Bagh-e Nazar

Bagh-e Nazar, 19(113), 99-116/ Nov. 2022
DOI: 10.22034/BAGH.2022.319442.5068

Persian translation of this paper entitled:
نقش ابزارهای طراحی در کیفیت ایده‌پردازی و ارائهٔ طرح‌های معماری
published in this issue of journal

Original Research Article

Examining the Role of Design Tools in Quality of Ideation and Presenting Architectural Designs

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Received: 26/12/2021 ; accepted: 12/06/2022 ; available online: 23/10/2022

Abstract

Problem Statement: The various design tools, which have received attention and have been used in educational structures and professional activities of architects, undoubtedly influence the design process, from the incidence of reinforcement aspects in ideation to presenting architectural projects. Hence, such tools must be chosen within the context of logical and unbiased interactions to identify their strengths and weaknesses.

Research Objective: The extant study aimed to identify and compare judgment criteria for design tools to improve the design and guide designers in choosing appropriate tools that are matched with various topics or design progress steps.

Research Method: The present paper was conducted based on futurology. The Delphi method was an approach adopted to identify experts' consensus. To this end, the factors affecting design tool selection were examined. The subject was studied and identified over three discussion courses by using binary matrixes for structure evaluation through the hierarchy method.

Conclusion: Design tools have various forms and potential. Each aspect of precision, ambiguity, functional simplicity, accessibility, and flexibility is evaluable based on the design topic and designers' inherent talents. Thus, it is not a smart action to be decisive in selecting a tool or insisting on a specific feature regardless of factors affecting design, designer(s), and design step.

Keywords: *Design Tools, Architectural Expression, Freehand Design, Digital Architecture, Maquette.*

Introduction

Finding a method for effective education is one of the main concerns among architecture instructors. This concern has led to the advent of much research and studies on this case. Some studies have focused on the interaction between individuals and existing tools for ideation and high-quality presentation. This is an identifiable case despite the theoretical dualities of the architectural process in rationalist and empiricist models due to the processing of ideas using different expression levels and the

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influence of perception in the intermediary role of design tools (Rezaie, 2014, 24–25).

Architecture is a multidimensional phenomenon with a sophisticated nature, and architectural design is also a multifaceted and indescribable process for the designer (Hosseini, Falamaki. & Hojat, 2019). In the opinion of Lang (2007), design is an analytical process that requires analysis, evaluation, and selection; therefore, in this case, it needs interaction between the individual, the design process, and finally, the architectural work. Hence, architectural knowledge depends on its specific tools to depict thoughts, convey concepts, etc., like any aspect of human life. This point in architecture education provides the field for a mutual connection, i.e., influencing and impressibility between tools and the design process. Juhani Pallasmaa believes that a design tool must keep the nature of ambiguity and imagination in it so the abstract design can contribute to the development of concepts of meaning in architectural design (Pallasmaa, 2016, 103–104). Moreover, Khiabanian assumes that architectural design is the most important knowledge and skill that architects use to express themselves and their thoughts and ideas. This expression is manifested through light, fabric, form, color, line, dots, and levels using design tools.

It is natural that humans become interested and connected when interacting with tools. Repetition of this path in similar processes influences individual judgment about tools; this case is observed in design but also in other functional aspects. However, this is an important case when selecting a tool for a person who does not have much architectural experience and is at the starting point of the learning route. All auxiliary tools can direct the design path and cover a person's capabilities and inabilities through this process. Regarding the diversity of individuals and talents of every generation in the architectural area and selection uncertainty, design tools must be investigated and criticized in a discussion context to identify effective aspects of each tool.

Design education in architecture schools and the presence of various tools have been crucial issues in the present era; hence, it is essential to find these tools, learn how to apply them, identify their features, and use them in different design situations. Therefore, design tools play a vital role in improving the quality of ideation and architectural design presentation.

Because there are various design topics with different functions and factors scoring the effect in each period, studies on design tools must be revised in terms of each generation's inherent and acquired potential. This issue is not a constraint but leads to research repetition. Accordingly, the main question of the study asks:

What factors and elements in the structure of a design tool can improve creativity and ability to work or prevent design errors and costs within the architectural design path regardless of the designer's attachment to the considered tool?

Research Background

Courses on how to use tools that can help humans in their daily affairs undoubtedly interact with understanding challenges and studying solutions; hence, there is reasonable equality between every tool and its attitude. In this case, it is possible to find the research aspect of peripheral studies on design tools through the scope of architecture education in Iran, which has about a century of history in the academic field. There are three courses for design tools in architectural design: pre-computer, competition with the computer, and design through the computer. These courses have been filed herein.

In conventional literature, design tools are divided into two groups: manual and computer tools. This case has been performed based on the instructors' focus and attention to manual drawing tools in architecture schools and faculties because they believed in enhancing students' mental creativity and insight. However, computer software and digital technologies have appeared in architectural design tools over recent decades, so architectural tools have become a debatable issue in the new era (Asefi &

Imani, 2017). In the past, design tools were based on the verbal history and documents of architecture education courses in the middle of the 13th century (e.g., an architect's life memories), pointing to maquette-based design. Some of Ali Akbar Saremi's writings in the book "Weaving in and out and still: my story and our architecture" are some examples (Saremi, 2010).

An unfair approach to manual tools can be seen in the research papers published in the last decade on the interaction between manual and computer tools in the 1380s (1960s) in Iran. On the other hand, Koleini Mamaghani and Azimi (2011) studied design from the shared viewpoint of associated disciplines and introduced manual sketches as effective factors in the precision and accuracy of design's functions and relations in their time scope. They found computers ineffective in this area, despite their numerous features.

Moreover, Gharibpour (2008 & 2014) carried out an analytical comparison of drawing by hand and computer; she concluded that design by hand is more efficient due to its close connection with mental creativity, while design and drawing by computer are effective for introduction and presentation.

It can be pointed out that an important part of architecture education and knowledge is done through handicrafts and manual experience, through which students acquire trial and error and re-fabrication experience when learning by doing, according to Farzian & Karbasi (2014).

Gradually, the realization and embodiment of computer design and the existence of architectural fab labs in Science and Technology Parks and some Iranian universities led to great attention to smart computer architecture in the 1970s.

Computer-based design became popular again for some reasons: three successive books by Khabazi (2012; 2014 & 2016); Ph.D. dissertations by Naser Khaki (2009) entitled "the role of the computer in the architectural design process: a comparative study of two generations of contemporary Iranian architects"; and Kaveh Shokouhi entitled "Effect of using the computer in early stages of the architectural design process"; and the advent of digital architecture technology disciplines in Iranian universities.

The consensus seen in the 2020s' new studies does not negate the creativity of computer-based design but also introduces innovative strategies and new creative routes for computer-based designs.

However, this issue has been at the center of attention in terms of initial costs and unpopularity; therefore, Asefi and Imani (2017) recommend using relevant software for high-quality ideation and presentation (rendering) in academic and professional climates, besides the requirement of a powerful computer system (rather than the computers used for ordinary and daily affairs), and the student or designer's knowledge about how to use various design software.

According to reviewed literature and studies, the existing papers have examined design thoughts based on the common tools without comparing the case based on the tools' potential in current conditions without any specific bias and moderate judgment. Therefore, each architectural design provides specific pros and cons and capabilities based on their specifications, so people can use them based on their needs. In the case of manual design tools, architects present their purpose and concept of design to audiences through manual sketches, maquette fabrication, freehand designs, drawing, and Rendu (artistic rendering), for example. Moreover, digital technologies in architecture propose a useful tool to register ideas, design 2D maps, three-dimensional volumes, etc.

In general, it can be stated that two groups can be identified and introduced in the reviewed literature. The first group includes studies on the strengths and weaknesses of design by hand and computer due to higher education actions and reactions over the last three decades. The second group encompasses studies on the design nature, expressing components affecting the design process with such tangible literature. Accordingly, the first group of studies has been included in the literature review because of

Table 1. Persian studies on design tools regarding bias around design tools. Source: Authors.

Period	Time scope	Author(s)	Conducted studies
1	Before the 1990s	Documents gathered from architects' memories and verbal history of architecture education in Iran	Attention to maquette and freehand design (sketches), short-time sketches' concepts, drawings on Calc paper, etc.
2	After 1990 and especially late 2000s	Gharibpour (2008) Doroodgar (2009) Koleini Mamaghani & Azimi (2011) Gharibpour (2014) Farzian & Karbasi (2014)	Comparing design using drawings based on manual and computer tools Expressing the adaption of manual techniques regarding the designer's subjective process and perceptual ability Adopting the computer as the rendering toll in final maps and design documents Hand-based design and maquette fabrication are important.
3	The 2010s	Naser Khaki (2009) Khabazi (2012; 2014 & 2016) Golabchi, Ednji Garmaroodim & Bastani (2012) Hashemnejad, Ekhlasi, Saleh Sedghpour & Shokuhi Dehkordi (2013) Shokuhi (2014)	Considering the computer as a smart tool with repeater and creative algorithms Introducing the computer and parallel processing speed of 2d and 3d documents Developing new forms and definitions of digital fabrication based on computer attitudes

the relevance and focus of the first group's studies, while the literature of the second category has been used in theoretical foundations to identify criteria for evaluating design tools.

Theoretical Foundations

In the case of design tools, there is a wide range of elements influencing the process, so this case does not have only an external structure but begins with the mind process, the brain's inherent talent, type of speech, and words. According to the literature, language is the most crucial and first tool for human expression (Hassanzadeh Nayyeri, 2000, 58), which is the starting point of the route, and the rest of the tools are involved based on their presence in two ideation and design product rendering areas based on their diversities (simple or technological, actual or virtual, 2D or 3D structure). In other words, design tools can be defined based on a spectrum from latent thoughts of a mind (that are achievable in raw forms using new knowledge) to maquettes in actual dimensions and even the final body of an architectural design.

Speeches are formed in architecture and design either by a designer or a 'design though' host [1] at the most primitive ideation level. These speeches can be conveyed by describing the space in question [2] using body language. This requires words' or literature's potential to convey messages or desires of the designer or audience of design projects. Continually, we build, compare, save, and share mental or neural models that have been provided and fostered through linguistic structures and words (Pallasma, 2016, 38). Because this case needs design development and design accuracy, various tools must be used in the scope of this intellectual exchange.

The rendering tools can be classified into four categories regardless of rendering method or product viewpoint [1] based on the definition mentioned above:

- Mental and linguistic structure-based tools
- Drawing-based tools
- Computer-based tools
- Maquette fabrication-based tools

Choosing an appropriate tool for a design has been a valuable concern resulting in discussion on tool selection. For instance, Kurt Hanks and Larry Belliston talk about a continuous cycle in the dependent design and drawing process of four elements: mind, hand, eyes, and image in drawing literature that is divided into various types due to the flexibility of drawing tools (Hanks & Belliston, 1977, 14), and this cycle considers design tools valuable considering two specifications: continuity and ambiguity, leading to the imagination (Gharibpour, 2014, 6). This claim that hand-drawn design literature from the 1990s to 2010s in Iran has criticized the computer tools indicates other criteria for tool selection, including speed and immediacy.

This claim, however, has not been the same in different design process intervals (initial ideation, development of documents, and design completion), and the computer has shown many positive aspects in terms of its capacities to edit, repeat, etc. (See Gharibpour, 2008, 11).

The development of digital architecture and mind translation for computers contributed to less disorder in Hanks and Belliston's cycle considering computer interface. This, however, severely reduces the speed of writing algorithms as system language. But the development of computer and parametric design methods (Khabazi, 2012, 14) gradually revealed two other attributes**:** "accuracy" and "process flexibility." John Zeisel introduces three imaging, presenting, and testing areas for the design process and design information management to determine various objectives for gathered data (Zeisel, 1981). These three areas that are influenced by design tools inherently include a cycle of two needs: "editing" and "flexibility" in the design proce**ss,** and "design perceptibility" in each stage of presenting and testing.

On the other hand, the design also faces various theoretical dualities, such as rationalism against empiricism, process orientation against product orientation, and normative versus positive (Rezaie, 2014, 23). In this case, theorists judge efficient tools based on the attitudes mentioned above.

According to rationalist and systematic literature, stepwise design requires "accuracy" and "simple reading" to move next step(s), while it depends on the "speed," "simple and inexpensive access," and "mind fusion" in empiricist literature. In this case, some individuals like Juhani Pallasmaa consider the lack of "precision" in manual tools as a privilege and a platform for the "emergence of ambiguity" (Pallasmaa, 2013, 104), or call this case prone to the development of neurons and the advent of intuitive ability in limbs and hand art (ibid., 38 & 56).

In process-oriented literature, the emergence of each step and the talent for using tricks to deal with the case are admired, so flexible tools are considered. Despite the theoretical difference between the opposite view and flexibility in product orientation, this gradually contributes to finding a solution (Lawson, 2016, 53).In terms of design education, architecture students and learners must learn three skills: visualization, representation, and performance in a design workshop. Because the reasoning system is not linear and 2D or 3D explorations create problems and solution interpretations and reflections, tools must be capable of progressing and having a volume of effective impact (Zandi Moheb, Dejdar & Talischi, 2020, 7). Accordingly, the "simultaneous production" criterion or "design tangibility" metaphor in Pallasmaa's literature can also be seen in this thought.

This case also exists in other keywords of design theorists so that this issue is seen in the complete intervention of perception in 3D tools such as maquette (model). In this case, Pallasmaa considers virtual modeling incomparable with tangible and actual modeling (Pallasmaa, 2013, 63). This topic, however, can not be discussed assertively under the development of computer and interface tools (Picon, 2013, 70).

Undoubtedly, dependence on existing tools used by researchers affects the tools' evaluation in extant literature. Hence, an unbiased investigation must be conducted regarding the requirement of interaction in design and the proportion of diverse talents in the work creation process, which is one of the origins of modern architectural education in the 21st century (Asgari, Nasir Salami, Soltanzadeh & Hashemzadeh Shirazi, 2019, 127).

Investigation of design tools in the selection process requires knowing a wide range of common tools. Therefore, authors have strived to propose a summary of tools' definitions to make the comparative literature more tangible.

Mental and linguistic-based tools

A language can be divided into two levels: basic (old) and advanced (based on modern technologies). As mentioned before, the designer had to introduce

the design based on their words of mother tongue or second language at the basic level or they had to move their bodies, like a pantomime actor, to show their thoughts. At the basic level, designers could use a combination technique of introducing the idea while using words or moving limbs (body language). This could be introduced in the expression process by showing some examples of the designer or employer's desires or confirmations to enhance expression function (e.g., showing images or referring to present forms). This auxiliary trick has been developed in the design process, so it is introduced as a solution for introduction or ideation entitled "collage."

Collage is a technique used to present space and also a method to produce space and design (Rezaie, 2014, 216). Collage is an intuitive method that fosters creativity by building self-confidence and mental sparks (Adibi & Karimi Moshaver, 2010), which can be used in various techniques, such as paper collage, drawing collage, photomontage, and digital collage methods (Shield, 2013) in combination with other design tools' potential.

At the same time, college or auxiliary references in the expression process at the advanced level have been prepared by understanding this need in some techniques to read thought by using new tools. A designer's mind can be read and perceived rapidly by simulating a virtual world (Shahsavar, 2014, 2). This type of perception can be examined in three categories:

Virtual reality: The introduction of virtual reality is the brief introduction of some new design tools that have been planned to enter the virtual world. The following classification has been made based on the presence of the person and the potential of each tool:

Placement outside the space

Placement inside the space (movement in the space)

Soft space (experimental space, memory space).

Soft space is the same as placement inside the space. It is a fully virtual space, like computer games that help designers enter a soft world with hats and clothes (mostly on their hands) equipped with different motion sensors. In this case, the designer can build the space in question by rotating inside the space and moving surfaces and volumes (Figs.1&2). It is worth noting that the virtual reality trick is now used more in idea presentation meetings (such as defense meetings for a final plan of students). However, the growth and development of smart tools and the development of algorithms influenced by artificial intelligence have led to the application of these tools in the design process[2].

Drawing-Based Tools

In the Persian dictionary, drawing means the art of illustrating forms or objects on a surface, mainly plotting lines with a pencil, while it means an instrument in architecture schools to draw from different pencils to computer software.

Drawing is a popular method for architectural expression, which has been the center of attention

Fig. 1. Virtual reality and augmented reality in urban development. Source: Shahsavar, 2014.

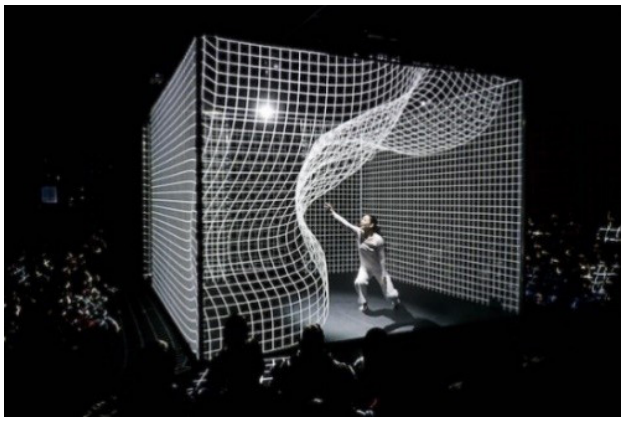

Fig. 2. Soft space in Hakanai program. Source: Mondot & Bardainne, 2013.

since the early years of architecture education at the Fine Art School of the University of Tehran. It is still seen in all architecture schools' curricula under the educational system approved by the Ministry of Sciences and Technology in 1999. This case is common in Iranian architectural education but is also influenced by architectural education in older schools such as Bauhaus and Beaux arts (Hojjat, 2012, 165). Hence, drawing and drawing skills encompass a broad area of architectural design. Therefore, drawings with non-computer tools are covered in this section (Table 2), then the computer-aided drawing is explained.

Compared to the previous method, drawing is used in both the ideation and rendering steps. In this case, drawing can play a vital role as an artistic work, creating accuracy and precision in presenting technical documents or design engravings to generate an idea.

In the third category, drawing tools ask for idea generation and design, which are the main reasons for the existing study. These tools are divided into two parts: tools without form (unformed) and tools with a basic form. Unformed tools include different drawing instruments based on their chemical structure, divided into three relatively overlapping groups: unformed dry-based tools (pencils, charcoal, pastel, etc.); unformed concentrated wet-based tools (pen, Rollerball Pen, Rapid, fountain pen), and unformed diluted wet-based tools (oil paint, Gouache, Ink Wash, and watercolor). However, the basic forms of drawing tools are ingle rulers (ordinary, Set Square), types of geometrical forms' templates, parallel line or curve templates, compasses, and color pistols.

Based on their applications, unformed tools can strengthen the design process, design specification, and diversity (Abel, 1988, 162).

Although the main origin of drawing tools has shape and form and helps designers in technical drawings, these tools can also be used in the design process. Tools with basic forms' structures are the same as tools mentioned above in drawing work on paper, but those designs that use such tools show their features due to their fixed shapes.

- **Computer-based tools**

After computers were used in absolute and engineering discussions, they appeared in design sciences with a delay. Meanwhile, the production of computing systems began at technical drawing levels, which itself became a transition heritage of a type of design with drawing software dependence. However, artificial intelligence has led to increasing computers' potential in entering design scope more than daily drawing.

Although computer drawing software was formed to process maps and prepare them for the implementation step, a close connection appeared between architecture students, designers, and computers in Iran and the world due to "frequent

Table 2. Differences between artistic, technical, and design drawings. Source: Gharibpour, 2008, 326.

	Artistic	Technical	Design
Common tool	Freehand	Drawing tools, complementary visual-textual signs	Freehand
Precision	Low	High	Precise, but free
Value	Artistic aspect, drawing tool, drawing method	Precision in the accurate and exact exchange of information	In showing the design process, development, forming, and showing its empirical qualities
Templets	Painting-sketching	Plan, façade, cuts, and various perspectives	Fluid in different templets
Objective	Showing how the person sees the environment and understands aesthetics in art and architecture	Preparation and registration of plans for construction and implementation	Externalization, expression, and evaluation of the designer's thought
Main difference	Liable and expressible	Descriptive and instructing	Productive, evaluator, and developer

comebacks," and "difficulty in keeping continuity in design's components," "complexity of searching for different solutions for the problem," "extent of design-related topics," "costly assessment of problem's solutions," and "alleviating the interaction with design context." Accordingly, three techniques for using computer-based tools are mentioned herein. The first category includes drawing software (such as AutoCAD), the second category includes computer-aided analytical software[1], and the third category comprises computer-aided design (CAD) software (Khabazi, 2012, 15). The first category of computer-aided drawing software includes software that prepares the design and modeling process for the designer by providing some allegories, such as dots, lines, surfaces, and volumes. Using such software, designers design based on their minds; in this case, it is important to understand software language knowledge to accelerate modeling. This is a challenge in the display cycle.

The second category of computer-aided analytical software includes software that creates defined computations with their engines to test design regarding structure or energy feasibility. This software provides a computational quality with a velocity and precision higher than the human designer's mind.

The third category differs from previous categories and designs by creating reasoning and information space inside the computer. In previous techniques, human brain ideas were shown by an interface after they were imagined, while in the third technique, the computer uses reasoning algorithms in design as a platform for artificial intelligence. This technique is called contemporary computation or computer-aided design; computers are designed after modeling digital understanding infrastructure in introduced parameters. In this design, design types are categorized as semi-intelligent or fully intelligent. However, this design is at experimental levels in some cases.

"Infinite repetition," "data bank preparation," "process simulation system," "formal and semantic instruments," "dynamic memory," "parallel progress of solutions," and "multiple communications" are undeniable advantages of the new technique.

- **Maquette fabrication-based tools**

According to historical documents, the oldest application of maquettes and models in architectural design belongs to the Renaissance period in the world (Prina & Demartini, 2011, 136) and the Safavid Era in Iran (Hosseini, 2010, 65). On the other hand, the maquette can use some senses, such as touch, in its functional process. Therefore, it can be stated that architecture that is a means for deepening the world can be manifested through action by the material embodiment (Pallasmaa, 2013, 121).

Hands are the eyes of a sculptor, but they are also used for thinking (Pallasmaa, 2014, 70). The hand moves based on thought. Each hand movement comprises a thought element (Heidegger, 1977, 357).

The eyes can interact with other senses. All senses, including eyesight, can be considered extensions of the sense of touch. As specialized branches of skin, they determine the shared surface between skin and the environment, between vague internal parts of the body, and the external appearance of the world (Pallasmaa, 2014, 54).

Maquette industries (model-making industries) strive to reinforce this scope, like other techniques, by providing amenities in maquette devices and relevant materials. In the case of design maquettes, this technique can be divided into maquette fabrication using old and modern technologies based on the extent to which modern technologies are used in processing a maquette.

Maquette fabrication with old technologies is classified into common modes based on the maquette size: soft materials (e.g., mud, gypsum, gypsum and soil, wet wipes, rock wool, glass wool, and petroleum products), surfaces and plates (various types of plast-o-foam, foam, foam board, board, balsa wood, different kinds of cardboards from thinnest to maquette cardboard, etc.), full hard volumes (materials that can be used to fabric the final

product by changing their forms such as ice, Plast-o-foam, etc.), and hard modular volumes (sugar cubes, matchsticks, pre-made wood cubes).

Maquette fabrication with modern technologies is done with four digital models: layout, injection, cutting, and tooling (Golabchi et al., 2012, 173). In general, maquette fabrication using old technologies is recommended in the ideation step because it makes it possible to be active in most educational spaces, while maquette fabrication with modern technologies is more suitable for the rendering or presentation step. However, maquette fabrication with modern technologies can be used as a tool in computer-aided design to develop design ideas in the test step. The origins of modern and new technologies are identical, which can be seen in the adjustment of old and modern model making. In the opinion of Zubin Khabazi, the significant point is to prefer practical laboratory experience or practical research to theoretical or bibliographic research. Digital architecture and digital fabrication experience contribute to the practical experiences of space (Khabazi, 2014, 139).

According to general ideation methods using maquettes, soft materials, and volumes have higher flexibility, so they can provide better coordination in velocity of interaction with the designer's mind. On the contrary, plate and modular maquettes provide a simpler design system organization and easier support than the first group.

Research Method

The extant study was done based on the futurology approach and the Delphi Method to organize and connect thoughts to discover the Analytic hierarchy process (AHP)[3]-based on innovative ideas. This study was performed to achieve a more realistic vision and simultaneously consider qualitative and quantitative criteria and decision-making processes in a multi-criteria space.

In this method, screening was done based on the experts' and scholars' ideas by employing instructors and designers who were familiar with the research question. Because validity and reliability of study are not based on the opinions' quantity in Delphi technique but rather on the considered experts' confirmation, the validity of the extant study was confirmed because it included clustering step and experts participated in the process of discussion with authors.

The most important step in the Delphi technique is selecting experts who know the topic. However, this was a relative case because of the emphasis on unanimity of audiences based on the research approach (Alizadeh, 2014) (regarding the introduction of the second category by the first group). Therefore, ideas from the first period influenced the entrance of the second category of this research.

The initial interview was done with elites, so this research discussed evaluation components among design tools (Fig.3). According to the incompatibility of experts' opinions in valuating components that are dependent on the design topic, the case led to an analysis of the results of consensus on a design with a definite subject (commercial and recreational complex) and an assumed context (northwest side of Chitgar Lake in Tehran, Iran). However, each tool is analyzed and examined based on the considered variables.

In the second round, first and second (suggested by elites in the first group) groups participated in research to analyze the initial evaluation of tools in terms of "physical structure," "learning literature," " the way they should be used," and "comparing willingness rates in educational and professional spaces within two recent decades." In the third round, hierarchy assessment was used to compare the tools in question based on the theoretical foundations of this study.

To identify experts, the preliminary list was proposed to help the focus group understand the problem; this list comprised 24 experts in the next step; these individuals were consulted to ensure they had a relevant specialty. Of them, two groups were chosen in the first round of study.

Ten experts were chosen from two groups and participated in the first round of research. The first group included university professors who knew

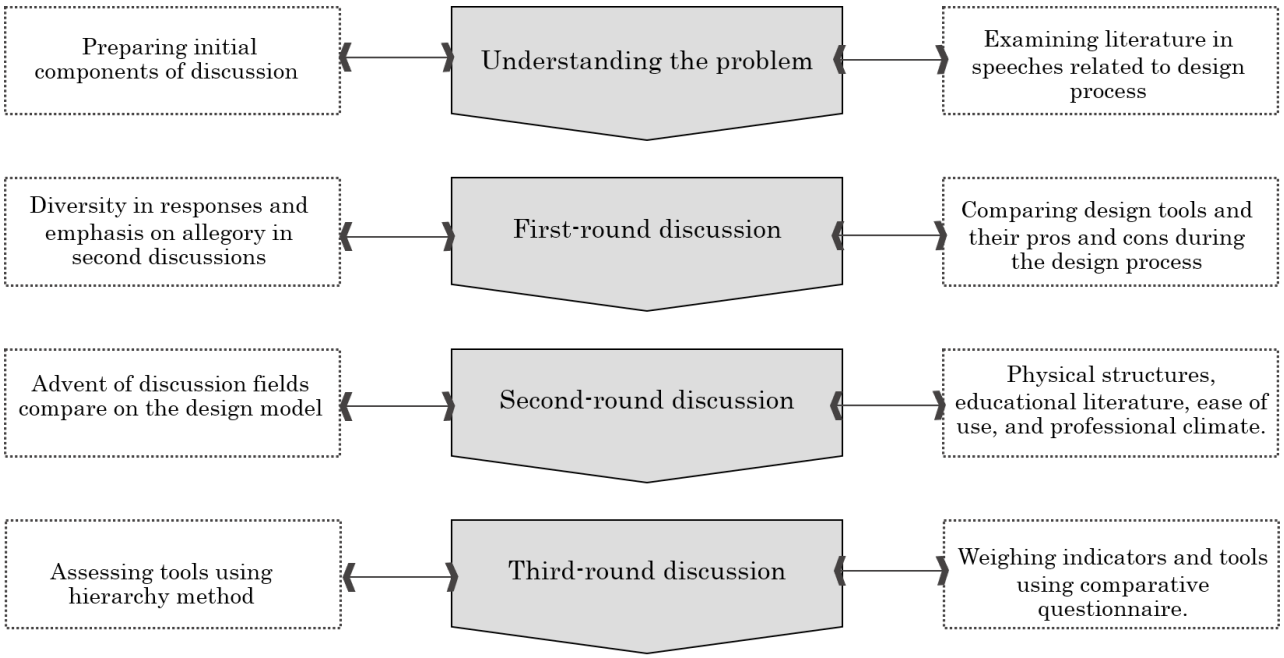

Fig. 3. Operational steps to research. Source: Authors.

design tools and used them to teach architectural design; they were also highly adept at computer-aided design and freehand design. The second group comprised skilled experts in professional environments and met three conditions: "leading a design team," "earning a rank in national and international competitions over the past five years," and "familiarity with diverse tools."

In the second round of study, experts of the first step suggested involving the third group in the research process; finally, feedback of 16 members (out of 20 members) was taken to distribute disciplines, experience, and education, and their ideas were inserted into the hierarchy method (Table 3 to 6).

It should be noted that reliability in the hierarchy analytic method is replaced with an inconsistency ratio, which indicates possible contradictions and inconsistencies in the Paired Comparison Matrix. If the inconsistency ratio is less than 0.1, the comparison matrix is confirmed; there will be conflicts between experts' judgments and evaluations, otherwise. For this purpose, relevant analytical software was used to calculate the inconsistency ratio of the extant study. The results have been reported in analytical tables.

The tool introduced in the design process was evaluated based on the audience's opinion throughout the research. Each question was put through the binary logic, and then the gathered data was analyzed through analytical Expert Choice software to control error and judge questions in a better way. The software environment, which is based on the hierarchy method, enabled the received data into table computations that presented the final evaluation within five overall models and one final model by weighing criteria.

Discussion

In the first round of research, design tools were discussed based on their strengths and weaknesses, then the keywords affecting negotiations in research documentation were studied in the second round for intervention. Table 7 reports a summary of the strengths and weaknesses of tools from the viewpoint of experts (Table 7).

It was seen in the first round that finding which one of the tools is more capable and effective in which modes highly depends on designers' habits. Therefore, designers usually introduced their intervention in choosing design tools under the influence of the "educational model in the learning process," "previous valuating adjudications,"

Table 3. Information about experts involved in the research process. Source: Authors.

Education degree	Specialty context	Professional context	N
MA	(housing, technology, sustainable) Architecture	Technology workshops (Fablab)	3
PhD	Architecture	Technology workshops (Fablab)	1
PhD	Architecture	Academic and research	5
PhD	Landscape architecture	Academic and research	1
PhD	Urban design	Academic and research	1
MA	Architecture	Private companies and institutions	2
MA	Landscape architecture	Private companies and institutions	2
PhD	Urban design	Private companies and institutions	1

Table 4. Abundance of experts according to education. Source: authors.

Education level	Frequency (%)
MA	43.7%
PhD	56.2%

Table 5. Frequency of experts according to field of study. Source: authors.

Specialty context	Frequency (%)
Architecture	50%
Architecture orientations	37.5%
Urban development orientation	12.5%

Table 6. Frequency of experts according to place of employment. Source: authors.

Professional context	Frequency (%)
Technology workshops (Fablab)	25%
Academic and research	43.7%%
Private companies and institutions	31.2%

"experienced processes in the workplace," and "using or experiencing tools." According to the initial survey, about 82% of research audiences chose an applicable tool in their design process and introduced it as a leading and reliable tool.

Accordingly, it was attempted in the second round of study to examine design tools used by individuals who had similar knowledge about design tools, and their experiences were in interaction with tools. Accordingly, interviewees were selected from two groups of designers and teachers. The first group comprises supervisors of an architecture gallery in Tehran Metropolitan, and the second group includes teachers of the "architectural design 1" course for MA architecture students. The members of these groups had interaction with students and learners, considering their willingness towards diverse tools when they were studying for a BA degree. According to discussions of the first round, the second round was assigned to five components affecting the application of tools: "directedness," "information exchange speed," "creative ambiguity within the design process," and "precision in design and dealing with the problem," and "flexibility of process during design." The components were prioritized due to the variety of indicators, diversity of topics, and interference of design applications. In the third round, however, a subject was considered in conversations and binary comparisons of audiences for the plan regarding Tehran's commercial and recreational complex.

As seen in Table 8, eleven choices of design tools were introduced to audiences and compared throughout the research in terms of five criteria in questions: "directedness," "information exchange speed," "creative ambiguity within the design process," and "precision in design and dealing with the problem," and "flexibility of process during design." In each question, audiences only compared two tools in terms of the criteria mentioned above. This issue was considered in the permutation of questions, so 50 questions were asked in terms of each research criteria. Totally, 200 questions were designed. Every 7-member group selected one of three options of "right-side option," "equal," and "left-side option" to answer the question within binary comparison; the mentioned options were calculated based on three mathematical criteria of

Table 7. Comparison of design tools' strengths and points regarding information codification. Source: Authors.

Tool	Strength	Weakness
Basic language: expressing ideas using body language and speech	Free, fast, and unlimited ideation and direct exchange. Popularity and widespread acceptance among designers, audiences, and employers	Inability to understand and solve different problems in the human mind coherently. Limited to the circle of words and dependent on the power to visualize the audience and the need to describe Lack of documentation is a possibility.
Advanced language: expressing ideas using smart mind-reading tools	Classifying problems in parameter-to-parameter form and registering design and modeling process Regardless of linguistic literature constraints and the diversity of tribes	Slow start of the project due to the necessity of defining each phenomenon in computer literature, high cost, and dependence on accurate interface processing Limited flexibility in built environments or the necessity of using tools to enter the virtual environment.
Unformed tools with dry and wet base (concentrated-diluted)	Sealing and ease of use as the oldest tool used by humans for drawing Possibility of displaying design processed Free ideation Capable of presenting the final product and indicating the outcome of the decisive design. Vague and causing free perceptions and synthetic creativity in design's spatial components	Depending on ability and talent in drawing Diverse audience perception steps Depending on audience practice and awareness of images' language (perspective) Inefficiency in showing the design process due to dependence on re-drawing Lack of autonomy in ideation
Basic formed (shaped) drawing tools (ruler, template, etc.)	Fast process in conveying thoughts due to more accuracy in drawing Assisting the ones with a lack of ability in the free drawing Making it possible to fabric and implement the plan.	Lack of ability to understand and solve different problems in the human mind coherently High dependence on the quality of drawing and rendering tools. Hardness or irreparability when revision and renovation are required.
Drawing software	Assuring quantitative forms Free ideation without considering dimensions or repetition Allowing people with the minimum potential to draw and understand perspective language allows Fast and easy editing	Inability to understand and solve different problems in the human mind coherently and non-coordination with drawing velocity. Low-speed design cycle to learn a software language. Having cost
Analytical software	No concern about computational mistakes if the modeling is accurate. Accelerating computation and analysis Respon accuracy and the possibility to show unperceivable spectra	Inability to understand parallel problems and push ideas forward synchronously Dependence on the power of strong and expensive computers Not applicable in initial creative ideation time
Computer-aided design software	The flexibility of all design requirements in design algorithms Parallel advancement of responses and simultaneous application of different dimensions of the problem	The complexity of realizing simple and qualitative problems in the form of computer algorithms Dependence on the computer's power and initial cost
Modular or layout maquettes	Fast process of creating volumes and 3D form of plan	Limitations caused by base forms existing in the structure or connection
Injection of soft maquettes	Flexible processing with thoughts and forces influencing the design process	Impossibility of simultaneous processing for interior and exterior spaces
Sheer or plate maquettes	Potential in spatial organization and arrangement.	Limitations in development paths regarding the 2D aspect of plates
Hard maquettes requiring tooling	Simple and step-by-step forming due to the involvement of the lowering tool.	Impossibility of simultaneous processing for interior and exterior spaces inability to edit or return to the design path

"-1," "0," and "+1" for design tools (Fig. 4). The sum of indicators in the hierarchy table of Expert Choice software was placed in the software's chart interval.

To select leading tools, the audience evaluated

Table 8. Binary comparison of design tools in terms of variables affecting the choice in the design process. Source: Authors.

Proposed tool	Total	Directedness	Information exchange Speed	Creative Ambiguity within the Design Process	Precision in Design and Dealing with the Problem	Flexibility
Hypothetical case with a topic identical to commercial and recreational complex to rank indicators		(L: .082)	(L: .082)	(L: .210)	(L: .279	(L: .348)
Drawing software	0.363	0.173	0.207	0.236	0.651	0.288
Analytical software	0.344	0.111	0.057	0.176	0.992	0.045
Computer-aided design software	0.733	0.120	0.144	0.403	1	1
Maquette fabrication using soft or injection materials	0.512	0.442	0.309	1	0.177	0.550
Modular or layout maquette fabrication	0.412	0.276	0.451	0.646	0.276	0.401
Maquette fabrication using hard tooled materials	0.167	0.276	0.309	0.188	0.177	0.086
Maquette fabrication with surfaces or shear materials	0.274	0.276	0.101	0.646	0.276	0.086
Drawing unshaped tools	0.494	1	0.706	0.283	0.120	0.753
Drawing tools with basic shape	0.493	0.676	0.507	1	0.427	0.192
Basic language: expressing ideas using body and speech	0.442	0.676	1	1	0.862	0.205
Advanced language: expressing ideas using smart mind-reading tools	0.261	0.105	0.073	0.215	0.651	0.055

Paired comparison questionnaire of design tools' function

1- Which one of the "**drawing software**" and "**analytical software**" tools is more **flexible** throughout the design?
A) Drawing software B) they have equal flexibility C) analytical software

2- Which one of the "**drawing software**" and "**CAD software**" tools is more **flexible** throughout the design?
A) Drawing software B) they have equal flexibility C) CAD software

3- Which one of the "**drawing software**" and "**maquette fabrication using soft or injection materials**" tools are more **flexible** throughout the design?
A) Drawing software B) they have equal flexibility C) maquette fabrication using soft or injection materials

3- Which one of the "**drawing software**" and "**maquette fabrication using modular or layout**" tools are more **flexible** throughout the design?
A) Drawing software B) they have equal flexibility C) maquette fabrication using modular or layout

Fig. 4. Sample of the questionnaire in the third round. Source: Authors.

criteria through 16 items by asking a question about the design subject of the "commercial and recreational complex in Tehran City." Most audiences believed that they could answer questions differently, so the reliability of this part of the study was not reliable.

As seen in Fig. 5, none of the design tools had full priority rather than other tools, so they had different ranks in various variables and aspects.

Design tools can be divided based on the origin or effective element in the type of ideation. Expression,

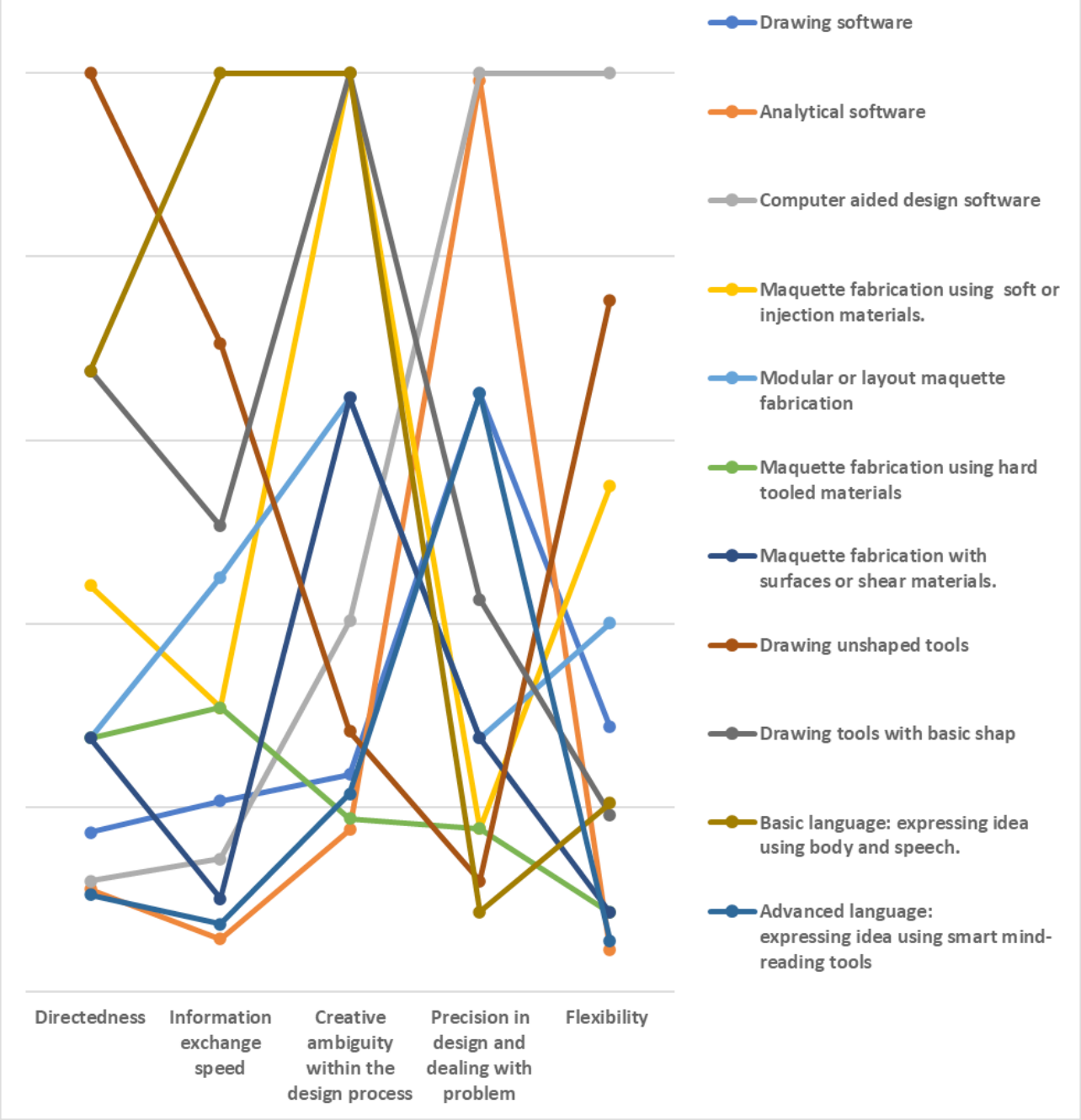

Fig. 5. Assessing design tools in terms of components affecting the choice. Source: Authors.

drawing, computer, and maquette tools can be classified based on their different natures. However, each tool can influence the nature of design due to its potential.

In this case, flexibility, the direction of the relationship between the opinions of designers and audiences, and common change trends in design are taken into account. The highest level, in this case, is seen in software with artificial intelligence. Therefore, changes in initial parameters play a role within the shortest time through the design process. In the second position, unshaped drawing tools can correct their role due to changes in velocity in vague plans. The dough-shaped materials of design maquettes have high flexibility if they do not have shape stability. Modular maquettes have rapid flexibility but have lower ranks due to their fixed initial shape. This trend is well seen in Fig. 6.

In terms of design and directly dealing with the problem (Fig. 7), design environment layout has different roles so that inflexible analytical software can be used at the highest level of precision and express project challenges. In this field, computers and their connected languages stabilize their positions in the next ranks due to the precision of computer environments.

In the case of creative ambiguity that depends on using specifications regardless of complexity, the previous order has been almost inversed, and the unshaped drawing tool is lower than basic language due to smarter transfer in ambiguity mode but was higher due to the possibility of creativity, and semi-precise maquettes are at lower levels (Fig. 8).

In terms of the speed of information transferring to the audience (professor or employer) or design group (Fig. 9), accessibility and drawing unshaped tools will be the simplest solutions to accelerate the inquiry process for design development if the designer has drawing skills and if modular maquette fabrication exists in the discussion space.

In terms of the directedness of the design process and the fast relationship between mind and tool (Fig. 10), the conversation was direct in appearance, but the dependence of this trick was at a lower rank compared to drawing tools, which had the lowest requirements due to the necessity of choosing the right words and the need to show samples (by the designer to the audience, for example). This case is shown in Fig. 5. In this case, analytical software and advanced language are ranked last due to interferences' volume and complexity of discussions.

Conclusion

It is essential to identify and classify design tools

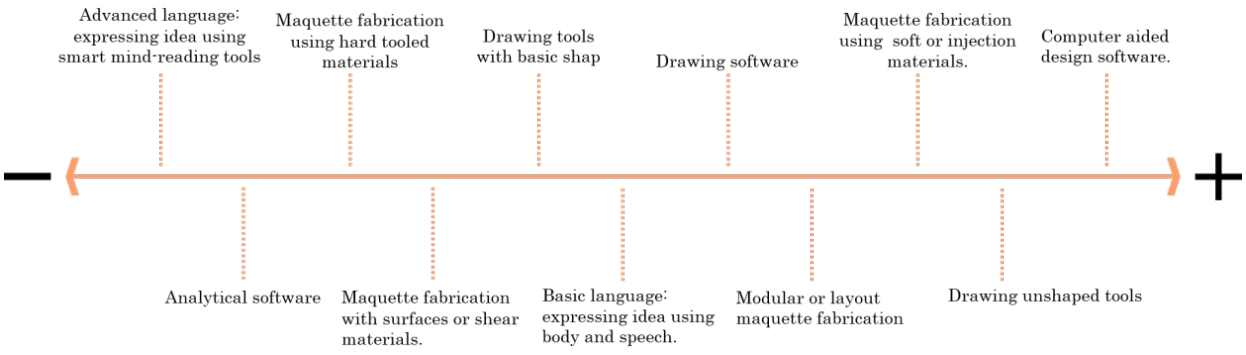

Fig. 6. Assessing design tools in terms of flexibility through the design process. Source: Authors.

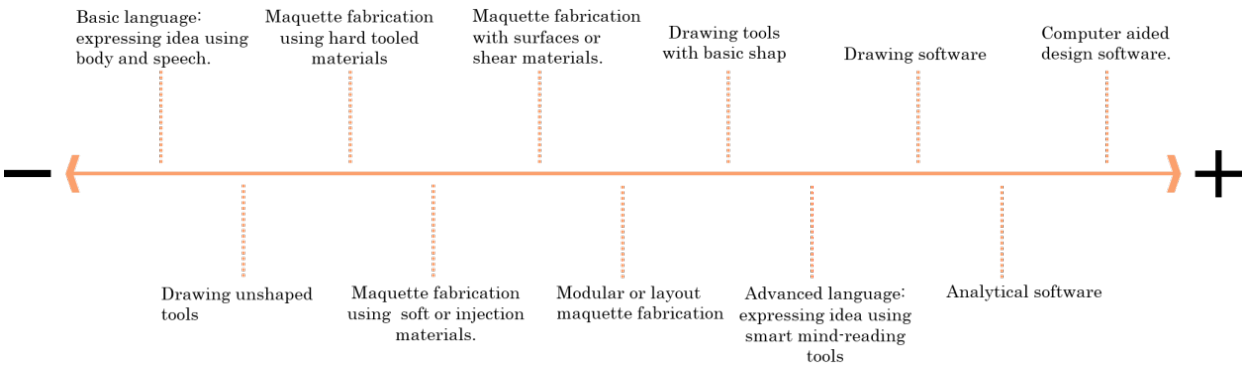

Fig. 7. Assessing design tools in terms of precision in design and dealing with the problem. Source: Authors.

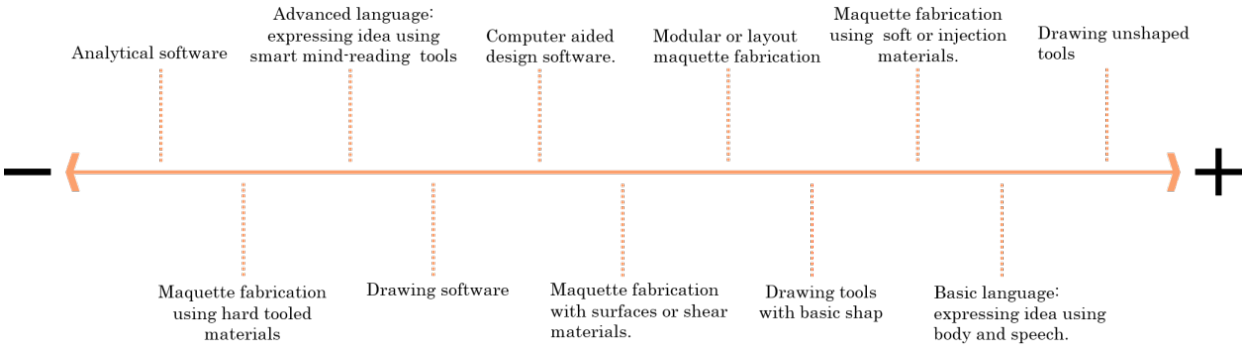

Fig. 8. Assessing design tools in terms of creative ambiguity through the design process. Source: Authors.

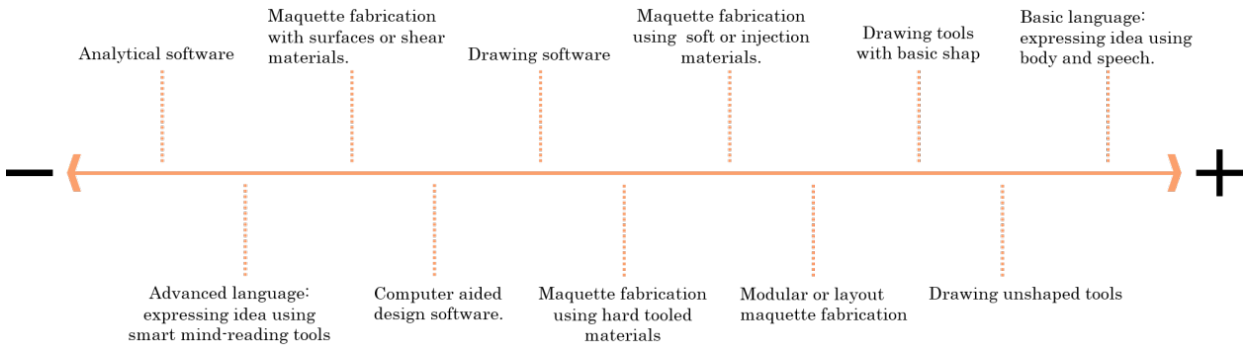

Fig. 9. Assessing design tools in terms of information exchange speed. Source: Authors.

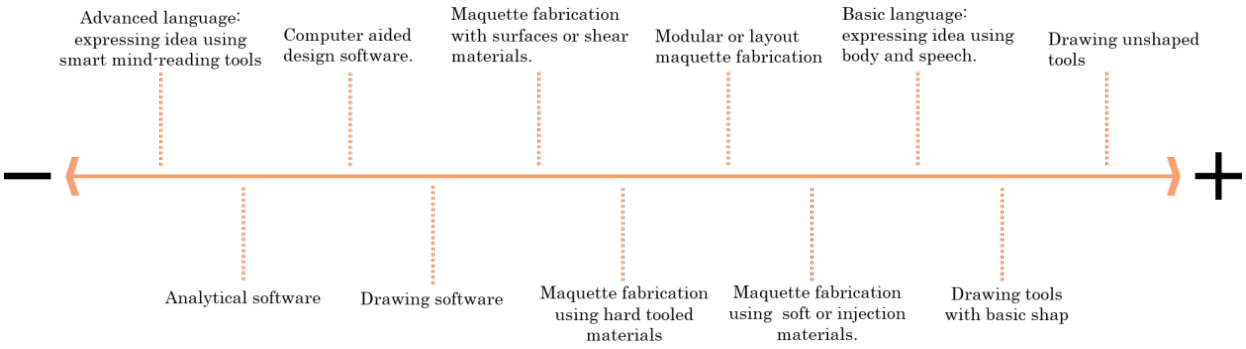

Fig. 10. Assessing design tools in terms of directedness through the design process. Source: Authors.

because the useful application of these tools in architects' plans and the use of design tools by many designer groups contribute to the more efficient utilization of these tools and skills.

In this regard, architectural expression in architecture cycle with the centrality of architecture and architect sides, architectural work, and audience in terms of the design process, information exchange, participation of members or audiences, and precision in implementation necessitate and depend on using all mentioned techniques in projects of an architecture office. Now, this substantial issue can be examined in terms of various aspects, including "flexibility," "precision in design and dealing with the problem," "creative ambiguity in design," "information exchange speed," and "directedness in design."

It can be explained that the main question of the research **is** that all design tools can influence the design process based on the designer's structure

and communication or accessibility. However, "conversation" or "dialogue" is the simplest but most fragile structure expressing design among individuals. This case requires the interference of other design tools due to technology and the "drawing" context, which re-enjoys a developed creative ambiguity but needs drawing skills and is poor in repairing the process. "Maquette" and "CAD" with various capacity levels can improve the two previous methods as independent methods by using human senses and artificial intelligence aids and provide the field for more flexible and interactive processes.

As mentioned before, it is wrong to pay attention to methods and make design tool**s** **w**ithout considering their shortcomings. Unfortunately, this issue always occurs in educational associations of Iranian universities. Students can learn to use various tools in different processes if they experience such design tools; it is important to consider and organize this point in the learning process. In the case of professional activities, however, each design tool can be used in the design process based on the person's functional area and design subject.

Therefore, the researcher can conduct further studies to test the findings of the extant studies but also carry out a comparative study on the interventions of these results in performance returns of students or design groups who know various techniques in creative competitions and creative ideation in the learning environment and use the results for more design interactions.

Endnote

1. Design from diagrams or ideograms to plans, sections, façades, and all perspectives
2. However, this case is now seen in the initial steps in some schools such as SAI ARC (Southern California Institute of Architecture) (based on observations of the first author)

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HOW TO CITE THIS ARTICLE

Asgari, A.& Fathi, R. (2022). Examining the Role of Design Tools in Quality of Ideation and Presenting Architectural Designs . *Bagh-e Nazar*, 19(113), 99-116.

DOI: 10.22034/BAGH.2022.319442.5068
URL: http://www.bagh-sj.com/article_153674.html?lang=en