Mock-up versus CAD Modeling Preferences of Architecture Students in the Early Design Phase

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Preferences for using physical mock-up modeling or computer-aided design (CAD) among architecture students in the early design phase are analyzed. The data is obtained from a questionnaire, consisting of a of nine questions. The majority of the respondents are still in their undergraduate studies. As quantitative analysis methods hypothesis tests based on the probability distributions known as the z-distribution, and the Chi-squared distribution were carried out. Three issues were investigated. The first is whether or not there is a significant difference in the efficiency of one representational technique in the early design phase. The second is, whether preference for one over the other technique depends on the experience level of the students. Here two indicators for experience level were analyzed separately, namely age and the number of years of study. Third is the relative importance of reasons for having a preference. The results indicate that there is a strong dependence between experience and preference. Explicitly, less experienced students prefer CAD, while more experienced ones prefer mock-up technique. Since the choice of mock-up modeling or CAD modeling can have a strong impact on the design processes of both, students and professionals, the result of the study is relevant, because it gives a hint about probable future architecture practice.

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Keywords: Mock-up modeling, Computer-aided design modeling, Architectural design studios, Early design phase.

Erken Tasarım Aşamasında Mimarlık Öğrencilerinin Fiziksel ve Bilgisayar Destekli Modelleme Kullanım Tercihleri

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Bu çalışmada mimarlık öğrencilerinin erken tasarım aşamasında fiziksel maket ve bilgisayar destekli tasarım (CAD) yoluyla modelleme konusundaki kullanım tercihleri analiz edilmiştir. Veriler, dokuz sorudan oluşan bir anketten elde edilmiştir. Ankette katılımcılara erken tasarım aşamasında hangi modelleme tekniğin verimliliği ve tercih sebebi sorulmuştur. Katılımcılar mimarlık öğrencileridir ve çoğunluğu lisans eğitimine devam etmektedir. Kantitatif analiz yöntemleri olarak, z-dağılımı olarak bilinen olasılık ve Ki-kare dağılımına dayalı hipotez testleri gerçekleştirilmiştir. Araştırma kapsamında üç konu araştırılmıştır. Birincisi, erken tasarım aşamasında bir temsil tekniğinin verimlilik açısından önemli bir fark gösterip göstermediğidir. İkincisi, bir tekniğin diğerine göre tercih edilmesinin öğrencilerin deneyim düzeyine bağlı olup olmadığıdır. Burada deneyim düzeyine ilişkin iki gösterge, yani yaş ve öğrenim yılı ayrı ayrı analiz edilmiştir. Üçüncüsü ise, tercih nedenlerinin tespit edilmesidir. Çalışmanın sonuçları deneyim ve tercih arasında güçlü bir bağımlılık olduğunu göstermektedir. Fiziksel maket yoluyla model üretiminin daha verimli olarak değerlendirilmesine rağmen bilgisayar destekli modellemenin erken tasarım aşamasında daha sık tercih edildiği bulgusu ortaya konulmuştur. Sonuç olarak, daha az deneyimli öğrenciler CAD'i tercih ederken, daha deneyimli olanlar ise maket tekniğini tercih etmektedir. Son olarak ortaya çıkan bu farkın nedenleri analiz edilmiştir. CAD tercihi daha çok teknik ve ekonomik nedenlere dayandırılırken fiziksel maket yaparak modelleme ölçek algısına dayandırılmıştır. Elde edilen sonuçlar uzaktan eğitim ve yaş faktörü ilişkilendirilip tartışmaya açılmıştır. Fiziksel maket yaparak veya CAD yoluyla modelleme seçimi hem öğrencilerin hem de profesyonellerin tasarım süreçleri üzerinde güçlü bir etkiye sahip olabileceği için çalışmanın sonuçları gelecekteki olası mimarlık uygulamaları hakkında önemli ipuçları ortaya koymaktadır.

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Anahtar Kelimeler: Fiziksel modelleme, Bilgisayar destekli modelleme, Mimari tasarım stüdyoları, Erken tasarım aşaması

1. INTRODUCTION

Design is a multi-phase problem-solving process in which the method used varies depending on the preferences a designer has. This process starts with the production of various suggestions/ideas on the determined problem and continues with the contribution of different architectural representational tools. This phase has been referred to as the ideation phase (Dorta, 2008). The utilization of representational means is known to influence the content of the idea being represented. This influence can be understood considering that the human mind has limitations as to the amount of information it is able to process overtly. One of the earliest and most well-known studies of the limitations is the study by Miller (1956) and the ensuing work on working memory in Psychology. From this perspective, the role of representation in design is to temporarily externalize properties of the design being developed in some abstract form. Theoretically, it is justified to expect the form of a selected representation to influence the refinement process of the design idea. This is because, each form permits the abstraction of a specific set of design properties more effortlessly, more precisely, or more flexibly compared to another one. For instance, mock-up modeling starts from some physical substance having inherent properties as to its amenability for bending, cutting, or molding, as well as its reflectance of light, Whereas in CAD modeling materiality is assigned after geometric features have been specified in sequence while constraints inherent to material as to interaction with light or ensuing shape modification are subject to explicit simulation in the computer-based representation, if such is taken care of at all. The process ends with the development of the most consistent proposal among the alternatives and obtaining a final product.

The early design phase refers to the preliminary process of developing a preliminary design idea, i.e., establishing a basis for specifying details of the design later on. From this point of view, a study with both qualitative and quantitative content was designed together with the hypothesis, experiment/research carried out, and it was aimed to bring a new perspective to the literature on this subject. The early design phase is one of the most important ones, in which the design idea is grounded in the conceptual sense. It covers the steps of researching, analyzing, and producing information about the problem, synthesizing information, searching for alternatives, screening, and forming ideas that will be input into the design. There may be transitions between the mentioned phases, or the early design phase can be completed with the idea based on a single phase.

For conceiving and verifying a design idea, every design discipline uses some technique to represent it. Techniques vary according to the working principle of the respective discipline. In architecture, there are two commonly used techniques, which are mock-up modeling and computer-aided design (CAD). Mock-up modeling refers to representing a design by means of a physical entity, generally produced at a significantly different scale compared to the design it represents. CAD refers to representing a design in virtual reality, namely via a 3-D object stored in computer memory, that is subject to visualization on a screen.

Each of the representational techniques has a specific benefit to the professionals and students using them. The extent to which these techniques are used becomes more important, especially for architecture students, since they are learning to express their thoughts and transform their ideas into the real world.

The hypothesis of the research is that in architectural design studios, the level of design experience of a student and the preference for representational means are independent; while the alternative hypothesis is they are dependent. Investigating the mock-up and CAD modeling preferences of architectural students in the early design phase, while taking the experience of the students into account, is an issue that has been omitted in the existing literature thus far. In this respect, this work fills a gap in the literature.

In a time where computer-aided-design techniques, such as parametric design are on the way to becoming an industry standard, it is relevant to make explicit the apparently prevalent popularity of a more traditional technique, namely mock-up modeling and the reasons for it, to verify the justifications of the preferences. The purpose is to conscientiously choose among the techniques for the benefit of the design result.

In section no.2, a literature review is presented, about the advantages of CAD modeling and mock-up modeling as well as the concept of the early design phase. A number of advantages one representational technique has over the other one have been described in the existing literature, and these were taken as the categories of the questionnaire prepared in this research. As a refinement of the existing works, the advantages described in the existing publications are further investigated in this study; namely, the existence of the preference is analyzed in terms of statistical significance; the dependence of preference on experience is analyzed as well as the relative importance among the reasons for the preference are quantified.

In section no.3, the research methodology is explained. According to the hypotheses, a questionnaire is prepared and applied to the students of architectural design studios from different universities including Istanbul Technical University and Middle East Technical University.

In section no.4, the collected data is statistically analyzed and discussed. Quantitative analysis is carried out by testing several hypotheses using the appropriate statistical tests; namely a test based on the z-distribution, and one based on the Chi-squared distribution. This is followed by conclusions.

2. LITERATURE REVIEW OF MOCK-UP MODELING AND CAD MODELING AND THEORETICAL FRAME

2.1 Literature Review

A design idea is essentially generated in the human mind essentially in three-dimensional form (Hadia & Elias Özkan, 2016). Until a design idea is converted into a physical object, a 'design is essentially a figment of the designer's imagination', although, ideas may be communicated through drawings or specialized design media (Collopy, 2004). Ideation, in this case, can be described as a reflective representational conversation (Dorta, 2008). The effective use of architectural representation media (sketches, physical-digital models, technical drawings, etc.), which serve as the expression of figments throughout different design phases, starting from the early design phase, contributes to the idea development process (Cannaerts, 2009). Marcos (2022, p.823) puts forward the stages of architectural design:

“The process of architectural design is complex and progressive. To achieve its final form a work of architecture must undergo several stages in a formative process such as inception design, schematic design, design development, and construction documentation. The two initial phases could be regarded as part of the ideation process whereas the other two could be regarded as more descriptive and representational: the development of the design.”

Different authors present different ideas on design processes and describe the phases of the design process. While these process definitions differ in detail, the common idea is that these steps consist of a set of definable activities in a logical way. However, it is not always possible to carry out these steps in a certain order. Analysis, synthesis, and evaluation steps are included in this process, but the development of the design process need not be in a foreseen direction. The design product emerges because of complex mental processes; thus, it is not the result of a linear production process. It is produced by experiencing different steps in a tight sequence, possibly with repetition (Lawson, 2005).

Throughout the design processes, students need to visualize their ideas in a 3-dimensional manner. For this purpose, a model of a design, either in physical or digital form is established. Such a model can be metaphorically referred to as a lens that accompanies the development of ideas throughout the design process from the early design phase, sometimes focusing on a specific point, and sometimes taking a general point of view. The purpose is to prepare the ground for the exploration of alternative approaches with transitions among different scales. A virtual model contributes to the development of ideas by revealing new questions and revealing non-obvious aspects such as a greater definition of each element, amount check, and details of data (Empler, 2018). Prototypes obtained by modeling are important to realize inconsistent situations in the solutions produced for the problem in design. Especially in the early design phase, the margin of error that may occur within the scope of the proposal can be reduced to the minimum, together with the inquiries and trials made by producing prototypes (Heidari, 2018).

There are two modeling techniques commonly used in architectural design. These are mock-up and CAD modeling. There are different studies in the literature about mock-up and CAD modeling preferences, their effects on education, design thinking, etc. (Table 1). Some of the research studies these different methods during the early design phase and some of them point out how the techniques are preferred among architecture students. Özbaki et al. (2016) compare a designer's preference between the physical model and the digital model. The comparison focuses on the relationship between design and productivity, suggesting that digital modeling provides higher productivity than physical modeling. Kristianova et al. (2018) investigate the trends in the use of mock-up and CAD combination in the design of architecture, trends can be listed as the capacity for production, the sophistication of representations, and the ability to define complex geometries. Throughout the article, the potential of the techniques to improve the educational environment in the academy is emphasized while handling different techniques simultaneously. Sun et al. (2013) put forward the reason why physical modeling is still used commonly even after the developments in digital modeling is because of enhanced comprehension of the scale of a design. Hadia and Elias Özkan (2016) found that among the two different techniques, the majority of architecture students prefer mock-up modeling compared to CAD.

Production of mock-up models is one of the means of expression in design processes. It is an important tool in terms of testing the three-dimensional organization of the design and studying the visual perception of spatial relations. Preparing a mock-up model is to produce in physical form a scaled variant of the proposed design. Sometimes the representation includes the surroundings of the design object; it can be made from different materials having different textures.

The mock-up model, as a three-dimensional and concrete expression, has an important place in design studios and architectural design processes. Beginning from the early design phase, in terms of practical intellectual expression, a product can be easily created even with a small number of materials. Learning continues while making the mock-up model during the production process. When combining the materials used, new possibilities are investigated with the material properties (Kim, 2019). The usage areas of mock-up modeling in the studio environment and professional life have been diversified since the early design phase, such as working models, sketch models, presentation models, etc. (Empler, 2018). The fact that the mock-up model is a tangible entity makes it easy for the designer to become aware of the implications of the design idea (Rowe, 1987).

With the development of personal computers, CAD became another frequently used representation technique in design processes (Sun et al., 2013). CAD offers a new medium for designing architectural objects, enriching the design process culture. It has features that pertain to different phases of the design process. It is sensitive, detailed, easy to produce, can be easily intervened, and can construct different options with different geometries (Empler, 2018). However, according to Dorta (2008), when it comes to generating new ideas, there is a void of digital tools in the early design phases. On the other hand, Lee and Yan (2016) show that participants feel restricted in ideation while sketching in terms of expressive capability after using CAD.

During the modeling process in CAD, the designers' personal speed, and dominance over the program allows them to express themselves competently through that design. The CAD features and digital modeling process gives faster results compared to the mock-up modeling process. However, the longer time spent producing the mock-up model compared to CAD has perhaps more potential for the development of ideas. A good understanding of the limits of CAD can generate new inspiration for its design potential (Empler, 2018).

The other spatial technological movements such as augmented reality VR (Virtual Reality), and AR (Augmented Reality) in CAD have also increased the popularity of this genre. Such developments offer designers an experience, similar to the spatial experience directly delivered by the mock-up model. VE (Virtual Environment) studies are carried out to strengthen the physical experience side of VR and AR technologies (Kristianova et al., 2018). With the easy manipulation of CAD, student groups working in studios, especially in the early design period, are likely to use environmental factors as input to the design and quickly create options with new geometries (Heidari, 2018). In addition, another important feature of CAD is the ability to quickly produce alternative ideas, which are developed with computational designs of geometric forms with its parametric, algorithmic, infrastructure (Empler, 2018). As changing the viewing location and direction in CAD is effortless, the same virtual object is subjected to visual inspection from different angles, such as the perception of space from the perspective of a driver and a pedestrian (Özbaki et al., 2016).

From **Table 1**, one notes that there are very few quantitative studies dealing with a similar research question. Among those that do use a quantitative method, it is important to point out that their research question does not concern the difference in the preference between CAD and mock-up modeling, which is the question addressed in this work. There is a single study in the table, Hadia, H. & Elias Özkan, B. S. (2016), that does the preference question. The differences with the present work are as follows. The sample is not exclusively taken from students, but it involves practicing architects. The experience levels among students are not specified and therefore the dependence of preference on experience level is not subject to consideration in that study. Thirdly, the usage data of CAD in phases other than the early design phase is mixed with the data for the early phase. That is, the present work uniquely deals with the preference question for the early phase in a quantitative manner.

Table 1: Table summarizing the comparison of some of the existing literature.

REF.	*Subject / Aim*	*Qualitative / Quantitative*	*Statistical Method & Significance Level (if any)*	*Result*
Bhavnani, S. K. (2000).	Comparing the functionality among different commonly used software for visualization, propagation, organization, and iteration	Qualitative	not applicable	Identification of a set of effective strategies; guidelines for developing such strategies and detecting missing functionalities.
Bhavnani, S. K., & Bates, M. J. (2002).	Develop a method that is suitable as a basis for testing and research on the cognitive aspects of information searching on CAD	Qualitative	not applicable	Suggesting potential applications in improving search expertise, training, and design of educational materials.
Bhavnani, S. K., & John, B. E. (1997).	Improve design processes in CAD environment. The different ways of design are analyzed and an efficient one is found to decrease time consumption in processes.	Qualitative	not applicable	The study analyzes and suggests user algorithms to increase efficiency and productivity.
Bhavnani, S. K., John, B. E., Flemming, U. (1999).	Teaching students efficient strategies to use computer-aided drafting systems rather than the persistence of inefficient methods.	Qualitative	not applicable	The study shows the strategic use of CAD training can provide efficiency and productivity.
Bhavnani, S. K., Reif, F., & John, B. E. (2001).	Presenting efficient and general strategies for using computer applications, and identifying the components of strategic knowledge required to use them.	Qualitative	not applicable	Efficient and general strategies can be taught to students of diverse backgrounds in a limited time without harming command knowledge.
Bhavnani, S., Garrett, J., & Shaw, D. (1993).	To advocate for the development of adaptive interfaces in CAD systems, based on the study of user behavior patterns, to improve user performance, and to address the challenges posed by the complexity of CAD software.	Qualitative	not applicable	If today's CAD interfaces are designed for an unchanging canonical user and allow minimal customization, tomorrow's CAD interfaces should dynamically adapt to the needs of many different users.
Bhavnani, S., Garrett, J., & Shaw, D. (1993).	To advocate for the development of adaptive interfaces in CAD systems, based on the study of user behavior patterns, to improve user performance, and to address the challenges posed by the complexity of CAD software.	Qualitative	not applicable	If today's CAD interfaces are designed for an unchanging canonical user and allow minimal customization, tomorrow's CAD interfaces should dynamically adapt to the needs of many different users.

REF.	*Subject / Aim*	*Qualitative / Quantitative*	*Statistical Method & Significance Level (if any)*	*Result*
Cannaerts, C. (2009).	Questioning the relationship between digital and physical models and their status as architectural models through their relationship with the early design phase.	Qualitative	not applicable	Digital modeling brings an exploratory approach in the design stages, as it is faster than physical modeling and allows for multiple changes.
Chapman, G. (1995).	To show the links between the learning process of industrial design with the adaptation of CAD.	Qualitative	not applicable	Students experimented extensively with the computer and came up with designs that they would never have thought of had they been using conventional means.
Chester, I. (2008).	To discuss the teaching environment of CAD learning by understanding and showing pedagogic links between expert-studentrelations.	Qualitative	not applicable	Students, who spend more time on the computers, had equal command knowledge but greater strategic knowledge.
Çil, E., & Pakdil, O. (2007).	To explore and identify the instructors' conceptualizations and evaluations of the relationship between design and computers in education.	Qualitative	not applicable	The design faculty sees the computer as a drafting tool and an aid for visualization and 3D modeling, emphasizing that the potential of computers is not fully used in terms of design thinking tools.
Dorta, T. (2008).	To create a system that enables designers to sketch and make models all around them in real-time and real scale using a digital tablet, image capture, and a spherical projection device.	Qualitative & Quantitative	NASA Task Load Index (TLX). Significance Level is not given.	The students reported being in the state of flow more often in the Hybrid-Ideation-Space (HIS) than with digital or physical modeling.
Hadia, H. & Elias Özkan, B. S. (2016).	To establish the degree of tangibility in model making as opposed to conventional and computational design approaches; and the iconic limitation of both types of modeling in design.	Qualitative & Quantitative	descriptive statistics	Between the two different, handcrafted and digital modeling, 61% of the 87 participants, preferred to use the handmade while 39% chose digital modeling techniques.
Hanna, R., & Barber, T. (2001).	To examine the advantages and disadvantages of students' design experiences before and after using CAD through an experiment.	Qualitative	not applicable	The shifting in the quality of design solutions is observed. However, CAD was found to help design cognition, creativity, and intuition.
Kristianova, K., Meciar, I., Joklova, V. (2018).	To evaluate the possibilities and the feasibility of using innovative technologies in physical 3D modeling education.	Qualitative	not applicable	Rapid developments of new technologies that influence the design process substantiate the constant research on aspects of their impact on the ways of education.
Lee, S. & Yan, J. (2016).	Questioning how the experience of a design tool affects the designer's ideation.	Qualitative & Quantitative	Wilcoxon's signed-ranks test. * p < 0.05; ** p < .01; *** p < .001	The silhouette-drawing interface of Silhouette Modeler performed better than SketchUp in terms of the diversity of supported shapes a decisive advantage in the conceptual stage.
Özbaki, Ç., Çağdaş, G., Kilimci, E. (2016).	To analyze the design processes carried out with different design tools on an individual designer basis in terms of design productivity.	Qualitative & Quantitative	Linkograph method. 4 CM4> and 2 CM4< in the range M1-43	Productivity levels of protocol studies carried out in mock-up and CAD environments are close to each other. Structural patterns seem to be different.
Stevens, G. (1997).	To describe the evolution of CAD-based programs in the market over time, and their use by designers, firms, and architecture schools.	Qualitative	not applicable	CAD programs should be used to assist the professional development of designers.
Sun, L., Fukuda, T., Tokuhara, T., Yabuki, N. (2013).	To focus on the differences in spatial understanding between physical and virtual models. In particular, it emphasizes the perception of scale.	Qualitative & Quantitative	Infinitesimal change calculation %5 & %1	Compared with the virtual model, the physical model tended to enable quicker and more accurate comparisons of building heights.
Taşlı-Pektaş, Ş, & Erkip, F. (2006).	The article aims to show the link between CAD user and their attitudes to the design process.	Qualitative & Quantitative	*t*-test *p< 0.05; **p<0.001; *** p < .005	As a result, the male learning attitude is more positive than the female attitude towards the CAD design process. However, it is not related to the instructor or learning environment.
Togay, A., Coşkun, M., Güneş, S. & Güneş, C. (2016).	To frame the problems related to the structure and timing of CAD courses.	Qualitative	not applicable	It was observed that their knowledge regarding the program that they first met is more durable and they were more enthusiastic to develop their skills.
Wood, J. (2003).	To investigate and compare how technology, specifically information and communication technology (ICT), is used in the field of Art and Design education compared to its use in other subjects.	Qualitative	not applicable	The study found that each curriculum subject uses ICT distinctively, has singular hardware requirements, and is treated differently in terms of resourcing and access.
Yang, F. C., & Lynch, R. (2014).	To create a database for student learning types and differentiation; comparison of learning styles, learning performance of learning styles, of new and current students and their styles of learning, the exercise repetition numbers of the CAD users to learn and improve.	Qualitative & Quantitative	ILS Test. CTC Score. Significance Level is not given.	There was a correlation between the perception of learning style and grade; in terms of demographic factors and learning style preferences, no statistically significant differences were found
Ye, X., Peng, W., Chen, Z., & Cai, Y. (2004).	The article aims to answer the roles of CAD education curricula in the professional industry.	Qualitative	not applicable	Certain topics are required for all CAD users and should be taught in university education for the professional career. However, for engineering disciplines CAD is a communication tool, it does not do their job or make them better engineers.

2.2 Theoretical Frame

Recognizing the complexity and diversity of the cognitive process involved in the early design phase, as well as the diversity of objects that can be subject to architectural design, postulating a general preference for one representational medium over another one exclusively based on theory is a problematic issue. Accordingly, a study combining qualitative and quantitative considerations was devised, establishing several hypotheses and carrying out the experimental verifications of them. It was tried to find answers to the question, of whether one of the representational techniques is to deem more preferable and more efficient by students in early design phases, and on which condition such a preference depends, if any. A number of advantages one representational technique has over the other one have been described in the existing literature, and these were taken as the categories of the questionnaire prepared in this research.

Due to the complexity of the cognitive process involved in the early design, in particular, referring to the entanglement of ideation and representation, the theoretical frame underlying the knowledge elicitation in the study at hand is the probability theory of mathematics. Specifically, the concept of probability density is applied, while the following two positions are taken. The first one: the probability density known as the Chi-squared distribution is deemed to duly represent the sample noise when the independence in probabilistic sense among two variables is being verified, while no assumption is being made about the probability distribution underlying the variables themselves. The latter approach belongs to the inference paradigm known as non-parametric statistics. The second one: the Gaussian-shaped probability distribution known as the z-distribution, when the shape parameter of the distribution is determined by the quantity known as the standard error of the mean, is deemed to represent sample noise when two samples are taken from the same population. The latter approach belongs to the inference paradigm known as parametric statistics. Details on the probability theoretical aspects of both paradigms are described, for instance, in (Ash 1996), while details on the justification from the application perspective are described, for instance, in (Freund and Perles 2004).

3. METHODOLOGY

3.1 Scope of the Research Methodology

The scope of the research is to investigate the preference for mock-up and CAD modeling in the early design phase, in terms of different age groups as well as revealing the preference reasons of each. Also, it examines the efficiency rate of these modeling types for the early design phase. The hypothesis of the research is that the modeling type preference is independent of age, whereas the alternative hypothesis is that the younger generation tends to use CAD, whereas the older generation is inclined to use mock-up modeling in the early design phase.

To test these hypotheses, a questionnaire is prepared to use both qualitative and quantitative data. While the questionnaire consists of questions for ensuing statistical treatment based on the z-distribution, and Chi-squared distribution, it also includes questions that can be analyzed according to the qualitative value of the answers.

One can note that the above data collection implies that the conclusions are limited to the student population, that is the result may not apply to professionals in the same way. Another limitation of the study is that it is restricted to comparing CAD with mock-up modeling, that is other representational techniques are out of the scope. The third limitation is that the questionnaire is used as a data collection technique rather than an interview or other techniques. The rationale is the effectiveness of statistical inference.

3.2 Data Collection

The questionnaire technique was used to collect data from graduate and undergraduate architecture students. It is collected online via forums, social media of two state universities, and commonly used telecommunication applications. It must be supposed that the access to the questionnaire was equal for every student. The age of the students differed from 18 years to about 30 years of age, a total of 101 people participated in the questionnaire. The sample was formed by randomized sampling as it always must be in statistical inference. The questionnaire was created with the title "*Which is better; Mock-up modeling versus CAD modeling in the early design phase in architectural design studios?*". The questionnaire consists of 9 questions. 1 question is to determine the preference of modeling technique, 2 of the questions are rating-based, 5 of them are multiple-choice, and 1 of them is an open-ended question (Table 2). The questionnaire starts with general questions, such as which one is preferred, and which one is more effective as well as the reasons for preference of use. Then, the reasons to prefer the chosen modeling type were the subject of the questions. Some of the options of reasons for preferences were listed according to the codes mentioned in the existing literature. It was also asked to rate the preferred modeling technique in terms of efficiency. Another question was to select three advantages of efficiency for mock-up and CAD modeling respectively. In the open-ended question, the participants were asked to explain the reasons for their preferences, which were not mentioned in the other multiple-choice questions. The last three questions of the questionnaire concerned the participants' educational status, age, and gender information as demographic information.

Table 2: Questions that are conveyed to the respondents.

	Questionnaire
1.	Which tool (CAD or Mock-up) do you usually prefer in the early design phase?
2.	Which of the following are the reasons for the preference for mock-up modeling?
3.	How would you rate the efficiency of using a Mock-up model in the early design phase?
4.	Which of the following are the reasons for the preference for CAD modeling?
5.	How would you rate the efficiency of using CAD modeling in the early design phase?
6.	Is there anything that you want to add about your preference for Mock-up or CAD modeling in the early design phase?
7.	What is your academic level?
8.	How old are you?
9.	What is your gender?

3.3 Analysis Techniques and Respective Purposes

To examine the hypothesis about the relationship between the preference for modeling technique and age groups, the hypothesis test for two means based on the z-distribution was used to test whether the efficiency of two different modeling techniques differs significantly or not. The sample size is selected so that the probability distribution known as the z-distribution applies for high sensitivity in the estimation of the standard error of the mean. The explanation is included in the theoretical part of the work. The chi-squared distribution is applied to identify whether the preference is dependent on age or not. To compare the dependency of preference for modeling technique and age, the data consisting of 101 responses are categorized with respect to age.

4. FINDINGS & DISCUSSION

4.1 Descriptive Statistics

The first question was 'Which one do you use more frequently in the early design phase'. It is to obtain an important part of the answer to the main question of the study. The majority of the participants (62.4%) prefer CAD modeling over mock-up modeling (37.6%) as seen in Figure 1.

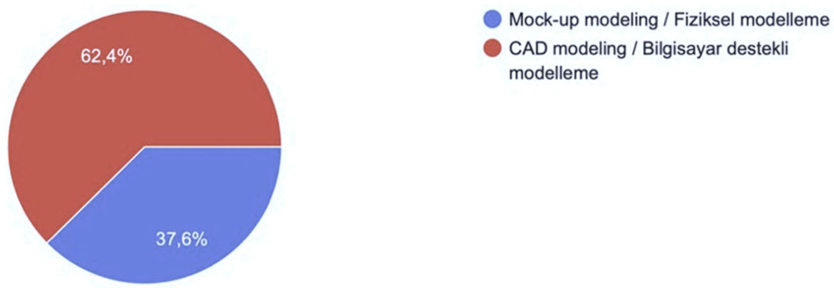


Figure 1: Pie chart showing the preference ratio of mock-up versus CAD.

Among the most preferred reasons for using a mock-up model, *perceiving the scale* ranks first, *flexibility to modify* ranks second, and *producing time and efficiency* ranks third among the relevant reasons for preference. From this point of view, it may be possible to evaluate the reasons for to use of physical models as tangible aspects (Figure 2). Understandably, none of the 38 students had chosen the economic issues for mock-up modeling, since clearly, mock-up requires the purchase of materials.

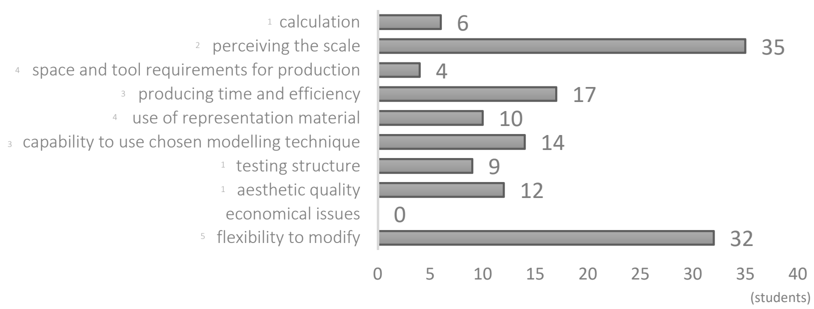


Figure 2: The histogram showing the reasons why students prefer mock-up modeling.

[1] Empler, 2018
[2] Sun et. al., 2013
[3] Özbaki et. al., 2016
[4] Kristianova et. al., 2018
[5] Heidari, 2018

The question underlying **Figure 3** was rating the efficiency of mock-up modeling and **Figure 4** of CAD modeling. The two mean values and standard deviations are indicated in the figure in red font. The mean of mock-up is higher than that of CAD, and the significance of this difference is identified in the following subsection.

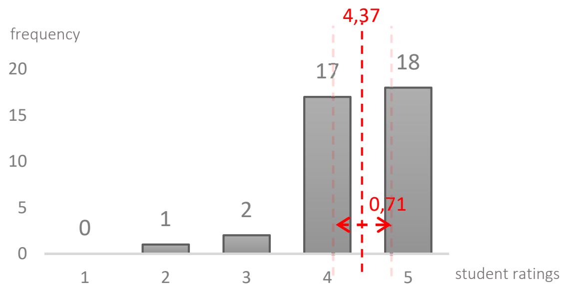


Figure 3: The histogram showing the efficiency ratings of mock-up modeling.

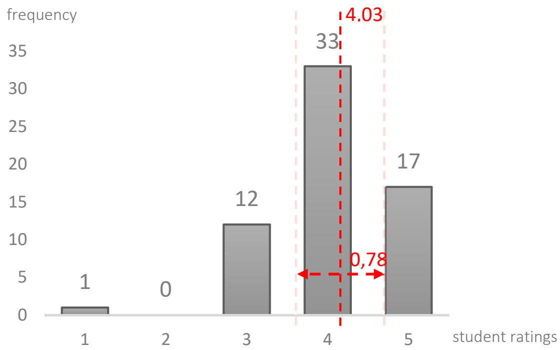


Figure 4: The histogram showing the efficiency ratings of CAD modeling.

The questions were asked in the same order in CAD modeling. Among the most preferred reasons for using a CAD model, *flexibility to make changes* ranks first. This answer was one of the most given answers for Mock-up modeling. Therefore, the flexibility to make changes has been a valid and important reason for both methods in this sense. *Production time and efficiency* rank second and, *economic reasons* rank third among the relevant reasons for preference as seen in **Figure 5**.

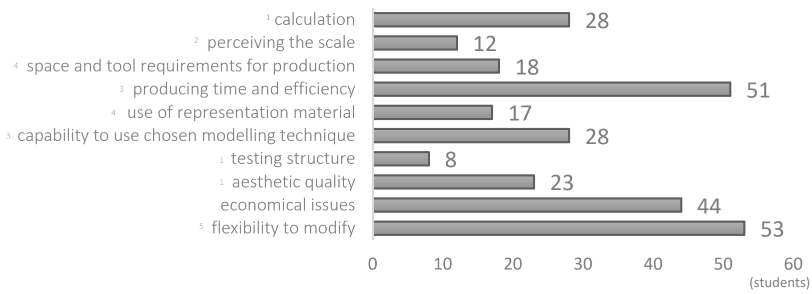


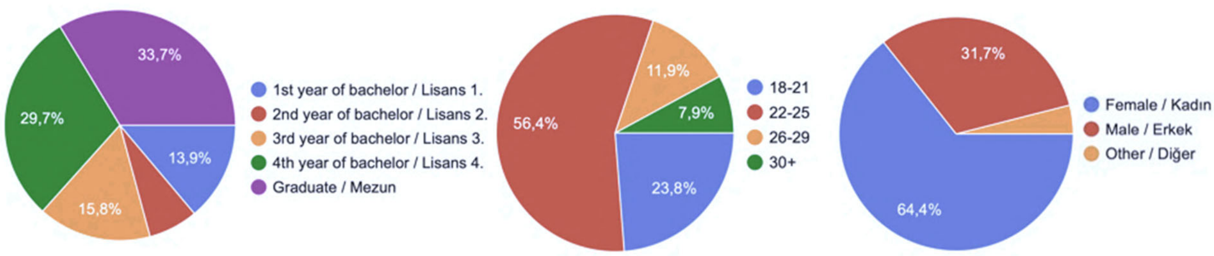
Figure 5: The histogram showing the reasons why students prefer CAD modeling.

[1] Empler, 2018
[2] Sun et. al., 2013
[3] Özbaki et. al., 2016
[4] Kristianova et. al., 2018
[5] Heidari, 2018

In this age of technology, where everything starts going digital, economic reasons may be both a preference based on location and a result of this transformation. The possibility to calculate fast and design accordingly seems to be another important factor in the preference for CAD modeling.

In the open-ended question left as an option, the reasons for preferring Mock-up or CAD modeling in the early design period were asked and different answers were received. The most common point is that the form of education and experience in the chosen technique play an active role in making one of these two choices. 33.7% of the respondents are graduates. 29.7% of them are 4th-year, 15.8% of them are 3rd-year, 6.9% are 2nd-year and 13.9% are 1st-year undergraduate students. The age range of the responders; is 56.4% of them are 22-25; 23.8% of them are 18-21; 11.9% of them are 26-29; and 7.9% of them are 30+ years old. 64.4% of the respondents were female and 31.7% were male (Figure 6). As a result, the fact that experience and education are kept in the foreground together with the open-ended question and the radical change in age ranges emphasizes that preferences change over age in the early design phase. After training in CAD programs at a younger age, young people tend to prefer CAD more, while the older generations tend to produce physical modeling. CAD modeling, which started to be used more widely and frequently with online education, was seen as more productive by the students who coincided with this online education period.

Figure 6: Demographic characteristics of respondents.



4.2 Inferential Statistical Analyses

We identify whether the difference between the two mean values seen in Figure 3 and Figure 4 is significant. For this hypothesis test for two means using z-distribution applies (Johnson & Wichern,2007). The z score obtained was z = 2,21 (Table 3). The hypothesis we are about to test is explicit as follows:

H_o: the difference among the sample means is not significant, i.e. it is likely to be merely a manifestation of sampling noise, and unlikely due to some discernable cause or reason.

H_A: the difference among the sample means is significant, i.e. it is unlikely to be merely a manifestation of sampling noise, but it is likely due to some discernable cause or reason.

The obtained z value is above the z critical value (1,96) when significance level $\alpha = 0.05$ is applied. As a result of this test, it can be said that the efficiency of mock-up and CAD in architectural studios differs. Mock-up modeling is considered significantly more efficient than CAD modeling. (Table 3).

Table 3: Z distribution on efficiency of two techniques.

	CAD MODELING	MOCK-UP MODELING
Mean	4,03	4,37
Standard Deviation	0,78	0,71
Number of participants	63	38
z	2,21	
z Critical one-tail	1,64	
z Critical two-tail (α=0.05)	1,96	

At first glance, the superiority of mock-up as to efficiency is contradictory to the preference for CAD modeling seen in Figure 1. The reconciliation of this apparent contradiction will be given in the discussion section.

Emphasizing the age of the students differs substantially, it is interesting to consider whether age affects the preference of CAD over mock-up. To verify the possible dependency among the two variables age and preference we apply the Chi-squared test of independence (Johnson & Wichern, 2007). A contingency table was formed by classifying the respondents into CAD or mock-up preference, as well as four age groups as seen in Table 4. The hypothesis we are about to test is explicit as follows:

$H_o: p(age|pref) = p(age)$; that is, age and preference are independent variables.

$H_A: p(age|pref) \neq p(age)$; that is, age and preference are dependent variables.

Table 4: Chi-Squared distribution calculations of the parameters age & preference.

Contingency table						
Age	18-21	22-25	26-29	30+	Grand Total	
CAD modeling	21	38	3	1	63	0,62
Mock-up modeling	3	19	9	7	38	0,38
Grand Total	24	57	12	8	101	
	0,24	0,56	0,12	0,08		
Probabilities under hypothesis						
Age	18-21	22-25	26-29	30+	Grand Total	
CAD modeling	0,15	0,35	0,07	0,05		
Mock-up modeling	0,09	0,21	0,04	0,03		
Grand Total	24	57	12	8	101	
expected frequency						
Age	18-21	22-25	26-29	30+	Grand Total	
CAD modeling	14,97	35,55	7,49	4,99		
Mock-up modeling	9,03	21,45	4,51	3,01		
Grand Total						
chi-squared value						
Age	18-21	22-25	26-29	30+	Grand Total	
CAD modeling	2,43	0,17	2,69	3,19		
Mock-up modeling	4,03	0,28	4,46	5,29		
Grand Total					22,53	

A contingency table was created by considering age groups and preference parameters as prescribed by the statistical inference method. Explicitly, the number of students in each parameter was summed. The probability of each parameter is estimated based on the data obtained from a total of 101 students. Then, a common probability is obtained by multiplying the disaggregated probabilities to get the common probability of the two parameters. The expected frequency is obtained in accordance with the rule from probability theory. As a result, the frequency of students expected under the hypothetically assumed independence is subject to comparison with the observed frequency. The comparison is carried out by applying the Chi-squared distribution as follows. The noise that is due to sampling, thus that is not indicative of the hypothesized independence of the two variables at hand, is deemed to be Chi-square distributed when the squared difference between the two frequencies are respectively scaled by the expected frequency and the results summed up (Freund and Perles, 2004).

The total Chi-squared value for the contingency table is 22,53 and applying the significance level $\alpha = 0.01$ the value is significantly greater than 11,34 which is the critical Chi-squared value at this significance level (Table 4). Therefore, the null hypothesis is to reject, and the alternative hypothesis is to accept; namely, the result is strong evidence that the two variables are dependent on each other.

The expected frequency of CAD modeling between the ages 18-21 was approximately 15 students, and mock-up modeling was 9 students; although, it obtained 21 CAD and 3 mock-up on the questionnaire. Moreover, the expected frequency of CAD modeling at the age of 30+ was 5, and mock-up modeling was 3 students; although, it is obtained 1 of CAD and 7 of mock-up modeling. The expected frequency and the obtained values from the questionnaire would be similar if the two variables were independent of each other. Following the lower Chi-squared value would result in a lower than the Chi critical value.

Explicitly, older students prefer mock-up modeling over CAD modeling, while younger students prefer CAD modeling over mock-up. The Chi-squared distribution value of the participants aged between 22-25 is close to zero. This means the observed frequency of preference is close to that in case the two variables age and preference are independent.

However, age is not the sole indicator of the experience level of a student. A second indicator is in the education level, i.e. the year of study the student is currently registered in. Thus, in order to verify the dependence between preference and experience level more thoroughly, a second Chi-squared test of independence is carried out. This time, five categories containing the educational level are taken into account with respect to their preference for modeling techniques. The aim is to compare two results of the two Chi-squared tests to verify whether both yield the same conclusion or not. Explicitly, the hypotheses we are about to test are explicit as follows:

$H_o: p(experience\ level|pref) = p(experience\ level)$; that is, experience level and preference are independent variables.

$H_A: p(experience\ level|pref) \neq p(experience\ level)$; that is, experience level and preference are dependent variables.

The total Chi-squared value for the contingency table is 24,41 and applying the significance level $\alpha = 0.01$ the value is significantly higher than 13,28 which is the critical Chi-squared value at this significance level (Table 5). Therefore, the null hypothesis is to reject, and the alternative hypothesis is to accept: the result corroborates the one that is due to Table 4; namely, there is strong evidence that the two variables are dependent on each other. Explicitly, when the educational level is high, mock-up modeling is preferred over CAD modeling, while students who are early in their study prefer CAD modeling over mock-up. The Chi-squared distribution values of the participants of the 2nd, 3rd, and 4th levels are close to zero. This means the observed frequency of preference is close to that in case the two variables age and preference are independent.

Table 5: Chi-Squared distribution calculations of the parameters experience level & preference.

Contingency table							
Bachelor Degree	1st Year	2nd Year	3rd Year	4th Year	Graduate	Grand Total	
CAD modeling	14	5	13	20	11	63	0,62
Mock-up modeling	0	2	3	10	23	38	0,38
Grand Total	14	7	16	30	34	101	
	0,14	0,07	0,16	0,30	0,34		

Probabilities under hypothesis						
Bachelor Degree	1st Year	2nd Year	3rd Year	4th Year	Graduate	Grand Total
CAD modeling	0,09	0,04	0,10	0,19	0,21	
Mock-up modeling	0,05	0,03	0,06	0,11	0,13	
Grand Total	14	7	16	30	34	101

expected frequency						
Bachelor Degree	1st Year	2nd Year	3rd Year	4th Year	Graduate	Grand Total
CAD modeling	8,73	4,37	9,98	18,71	21,21	
Mock-up modeling	5,27	2,63	6,02	11,29	12,79	
Grand Total						

Chi-squared value						
Bachelor Degree	1st Year	2nd Year	3rd Year	4th Year	Graduate	Grand Total
CAD modeling	3,18	0,09	0,91	0,09	4,91	
Mock-up modeling	5,27	0,15	1,51	0,15	8,15	
Grand Total						24,41

The expected frequency of CAD modeling on the 1st level was approximately 9 students, and mock-up modeling was 5 students; although, it obtained 14 of CAD and 0 of mock-up on the questionnaire. Moreover, the expected frequency of CAD modeling at the graduate level was 21, and mock-up modeling was 13 students; although, it obtained 11 CAD and 23 mock-up modeling.

Taking both tests of independence together, very strong evidence is obtained that the two variables, experience level and preference for representational technique are dependent in the sense defined by probability theory. When the experience level of students is very high compared to novice students it is significantly more likely compared to the other students that he or she uses mock-up. The same conclusion applies in reverse. From Table 5 one notes the influence of experience on the preference of mock-up becomes gradually more and abruptly more after graduation. Precision identification of the cause of this sudden increase in preference is subject to further study in future work.

4.3 Discussion

According to the statistical analyses mock-up modeling is considered to be more efficient for the early design phase among architectural design studio students, for the following top three reasons that are provided by those respondents, for whom the preference rate of mock-up is as low as 37.6%. The leading reason why mock-up modeling is preferred is that *it helps to perceive the scale of the work*, which 35 of 38 people chose in the questionnaire (92%). The second leading reason is that mock-up modeling *gives the flexibility to modify the model*, with the choice rate being 32 of 38 people (84.2%). The third leading reason is that *producing time is efficient*, with the choice rate being 17 out of 38 people (44.7%). In the 'other' section, a respondent who is between 26-29 years old has written down the reason why she prefers the mock-up modeling as '*including the coincidence circumstances into the model while producing*'. Other additional responses can be listed as '*better kinesthetic perception of the model*' and '*the feeling of the modeling*'. When these answers are analyzed and compared within the group of mock-up modeling sections, the options that have more sensual and aesthetical qualities are selected as the reasons why mock-up modeling is preferred.

CAD modeling is more frequently used in the early design phase among architectural design studio students. In this case, CAD modeling is the preferred technique because of the following three reasons that are provided by the respondents, among which the preference rate of CAD modeling is 62.4%. The leading reason why CAD modeling is preferred is that *it is flexible to modify* CAD models, which 53 of 64 people chose in the questionnaire (82.8%). The second leading reason is the *production time and efficiency*, with the choice rate being 51 out of 64 people (79.7%). The third leading reason is *economic issues*, with the choice rate being 44 out of 64 people (68.7%). Another reason that has been mostly selected is the *potential of calculation* and *capability to use the chosen modeling technique* at the rate of 28 of 64 people (43.7%). Also, in the 'others' section, another reason was written that can be considered very important, being '*the possibility to produce different types of drawing by using a single digital model*'. When the CAD modeling answers are analyzed within the group CAD modeling section, it can be said that the options that have more technical qualities are selected as the reasons why CAD modeling is preferred. Moreover, according to the data from the questionnaire, it is interesting to find that even though sometimes students know that a specific modeling technique is more appropriate for them, they prefer the other one. The result of the efficiency comparison of CAD and mock-up modeling of this research verifies this fact. The ability to use "control + z" in computers to erase their mistakes in a millisecond, duplicate their work with no effort, or save money from the rising cost of corrugated/modeling cardboards become more appealing to students who have the technological backup knowledge to support their work. Although they think mock-up is more efficient in early design phases, they mostly prefer to use CAD modeling.

It is worth dwelling on the apparent contradiction that the more efficient technique is not used as much as the less efficient technique. The logical reconciliation of this finding is that efficiency is of inferior importance in the face of other reasons. Apparently, the shorter production time, lower cost, and greater flexibility to modify CAD are more relevant issues for the students than more accurately perceiving the scale of the design that mock-up would provide them.

Some students prefer to use mock-up because they believe that the 2D screen of a computer is interfering with 3D perception and the understanding of the spatial relations and the conceptual masses. When the reasons and comments are considered synoptically, the commonly held expectation, that each modeling method has its own advantage in producing a design, is verified. Some students specified in the additional part of the questionnaire that they both use mock-up modeling and CAD modeling for different purposes simultaneously in the early design phase. A student specified that s/he uses mock-up modeling because the education system in her/his time was mock-up dominant. This brought the research to a point that not only the advantages and qualities of both methods but also the age is important in preference of the students.

When the age of the respondents is considered for calculations, a strong argument has been raised. It is a fact that the younger population prefers to use CAD modeling when compared to the older population which prefers to use mock-up modeling. However, students aged under 26 tend to use both mock-up modeling and CAD modeling. When the additional analysis is made by the written open-ended questions of the questionnaire, remember that the previously mentioned student says the reason for preferring mock-up modeling is because of the dominant education system of her/his times. It is interesting that the circumstances of the education system are so dominant that most of the students seem to follow this dominance. Especially when the COVID-19 pandemic is thought of, almost every architectural studio has become online, in most times there was no opportunity to produce mock-up modeling but the rising possibility to use computer-aided programs for designing, sharing, and even meeting online. The students did not develop the concept by producing mock-up in the early design phases, so they continued to produce digital models because it was a useful method in that condition. It is again interesting and might be coincidental that the age group under 26 is the interval where the population in this group mostly consists of the students who caught the pandemic in their 3rd or 4th year of bachelor's degree. For this reason, it is possible for them to use both mock-up and CAD modeling because they have the concept of mock-up modeling from the preliminary years of their bachelor's degree and the CAD practice throughout their education. The population aged between 18-21 is the population that started the preliminary years of their bachelor's degree during the pandemic. When it is considered that most of the architectural schools did not necessitate the production of mock-up modeling among students, the concept of it was not practiced for those who started their education during the pandemic.

The preference for a modeling technique is apparently influenced by the experience a student has gained using the technique as well as cost factors. This factor may be more important knowing the technique's superiority. For this reason, architecture faculties ought to encourage or even financially support the use of mock-up models in the early design phase.

With reference to the study by Hadia and Elias Özkan (2016) seven years later, an opposite result is found. The preferred technique of the architectural students is reversed. A possible explanation of this is that during the Covid-19 pandemic, online education forced a preference for CAD identifying whether this is the cause or whether there is a trend toward CAD at large that is independent of pandemic conditions and would prevail anyhow, for instance, frequent computer usage in daily life, is beyond the scope of the study at this time.

When the findings are discussed together, it can be seen that a significant number of students, whether classified over age or expertise level, use both tools in their early design phases. These observations also corroborate the work of Dorta. As mentioned above, Dorta (2008) introduced a concept called Hybrid Ideation Space (HIS). The idea is that the students are in the state of 'flow' more often while working in a hybrid manner (using mock-up and CAD together) than with only digital or physical modeling. Remembering each student's unique ideation process in the early design phases, design schools are encouraged to embrace a variety of representational techniques rather than focusing on only one of them.

For this study, the two architecture faculties from where the student sample was taken are state universities that are among the best-known and oldest architecture faculties of the country, and the students permitted to join these faculties are among the high school graduates with the highest grades in the country. That is the architecture curricula have been refined over a long period of time. Regarding the importance given to CAD and mock-up modeling, the curricula do not imply obvious bias for one technique over the other. In this respect, the sample can be considered rather representative of architecture education at large. Considering the significance level of the results we found in our study, and the fact that the non-parametric tests are rather conservative, it is likely the results we found will show up in other educational contexts within the field of architecture as well.

5. CONCLUSION

There are differences between the efficiency as well as the preference for using physical mock-up and CAD in the early design phase. Mock-up is considered to be more efficient by students in case we do not differentiate the students with respect to their age. In case we do take the age of the students into account, then we find that the younger students prefer CAD whereas the older students prefer mock-up. In case we take the experience level into account, then we find that freshman students prefer to use CAD modeling and more experienced students prefer mock-up modeling in their early design phases. The most relevant reasons for preferring mock-up are perceiving the scale and flexibility to modification. The most relevant reasons to prefer CAD are flexibility to modify, production time & efficiency, and lower cost. It is noteworthy that, although the majority of students find mock-up more efficient, nevertheless they prefer CAD modeling. Although it might be coincidental, it is possible that with the online education forced by COVID-19, another reason why students prefer CAD modeling came into play. The youngest population consists of the students, who started their undergraduate studies during the pandemic, in which mock-up modeling was inconvenient and therefore minimally applied.

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Conflict of Interest Statement

The authors of the study declare that there is no financial or other substantive conflict of interest that could influence the results or interpretations of this work.

Author Contribution

The authors' contribution ratios are as follows, Buket Samancı (25%), Michael S. Bittermann (25%), Dilek Yıldız Özkan (20%), Özge Taşpınar (10%), Başak Cengiz (10%), Yaşar Emir Karcı (5%), Selen Özdoğan (5%).

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