the three-dimensional digital format and remains digital through out the design process:

- Screen-based design gives architects the ability to design in a highly effective simulated three-dimensional environment. In formal level, the created shapes can be more complex and dynamic.
- Within the approach of Digitally-Based Design, the sole use of digital media has resulted in the emergence of many theories which would not have been implemented without the available digital environment and its software, for example: the Animate Form of Greg Lynn.
- Conceptualization and formulization used in the design theories of the Digitally-Based Design approach would have been very difficult to implement without the technology used in digital media.
- Although concepts and forms are initially shaped by architects, forms have more importance and their developments are derived within the powerful use of digital media. This gives formulization

the priority over many important issues that architecture should be concerned with, such as environmental, social, economic, etc.

* **Digitally-Based Form**, the use of the software within this class creates forms and shapes, in terms of some constraints to be satisfied. From an array of the created forms and shapes, either the architect selects to develop and proceed on the process of design, or computation executes this episode instead of the architect.

  There are two main concepts and theories of the Digitally-Based Form approach, within which form generation is computationally pursued through a diverse set of techniques, namely, Knowledge Based, and Form-Parameter Based.

  - Knowledge Based: Algorithms and software computationally produce a model of designing using situated processes in order to simulate what occur of the consequential actions of design during the design process. Systems of Artificial Intelligence represent examples of the Knowledge Based concept.

  - Regardless of what has been accomplished within this concept, the full computational simulation of conceptual design process can never replicate the designer's experiential world, especially in immaterial arenas without major limitations (e.g. in complexity level, in cost, etc.).

  - Form-Parameter Based: Contrary to the systems of the Knowledge Based concept, the systems of the Form-Parameter Based concept leave issues such as content, interpretation, resolution, and form suggestiveness, for architects to perform, as computation does not try to implement them. Genetic Algorithms, Shape Grammar,

Algorithmic Design, and Generative System are implementations of the Form-Parameter Based concept.

- The computer, under the influence of certain contextual parameters, can introduce an array of forms that respond through algorithmics to the creative intents of architects. The paradigms of these contextual parameters find their definition in various prototypical visual design precepts of geometry, such as scale, proportion, order, adjacency, and rhythm.
- Consequently, formulization has the priority over many important issues, such as environmental, social, economic, etc. The role of the Conceptualization capability, within this concept, is not a mainstream of form generation but rather a scale of form suggestiveness.

**c- Digital Knowledge through Technical Information and Visual Drawings**: The role of computer in this class is an indirect assistance to the architect, through two different types: 1) Technical Information, by introducing the information of a particular design case that is related to the design problem at hand. 2) Visual Drawings, through the exposure to the drawings of the precedents from which concepts and forms can be partially extracted.

After the discussion of digital media used in the design process through what each concept introduces to the design process, the next chapter is concerned with the impact of digital media use on the design capabilities of architects.

# Chapter 6 Digital Media and Architectural Design Capabilities

## 6-1 Introduction

In general, the culture of today turns from the corporeal to the informational, or from reality to virtuality[1]; this is the generative concept of digitalizing trends in all areas of our life (not only architecture). Therefore, the theory behind digital media used in the architectural design process can be related to two main generators: 1) the rising forces that drive contemporary civilization and profession, for example: information technologies, post-industrial society, etc.[2], and 2) the opportunities that digital media introduce to the design process.

This part of the research attempts to: 1) verify the third hypothesis (the nature of the impact of digital media on the design capabilities of architects varies according to the design capability and the type of media use), and 2) achieve the third objective (exploring the impact of digital media on the design capabilities of architects). This attempt will be through exploring positive or negative areas of impact on the design capabilities of architects, which are introduced by the various settings of the use of digital media. To achieve this, a two-fold methodology is applied:

1- Extracting this impact from the synthesis of previous research in related areas, most of which have been previously discussed in the fifth chapter. This methodology overcomes obstacles resulting from the fact that some concepts of media use are not available for many architects to employ because of the cost (of the sophisticated software or hardware), or because of the relation to computer science (which requires a programming background to benefit from).

[1] Bermudez, Julio, 1997 a, p. 520-523.

[2] Lange, Karen, 1997, p. 524-528; and McCullough, 1996.

2- Assessing the impact by surveying a sample of experts and professional architects. The impact in this case is according to the vision of the respondents.

The potential of digital media opens up new possibilities beyond the limited ones derived from analog media. The most significant advances of digital media are acknowledged, when designs which architects produce exceed their expectation, and even imagining. The use of digital media proceeds beyond amplifying and speeding up the design capabilities of architects, to contribute in design activities as partners. In other words, this role helps the process of form generation by shaping forms.

## 6-2 Digital Media Impact on the Architectural Design Capabilities

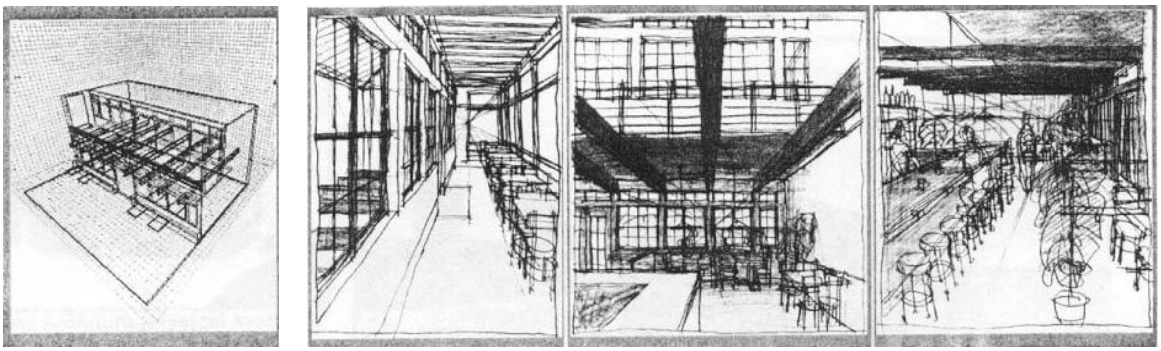
The use of digital media continues to replace the traditional practices of the architectural design process. This process of replacement began with drafting, image processing, and rendering, and now exceeds that to three-dimensional modeling, animation, interactivity, and multimedia. At the end of this process, traditional practices will survive only in those areas where the new techniques of digital media cannot outperform them[3], if there are any such areas, as many scholars and architects maintain, e.g. Marx[4], Lynn[5], etc. Regardless of these different trends, the use of digital media reshapes what architects do during designing.

This chapter is concerned with the impact of media on each design capability of architects:

[3] Bermudez, Julio, 1997 a, p. 520-523.
[4] Marx, J., 1998.
[5] Lynn, G., 1999.

### 6-2-1 The Impact on the Conceptualization Capability

Design ideas are intuitive, at times irrational, and rarely follow consistently identifiable patterns[6]. Initializing design ideas, inquiring into them freely, developing what are potentially suggestive, and stimulating imagination regarding modification of these ideas, all these tasks of conceptualization and problem definition are more close to the nature of manual media, Figure (6-1). Manual drawing has the flexibility that allows architects to start without having a certain idea. Conversely, computing requires predictability in these endeavors, or does not have at the very least, a similar nature to manual drawing. However, the transformation and exploration of tentative forms within the ability of digital media, such as scale, move, rotate, etc. introduce a remarkable help in such area.



I Hour CAD Model 10-20 Minute Sketches

**Figure 6-1 The Flexibility in Using Manual Media to Initialize Ideas, from the Work of Students of Kellett**

From [Kellett, 1996, p. 38]

#### 6-2-1-1 Extracting the Impact from Previous Research

In Conceptualization tasks, architects generate many kinds of artifacts which represent their design ideas in the both types of media, through a heterogeneous mix of sketches, models, and rendering, in terms of not only exploring and conceiving these design ideas, but also in terms of having a

[6] Gardner, B., 1998.

design problem in a more defined form. To modify the forms of these design ideas, architects may employ the powerful use of digital media, for example, in massing studies and their dimensions before these masses have final specified dimensions, etc.

The primary responsibility of the creation of conceptual frameworks lies on architects; in this particular of shaping concepts and defining the design problem, digital media use helps in different ways, according to the use of concepts which were discussed in the previous chapter:

**1) Media Interaction Concept**

Within this concept, tasks of Conceptualization capability are initially performed in manual media; the use of digital media helps in somewhat later phases of the design process. Many scholars and architects assert the effectiveness of this use (for example, Kellett, Cheng, Johnson, Bermudez and king, Gehry, and Wood, as mentioned previously), as "CAD drawings force a precision in defining geometry, and require an abstract understanding of design organization"[7].

A prominent portion of the architect's design thinking which takes part in formalizing concepts during the process of design, is the traditional concerns towards issues of program, such as physical and social context, and environmental requirements. There is a controversy (contradicting evidence) regarding how the use of digital-manual media interaction affects the nature of design content which may be represented in roles and tasks of concepts, and streams of concepts' emergence:

[7] Cheng, Nancy, 1995 a, citing McLuhan, 1964.

- According to Herbert (1995), media interactions do not necessarily displace the concerns of architects towards other important issues other than form[8].
- Bermudez and King (1998) maintain that producing high levels of design associated with form, space, technology, and materiality by the strong capability of digital media through the Media Interaction concept, decreases the attention to social, contextual, and programmatic aspects of buildings. Digital depictions begin to bias the design process towards an aesthetic formalism[9].

**2) Digitally-Based Media Concept**

The two concepts classified into the Digitally-Based Media are:

**a) Digitally-Based Design**

In spite of what has been said of the negative impact of digital media use on the Conceptualization capability regarding design content, many scholars and distinguished architects maintain the effectiveness of Digitally-Based Design "screen-based" (for example, Marx, Lynn, as mentioned previously).

The powerful use of digital media enables architects to:

- perform the tasks and roles of Conceptualization by exploring and developing their design ideas which emerge from various streams,
- employ conceptual frameworks and concepts which would not be possible to implement through manual media use. These concepts are related to formalization rather than to other immaterial issues of design.

[8] Herbert, Daniel, 1995, citing Herbert, 1994.

[9] Bermudez J. and K. King, 1998.

Conceptualization capability, within this concept, begins to be concerned more with an aesthetic formalism, such as the Form Z look, the three-dimensional Studio look, the three-dimensional nature, etc.

**b) Digitally-Based Form**

Within the two concepts of Digitally-Based Form (Knowledge Based and Form-Parameter Based), form evolves according to some specified parameters which at the very least do not cover all the immaterial issues related to the design problem. The Conceptualization process, therefore, does not have the main role in guiding the initial phases of problem solving and form generation.

In general, the role of digital media is limited to helping the Conceptualization capability by introducing the generated array of created forms, rather than by constructing concepts or exploring design ideas. The design process has a particular model in which form is generated without the overall effect of immaterial issues of the design-problem context. Consequently, the role of some Conceptualization tasks in initial design phases, which share in form generation and in form evaluation, is postponed to affect in later stages after form generation.

**3) Digital Knowledge through Visual Drawings and Technical Information**

This concept of digital media use introduces knowledge related to the design problem at hand, in drawing format or text format, from which architects can adapt and adopt concepts.

Table (6-1) summarizes the overall impact of various concepts of digital media use on the Conceptualization capability, extracted from previous research in related areas which is collected, analyzed, and synthesized in the forth and fifth chapters.

**Table 6-1 The Extracted Impact of the Concepts of Digital Media Use on the Conceptualization Capability**

| Areas of the Design Capability Exposed to Impact / Various Concepts of Digital Media Use | | Media Interaction | Digitally-Based Media | | | Digital Knowledge through Visual Drawings and Technical Information |
|---|---|---|---|---|---|---|
| | | | Digitally-Based Design | Digitally-Based Form | | |
| | | | | Knowledge Based | Form Parameter Based | |
| Streams of Concepts' Emergence | Context of Design Problem | Positive Impact | Positive Impact | Negative Impact | Negative Impact | No Impact |
| | Individual Interpretation | Positive Impact | Positive Impact | No Impact | No Impact | No Impact |
| | A Priori Use of Similar Model of a Design Problem | Medium Impact | No Impact | No Impact | No Impact | Positive Impact |
| | Multiple Sources | Positive Impact | Positive Impact | No Impact | No Impact | Positive Impact |
| Roles and Tasks of Concepts | Defining and Exploring the Design Problem | Positive Impact | Positive Impact | Negative Impact | Negative Impact | No Impact |
| | Constructing Organizational Rules | Positive Impact | Positive Impact | Negative Impact | Medium or Negative Impact | Medium Impact |
| | Evaluating the Proposed Solutions | Positive Impact | Positive Impact | No Impact | No Impact | No Impact |

### 6-2-1-2 Assessing the Impact from the Results of the Questionnaire

Table (6-2) and Figure (6-2) summarize the results of the survey in a comparative way; the columns represent various media settings while rows represent the various impact levels of each setting as surveyed by respondents.

**Table 6-2 Comparison of the Impact of Various Digital and Manual Media Settings on the Conceptualization Capability of Architects**

| Impact Level \ Media Setting | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
|---|---|---|---|---|
| Very High Impact | 36.4% | 8.93% | 24.5% | 26.78% |
| High Impact | 9.1% | 17.86% | 24.5% | 37.5% |
| Medium Impact | 9.0% | 25.0% | 20.4% | 0.0% |
| Little Impact | 27.3% | 30.35% | 10.2% | 17.86% |
| No Impact | 18.2% | 17.86% | 20.4% | 17.86% |

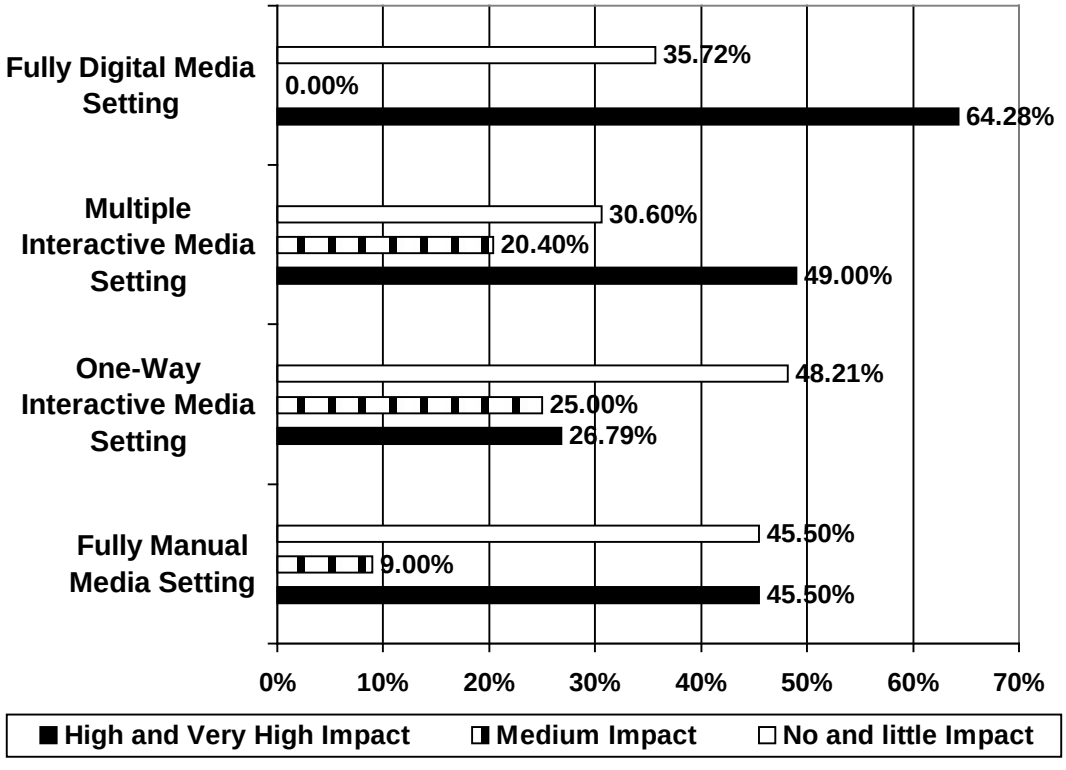



**Figure 6-2 Comparison of the Impact of Various Digital and Manual Media Settings on the Conceptualization Capability of Architects**

## 1) The Impact of Fully Manual Media Setting

Architects were asked to assess the impact of their use of fully manual media on their Conceptualization capability. Two major trends of impact were

recorded: 1) 45.5% of the respondents find that the use of fully manual media has no or a little impact on their Conceptualization capability. 2) 45.5% of the respondents find that the use of fully manual media has a high or a very high impact on their Conceptualization capability. In other words, almost half of the respondents find that using free-hand sketching and manual drawing techniques does not have significant impacts on their definition of design problems, exploration of design ideas, and formation of concepts and conceptual frameworks, Table (6-2) and Figure (6-2).

These results refer to: 1) there is possible decrease in the impact of manual media use on the Conceptualization capability, as this impact was more dominant in the past, and 2) there are other methods than manual media use which help architects perform their Conceptualization capability.

**2) The Impact of One-Way Interactive Media Setting**

Architects were asked to assess the impact of their use of one-way interactive media on their Conceptualization capability. Two trends of impact were recorded: 1) 48.2% percent of the respondents find that the use of one-way interactive media has no or a little impact on their Conceptualization capability. 2) 26.8% of the respondents find that the use of one-way interactive media has a high or a very high impact on their Conceptualization capability. In other words, half of the respondents find that using this kind of media setting does not have a significant impact on their procedures of defining design problems, exploring design ideas, and forming concepts and conceptual frameworks, Table (6-2) and Figure (6-2).

**3) The Impact of Multiple Media Interactive Setting**

Architects were asked to assess the impact of their use of multiple interactive media on their Conceptualization capability. One major trend of impact was recorded where 49.0% of the respondents find that the use of multiple

interactive media has a high or a very high impact on their Conceptualization capability. Also, there were two other trends: 30.6 % of the respondents find that this media setting has no or a little impact on the Conceptualization capability, while 20.4% of the respondents find that it has a medium impact. In other words, almost half of the respondents find that the use of multiple interactions of both manual and digital media has a significant impact on their procedures of defining design problems, exploring design ideas, and forming concepts and conceptual frameworks, Table (6-2) and Figure (6-2). This result refers to increase in the positive impact of the use of multiple interactive media on the Conceptualization capability.

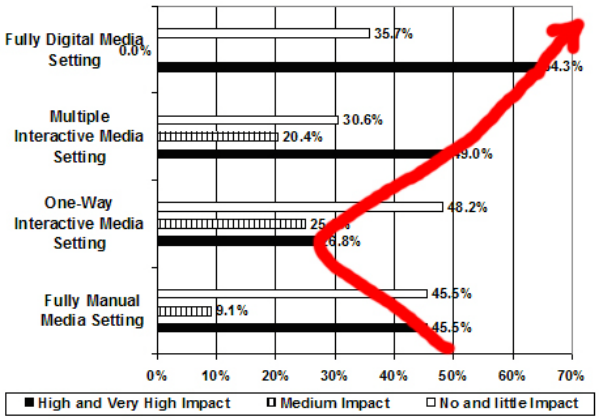
**4) The Impact of Fully Digital Media Setting**

Architects were asked to assess the impact of their use of fully digital media on their Conceptualization capability. One major trend of impact was recorded where 64.3% of the respondents find that the use of fully digital media has a high or a very high impact on their Conceptualization capability. In addition, there was another trend representing 35.7% of the respondents which considers that the use of fully digital media has no or a little impact on their Conceptualization capabilities. In other words, almost two-thirds of the respondents find that the use of fully digital media has a significant impact on the procedures of defining design problems, exploring design ideas, and forming concepts and conceptual frameworks, Table (6-2) and Figure (6-2). This result refers to increase in the positive impact towards the use of fully digital media on the Conceptualization capability.

**5) The Summary of the Results**

The major trend of the high and very high impact derived from the various uses of media on the Conceptualization capability of the respondents refers to increase in the positive impact towards the use of fully digital media. This

major trend is represented by the gray curved arrow in Figure (6-3). The positive impact of the one-way interactive media setting is less than the one of the fully manual media setting. Therefore, the respondents find that the intensive use of digital media in the initial phases of the design process has a very positive impact. This contradicts the controversy derived from the synthesis of previous research regarding the effects of the use of digital media on the nature of design content.




The High and Very High Impacts of Various Media Settings on the Conceptualization Capability are Linked together through the Gray Arrow

**Figure 6-3 The Major Trend of Media Impact on the Conceptualization Capability**

### 6-2-2 The Impact on the Form Giving Capability

The creation of form is by the use of three-dimensional Boolean operations to handle spatial manipulation and the creation of architectonic spaces. These spaces and forms result from the various logical intersections of forms in three-dimensional space. Form generation requires flexible transformation, particularly during the initial stages of this phase. The use of digital media is more appropriate in performing the initial operations of form generation, in terms of exploring, evaluating, and developing these forms.

Media interface hardware (e.g. scanner, video cam, etc.) and software of both video capture and image manipulation (such as Photoshop, Premiere, etc.),

are helpful tools of digital media which are more prominently effective than CAD programs (e.g. AutoCAD, etc.) in enhancing Form Giving capability. In order to speed up and elevate their Form Giving capability, architects generate an infinite array of techniques through using these kinds of digital media according to their own vision and creativity[10].

#### 6-2-2-1 Extracting the Impact from Previous Research

The programs of form generation make the creation of forms relatively easy not only to accomplish by helping in understanding metal forms in complex junctions, but also to demonstrate architectonic forms that may at the very least extend the range of forms architects can master[11]. Moreover, architects can see the progression and change from one form to another. They, therefore, may have a higher level of awareness of their own forms and shapes, perceiving them through computer screen in every possible way. Furthermore, computer use through programs of form generation can be considered a stream of form emergence.

Designed forms, therefore, should not be currently studied according to their idealized abstraction of geometry[12]. For it can be stated that techniques used in media interactions have released designed forms from the production tyranny of the simple geometric shapes (e.g. rectangle, circle, etc.) to the more complicated three-dimensional curvaceous forms (like designs of Gehry, Lynn, etc.), which are beyond the potential outputs of manual media use.

In this particular of form generation, digital media use helps in different ways according to the use of concepts which were discussed in the previous chapter:

[10] Neiman, Bennett, 1997, citing Neiman, 1994; Herbert, D., 1995; Smulevich, Gerard, 1997; and Bermudez and King, 1998.

[11] Glanville, R., 1995.

[12] Ibid.

**1) Media Interaction Concept**

The use of manual media helps the creativity of architects to play an important role in form emergence, as characteristics of manual media suit the performing of this episode of early phase of design. The computer, within this concept of digital media use, can help the Form Giving capability in finding and exploring forms that are hard to be accurately represented through physical models or manual drawings - for example, Figure (5-4). Furthermore, computer excels in geometric transformation, structural analysis, and hierarchical design[13], so that manipulation tasks cannot be possible within the use of manual media[14].

**2) Digitally-Based Media Concept**

The two concepts classified into the Digitally-Based Media are:

**a) Digitally-Based Design**

To benefit from the powerful use of modeling programs as early as possible, initializing the design in three dimensions on computer screen allows the architect to explore forms of three-dimensional models relatively free of the usual requirement to redraw subsequent transformations.

In spite of what has been stated of the positive impact of digital media use on the tasks of the Form Giving capability, formalism, within this concept, may become the main concern of form generation, and thus overshadow the main issues which architecture should provide man with, i.e. environmental, social, or structural requirements and needs.

[13] Cheng, Nancy, 1995.

[14] Gardner, B., 1998, citing Gianni, 1991.

**b) Digitally-Based Form**

Within the two concepts of the Digitally-Based Form (Knowledge Based and Form-Parameter Based), computational algorithms of form-generation systems (e.g. Genetic Algorithms, Shape Grammar, Algorithmic Design, etc.) produce forms that may be beyond our conception. Although some of these forms may be impractical, they can be adapted or adopted in case of their suggestiveness, opening up new paths of form that are generated by this use.

The generated forms in most cases of the Digitally-Based Form concept do not satisfy all immaterial issues of the design problem. In such concepts, tasks of the Form Giving capability, represented in the validation of function and suggestiveness of the generated forms, are delayed until after the form is completely generated. Architects employ their Form Giving capability to modify and adjust these generated forms.

**3) Digital Knowledge through Visual Drawings and Technical Information**

This concept of digital media use introduces knowledge, through computer screen in drawing format and text format, from which architects adapt and adopt forms.

Table (6-3) summarizes the overall impact of various concepts of digital media use on the Form Giving capability, extracted from previous research in related areas which is collected, analyzed, and synthesized in the forth and fifth chapters.

### 6-2-2-2 Assessing the Impact from the Results of the Questionnaire

Table (6-4) and Figure (6-4) summarize the results of the survey in a comparative way; the columns represent various media settings while rows represent the various impact levels of each setting as surveyed by respondents.

**Table 6-3 The Extracted Impact of the Concepts of Digital Media Use on the Form Giving Capability**

| Various Concepts of Digital Media Use / Areas of the Design Capability Exposed to Impact | | Media Interaction | Digitally-Based Media | | | Digital Knowledge through Visual Drawings and Technical Information |
|---|---|---|---|---|---|---|
| | | | Digitally-Based Design | Digitally-Based Form | | |
| | | | | Knowledge Based | Form Parameter Based | |
| **Streams of Form Emergence** | **Creativity** | Positive Impact | Positive Impact | Negative Impact | Negative Impact | Medium Impact |
| | **Literal Analogies** | No Impact | No Impact | No Impact | No Impact | Positive Impact |
| | **Typologies** | No Impact | No Impact | No Impact | No Impact | Positive Impact |
| **Tasks of Form Giving** | **In Two Dimensions** | Positive Impact | Positive Impact | Negative Impact | Medium Impact | No Impact |
| | **In Three Dimensions** | Positive Impact | Positive Impact | Negative Impact | Medium Impact | No Impact |

**Table 6-4 Comparison of the Impact of Various Digital and Manual Media Settings on the Form Giving Capability of Architects**

| Media Settings / Impact Level | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
|---|---|---|---|---|
| Very High Impact | 14.55% | 12.5% | 42.86% | 28.558% |
| High Impact | 56.36% | 0.0% | 28.57% | 14.288% |
| Medium Impact | 29.09% | 50.0% | 14.29% | 28.558 % |
| Little Impact | 0.0% | 37.5% | 14.29% | 14.288% |
| No Impact | 0.0% | 0.0% | 0.0% | 14.288% |

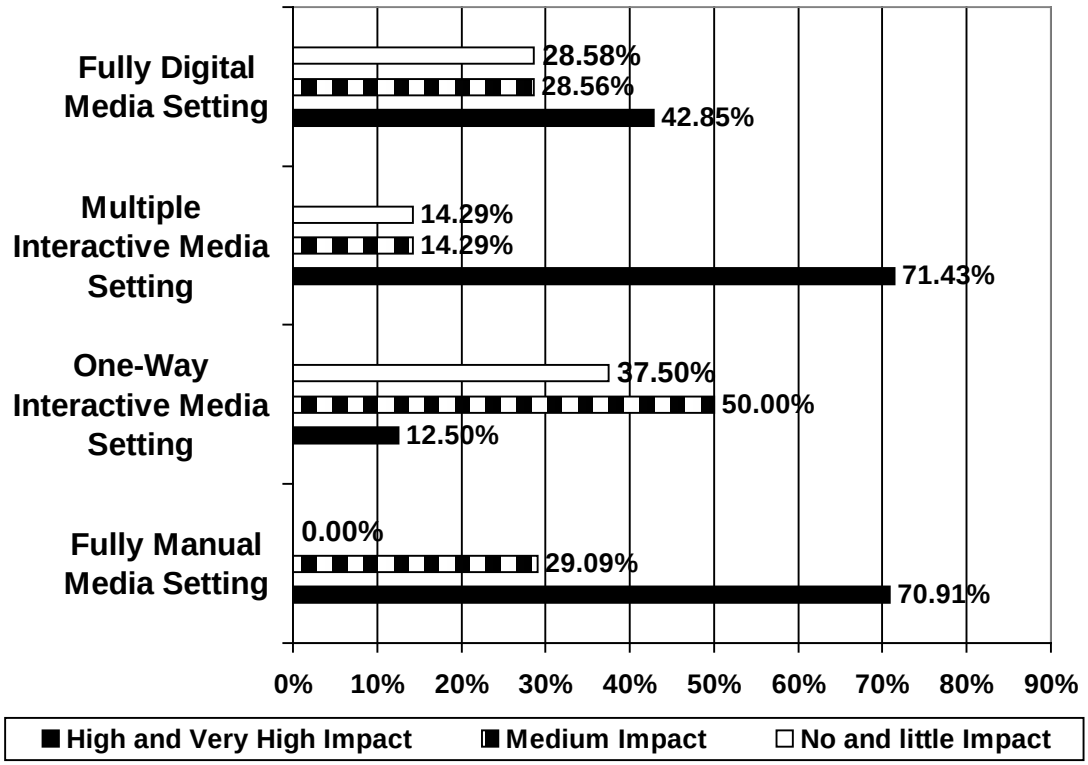



**Figure 6-4 Comparison of the Impact of Various Digital and Manual Media Settings on the Form Giving Capability of Architects**

### 1) The Impact of Fully Manual Media Setting

Architects were asked to assess the impact of their use of fully manual media on their Form Giving capability. Two major trends of impact were recorded: 1) 70.9% of the respondents find that the use of fully manual media has a high or a very high impact on their Form Giving capability. 2) 29.1% of the respondents find that the use of fully manual media has a medium impact on their Form Giving capability. In other words, seventy percent of the respondents find that using free-hand sketching and manual drawing techniques has significant impacts on their capability of creating formal ideas, and exploring and shaping architectural forms, Table (6-4) and Figure (6-4).

More than twenty five percent find that there are other ways than manual media use to perform the Form Giving capability. This result refers to

possible decrease in the positive impact of manual media use on the Form Giving capability, whereas this impact was more dominant in the past.

**2) The Impact of One-Way Interactive Media Setting**

Architects were asked to assess the impact of their use of one-way interactive media on their Form Giving capability. Three trends of impact were recorded: 1) 50.0% percent of the respondents find that the use of one-way interactive media has a medium impact on their Form Giving capability. 2) 37.5% of the respondents find that the use of one-way interactive media has no or a little impact on their Form Giving capability. 3) 12.5% of the respondents find that the use of one-way interactive media has a high or a very high impact on their Form Giving capability In other words, half of the respondents find that using this kind of media setting does not have a significant impact on their procedures of creating formal ideas, and exploring and shaping architectural forms, Table (6-4) and Figure (6-4). This result refers to the fact that half of the respondents find that there is a certain impact of this kind of media use.

**3) The Impact of Multiple Media Interactive Setting**

Architects were asked to assess the impact of their use of multiple interactive media on their Form Giving capability. One major trend of impact was recorded where 71.4% of the respondents find that the use of multiple interactive media has a high or a very high impact on their Form Giving capability. Also, there were two other equal trends: each represents 14.3% of the respondents. One finds that this media setting has no or a little impact on the Form Giving capability, while the other finds that it has a medium impact. In other words, over seventy percent of the respondents find that the use of multiple interactions of both manual and digital media has a significant

impact on their procedures of creating formal ideas, and exploring and shaping architectural forms, Table (6-4) and Figure (6-4).

This result refers to increase in the positive impact of the use of multiple interactive media on the Form Giving capability.

**4) The Impact of Fully Digital Media Setting**

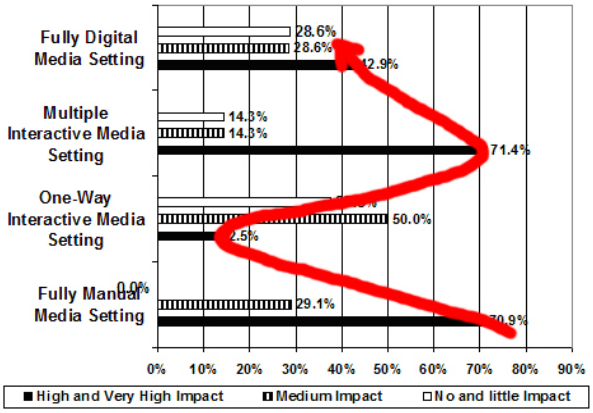
Architects were asked to assess the impact of their use of fully digital media on their Form Giving capability. One major trend of impact was recorded where 42.9% of the respondents find that the use of fully digital media has a high or a very high impact on their Form Giving capability. Two other trends are almost equal in the percentage of the respondents. Each one represents 28.6%. One finds that this media setting has no or a little impact on the Form Giving capability, while the other finds that it has a medium impact. In other words, over forty percent of the respondents find that the use of fully digital media has a significant impact on the procedures of creating formal ideas, and exploring and shaping architectural forms, Table (6-4) and Figure (6-4).

This result refers to increase in the positive impact of the use of fully digital media on the Form Giving capability.

**5) The Summary of the Results**

The major trend of the high and very high impact, derived from the various uses of media on the Form Giving capability of the respondents, refers to the positive impact of the use of both the fully manual media setting and the multiple interactive media setting. This major trend is represented by the gray curved arrow in Figure (6-5). The positive impact of the fully digital media setting is less than of the multiple interactive media setting. Therefore, there is a controversy resulting from the survey, regarding the effects of the use of digital media on the Form Giving tasks. This controversy can be explained

from the synthesis of previous research. It can be stated that, although the use of digital media through programs of form or model manipulation in somewhat later phases of the design process offers a significant help which is acknowledged by most architects, the trend of digital media use during form generation (initial phases of the design process) is still not available for many architects.




The High and Very High Impacts of Various Media Settings on the Form Giving Capability are Linked together through the Gray Arrow

**Figure 6-5 The Major Trend of Media Impact on the Form Giving Capability**

### 6-2-3 The Impact on the Representation Capability

Representation, through drawings, colors, or models, allows ideas to be effectively evaluated. Therefore, utilizing what digital media introduce in this realm strongly augments architects' performance in representation and evaluation. The main characteristics of digital media introduced in Representation tasks are: 1) the higher levels of geometrical definition and abstraction, 2) the elaboration and coordination of complexity and details, and 3) the transformation and manipulation of both images and models in an easy way comparing to the analog media use[15].

[15] Novitski, B. J., 1991, p. 97-99; Kaiser, Keel and Alexander Maller, 1993, p. 75-80; Cheng, Nancy, 1995a; Barreneche, Raul A., 1996, p. 177-181; Groh, Paul, 1997, p. 243-248; Delaura, Louis, 1997; Cheng, Nancy, 1999; and Bermudez, Julio et. al, 2000.

Representation tasks, as illustrated previously, are performed in conjunction with other tasks along the design process (e.g. Conceptualization tasks, Form Giving tasks, etc.). Consequently, the impact of digital media on the Representation capability is interrelated with the impact on other capabilities. This is evident in the areas of the basic act of drawing and representation, namely visual design thinking, germination of design ideas, and development of design. The impact of digital media on these areas was discussed previously, within the impact related to the Conceptualization capability and the Form Giving capability.

#### 6-2-3-1 Extracting the Impact from Previous Research

Representation through digital media use allows architects to initialize the design in three dimensions in a very easy way which more apt to the nature of today architecture. The use of digital media releases form from the geometric abstract to more complex and curvaceous horizons. Forms developed within digital media may have formal qualities that cannot be introduced within manual media use[16].

Within digital media use, the Representation capability encompasses the use of programs, such as image editing, digital video capture, 3D modeling, 3D manipulating, etc., instead of free hand sketching, manual drawing, and physical modeling.

The ability of digital media introduced through image editing programs enhances the Representation capability, as they allow almost an infinite number of independent layers of imagery and text. Architects can manipulate some layers without affecting the other layers, always preserving the ability to change back to a previous version. Moreover, the source of images used in

[16] Marx, J., 1998.

presentation, has been expanded to include photographic, hand-sketched, etc. Traditionally, the inclusion of this kind of images would have been unreasonable because of the difficulty of transition and manipulation[17].

In general, manual media restrict design to what architects could reasonably draw or model by hand. Currently, through integrating what image editing programs offer in the presentation field, digital representation[18] can include images, text, etc., in a way within which the concepts and meanings of drawings can be more comprehendible and expressible.

The representation in final phases of the design process suits the nature of computing CAD as an algorithmic process. Within some techniques of digital media, the produced images (such as, images of Virtual Reality) are so visually real that their reality may be opened to question. Architects should be aware that this use may have a negative impact on the design process[19].

In this particular of representation, digital media use helps in different ways according to the use of concepts which were discussed in the previous chapter:

**1) Media Interaction Concept**

Architects benefit from the use of digital media, as some tasks of representation may not be possible within the use of manual media[20]. The interaction use between digital and analog media is not only about

[17] Bermudez, J. and A. Smith, 1999, p. 26-29.

[18] This kind of representation is basically a Graphic Design which can be defined as "the use of imagery and text to create meaning in an organized and clear fashion. It can include the use of symbolism, metaphor, and comparison. It can use imagery that shows context, design process, and can make obvious relationships and the ideas that connect them" [Marx, 1998].

[19] As mentioned before, many researchers maintain that images of Virtual Reality are more appropriate for commercial use, rather than for design use (for example, Cheng, 1995; Bermudez, 2000; etc.).

[20] Gardner, B., 1998, citing Gianni, 1991.

manipulating, but also about continually making what was accomplished previously.

Manual media, especially through free hand sketching, give architects the potential to freely explore and represent what is imprecise in mind. The computer, within this concept of digital media use, helps the Representation Capability in saving time and effort of manually redrawing or remodeling.

In addition, static standard projections, such as plans, elevations and sections, may fail to convey certain spatial qualities which may be experienced by visualizing the movement through buildings, as programs of computer graphics display. In order to have similar spatial qualities through manual media use, the free hand sketching capability of architects must be a powerful one (like the style of Le Corbusier in design).

**2) Digitally-Based Media Concept**

The two concepts classified into the Digitally-Based Media are:

**a) Digitally-Based Design**

Digital media have stronger tools than manual media in terms of developing a design, as they allow easy articulation, imagery manipulation, store of various stages of models and images, and generation of multiple viewpoints.

The sole use of digital media enhances the Representation capability along the design process. While making changes in a design, within digital media use, through many tasks such as undo, redo, save, alter (transform, scale, move, etc.), save again, alter again, etc., architects save much effort from the earliest point of the design process.

**b) Digitally-Based Form**

Within the two concepts of Digitally-Based Form (Knowledge Based and Form-Parameter Based), computational algorithms of form-generation systems (e.g. Genetic Algorithms, Shape Grammar, Algorithmic Design, etc.) generate forms instead of the Representation capability of architects. Although architects may use their Representation capability in later phases to develop the design, margining the Representation capability has a negative impact, especially on the areas related to this capability in the early phases of design, such as form emergence or design idea.

**3) Digital Knowledge through Visual Drawings and Technical Information**

This concept of digital media use does not have a direct impact on the Representation capability of architects. Architects may adapt or adopt ways of presentation introduced through this concept, which were used in design precedents (past cases).

Table (6-5) summarizes the overall impact of various concepts of digital media use on the Representation capability, extracted from previous research in related areas which is collected, analyzed, and synthesized in the forth and fifth chapters.

### 6-2-3-2 Assessing the Impact from the Results of the Questionnaire

Table (6-6) and Figure (6-6) summarize the results of the survey in a comparative way; the columns represent various media settings while rows represent the various impact levels of each setting as surveyed by respondents.

**Table 6-5 The Extracted Impact of the Concepts of Digital Media Use on the Representation Capability**

| Various Concepts of Digital Media Use / Area of the Design Capability Exposed to Impact | | Media Interaction | Digitally-Based Media | | | Digital Knowledge through Visual Drawings and Technical Information |
|---|---|---|---|---|---|---|
| | | | Digitally-Based Design | Digitally-Based Form | | |
| | | | | Knowledge Based | Form Parameter Based | |
| **Tasks of Representation along with the Design Process** | **Early Phase** | Positive Impact | Positive Impact | Negative Impact | Negative Impact | No Impact |
| | **Design Development** | Positive Impact | Positive Impact | Medium Impact | Medium Impact | No Impact |
| | **Final Phase** | Positive Impact | Positive Impact | No Impact | No Impact | Medium or Positive Impact |

**Table 6-6 Comparison of the Impact of Various Digital and Manual Media Settings on the Representation Capability of Architects**

| Media Settings / Impact Level | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
|---|---|---|---|---|
| Very High Impact | 29.09% | 0.0% | 28.57% | 42.86% |
| High Impact | 14.55% | 37.5% | 14.29% | 14.285% |
| Medium Impact | 0.0% | 37.5% | 28.57% | 14.285% |
| Little Impact | 41.81% | 12.5% | 28.57% | 14.285% |
| No Impact | 14.55% | 12.5% | 0.0% | 14.285% |

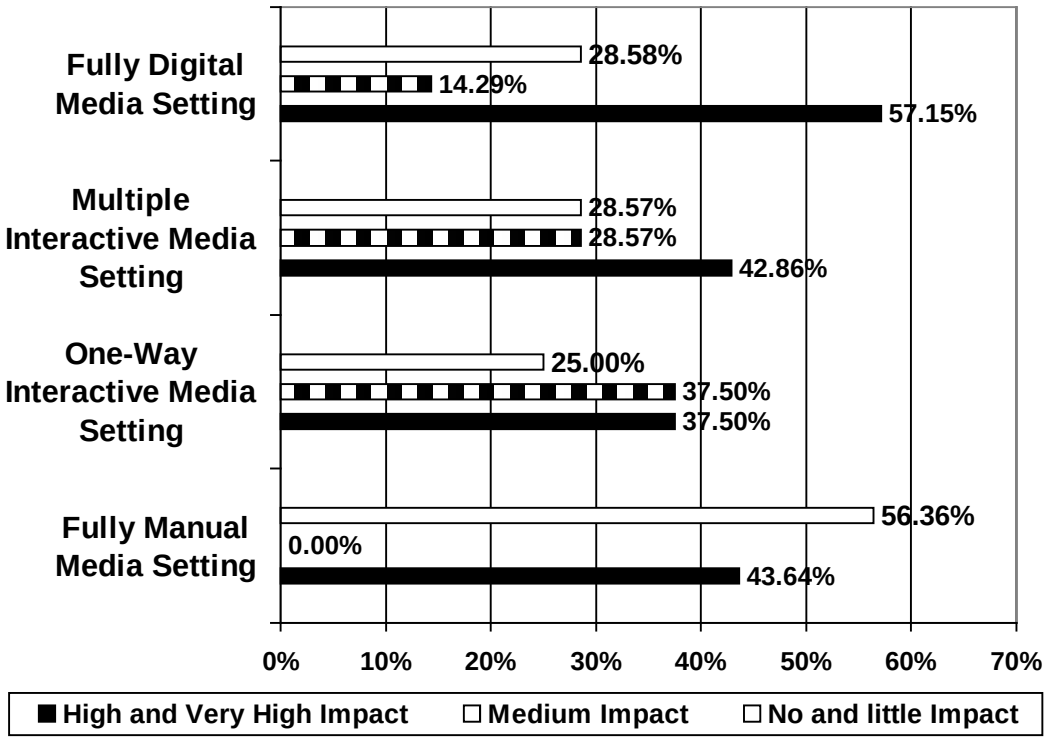



**Figure 6-6 Comparison of the Impact of Various Digital and Manual Media Settings on the Representation Capability of Architects**

### 1) The Impact of Fully Manual Media Setting

Architects were asked to assess the impact of their use of fully manual media on their Representation capability. Two trends of impact were recorded: 1) 56.4% of the respondents find that the use of fully manual media has no or a little impact on their Representation capability. 2) 43.6% of the respondents find that the use of fully manual media has a high or a very high impact on their Representation capability, Table (6-6) and Figure (6-6).

This result refers to a controversy between the respondents regarding the impact of this kind of media setting on their Representation capabilities.

### 2) The Impact of One-Way Interactive Media Setting

Architects were asked to assess the impact of their use of one-way interactive media on their Representation capability. Three trends of impact were recorded: 1) 37.5% percent of the respondents find that the use of one-way

interactive media has a high or a very high impact on their Representation capability. 2) 37.5% of the respondents find that the use of one-way interactive media has a medium impact on their Representation capability. 3) 25.0% of the respondents find that the use of one-way interactive media has no or a little impact on their Representation capability, Table (6-6) and Figure (6-6).

This result shows that 75.0% of the respondents find that there is a certain impact of this kind of media use. Half of this percentage (75.0%) finds that this impact is high or very high.

**3) The Impact of Multiple Media Interactive Setting**

Architects were asked to assess the impact of their use of multiple interactive media on their Representation capability. One major trend of impact was recorded where 42.9% of the respondents find that the use of multiple interactive media has a high or a very high impact on their Representation capability. Also, there were two other equal trends where each trend represents 28.6% of the respondents. One finds that this media setting has no or a little impact on the Representation capability, while the other finds that it has a medium impact, Table (6-6) and Figure (6-6).

This result refers to increase in the positive impact of the use of multiple interactive media on the Representation capability.

**4) The Impact of Fully Digital Media Setting**

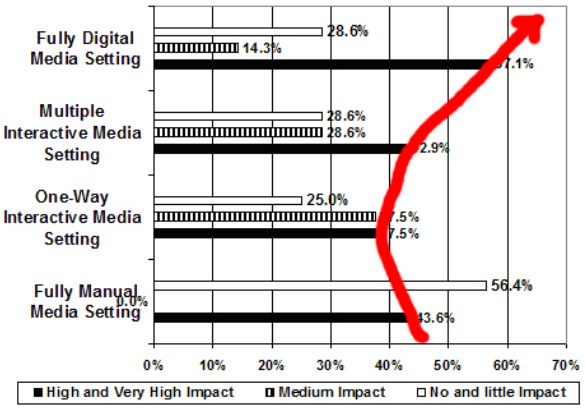
Architects were asked to assess the impact of their use of fully digital media on their Representation capability. One major trend of impact was recorded where 57.1% of the respondents find that the use of fully digital media has a high or a very high impact on their Representation capability. There were two other trends. One trend, representing 28.6% of the respondents, finds that this media setting has

no or a little impact on the Representation capability. The other representing 14.3% finds that this impact is a medium impact, Table (6-6) and Figure (6-6).

This result refers to increase in the positive impact of the use of fully digital media on the Representation capability.

**5) The Summary of the Results**

The major trend of the high and very high impact derived from the various uses of media on the Representation capability of the respondents refers to increase of the positive impact towards the use of fully digital media. This major trend is represented by the gray curved arrow in Figure (6-7). The positive impact of the multiple interactive media setting is equal to that of the fully manual media setting. However, the sole use of digital media has the highest impact on the Representation capability; and this result confirms the synthesis of previous research regarding the positive effect of digital media use on the Representation capability.




The High and Very High Impacts of Various Media Settings on the Representation Capability are Linked together through the Gray Arrow

**Figure 6-7 The Major Trend of Media Impact on the Representation Capability**

## 6-2-4 The Impact on the Decision-Making Capability

The tools and techniques of media architects employ, harmonize with their own objectives during designing. Architects, therefore, may seize the

advantages of each type of media, by which a better position is offered to make decisions. This can be achieved through acknowledging the characteristics and qualities of each of digital or manual medium.

For example, a design idea may emerge from a prior use of a design precedent, the architect in this case may prefer using digital media to develop this design idea which he already has. The decision, in this case, is which type of digital media will be used: Image editing programs (such as: Photoshop, Premiere, etc.), three-dimensional creating and manipulating programs (such as: Form Z, 3D Studio, etc.), or other techniques (such as: scanning a physical model for developing and manipulating in a digital environment). In another case, a design idea may originate from the design-problem context, where the architect uses sketching or physical modeling in analyzing, defining, and evaluating the constraints of the problem at hand in order to construct design ideas and concepts.

#### 6-2-4-1 Extracting the Impact from Previous Research

Previous research provides evidences that different kinds of conceiving are essential to the intwined processes of designing, exploring, and decision making within and between design episodes[21]. There is a reciprocal relationship between Decision Making tasks and the types of media utilized within the design process. Where the decisions architects take during the design process, specify these types of used media, on the one hand, perception and conception of what is represented depends on the type of media used in this representation, on the other hand. This fact results in affecting the Decision-Making routes which lead the process of design. It can be stated that what might be conceived, perceived, and comprehended of a design idea, is related to how this design idea is modeled, presented, and represented (by the type of media), Figure (6-8).

[21] Gero, J. and R. Saunders, 2000, citing, Schön and Wiggins, 1992.

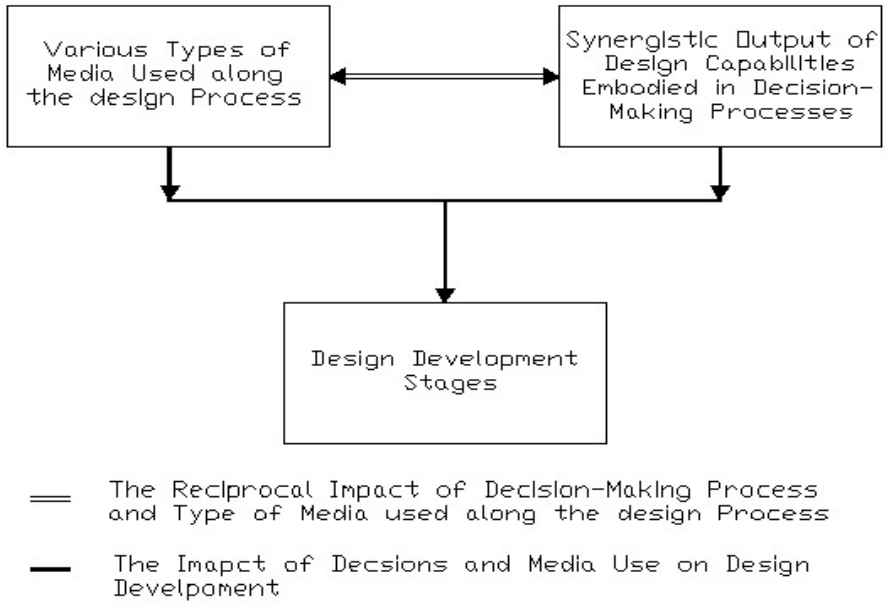



**Figure 6-8 The Relation between Decision-Making Processes, Types of Media Used, and Design Development Stages along with the Design Process**

The Figure is prepared by the researcher

The contributions digital media use introduces to Decision-Making process during the design process, can be classified according to the concepts of media used:

### 1) Media Interaction Concept

Within using this concept, the role of Decision-Making capability is prominent from the initial phases of the design process, in areas of influencing early design structure, selection of organizational principles, evaluation of organizational principles, and Choice of Decision Routes. In these areas, architects construct concepts and generate an initial form, by manual media use. Then, within digital media use (e.g. image editing programs, etc.), the form is developed, and details of the from (e.g. building material, structural systems, etc.) are finalized.

The architect conducts the process of decision shaping, while the use of digital media just helps and supports the Decision Making capability in somewhat later phases of the design process.

**2) Digitally-Based Media Concept**

The two concepts classified into the Digitally-Based Media are:

**a) Digitally-Based Design**

Architects may let digital media empower the positions, within/by which they shape decisions that direct the process of design. The productive conversation with the computer as a participant leads to develop design ideas, or suggests forms architects cannot even envisage in some cases. The process of conducting decisions is still up to the architect. However, digital media powerfully enhance what they can perceive, explore, and conceive.

Initializing and developing designs in digital environment elevates the Decision Making capability of architects to horizons beyond what would have been possible if these designs have been explored and developed manually, as this gives architects the full clarity of what is being developed, without dependence on their imagining[22].

**b) Digitally-Based Form**

Within the two concepts of the Digitally-Based Form (Knowledge Based[23] and Form-Parameter Based), architects may allow the digital media, metaphorically speaking, to entirely take command to lead the design process which would be executed through computational algorithms of form-generation systems (e.g. Genetic Algorithms, Shape

[22] Glanville, R., 1995.

[23] Many researchers maintain the point of view of this concept being dense with many limitations to be successfully applied in a complete form. For example, Tapia (1979) maintain that in spite of the theoretical appeal of this concept, there are limitations of implementation most probably as a result of several factors: 1) the relative complexity of the underlying algorithms, despite the elegance and simplicity of the underlying mechanism; 2) the general lack of awareness of this technique within the computer science community; and, in particular, 3) the difficulty of developing an integrated digital system to produce a complete design that satisfy immaterial factors [Tapia, Mark, 1979, p. 59–73]

Grammar, Algorithmic Design, etc.). The computer introduces forms and shapes as design-problem solutions. Although architects may modify these forms and shapes in later stages, the influence of this first arrangement of a design-problem solution will be long lasting, as mentioned previously.

Within using this concept, the role of the Decision-Making capability is not prominent in the initial phases of the design process, as form is generated by software and concepts are constructed by architects. Constructing concepts that take part in shaping decisions is delayed to later phases. This results in a negative impact on the Decision Making capability and its role in the design process.

**3) Digital Knowledge through Visual Drawings and Technical Information**

This concept of digital media use does not have a direct impact on the Decision Making capability of architects. During the design process, the computer may offer the knowledge used by Decision Making capability.

Table (6-7) summarizes the overall impact of various concepts of digital media use on the Decision Making capability, extracted from previous research in related areas which is collected, analyzed, and synthesized in the forth and fifth chapters.

### 6-2-4-2 Assessing the Impact from the Results of the Questionnaire

Table (6-8) and Figure (6-9) summarize the results of the survey in a comparative way; the columns represent various media settings while rows represent the various impact levels of each setting as surveyed by respondents.

**Table 6-7 The Extracted Impact of the Concepts of Digital Media Use on the Decision Making Capability**

| Various Concepts of Digital Media Use / Area of the Design Capability Exposed to Impact | | Media Interaction | Digitally-Based Media | | | Digital Knowledge through Visual Drawings and Technical Information |
|---|---|---|---|---|---|---|
| | | | Digitally-Based Design | Digitally-Based Form | | |
| | | | | Knowledge Based | Form Parameter Based | |
| Roles of the Decision Making Capability | Influencing Early Design Structure | Positive Impact | Positive Impact | Negative Impact | Negative Impact | Positive Impact |
| | Selection of Organizational Principles | Positive Impact | Positive Impact | Negative Impact | Negative Impact | Positive Impact |
| | Evaluation of Organizational Principles | Positive Impact | Positive Impact | Negative Impact | Medium Impact | No Impact |
| | Choice of Decision Routes | Positive Impact | Positive Impact | No Impact | No Impact | No Impact |

#### 1) The Impact of Fully Manual Media Setting

Architects were asked to assess the impact of their use of fully manual media on their Decision Making capability. One major trend of impact was recorded where 43.6% of the respondents find that the use of fully manual media has no or a little impact on their Decision Making capability. Also, there were two other trends. One that represents 29.1% finds that this media setting has a high or a very high impact on the Decision Making capability, while the other

that represents 27.3% finds that it has a medium impact, Table (6-8) and Figure (6-9).

This result refers to decrease in the impact of manual media use on the Decision Making capability, whereas this impact was more dominant in the past.

**Table 6-8 Comparison of the Impact of Various Digital and Manual Media Settings on the Decision Making Capability of Architects**

| Impact Level \ Media Settings | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
|---|---|---|---|---|
| Very High Impact | 14.55% | 0.0% | 14.29% | 42.85% |
| High Impact | 14.55% | 37.5% | 28.57% | 14.29% |
| Medium Impact | 27.27% | 12.5% | 42.85% | 28.57% |
| Little Impact | 43.63% | 25.0% | 0.0% | 0.0% |
| No Impact | 0.0% | 25.0% | 14.29% | 14.29% |

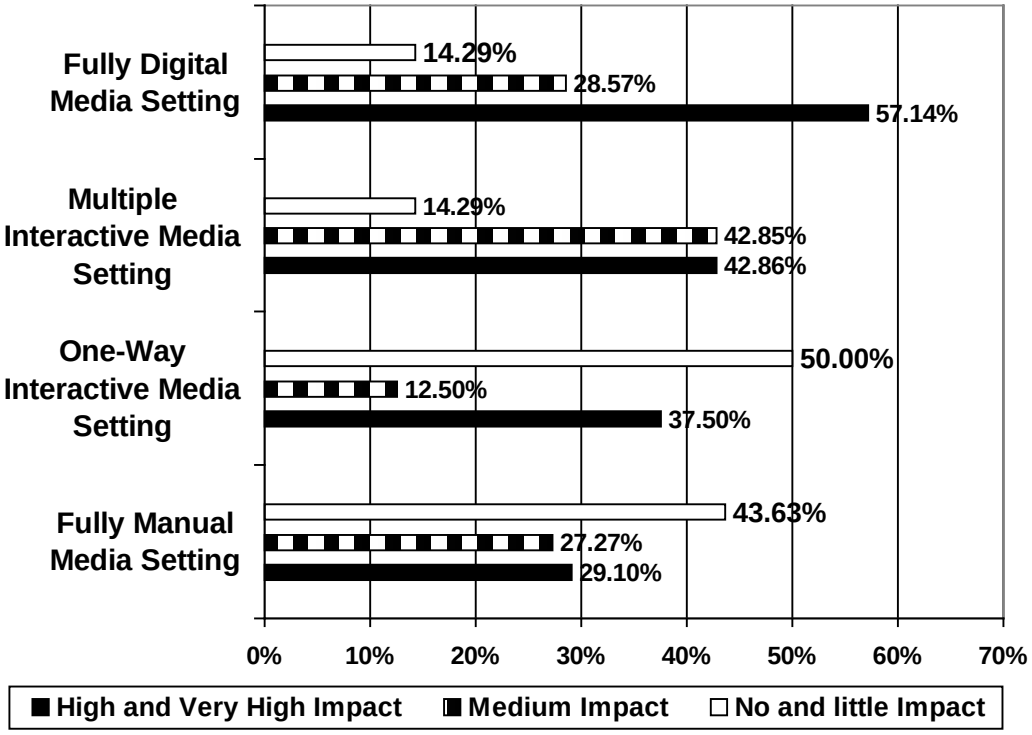



**Figure 6-9 Comparison of the Impact of Various Digital and Manual Media Settings on the Decision Making Capability of Architects**

**2) The Impact of One-Way Interactive Media Setting**

Architects were asked to assess the impact of their use of one-way interactive media on their Decision Making capability. Two major trends of impact were recorded: 1) 50.0% of the respondents find that the use of one-way interactive media has a medium impact on their Decision Making capability. 2) 37.5% of the respondents find that the use of one-way interactive media has a high or a very high impact on their Decision Making capability. Also, there were 12.5% of the respondents who find that the use of one-way interactive media has a medium impact on their Decision Making capability, Table (6-8) and Figure (6-9).

This result refers to the fact that half of the respondents find that this kind of media setting does not have a significant impact on processes of Decision Making.

**3) The Impact of Multiple Media Interactive Setting**

Architects were asked to assess the impact of their use of multiple interactive media on their Decision Making capability. There were two major equal trends where each represents 42.9% of the respondents. One finds that this media setting has a high or a very high impact on the Decision Making capability, while the other finds that it has a medium impact. Also, there was one trend representing 14.3% of the respondents who find that this media setting has no or a little impact on the Decision Making capability, Table (6-8) and Figure (6-9).

This result refers to increase in the positive impact of the use of multiple interactive media on the Decision Making capability.

**4) The Impact of Fully Digital Media Setting**

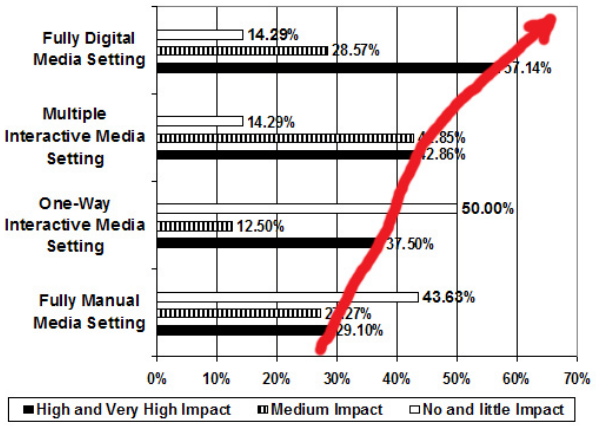
Architects were asked to assess the impact of their use of fully digital media on their Decision Making capability. One major trend was recorded where 57.2% of the

respondents finds that the use of fully digital media has a high or a very high impact on their Decision Making capability. Two other trends were recorded. One trend representing 28.6% of the respondents finds that this media setting has a medium impact on the Decision Making capability, while the other representing 14.3% of the respondents finds that it has no or a little impact, Table (6-8) and Figure (6-9).

This result shows that more than half of the respondents find that the use of fully digital media has a very positive impact on the Decision Making capability.

### 5) The Summary of the Results

The major trend of the high and very high impact derived from the various uses of media on the Decision Making capability of the respondents refers to constant increase of the positive impact towards the use of fully digital media. This major trend is represented by the gray curved arrow in Figure (6-10). This result of the questionnaire conforms to the synthesis of previous research, regarding the powerful use of digital media that enhances the position by/within which architects make decisions.




The High and Very High Impacts of Various Media Settings on the Decision Making Capability are Linked together through the Gray Arrow

**Figure 6-10 The Major Trend of Media Impact on the Decision Making Capability**

### 6-2-5 The Impact on the Knowledge Building and Retrieving Capability

The Knowledge Building and Retrieving capability has an important role for each architect in achieving her/his own style/s in architectural design thinking. By the same token, the use of media (analog and digital) corresponds with the vision and experience of the architect. Thus, this use is basically employed within the architect's experiences and styles.

The individual styles regarding the use of digital and manual media are diverse, as the fluency of each architect in specific methods, which is derived from the architect's division of labor, enables the architect to use these specific methods in solving different design problems (for example, designs of Steven Holl represent the sole use of manual media).

#### 6-2-5-1 Extracting the Impact from Previous Research

Architects continuously develop their ways of media use in order to improve their tools of design. The right tool at the right time for the right job means reducing representation redundancy and enhancing representation appropriateness, during design[24]. A prominent part of the Knowledge Building and Retrieving capability is the fluency in different types of media. This enables the architect to take a design from one medium to another according to the requirements of a design situation.

In this particular of the Knowledge Building and Retrieving, digital media use helps in different ways according to the use of concepts which were discussed in the previous chapter:

[24] Novitski, B., 1991, citing Steven Canter; Bermudez, J., 1997 b; and Martens, Bob and Ziga Turk, 2001, p. 380-385.

**1) Media Interaction Concept**

Within this concept, architects use manual and digital media along the design process. Therefore, the Knowledge Building and Retrieving capability encompasses the skills of using the two types of media which are employed according to the vision of the architect.

**2) Digitally-Based Media**

The sole use of digital media within this concept enables architects to concentrate on gaining the various skills of this use. The two concepts classified into the Digitally-Based Media are:

**a) Digitally-Based Design**

Within this concept, architects use digital media from the earliest point in the design process, so that they have to utilize various tools of digital media throughout all phases of the design process.

**b) Digitally-Based Form**

Within the two concepts of Digitally-Based Form (Knowledge Based and Form-Parameter Based), the role of architects appears after form is generated through computational algorithms. Therefore, architects employ their skills of digital media use in somewhat later phases of the design process.

**3) Digital Knowledge through Visual Drawings and Technical Information**

The impact of the Digital Knowledge through Visual Drawings and Technical Information concept on this capability of architects is introduced through the references that architects may need in design-problem solving. What are digitally offered on line (such as information, images, plans, elevations, etc.) exceeds what architects may get depending on their minds in retrieving this kind of knowledge. As a result, through the easy accessibility

of knowledge which this concept offers, the Knowledge Building and Retrieving capability is enhanced and elevated.

Table (6-9) summarizes the overall impact of various concepts of digital media use on the Knowledge Building and Retrieving capability, extracted from previous research in related areas which is collected, analyzed, and synthesized in the forth and fifth chapters.

**Table 6-9 The Extracted Impact of the Concepts of Digital Media Use on the Knowledge Building and Retrieving Capability**

| Various Concepts of Digital Media Use / Area of the Design Capability Exposed to Impact | | Media Interaction | Digitally-Based Media | | | Digital Knowledge through Visual Drawings and Technical Information |
|---|---|---|---|---|---|---|
| | | | Digitally-Based Design | Digitally-Based Form | | |
| | | | | Knowledge Based | Form Parameter Based | |
| Characteristics of the Knowledge Building and Retrieving Capability | Personal Style and Subjective Point of View | Positive Impact | Positive Impact | Negative Impact | Negative Impact | Positive Impact |
| | Background of Decisions | Positive Impact | Positive Impact | Medium Impact | Medium Impact | Positive Impact |

### 6-2-5-2 Assessing the Impact from the Results of the Questionnaire

Table (6-10) and Figure (6-11) summarize the results of the survey in a comparative way; the columns represent various media settings while rows represent the various impact levels of each setting as surveyed by respondents.

**Table 6-10 Comparison of the Impact of Various Digital and Manual Media Settings on the Knowledge Building and Retrieving Capability of Architects**

| Impact Level \ Media Settings | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
|---|---|---|---|---|
| Very High Impact | 0.0% | 12.5% | 14.29% | 57.14% |
| High Impact | 41.82% | 12.5% | 57.13% | 28.57% |
| Medium Impact | 0.0% | 25.0% | 14.29% | 0.0% |
| Little Impact | 58.18% | 37.5% | 0.0% | 0.0% |
| No Impact | 0.0% | 12.5% | 14.29% | 14.29% |

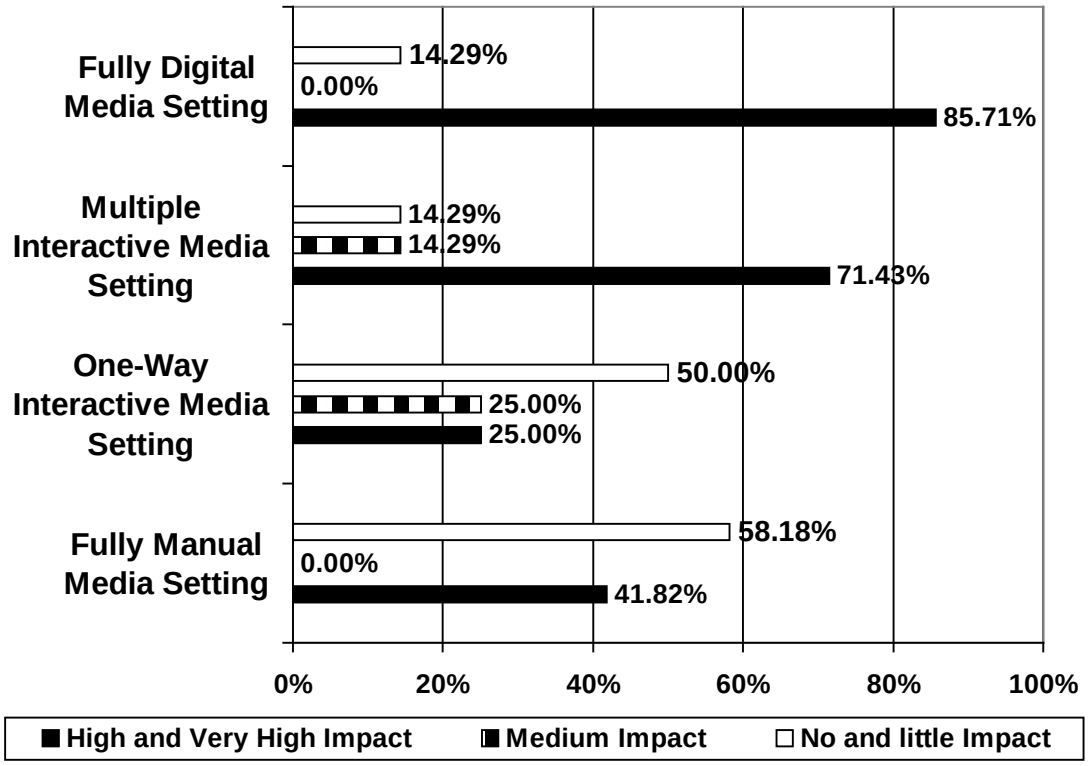



**Figure 6-11 Comparison of the Impact of Various Digital and Manual Media Settings on the Knowledge Building and Retrieving Capability of Architects**

**1) The Impact of Fully Manual Media Setting**

Architects were asked to assess the impact of their use of fully manual media on their Knowledge Building and Retrieving capability. Two trends of impact were recorded: 1) 58.2% of the respondents find that the use of fully manual media has no or a little impact on their Knowledge Building and Retrieving capability. 2) 41.8% of the respondents find that the use of fully manual media has a high or a very high impact on their Knowledge Building and Retrieving capability, Table (6-10) and Figure (6-11).

This result shows to that there is a controversy between the respondents regarding the impact of this kind of media setting on the Knowledge Building and Retrieving capability.

**2) The Impact of One-Way Interactive Media Setting**

Architects were asked to assess the impact of their use of one-way interactive media on their Knowledge Building and Retrieving capability. One major trend of impact was recorded where 50.0% of the respondents find that the use of one-way interactive media has no or a little impact on their Knowledge Building and Retrieving capability. Also, there were two other equal trends where each trend represents 25.0% of the respondents. One trend finds that this media setting has a high or a very high impact on the Knowledge Building and Retrieving capability, while the other finds that it has a medium impact, Table (6-10) and Figure (6-11).

This result refers to the fact that half of the respondents find that there is no impact of this kind of media use on the Knowledge Building and Retrieving capability.

### 3) The Impact of Multiple Media Interactive Setting

Architects were asked to assess the impact of their use of multiple interactive media on their Knowledge Building and Retrieving capability. One major trend was recorded where 71.4% of the respondents find that the use of multiple interactive media has a high or a very high impact on their Knowledge Building and Retrieving capability. Also, there were two other equal trends where each trend consists of 14.3% of the respondents. One finds that this media setting has no or a little impact on the Knowledge Building and Retrieving capability, while the other finds that it has a medium impact, Table (6-10) and Figure (6-11).

This result shows that over seventy percent of the respondents find that the use of multiple interactions of both manual and digital media has a very positive impact on their Knowledge Building and Retrieving capability.

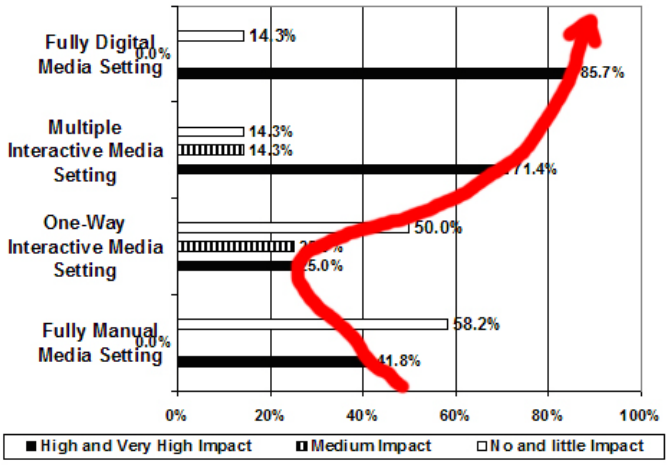
### 4) The Impact of Fully Digital Media Setting

Architects were asked to assess the impact of their use of fully digital media on their Knowledge Building and Retrieving capability. One major trend of impact representing 85.7% of the respondents finds that the use of fully digital media has a high or a very high impact on their Knowledge Building and Retrieving capability. Also, there was another trend representing 14.3% of the respondents who find that this media setting has no or a little impact on the Knowledge Building and Retrieving capability, Table (6-10) and Figure (6-11).

This result refers to significant increase in the positive impact of the use of fully digital media on the Knowledge Building and Retrieving capability.

### 5) The Summary of the Results

The major trend of the high and very high impact derived from the various uses of media on the Knowledge Building and Retrieving capability of the respondents refers to increase of the positive impact towards the use of fully digital media. This major trend is represented by the gray curved arrow in Figure (6-12). Most of the respondents find that the fully digital media setting has a very positive impact on the Knowledge Building and Retrieving capability. This result of the questionnaire conforms to the synthesis of previous research, regarding the powerful use of digital media in the field of knowledge accessibility.




The High and Very High Impacts of Various Media Settings on the Knowledge Building and Retrieving Capability are Linked together through the Gray Arrow

**Figure 6-12 The Major Trend of Media Impact on the Knowledge Building and Retrieving Capability**

## 6-3 Conclusion of the Chapter

1- This chapter has: 1) verified the third hypothesis, that is the nature of the impact of digital media on the design capabilities of architects varies according to the design capability and the type of media use, and 2) achieved the third objective, that is exploring the impact of digital media on the design capabilities of architects. To explore positive or negative areas of

impact introduced by the various concepts of digital media use, the research methodology has followed two ways:

* Extracting this impact from the synthesis of previous research in related areas. This methodology overcomes obstacles resulting from: some concepts of media use are not available for many architects to employ because of the cost (of the sophisticated software or hardware), or the relation to computer science (which requires a programming background).

* Surveying a sample of experts and professional architects, to assess the impact of various media settings. This methodology introduces the impact according to the vision of the respondents.

2- The potential of digital media opens up new possibilities beyond the limited ones derived from analog media. The most significant advances of digital media are acknowledged, when the designs which architects produce exceed their expectation, and even imagining. The use of digital media reaches beyond amplifying and speeding up the design capabilities of architects, to contribute in design activities as partners.

3- **The impact on the Conceptualization capability:** The major trend of the high and very high impact derived from the various uses of media on the Conceptualization capability of the respondents refers to increase of the positive impact of the use of fully digital media. The respondents find that the intensive use of digital media in the initial phases of the design process has a very positive impact. This result contradicts the controversy derived from the synthesis of previous research regarding the effects of the use of digital media on the nature of design content.

4- **The Impact on the Form Giving Capability:** There is a controversy resulting from the respondents' surveying, regarding effects of digital

media use on the Form Giving tasks. This controversy can be explained, from the synthesis of previous research: the trend of digital media use during form generation (initial phases of the design process) is still not available for many architects, although the use of digital media through programs of form manipulation in somewhat later phases of the design process, offers significant help which is acknowledged by most architects.

5- **The Impact on the Representation Capability:** The major trend of the high and very high impact derived from the various uses of media on the Representation capability of the respondents refers to increase of the positive impact towards the use of fully digital media. The sole use of digital media has the highest impact on the Representation capability. This result confirms the synthesis of previous research regarding the positive effect of digital media use on the Representation capability.

6- **The Impact on the Decision-Making Capability:** The major trend of the high and very high impact derived from the various uses of media on the Decision Making capability of the respondents refers to constant increase of the positive impact towards the use of fully digital media. This result of the questionnaire conforms to the synthesis of previous research, regarding the powerful use of digital media which enhances the position by/within which architects make decisions.

7- **The Impact on the Knowledge Building and Retrieving Capability:** The major trend of the high and very high impact derived from the various uses of media on the Knowledge Building and Retrieving capability of the respondents refers to increase of the positive impact towards the use of fully digital media. Most of the respondents find that the fully digital media setting has a very positive impact on the Knowledge Building and Retrieving capability. This result of the questionnaire conforms to the

synthesis of previous research, regarding the powerful use of digital media in the field of knowledge accessibility.

# Chapter 7 Conclusion and Implications

The research has proved its hypotheses and accomplished its objectives as previously stated in the first chapter. The research leads to concrete results regarding the following:

- Identifying the nature and the characteristics of the design process.
- Defining a conceptual framework for the design capabilities of architects.
- Classifying the various approaches and trends of digital media use in the design process.
- Exploring the impact of digital media use on the design capabilities of architects.

This part of the research is concerned with the summary and the implications of all these findings and results, and with the future research work.

## 7-1 Design Thinking

**1) Observations and Findings:**

Regarding the design thinking of architectural problem the dissertation, from the literature review of the realms of problem solving and design thinking, has highlighted the following:

- Design thinking is a conscious exploration activity, rather than an inspiration or illumination, in terms of achieving creativity in design-problem solving.
- Although creativity has an important role in the activities of the architectural design thinking, rules and principles are necessarily invoked while architects pursue the tasks of problem solving. Invoking such appropriate rules, in order to relate the results from an evaluation of potential solutions to further courses of action, reveals that architects

employ streams and references to have the derivation of design ideas or partial solutions.

- Design ideas can be generated from: 1) the architect: her/his creativity, subjective or objective interpretation of design-problem context, personal prejudice of design thinking, individual style of the design process, and way of media use, and 2) the design problem at hand: its context.
- Different styles of design thinking lead to different solutions of the same design-problem. In addition, the solutions of different design problems, conducted by single design thinking, may have similar characteristics.
- The dissertation, from the literature review of problem-solving models, has identified the role of media (such as drawing, modeling, etc.) in the design process even before the complete definition of this process, and the total exploration of its phases and tasks, in the form that is known today. Moreover, the dissertation has illustrated this role by the fact that what might be conceived, perceived, and comprehended of a design idea, is related to how this design idea is modeled, presented, and represented by the type of media.

**2) Implications:**

- Design thinking and architectural problem solving should be conducted on the bases of creativity, and concepts.
- There are some activities that should be emphasized in architectural education such as, the derivation of design ideas, the construction of design concepts, and the role of media in the design process.

## 7-2 The Design Process

### 1) Observations and Findings:

Concerning the design process, the dissertation has concluded that:

- Along the design process, three are overlaps of the phases. These overlaps dynamically move from one model of the process to another, according to the architect's vision and perception of the design problem at hand.
- The design process has main characteristics as follows: numerous models, organizing and dominating concepts, continuous refinement and enhancement, nonlinear nature of design phases, correlation with visual design thinking, and progression in representation environments.
- Tasks and activities of the design process can be represented as a repeated cycle of decision-making and evaluation. Each single cycle may result in modifying either the problem definition and the concepts or the design and form. The output of one single cycle is the input of the next one.
- The impact of analog and digital media use on the design process may be generally summarized in two major contributions: new ideas and new forms.

### 2) Implications:

- The captious exploration of the areas of: the design process, the design capabilities of architects, and the use of digital media, should be continuously maintained, in order to help accelerate both the application of the concepts of digital media used in the architectural design process, and the enhancement of the design capabilities of architects with the new uses.

- The design process and its characteristics should be emphasized in architectural education.

## 7-3 Architectural Design Capabilities

**1) Observations and Findings:**

Concerning the design capabilities of architects the dissertation has reached the following findings:

- The design capabilities of architects are classified into five types: Conceptualization capability, Form Giving capability, Representation capability, Decision-Making capability, and Knowledge Building and Retrieving capability.
- Within the conceptual model which has been developed, architects move back and forth inside a loop of reciprocal influences which connects Conceptualization, Form Giving, and Representation capabilities. Although these three capabilities may be performed simultaneously, the Conceptualization capability has the main role in leading this loop. Meanwhile architects use a mixture of both Decision-Making, and Knowledge Building and Retrieving capabilities in order to guide the foregoing mental loop in evaluating and choosing between the tentative proposals they have in mind for solving the given problem as a whole or in parts.
- The design capabilities of architects are defined as follows:
    - **Conceptualization Capability** is the capability to set concepts and conceptual frameworks that will guide the design process towards its final product, evolved by the ambit of the given problem, and by the interpretation of the architect.

- **Form Giving Capability** enables architects to express their concepts and conceptual frameworks into architectural formal propositions and compositions.
- **Representation capability** of architects is the capability to compose thoughts in representative ways through lines, areas, volumes, colors, etc. This capability encompasses two and three dimensional drawing, physical modeling, and coloring capabilities, regardless of the type of media (be it analog or digital) which is used during these activities.
- **Decision-Making Capability** allows architects during the design process to understand, specify, evaluate, and decide how the designed forms are suitable for the required functions, regardless of the media used.
- **Knowledge Building and Retrieving Capability** of architects is the ability to accumulate and retrieve knowledge based on architectural design experience, i.e. the use of architectural shapes and forms, different types of media, building materials, and structural systems.

**2) Implications:**

- Building and enhancing the design capabilities of architects have to be a prominent component of architectural education.
- The fields related to each design capability have to be searched, and be emphasized in architectural education.

## 7-4 Digital Media

**1) Observations and Findings:**

Regarding the use of digital media, the dissertation has highlighted the following points:

- Computer use has been changed from a tool for Aided Drafting to a medium for Aided Design. Digital media use in the architectural design process, has been switched to be questioning or suggesting, not confirming. Their role is exploration of what is being made, rather than illustration of what has been already made.
- The transition of architecture from the two dimensional nature to the three dimensional one, because of the use of digital media, generates deep inconformity between the traditional tools and methods of architectural creation and the novel nature of architectural objects. The potential output of the design process, resulting from the novel uses of digital media, leads to the theory of digitalizing within this process.
- Media and visual design thinking are inextricably related, for certain ideas only emerge with specific tools and from individual uses. For the design-exploration process, three-dimensional modeling is the essence of computer media while sketching is the essence of manual media.
- The three-dimensional nature of digital media helps the architect think and act effectively in the third dimension. In addition to, digital media help presenting the complexity of shapes and forms which can be hardly represented (or never, in some cases) without this use.
- According to the fluency and creativity of the architect in utilizing each medium, and in organizing the interaction of media, the interactive use of analog and digital media introduces a massive array of techniques and methods.
- The trends and concepts behind the use of digital media in the architectural design process can be classified into three major classes: first, Media Interaction (One-Way Interactions, and Multiple Interactions); second, Digitally-Based Media (Digitally-Based Design,

and Digitally-Based Form “Knowledge Based and Form-Parameter Based”); and third, Digital Knowledge through Technical Information and Visual Drawings.

- The main characteristics of media use can be described as follows:

  - **Manual Media Use**: Manual media have the flexibility that allows the architect to start without having a certain idea. The characteristics of analog media use during the design process may encompass the following:

    - Ability to engage both the mind and the hand in the same time and matter.
    - Initializing ideas in fluid and quick appropriate manner.
    - Ability to work with imprecise design-idea or information.
    - Providing creativity and experience of vitality through physical model making.

  - **Digital Media Use**: The sole use of digital media from as early a point as possible in the design process has resulted in emerging concepts of media use which would not have been implemented without the available digital environment and its software.

    Digital media proceed beyond amplifying the design capabilities of architects, to contribute in design activities as partners.

    Within some concepts of digital media used in form generating, the computer under the influence of certain contextual parameters can provide the architect with a set of forms from which the architect chooses responding to her/his creative intents. These computational programs are agile explorers, rather than definers, of architectural composition. To benefit

from these concepts is achieved by using the computational diversity inherent in computer hardware and software to bring conceptual form to computer screen, leaving form suggestiveness of issues, such as social, environmental, etc. for the architect to evaluate.

There are many characteristics of the sole use of digital media during the design process; most of them are included under the following:

- Quick and multiple interdependences of alternative ideas.
- Instantaneous shifts of various points of views.
- Sophisticated calculations of complex operations.
- Ability to quickly and accurately manipulate images or models (cut, copy, paste, scale, etc.).
- Access to images, models, and data of the Internet.

- **Interactive Use of Media:** The interaction between digital and manual media generates synergistic opportunities which transcend by far their own individual strength, because each concept of media use has its own idiosyncrasies, praxes, and territories which are inaccessible by others.

  The use of digital and analog media enhances the design process in cognitive, qualitative, and productive terms through the transition and reinterpretation, within the both types of media.

**2) Implications:**

- Architects should employ the computer as a medium in the exploration of design ideas in the initial phases of the design process, rather than a tool for drawing generating.
- While delaying the validation of the form until it is completely designed, architects should be aware of that the total concentration on the form may: 1) stray the content of design away from important architectural issues, 2) put formalism in the center of concern throughout the design process, and 3) give formalism the priority over main functions of architecture, which man should be provided with (i.e. environmental, social, or structural needs).
- Through the use of digital media, it is required from architects to think, decide, and design in a digital-three-dimensional environment. Thus, programs of 3D modeling, image editing, and 3D manipulating should be the most important component of the Representation capability and the Knowledge Building and Retrieving capability.

## 7-5 Digital Media and Architectural Design Capabilities

**1) Observations and Findings:**

Concerning the impact of digital media on the design capabilities of architects, the dissertation has resulted in concrete observations and contributions as follows:

**a) The dissertation has highlighted the following points:**

- The potential of digital media opens up new possibilities beyond the limited ones derived from analog media. The most significant advances of digital media are acknowledged, when the produced designs exceed architects' expectation.

- The techniques of media use, derived from various models of the architectural design thinking, are quite different. Some architects still prefer the sole use of manual media, while others prefer the sole use of digital media. Between these two concepts of the use lies what is classified as the Interactive Media Use, where the digital use is combined with the analog one, introducing a numerous number of techniques. The two foregoing concepts represent the opposite points on the conceptual scale of digital/manual media use. Steven Holl's designs are examples presenting the first one, and Greg Lynn's designs are examples presenting the second. Designs of Frank Gehry and Benjamin Wood are examples from the interactive use.
- Digital media use may introduce forms that are much more dynamic than what can be created without this use. The dissertation has resulted in highlighting the fact that the approaches of digital media use (e.g. CAD, CAM, etc.) have released designs from the production tyranny of the simple geometric shapes (e.g. rectangle, circle, etc.) to more complicated three-dimensional curvaceous forms (like designs of Greg Lynn, Frank Gehry, etc.), which are beyond the potential output of analog media use.

**b) The dissertation has concluded to the following contributions:**

- **The impact on the Conceptualization capability:** The major trend of the high and very high impact derived from the various uses of media on the Conceptualization capability of the respondents refers to increase of the positive impact of the use of fully digital media. The respondents find that the intensive use of digital media in the initial phases of the design process has a very positive impact. This result contradicts the controversy derived from the synthesis of previous

research regarding the effects of the use of digital media on the nature of design content.

- **The Impact on the Form Giving Capability:** There is a controversy resulting from the field survey, regarding effects of digital media use on the Form Giving tasks. This controversy can be explained, from the synthesis of previous research: the trend of digital media use during form generation (initial phases of the design process) still is not available for many architects, although the use of digital media through programs of form manipulation in somewhat later phases of the design process, offers significant help which is acknowledged by most architects.
- **The Impact on the Representation Capability:** The major trend of the high and very high impact derived from the various uses of media on the Representation capability of the respondents refers to increase of the positive impact towards the use of fully digital media. The sole use of digital media has the highest impact on the Representation capability. This result confirms the synthesis of previous research regarding the positive impact of digital media use on the Representation capability.
- **The Impact on the Decision-Making Capability:** There is a major trend of the high and very high impact derived from the various uses of media on the Decision Making capability of the respondents. This major trend refers to constant increase of the positive impact towards the use of fully digital media. This result of the questionnaire conforms to the synthesis of previous research, regarding the powerful role of digital media use in enhancing the position by/within which architects make decisions.

- **The Impact on the Knowledge Building and Retrieving Capability:** The major trend of the high and very high impact derived from the various uses of media on the Knowledge Building and Retrieving capability of the respondents refers to increase of the positive impact towards the use of fully digital media. Most of the respondents find that the fully digital media setting has a very positive impact on the Knowledge Building and Retrieving capability. This result of the questionnaire conforms to the synthesis of previous research, regarding the powerful use of digital media in the field of knowledge accessibility.

**2) Implications:**

- Each architect should be left to shape his/her own style of digital media use according to her/his style of architectural design thinking and fluency of media type.
- Architects should be equipped with: a curriculum based on multimedia, and the basics needed to face changing technology of digital media. What architects should learn and practice is the concepts behind the heterogeneous uses of digital and analog media in the design process, since learning and practicing specific techniques does not provide architects with what they need to compete with the challenging progress of digital media use.
- Architects should have broad knowledge of different uses of media, and deep experience of a few which fit their own styles of design thinking used in the design process. Consequently, architects will have the ability to generate ideas in various ways and by different types of media, which leads to having the experience to effectively convey

ideas. A well-informed architect should know exactly which medium to use for a particular kind of job.

- Architectural education should constructively emphasize the three above implications.

## 7-6 Future research work

The research has reached to achieve its objectives. However, under the increasingly digitalized use of media in the future, there still remains a set of questions which have to be answered, which can represent the focus of future research avenues:

a) What is the evaluation of different techniques introduced by digital media use on the design process and on the different design capabilities?

b) What are strategic and methodological alterations of our architecture, embodied in the output (building form), ways of practice, and ways of teaching?

c) What are the teaching methods which implement the design capabilities and the use of analog and digital media in the architectural education? In other words, how should digital media be addressed to architecture students?

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# Chapter 9 Appendixes

## 9-1 Appendix 1: The Questionnaire

## 9-2 Appendix 2: Tables of the Number of Respondents

The following tables show the number of respondents for each design capability per various media settings and for each kind of impact per various media settings:

**Table 9-1 The Number of Respondents for Each Digital and Manual Media Settings of Different Architectural Design Capability**

| | | The Total Number of Respondents for Each Media Setting | | | |
|---|---|---|---|---|---|
| | | **Fully Manual** | **One-Way Interactive** | **Multiple Interactive** | **Fully Digital** |
| **Architectural Design Capabilities** | **Conceptualization** | 55 | 56 | 49 | 56 |
| | **Form Giving** | 55 | 56 | 49 | 56 |
| | **Representation** | 55 | 56 | 49 | 56 |
| | **Decision-Making** | 55 | 56 | 49 | 56 |
| | **Knowledge Building and Retrieving** | 55 | 56 | 49 | 56 |

**Table 9-2 The Number of Respondents for Various Digital and Manual Media Settings per the Total Number of Respondents on the Conceptualization Capability of Architects**

| **Level of Impact** | **Number of Respondents per the Total Number for Each Media Setting** | | | |
|---|---|---|---|---|
| | **Fully Manual Media Setting** | **One-Way Interactive Media Setting** | **Multiple Interactive Media Setting** | **Fully Digital Media Setting** |
| **Very High Impact** | 20/55 | 5/56 | 12/49 | 15/56 |
| **High Impact** | 5/55 | 10/56 | 12/49 | 21/56 |
| **Medium Impact** | 5/55 | 14/56 | 10/49 | 0/56 |
| **Little Impact** | 15/55 | 17/56 | 5/49 | 10/56 |
| **No Impact** | 10/55 | 10/56 | 10/49 | 10/56 |

**Table 9-3 The Number of Respondents for Various Digital and Manual Media Settings per the Total Number of Respondents on the Form Giving Capability of Architects**

| Level of Impact | Number of Respondents per the Total Number for Each Media Setting | | | |
|---|---|---|---|---|
| | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
| Very High Impact | 8/55 | 7/56 | 21/49 | 16/56 |
| High Impact | 31/55 | 0/56 | 14/49 | 8/56 |
| Medium Impact | 16/55 | 28/56 | 7/49 | 16/56 |
| Little Impact | 0/55 | 21/56 | 7/49 | 8/56 |
| No Impact | 0/55 | 0/56 | 0/49 | 8/56 |

**Table 9-4 The Number of Respondents for Various Digital and Manual Media Settings per the Total Number of Respondents on the Representation Capability of Architects**

| Level of Impact | Number of Respondents per the Total Number for Each Media Setting | | | |
|---|---|---|---|---|
| | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
| Very High Impact | 16/55 | 0/56 | 14/49 | 24/56 |
| High Impact | 8/55 | 21/56 | 7/49 | 8/56 |
| Medium Impact | 0/55 | 21/56 | 14/49 | 8/56 |
| Little Impact | 23/55 | 7/56 | 14/49 | 8/56 |
| No Impact | 8/55 | 7/56 | 0/49 | 8/56 |

**Table 9-5 The Number of Respondents for Various Digital and Manual Media Settings per the Total Number of Respondents on the Decision-Making Capability of Architects**

| Level of Impact | Number of Respondents per the Total Number for Each Media Setting | | | |
|---|---|---|---|---|
| | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
| Very High Impact | 8/55 | 0/56 | 7/49 | 24/56 |
| High Impact | 8/55 | 21/56 | 14/49 | 8/56 |
| Medium Impact | 15/55 | 7/56 | 21/49 | 16/56 |
| Little Impact | 24/55 | 14/56 | 0/49 | 0/56 |
| No Impact | 0/55 | 14/56 | 7/49 | 8/56 |

**Table 9-6 The Number of Respondents for Various Digital and Manual Media Settings per the Total Number of Respondents on the Knowledge Building and Retrieving Capability of Architects**

| Level of Impact | Number of Respondents per the Total Number for Each Media Setting | | | |
|---|---|---|---|---|
| | Fully Manual Media Setting | One-Way Interactive Media Setting | Multiple Interactive Media Setting | Fully Digital Media Setting |
| Very High Impact | 0/55 | 7/56 | 7/49 | 32/56 |
| High Impact | 23/55 | 7/56 | 28/49 | 16/56 |
| Medium Impact | 0/55 | 14/56 | 7/49 | 0/56 |
| Little Impact | 32/55 | 21/56 | 0/49 | 0/56 |
| No Impact | 0/55 | 7/56 | 7/49 | 8/56 |

## 9-3 Appendix 3: Theories of Problem Solving

Within these two themes, there were many doctrines; each of them is developed benefiting from the previous. The main doctrines were Associationism, Würzburg School, Gestalt movement, and Behaviorism. Associationism's concepts, analysis, creativity was seen to be largely a matter of happenstance, a random kind of event. During the first decade of twentieth century, creative problem solving was thus regarded as essentially purposeful and, therefore, controlled in a manner that was far more circumscribed than by pure chance. In more specific realm of problem-solving theory, the behaviorist position gave rise to, or certainly supported, the development of phase, or rigid-state, models of creative problem-solving behavior [Arieti, 1976, ch. 2; Ghiselin, 1952; Gregory, 1966]. Such behavior was widely acknowledged as conforming to an episodic process consisting of distinct and almost discontinuous phases of activity. The aim of many models, generated from this realm, was to identify and describe each phase and the sequence of phases of problem. These phases were: 1- preparation for the task or situation at hand, 2- incubation, 3- illumination or inspiration, and 4- verification, involving the testing of proposed solutions [Rowe, 1987, p. 42-46].

## 9-4 Appendix 4: Different Kinds of Scanners Used in the Design Process

**Three-Dimensional Scanning**, Different scanners –digitizers- may be categorized by their primary capturing strategy in order to create computer models based on physical models. There are five essential types; the Mechanical Probe, Photogrammetric, Laser-Aided, Phase Shifting, and Tomogramatic Scanners [Entous, 1998]. **The mechanical Probe** captures a series of points in a three-dimensional space using a stylus. The maximum size of objects digitized with this method is limited by the range of the stylus arm. The stylus digitizer is often able to capture concavities. Frank Gehry's architectural office is noted for their incorporation of a mechanical probe or stylus digitizer in their design process. **Photogrammetric** scanners capture a model photographically and most often use multiple views that are seamed together with varying levels of automated assistance. These scanners are used in a similar way as the stylus digitizer but avoid the manual labor involved in plotting each point on the model. **Laser-Aided** scanners' technology scans an object by laser reflection off of a physical model, and creates a detailed texture map of the surface's color. This can scan very large object. **Phase Shifting**, a well-defined and high-contrast moiré pattern is projected on the model and recorded by a video camera. Uneven points on the object produce characteristic changes in the moiré thus permitting determination of surface points. This method is capable of capturing both exterior and interior geometry and passing through an object to find the void spaces. **Computer Tomograms** (CT) produce a voxel structure of an object. Due to the energetic performance of the scanning beam, it is possible to penetrate solid material, the inner structure, connections, and even differentiate between materials. However, the file size can be substantial. There are limited accuracy levels and the images must be transformed from a bitmap imaging system to a CAAD accurate model for architectural purpose [Streich, 1996, in (Entous, 1998)].

## 9-5 Appendix 5: Artificial Intelligence

**Artificial Intelligence**, In such a complex and poorly understood area as design –as general not only architectural design-, there are many research issues. The IntCAD research community now consists of CAD researchers, who use AI techniques to expand the capabilities of CAD systems; AI researchers, who study design knowledge and reasoning; Engineers, who are eager to use smarter tools; and Cognitive Scientists, who study how designers think. Consequently, the literature on AI in Design is spread quite widely. In addition to basic work on representing features, function and other aspects of design objects, it will be necessary to devise ways to integrate these types of knowledge, and integrate them with more 'traditional' representations so that reasoning processes can exploit them fully.

### Using AI Techniques

Some AI techniques might be used to implement functions that play roles in the building of design systems:

1- Knowledge Representation:

In design, many types of knowledge can be used. For example, knowledge about components, knowledge about design requirements, and knowledge about processes are useful. Knowledge about the capabilities of processes is important if the design system needs to select an appropriate method. This can be as simple as picking a prestored plan [Punch et al 1995], or as sophisticated as reasoning about which design method is most likely to be able to produce the desired outcome. Other knowledge can be about which decision should take priority [Stefik 1980], how to decompose a problem [Liu & Brown 1994], or what tradeoffs might be made between conflicting goals [Tong 1987].

2- Constraint Satisfaction:

Constraints can be used to maintain consistency, prune search and to record interactions between sub problems. They can express many things –i.e. design heuristics-. Adding constraints to the design as a result of making decisions is "constraint formulation". The creation of new constraints from old is "constraint subsumption". Decisions can be communicated by "constraint propagation", or by propagating acceptable values or relationship. Propagation enables a "least commitment" strategy. There are several approaches to "constraint satisfaction" -i.e. finding values that satisfy a set of constraints.

Many problems can be solved using these methods [Stefik 1980] (Steinberg in [Tong & Sriram 1991a]; Bowen & O'Grady in [Gero 1990]). In some design problems, variables and constraints emerge during the design [Mittal & Falkenhainer 1990]. The use of constraints to handle large design problems has been criticized as being too computationally expensive, and not a good model of human problem solving.

3- Search:

In general, design cannot be completely modeled by a standard heuristic search, as evaluation functions are not always available, and as, at best, several search spaces are

required, such as: possible plans, possible configurations, and possible combinations. In addition, not all problems have fully specified requirements that can act as goals or goal recognizers for a search. However, despite the often-exploratory nature of conceptual design, much of design can be described as search.

4- Learning:

Some researchers, especially those interested in automatic generation of design tools, have used a learning mechanism with a simple search to learn problem decompositions, or with Generate & Test to improve the generator by moving knowledge from the Test back into the generator ([Tong 1990] for references to these and other systems). These are examples of Knowledge Compilation systems, which learn in order to increase efficiency [Keller 1991] [Brown 1991].

5- Case-based Reasoning (CBR) & Analogy:

The direct or analogical use of previous designs or design plans can reduce search and improve quality by taking advantage of stored experience [Maher et al 1995] [Maher & Pu 1997]. Mostow [1990] discusses the replaying of design plans, and compares some systems, including BOGART and ARGO (Mostow et al, and Huhns & Acosta in [Sriram & Tong 1991]), according to how cases are represented, stored, retrieved, and adapted.

Case-based design is also discussed by Sycara et al, and by Goel (both in [Sriram & Tong 1991]). Gero [Maher & Gero 1990, p. 26] proposes that design cases and all other design knowledge be organized into Schema for efficient access during design. Goel [1997] provides an overview of the use of Analogy in design, while Maher and Gomez de Silva Garza [1997] give a similar overview of CBR.

7- System Architectures:

Blackboard-based architectures are useful for the integration of many sources of knowledge, such as in building design (Sriram et al in [Tong & Sriram 1991b], and Schmitt in [Yoshikawa & Holden 1990]). Rule-based or Grammar-based [K.Brown 1997] methods are often used for individual sources of knowledge.

Groups of multiple, autonomous knowledge-based systems can be used to build Multi-Agent Design Systems (MADS) [Lander 1997]. These systems may also incorporate legacy systems such as databases and solid modelors. These systems allow distributed and asynchronous designing; such as can be found in Concurrent Engineering design teams. MADS architectures include those that have the agent relationships decided a priori, and those that are organized dynamically: by making bids for tasks, for example.

## 9-6 Appendix 6: Genetic Algorithms

**Genetic Algorithms** (GAs) were invented by John Holland and developed by him and his students and colleagues. Idea of evolutionary computing was introduced in the 1960s by I. Rechenberg in his work "*Evolution strategies*" (*Evolutionsstrategie* in original). His idea was then developed by other researchers. And this lead to another step of Holland's book "*Adaption in Natural and Artificial Systems*" that was published in 1975. In 1992 John Koza has used genetic algorithm to evolve programs to perform certain tasks. He called his method "genetic programming" (GP). LISP programs were used, because programs in this language can expressed in the form of a "parse tree", which is the object the GA works on.

From [http://cs.felk.cvut.cz/~xobitko/ga/]

The use of Genetic Algorithms (in conjunction with Grammars, for example) and Simulated Annealing is very promising. Algorithm is started with a **set of solutions** (represented by **chromosomes**) called **population**. Solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected to form new solutions (**offspring**) are selected according to their fitness - the more suitable they are the more chances they have to reproduce. This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.

**The Outline of the Basic Genetic Algorithm:**

[Start] Generate random population of *n* chromosomes (suitable solutions for the problem)

[Fitness] Evaluate the fitness *f(x)* of each chromosome *x* in the population

[New population] Create a new population by repeating following steps until the new population is complete

[Selection] Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)

[Crossover] With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.

[Mutation] With a mutation probability mutate new offspring at each locus (position in chromosome).

[Accepting] Place new offspring in a new population

[Replace] Use new generated population for a further run of algorithm

[Test] If the end condition is satisfied, stop, and return the best solution in current population

[Loop] Go to step 2

From [http://cs.felk.cvut.cz/~xobitko/ga/].

## 9-7 Appendix 7: Shape Grammars

**Shape Grammars** specify a mechanism for performing recursive shape computations. A general paradigm is established for a computer implementation supporting this computation in the algebras of points and lines in two-dimension.

Shape grammars naturally lend themselves to computer implementations: the computer handles the book keeping tasks of the representation and computation of shapes, rules and grammars and the presentation of correct design alternatives, while the designer specifies, explores, develops design languages, and selects alternatives.

**The process of developing and using a shape grammar can be divided into several logical phases:**

1. *Creating and modifying the shape grammar*. The designer creates the rules and initial shape, and verifies or changes the spatial and logical constraints.
2. *Compiling the gramma*r. While converting the grammar into internal form, the system checks that each rule always applies in only a finite number of ways.
3. *Exploring the language of designs defined by the gramma*r. The designer explores the language of designs, generating designs, imposing additional constraints, halting the generation process, backtracking to a previous design, or saving the current state. The designer may interpret the resulting designs in a curvilinear world and use them as the basis for a design.

From [http://ceca.uel.ac.uk/cad/cookbook/sg.html].

Stiney's formalization of the shape grammar provides a semantic model with a compressed representation of architectural form (Stiney, 1978, 1980). The discipline of space syntax, developed by Hillier provides analysis of spatial configurations with empirical data that could be developed into fitness criteria (Hillier et al., 1984, 1993, and 1996) .

From [http://www.vterrain.org/Culture/shape_grammar.html].

## 9-8 Appendix 8: Generative Design System

**Generative System (GS):** Generative design is the systematic exploration of alternative solutions by specifying different combinations of elements taken from a fixed vocabulary [Mitchell, 1977]. Generative design describes a broad class of design where the design instances are created automatically from a high-level specification. Most often, the underlying mechanisms for generating the design instances in some way model biological processes: evolutionary genetics, cellular growth, etc. These artificial simulations of life processes provide a good conceptual basis for designing products. One of the more popular of these mechanisms is evolutionary programming. Early experiments of applying these genetic algorithms to design tasks required expensive massively parallel computers to generate and evaluate the many thousands of generations of design instances, where each generation would consist of hundreds of individual instances.

From [http://www.fek.su.se/home/rgi/public/bbd_1999-03-10.pdf]

Model of a Generative Design is based on the concept of a Generative System. A generative system consists of : (1) a scheme for representation of potential solutions, (2) a set of operators that map from one state of the system to another, and (3) a set of rules that govern the selection and application of the operators.

From [Mitchell, 1977].

**Generative Design System (GDS)**

At its most basic, a Generative Design System (GDS) consists of four elements: (1) the design representation, (2) a generation engine, (3) an expression engine, and (4) a mechanism for evaluation and selection of the newly generated design specifications

1. Representations: In an evolutionary-based generative system, design representations are specified as a set of parameters and a corresponding set of constraints. The parameter-set forms the 'genetic' elements of the design. It defines the form and structural aspects of the design instances. Added to this is the constraint-set, which controls the aesthetic and fabrication aspects of the design. These rules limit the range of generated design descriptions.
2. Generation Engine: The generation engine is the mechanism that actually generates new design instance descriptions. An evolutionary based generation engine takes a set of prototype design descriptions (or parents) and uses an algorithm to recombine their parameter sets into new design descriptions (children).

   Commonly these generation algorithms utilize operations that emulate the concepts of crossover and mutation in genetics. Crossover ensures that the new descriptions draw from the pool of parameter values in the prototype set. Mutation adds a random element in which parameter values not found in the prototype pool will be introduced into the system.
3. Expression Engine: The expression engine is an interpreter, which translates a design description and renders it into a perceivable structure. For humans this normally translates to visual, aural, and tactile form. This expression process can be modular, and

hence able to support multiple alternative interpretations of the resulting design description.

4. Evaluation and Selection Mechanism: The GDS approach centers on having a means (or objective function) for evaluating the fitness of design specifications generated by the generation engine. In the area of creative design, this mechanism is most often embodied in the human user of the system. This 'human-designer-in-the-loop' approach is preferred, as it offers a more robust, intelligent, and subtle analytic capability than computed functions and is often a better match for the range of possibilities of the generative approach where this person-in-the-loop is the original designer, the additional refinement of the base representation itself is possible.

Practical application of these techniques is today made possible by a combination of the widespread availability of fast inexpensive computer hardware and an approach that relies on a human user to evaluate and select the viable design instances. Generative techniques are today utilized in a new generation of design tools including **MetaCreation's *Bryce* and *KPT Texture Explore*r**, **Animatek's** *WorldBuilde*r, **Emergent Design's *CityScape Ambient Design Agent* and *ED Workbench* technologies** [Pontecorvo, 1998]. Other existing applications and experiments include Cyberlife's *'Creatures'* Computer Game, Karl Sims' 1991 Animation *Panspermia* [Sims, 1991], and the Art of William Latham [Latham, 1992]. In the past few years an increasing number of motion picture special effects use some form of generative techniques. These effects include animal flocking motions like in Disney's Mulan, crowd scenes as in Paramount's Titanic and live action animation hybrids as in Spielberg's Jurassic Park. The list of experimental application of generative techniques to physical design includes Argenia, a system for architectural design by Soddu [Soddu, 1997], airfoil optimization [DeFalco et al., 1995], clothing design [Nakanishi, 1996], and an experimental test-bed for consumer controlled generative product design by Emergent Design [Pontecorvo, 1999].

From [Breed Better Designs: the generative approach, http://www.fek.su.se/home/rgi/public/bbd_1999-03-10.pdf]