ASSESSING THE IMPACT OF CAD TOOLS ON ARCHITECTURAL DESIGN QUALITY

A case study of graduation projects in Jordan

RANA AL-MATARNEH AND IHSAN FETHI
Al- Ahliyya Amman University, Amman, Jordan
ggcc_1995@hotmail.com | ihsanfethi@hotmail.com

Abstract. The current concept of architectural design education in most schools of architecture in Jordan is a blend between manual pen drafting and digital approaches. However, the disconnection between these two methods has resulted in the students' failure to transfer skills learnt through traditional methods to the digital method of CAD. The objective of this study is twofold: to first compare students' attitudes toward using both methods and to then assess the impact of CAD use on the quality of architectural design. An open-ended questionnaire was designed to measure variables related to students' preferences toward CAD and traditional methods. The quality of sixty graduation projects at three Jordanian universities was investigated. The results appear to support the assumption that CAD tools are used largely as visual means and thereby cause a marked decline in design quality. These findings call for a reconsideration of the status quo and a rethinking of perhaps the entire architectural educational model.

Keywords: Design; architectural design; design methodology; CAD; IT impact on design; architectural education; architectural education in Jordan

1. Introduction

In the last few decades, revolutionary developments in the field of Information and Communication Technology (ICT) have significantly impacted everyday life. The internet, advanced illustration tools and Computer Aided Design (CAD) software are obvious examples of this digital revolution that has affected the very process of teaching architectural design and, in fact, has even transformed the architectural profession itself. Thus, the development of such digital tools over a relatively short time and

their continuous advancement and refinement had, and continues to have, an inevitable major impact on many key pedagogical aspects of architectural education and curricula design.

A fundamental pillar of the contemporary theory of architectural design education is the approach of combining the traditional method of drafting with a drawing board and T-square with the new method of using digital tools in the design process. Most architectural schools developed and introduced computational courses into their curricula, which resulted in a dramatic shift in their educational context, i.e., from "traditional methods" to computational "new methods", and other various shifts in architectural design media, design thinking and design theory. Although digital media has become an essential part of the design studio culture, this transition has not been clearly addressed because schools of architecture have had difficulty in appreciating the dramatic impact of this new technology on their existing and long-established educational infrastructure.

This paper presents a framework to assess the impact of CAD on the architectural design process and the quality of its product. The framework focuses on four major aspects of the architectural design process, namely, the generation of design solutions, communication, the evaluation of design solutions and decision-making. Furthermore, the following group of indicators was also investigated: architectural program; site analysis; conceptual design development; buildability; and design presentation. This assessment may reveal certain indicators that can help educators and practitioners to understand the impact of this rapid and radical transition on the architectural design process and thus help to redirect the future of architectural education into a more adaptive and qualitative system.

1.1. DEFINTION OF THE PROBLEM

The current concept of architectural design education is a blend of the traditional method of drafting on paper and the modern method of using CAD in the design process. This paper argues that the transition to the new digital media has been vague and largely ill-defined, which causes several serious pedagogical problems. The introduction of these new tools into design teaching has been combined with a dysfunctional relationship between the tools and the intended end tasks. Consequently, this dysfunction has resulted in a separation between architectural design and the context of the project, specifically its sense of scale and proportion, and has led to a marked decline in the spatial quality experience and a disproportionate dependence on illustrative techniques. The inappropriate use of the digital tools and the heavy reliance on them, the lack of integration among different digital tools and, more importantly, the absence of effective coordination

between theoretical courses and design projects has resulted in a relatively poorer overall design quality.

1.2. AIM OF THE STUDY

The aim of this study is twofold. First, this study quantitatively compares students' preferences and attitudes toward the use of CAD tools and traditional methods and analyzes these attitudes. Second, this study assesses the potential impact of these digital tools on the quality and creativity of architectural design by examining graduation projects. The main objectives of this paper can be summarized as follows.

- What motivates the student to use CAD software in the design process?
- What is the importance of the role of CAD in an architectural curriculum?
- What impacts do CAD tools have on the overall quality of architectural design in all of its stages (conceptual, design development, presentation)?

1.3. METHODOLOGY OF THE STUDY

This study was designed to gather empirical data to assess the impact of CAD software programs on architectural design. The data collection methods that are used in this study included a paper-based questionnaire survey, interviews, and graduation projects.
This study was completed in two distinct stages. This study used a case-study approach to assemble the main data through the following.

(a) Qualitative in-depth interviews: The data and information used for evaluation were based on qualitative in-depth interviews that were conducted with a sample that comprised the following:
   - 90 fifth-year architecture students, who have acquired and developed various design skills and practices and whose studio work incorporates traditional and new architectural design methods; and
   - 60 educators from three universities in Jordan (Al-Ahliyya Amman University, Petra University, and Philadelphia University).

(b) Extensive survey questionnaire: The data that were used for assessment were based on an extensive survey questionnaire that was completed by the 90 fifth-year students and 60 educators in 3 different universities in Jordan.

The conducted interviews and questionnaire involved open ended-questions based on the collected qualitative data from the students, such as students' preferences and attitudes toward the use of CAD, the types of CAD software used by students, CAD learning methodology, proficiency level in CAD, the frequency of using CAD in different design phases, and the advantages of using CAD software.

(c) CAD impact matrix: Sixty graduation projects in the study area were examined through five suggested indicators to assess the architectural product quality (Table 1). The gathered data of graduation projects was important in providing evidence of the benefits that the respondents mentioned in the questionnaire survey and interview.

TABLE 1. *Matrix of main criteria assessed for the impact of CAD on the quality of architectural design of graduation projects. (scores 1 poor to 5 high).*

A. Architectural Program [15 points]	[1]	[2]	[3]	[4]	[5]
1. Analysis of the needs, values and main goals of the client, tentative cost analysis of the proposed project and its feasibility					
2. Provision of detailed inventories, required facilities, functional relationships of main components of the project.					
3. Compliance with local and/or international space standards and binding codes and regulations					
Total A					
B. Site Analysis [15 points]	[1]	[2]	[3]	[4]	[5]
1. Response to urban context, surroundings and accessibility					
2. Site layout, topography and overall landscape design					
3. Appropriateness of plot's shape, area and location					
4. Use of CAD to develop the overall site design					
Total B					
C. Architectural Concept [30 points]	[1]	[2]	[3]	[4]	[5]
1. Philosophical and intellectual basis adopted to explain the architectural concept to client					
2. Quality of conceptual development and evolution of main design theme					
3. Aesthetic and artistic considerations					
4. Regional/cultural/environmental considerations					
5. Appropriateness of adopted design approach to overall function and context					
6. Appropriate use of digital software in generating design?					
Total C					
D. Architectural Presentation [25 points]	[1]	[2]	[3]	[4]	[5]

1. Overall poster design theme and clarity					
2. Compliance to 2D minimum submission requirements (plans, elevations, sections, site plan, etc.)					
3. Compliance to 3D requirements (perspectives, 3D shots, interior, details, virtual models etc.)					
4. Physical modeling: Compliance to submit several study models showing design development at different stages					
5. Appropriate use of digital software?					
Total D					
E. Buildability [15 points]	[1]	[2]	[3]	[4]	[5]
1. Use of appropriate structural system(s)					
2. Submission of technical services & details					
3. Appropriate use of digital software?					
Total E	[1]	[2]	[3]	[4]	[5]
Total Score					

1.4. STUDY AREA

Table 2 shows the study area in the departments of architecture at three universities in Jordan, namely, Al-Ahliyya Amman, Petra, and Philadelphia, which were founded in 2009, 2010, and 2012, respectively.

Table 2. The CAD in architectural education stratified sample survey analyzed by universities numbers

University name	Year founded	Degrees offered	No. of students in	CAD type	Age of CAD employed at
Al-Ahliyya Amman	2009	B.Sc.	440	AutoCAD	4
				3-D MAX	4
				REVIT	2
				BIM	2
Petra	1991	B.Sc.	400	AutoCAD	7
				3-D MAX	7
				REVIT	2
				BIM	0
Philadelphia	2005	B.Sc.	350	AutoCAD	5
				3-D MAX	5
				REVIT	00
				BIM	0

2. Theoretical Framework

2.1. ARCHITECTURAL DESIGN

Architectural design is a complex process of creating a coherent structure or system that comprises many unified elements. During the past several years, many theoreticians and practitioners have attempted to define the word "design". Some of these attempts are the following:

"A goal-directed problem-solving activity", L.B. Archer;

"Decision-making, in the face of uncertainty, with high penalties for error", M. Asimov;

"A creative activity - it involves bringing into being something new and useful that has not existed previously", J.B. Reswick; and

"Design is a process of inventing physical things which display new physical order, organization, form, in response to function".

During the last two decades, architecture has been influenced by the increasing use of digital technology—both in the process and in the final outcome of design—to meet certain functional, cultural, aesthetic, environmental, and socio-economic needs. Thus, digital technology became the mediating factor between design theory and architectural theory. Accordingly, architectural design has become engaged in the exploration of complicated forms that depend heavily on the use of sophisticated "generative" computational programs. This transformation has begun to show a significant influence on architectural design theory, concepts and approaches. Much of the earlier basis for design methodology, such as the study of typological precedents and contextual setting, has now been replaced by emerging digital tools, such as generative modeling, animation and performance-based indicators.

2.2. ARCHITECTURAL EDUCATION

The advance of the ICT revolution with the accompanied digital technologies has changed the traditional context of architecture as a profession and in education.1 Students have increasing tendencies toward ICT and are becoming more skilled and involved in using various design media in their design processes, which, in turn, has affected the traditional design studio culture. Thus, this transformation should be considered, which requires us to rethink architectural design education.

A study prepared by Andia suggested that ICTs have been used for different purposes at different times. ICTs have been used in the profession over the past 25 years to enhance existing practices by facilitating the production of vast quantities of drawings with high accuracy and over less

time. ICT has been used by schools of architecture to transform architectural imagination and architectural practical possibilities. Furthermore, Andia indicated that ICT has affected both practitioners and students in terms of their skills and the setting of educational and professional culture. 2 Simultaneously, combining traditional design approaches with digital technology is effectively improving architectural practice. Al-Qawasmi emphasized that digital media, as used in the e-studio, can bring important changes to the architectural design process but might have unintended restricting effects.

However, architectural schools are becoming a laboratory setting for various digital design media, and the architectural studio itself has become a space to examine the role of computers in architectural design (i.e., Schenk). In contrast, CAD software tools have had a negative impact in many ways. First, these tools have weakened, or sometimes totally replaced, physical design tools, such as manual sketching by pen on paper, which often provides the necessary direct physical link between the hand and the brain. Second, CAD software has provided an alluring, easy, and inexpensive alternative to physical architectural models and has replaced them with a set of seducing graphics that are usually designed to impress the audience.

According to Guney, the disadvantage of using CAD tools is to make the student addicted and design his/her projects without creativity.3 Salman et al. anticipated that the use of CAD tools by students came as early as the conceptual stage in the investigation of specific formal themes.4 However, many educators and practitioners have called for a combination of both physical and digital design methods rather than the use of either method separately. Breen indicated that the combination of both techniques gives the designer added insights and more “real” approaches to develop, reconsider and refine any design. Breen also emphasized that the combination of both techniques should be actively incorporated in the educational curriculum to prepare the students as they move toward practice.

2.3. THE STATE OF CAD EDUCATION IN ARCHITECTURE SCHOOLS IN JORDAN

CAD systems have been used in Jordan since the mid-1990s. Several engineering firms and contracting companies were interested in the potential of digital technologies as drafting and modeling tools. As an educational

tool, CAD software was installed as an introductory course for undergraduate architectural programs in 1994,5 but there were only a few faculty members who could teach it then. Several years later, CAD courses became obligatory (i.e., CAD I, CAD II) over two semesters, typically for second-year students. Moreover, most Jordanian schools of architecture attempted to update their curricula through software and digital technologies to bridge the gaps between design theory and practice. Since 2014, however, some schools have begun to re-think the use of digital software as an analytical, generative and constructive tool. Consequently, software such as "Revit" and "Introduction to BIM" were installed in their curricula.

Generally, schools of architecture in Jordan combine the physical method with the digital method to ensure that students enjoy the benefits of both methods. Thus, most, if not all, schools of architecture prohibit the use of CAD tools in design for students in their first two years. Design teaching for first- and second-year studios emphasize the importance of developing manual graphic communication skills, sketching, and the experience of making physical models. However, the current curriculum of architectural design education in most schools suffers from a lack of synchronization and integration between computer courses and design projects. The prevalent tendency at present is to treat each course as a separate entity with its own distinct particularity, which prevents the necessary coordination between theoretical and design courses and applied computer courses. Moreover, although the structure of the curricula remains relatively flexible to manage new digital technologies, integrating these technologies with design courses is highly advisable and will ensure a more holistic and creative environment and not to use this software only as drafting tools.

3. Findings from the Analysis

An open-ended interview and an extensive survey questionnaire were conducted with 150 participants to record their responses to certain parameters. The questions were therefore structured in four phases that included the following:

- Part one: questions that determine the preference and attitude toward the use of CAD, such as the type of CAD software used by students, CAD learning methodology, proficiency level in CAD, and preference toward the use of CAD compared with traditional methods;
- Part two: questions on the advantages of using CAD software compared with traditional methods; and

- Part three: questions regarding the impact of CAD on the quality and creativity of the design compared with traditional methods.

The interview survey was designed to measure separate variables concerning the students' preferences toward the use of CAD in design. The survey was prepared and conducted from January to June 2016. The questionnaire comprised a number of questions with 3 different scores for each answer.

The students evaluated each of the standardized answers on a three-step scale from absolute acceptance to absolute negation (each of them had an assigned numeric value to calculate the sum for each answer). To compare the answers, each sum was divided by the number of times that a specific answer was chosen.

3.1. DATA PRESENTATIONS

Part one, Question 1: Sixty respondents were asked to describe their attitudes toward the importance of CAD compared with traditional methods. Figure 1 shows that the majority (85%) of the respondents had positive attitudes. However, 5% of the respondents were indifferent, and 10% had negative attitudes regarding the use of CAD.

Figure 1. Respondents' preferences and attitudes toward the use of CAD.

Question 2: On the superiority of using CAD over the traditional method of sketching, 80% of the students preferred to use CAD media over traditional methods, whereas traditional-method users accounted for only 5% of the total (Figure 2). A great interest in CAD was noted among all respondents. There seems to be a strong trend for architectural students to convert from traditional methods to CAD. The dramatic increase of CAD users suggests that there should be a serious reconsideration of the current curriculum to adapt to the new CAD trends.

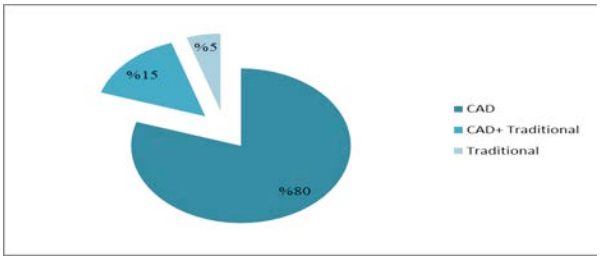

Figure 2. Responses to questions pertaining to preference toward the use of CAD versus traditional method tools.

Question 3: Type of CAD software used by students: The respondents were asked to identify the type of CAD software used in their graduation design project. Among the 60 respondents, 52 used AutoCAD, 3D-MAX and Photoshop, which are the most widely used software in education. However, the results revealed that the highest response rate was reported in Revit (7%), followed by Google Sketch-up (4.5%), Archi-CAD (4.5%), Grasshopper (2.1%), Maya (1.1%), and Vasari (1%) (Figure 3). None of the respondents used Heliotrope. Nevertheless, students employ various CAD software to produce the best graphical representations with minimum cost, maximum functionality, and the highest quality.

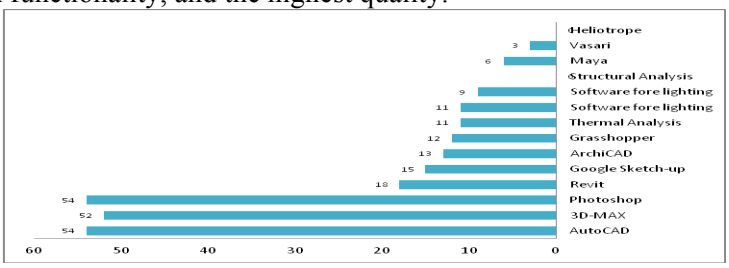

Figure 3. Type of CAD software used by students.

Question 4: The students were asked to evaluate their proficiency level with CAD applications. Figure 4 indicates that 90% of the respondents had high proficiency in AutoCAD, 85% had high proficiency in Photoshop, and 70% had moderate proficiency in 3-D MAX. In total, 40% and 35% of the respondents reported proficiency in Revit and Sketch-up, respectively. Moreover, 10% of the respondents used ArchiCAD, and 10% used Grasshopper. In contrast, regarding the use and performance of CAD environmental software, the results revealed that a very low response rate was reported for Heliotrope (0%), Vasari (1%) and software for lighting (3%) (Figure 4). This result can be explained by the lack of competent tutors in different CAD areas.

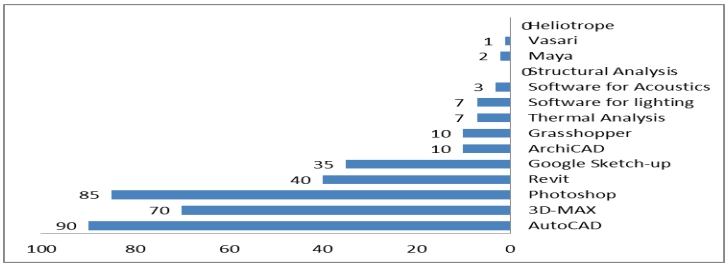

Figure 4. Proficiency level in CAD software application.

Question 5: CAD learning methodology by students: The respondents were asked to describe how they gained CAD proficiency based on the parameters of departmental courses, self-learning, and private classes. As shown in Figure 5, 30% of the respondents stated that they gained proficiency in CAD by self-learning first, and 25% gained their CAD proficiency through departmental courses. This result confirms the finding when students were asked about their preferences toward CAD. As shown in Figure 5, the majority (85%) of the respondents had positive attitudes concerning the use of CAD, which explains the percentage of the respondents who were interested (55%) in learning CAD either by themselves or in the department. The least number of respondents (15%) learned CAD through private classes.

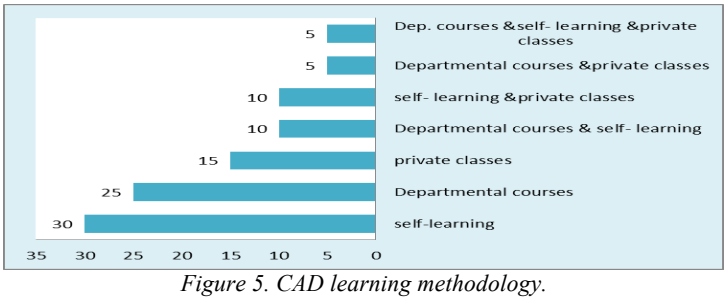

Figure 5. CAD learning methodology.

Question 6: The students were asked to specify the design method that was used in each stage/stages of the design process. Interestingly, both design methods were employed in all design stages. However, Figure 6 shows that traditional methods were used the most (80%) at the initial or conceptual stage and were utilized much less in the schematic design stage (30%). CAD was used as a design method mostly in design development, construction drawing, and the detailing and specification phases at 55%, 80% and 90%, respectively. Few respondents may use CAD in the conceptual stage because CAD has not replaced the traditional method of manually sketching designs. Instead, CAD acts as an extension of manual methods with a vast potential to advance various design ideals that previously were impossible to develop with traditional methods.

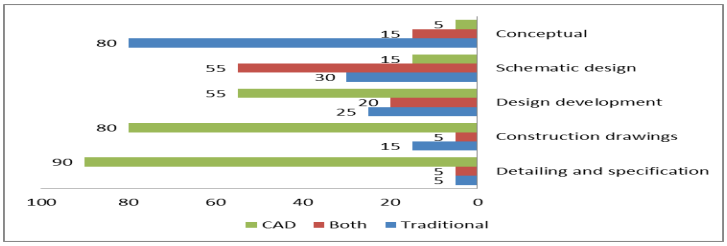

Figure 6. Responses to how much freehand sketching/CAD were employed in executing their designs' different stages.

3.1.1. Part Two: Questions about the Advantages of Using CAD Software

As shown in Figure 7, 90% of the respondents preferred to use CAD for its various advantages, such as accuracy, neatness, speed and lower cost. Interestingly, 70-90% of the students stated that using the combination of CAD with traditional methods typically helps them to visualize the end product better than using the CAD method alone.

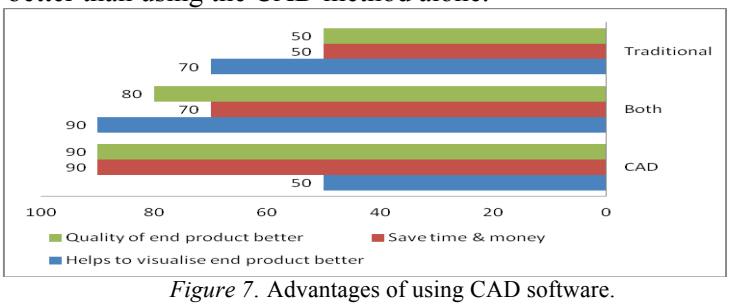

Figure 7. Advantages of using CAD software.

3.1.2. Part Three: Questions about the Quality of the End Product by Using CAD Compared with Traditional Methods

Figure 8 clarifies that the majority (90%) of the respondents considered the quality of the projects that used CAD to be higher than the quality of the projects that used traditional methods. However, 5% of the respondents are indifferent, and another 5% considered the design that is generated by CAD to be of lesser quality than the design that is generated by traditional drafting.

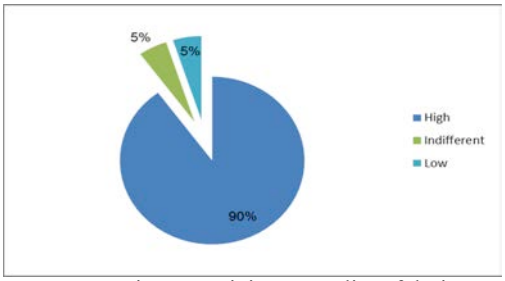

Figure 8. Responses to questions pertaining to quality of designs created with CAD.

3.1.3. The Role of CAD Courses Across the Curriculum of Architecture Schools

The respondents were asked to identify the importance of CAD in the architectural curriculum across the different knowledge areas. As shown in Figure 9, the results indicated that CAD has an important role in three central areas in the architectural curriculum, namely, design, urban design, and building technology, according to 90%, 85%, and 80% of the respondents, respectively. However, CAD has a weak role in other areas, such as theoretical courses (45%), engineering systems (35%), and project management (25%).

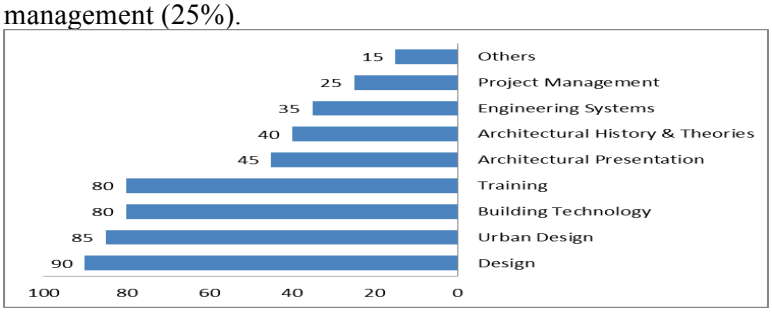

Figure 9. The role of CAD course across the curriculum of architecture schools.

3.2. GRADUATION PROJECT ANALYSES

3.2.1. Assessment Criteria

Five essential criteria were chosen to assess the quality of the graduation projects with differing score weights that totaled 100. These criteria were architectural program (15 points), site analysis (15 points), architectural concept (30 points), presentation and illustration (25 points), and buildability (15 points). The criteria are basically self-explanatory, but the architectural concept criterion needs some elaboration. Here, architectural concept was subdivided into 6 main considerations. First (1), a philosophical and intellectual basis is adopted to explain the concept and conceptual development and shows how the student arrived at his/her final solution and whether any design reference or precedent was adopted. Second (2), aesthetic and creative considerations refer to the overall formal, spatial and sculptural aspects of the project, including proposed materials, colors, patterns and textures. Third (3), regional and cultural factors refer to how the student responded to the sense of place and whether cultural influences such as local and/or regional architectural heritage had any role in the overall design or architectural trend that was adopted. Fourth (4), environmental considerations include the student's response to the question of sustainability, energy consumption, climatic factors, such as orientation and

solar shading devices, etc. Fifth (5), the appropriateness of the adopted trend refers to what degree the design approach has succeeded in being relevant and workable with the overall function of the project. The final (6) consideration is the degree of use of the CAD tools, including generative design software, to develop the final solution.

A. Architectural Program is the thorough and systemic evaluation of the interrelated values, goals, facts, and needs of users and the surrounding community. A well-conceived program leads to a high quality design. As shown in Table 3, the projects were assessed for their adherence to standards and codes, and the functional relationships of the main components.

Table 3. Architectural program assessment criteria

Criteria [15 points]	Low [1]	Below Average [2]	Average [3]	Above Average [4]	High [5]
Analysis of the needs, values and main goals of the project, and tentative cost estimate of the project					
Provision of detailed inventories, required facilities, functional relationships of main components of the project.					
Compliance with local and/or international space standards, codes and regulations.					

As shown in Figure 10, the majority (55%) of the graduation projects demonstrated that their designers were unaware of the projects' needs, values, main goals and tentative cost estimate. However, the designers of 30% of the examined projects were somewhat aware of these issues, and only 10% of the projects had a very clear architectural program with defined needs and values. Overall, 25-55% of the projects had problems with the functional relationships of the main components of the project. Finally, 60% of the projects' designs did not adhere to local or international standards, and the designers of only 15% of the projects actually considered the standards.

Site Analysis

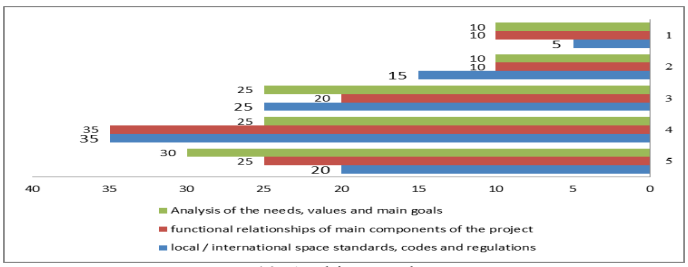

Figure 10. Architectural program.

Table 4. Site analysis assessment criteria

criteria [15 points]	Low [1]	Below Average	Average [3]	Above Average	High [5]
Response to urban context, surroundings and					
Site layout, topography and overall landscape					
Use of CAD to develop the overall site design					

A very interesting finding here was the absence of the use of CAD or any other digital software in analyzing the site. Figure 11 indicates that only 5% of the graduation projects had used digital applications in analyzing or planning the site. This result accords with the findings in part 2, question 2, regarding the types of CAD software. Because most respondents had a good command of traditional AutoCAD, the absence of specialized software to analyze or plan the site obviously caused the wrong design decisions. In all, 40-80% of the examined projects had no or low responses to the urban context, surroundings and accessibility. Furthermore, 80% of the projects in the study area did not have a proper plot in terms of shape, area and topography.

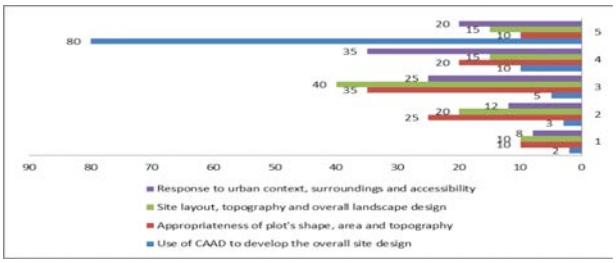

Figure 11. Site analysis.

C. Architectural Concept

Architectural concept is a representation of the designer thoughts of functional ideas that would become the adopted solution for the architectural design problem.i Architectural concept can be expressed through drawings, texts and verbal expressions. Table 5 shows the five essential criteria that were chosen to assess the impact of using CAD on architectural concept.

Table 5. Architectural concept assessment criteria

Criteria [30 points]	Low [1]	Below Avg [2]	Avg [3]	Above Avg [4]	High [5]
1. Philosophical and intellectual basis					
2. Aesthetic considerations					
3.Regional/cultural/environmental considerations					
4. Appropriateness of adopted approach to overall function and context					
5. Appropriate use of digital software					
6. Appropriate use of digital software in generating design?					

As shown in Figure 12, the majority of the students showed a tendency to use CAD even at the conceptual stage for drafting or site planning. Meanwhile, only 5% of the projects showed a tendency to use "generative" software to investigate a specific conceptual theme and its formal potential, such as Grasshopper, Maya, and Vasari. The interviews also revealed that because generative design software is not taught at the 3 schools, few students used this software by learning it on their own. Consequently, the projects were largely developed by using CAD for drafting and illustrative goals and lacked the necessary basis to comply with the required criteria to generate rational and creative designs, with little or no attention paid to regional, cultural and environmental or artistic considerations.

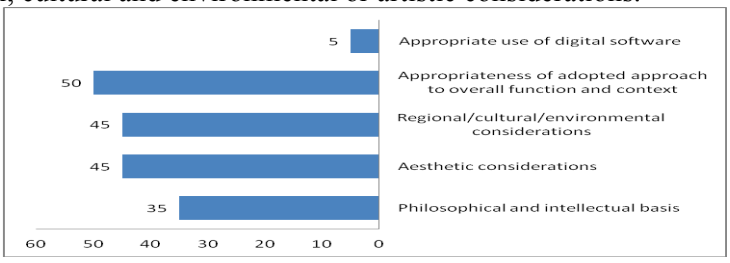

Figure 12. Architectural concept.

Architectural Presentation

Table 6. Architectural presentation assessment criteria.

Criteria [25 points]	Low [1]	Below Avg [2]	Avg [3]	Above Avg [4]	High [5]
Overall poster design theme					
Adherence to 2D requirements (plans, elevations, sections, site plan, etc.)					
Adherence to 3D requirements (perspectives, 3D shots, interior, details, virtual models)					
Physical modeling: Adherence to present several sketch models showing design development					
Appropriate use of digital software?					

As shown in Figure 13, the majority (90%) of the analyzed graduation projects were mainly concentrated on the poster design theme. Regarding "3D presentation", a higher use was reported; 85% reported that they used it in their graduation projects, whereas only 35% responded that they employed the traditional methods of physical modelling in their projects. Furthermore, the 3D presentations were delivered as seductive conceptual images that were incompatible with the 2D drawings and in some cases, with the physical models. This result means that the students are concentrating on images rather than on content, which leads to irrational and unrealistic projects. This result confirms our findings from the questionnaire survey, part 3, where most respondents indicated that CAD would guarantee a higher quality project. Certainly, there is no integration between CAD and other courses in the curricula.

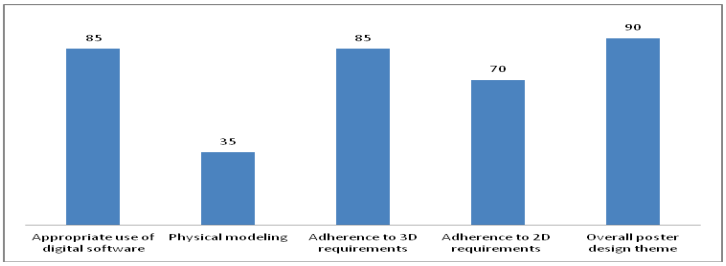

Figure 13. A sample of architectural graduation projects from three different Jordanian universities, 2012-2016.

Buildability

Buildability refers to the feasibility of realizing the proposed design and includes how the designer intends to integrate all the architectural and engineering elements into a wholesome building that has a proper structure, internal technical services and external skin (see Table 7).

Table 7. Buildability assessment criteria.

Buildability [15 points]	Low [1]	Below Avg [2]	Avg [3]	Above Avg [4]	High [5]
Use of appropriate structural system					
Submission of technical services & details (structural, electrical, mechanical, etc.)					
Appropriate use of digital software					

The survey revealed that no digital software was used to achieve a certain level of buildability (see Figure 14). The overwhelming majority of graduation projects lacked the necessary information regarding the structural and constructional aspects of the proposed design and mostly had a graphic nature with no meaningful impact on the architectural concept.

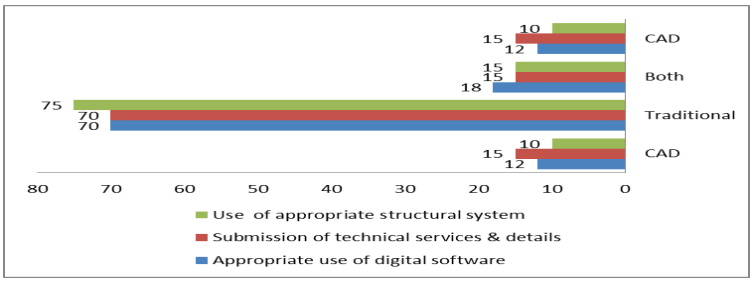

Figure 14. Buildability assessment criteria.

3.2.2. Main Criteria Used in the Assessment of the Impact of CAD on the Quality of the Architectural Design of Graduation Projects at Three Universities

As shown in Figure 15, the evaluation of 60 graduation projects from three architectural schools in Jordan according to criteria of program, site analysis, concept, presentation and realization revealed relatively similar results for the three schools. As expected, the architectural presentation criteria consistently scored the highest, ranging from 75 to 61.3, and the site analysis and concept criteria presented the next highest scores, ranging from 67.7 to 59.1 and from 59 to 55.1 respectively. However, the architectural program and buildability criteria had the lowest scores, in the ranges of 59.7 to 48 and 32 to 30.5 respectively. These disappointing results reinforce the notion that the overall quality of design has declined significantly due to the misuse of digital visual tools.

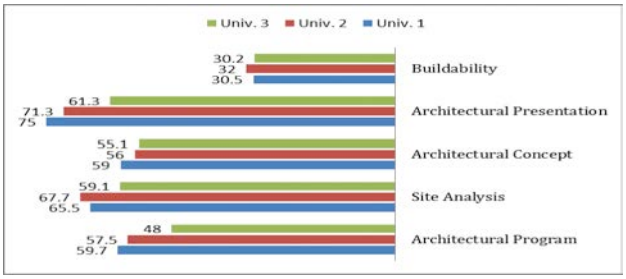

Figure 15. Criteria used in the assessment of the impact of CAD on the architectural design quality of graduation projects at three universities.

4. Discussion and Conclusions

This paper assessed the impact of CAD tools on the design process and on the quality of the architectural end product at three schools of architecture in Jordan. The findings revealed that all three schools have the same design educational approach that mixes traditional design methods with digital methods.

Although the students were found to have a strong tendency to employ new technologies, such as CAD software, in their design process, CAD is still being utilized for drafting and virtual modelling rather than as a problem-solving strategy. Moreover, the transformation of students' design trends from traditional methods to CAD is still not clearly defined; thus, students are unable to transfer the skills that are learned through traditional methods to the more complicated CAD method. Therefore, this shift in students' preferences toward CAD systems has resulted in a dramatic change in the study context together with other various shifts in design media, design thinking and design theory. The relationships among architectural design thinking, representation and media should be continual such that media provides the means for engaging in design thinking and progressing through various representational media. Moreover, digital media should be utilized as an essential part of the new design studio culture that integrates with other design methods and other courses in the architectural education curriculum. Thus, we must rethink and reconsider the potential of computers and communication technology to orient the entire institutional infrastructure and pattern of behavior for better architectural education and practice. There is also a crucial need to review the national accreditation criteria for architectural education to make them more adaptable to these emerging and ever-changing digital technologies.

References

ANDIA, A., (2002). "Reconstructing the Effects of Computers on Practice and Education During the Past Three Decades," *Journal of Architectural Education* 56, no. 2 (2002): 7-13.

ABU GHANIMA A., ET AL., (2006) "The Use of Computers in Architectural Research and Practice," in Proceedings of the 4th FAE International Symposium "Creating the Future" (North Cyprus, Jordan), 453-458.

ACHTEN, H., (2003) "New Design Methods for Computer Aided Architectural Design Methodology Teaching," International Journal of Architectural Computing 1, no. 1 (2003).

BREEN, J., (2004). "*Changing Roles for (Multi) Media Tools in Design: Assessing Developments and Applications of (Multi)Media Techniques.* in Design Education, Practice and Research," in the 22nd eCAADe Conference Proceedings (Copenhagen, Denmark: Architecture in the Network Society, September 2004): 530-539;

CHRISTOPHER ALEXANDER, "Information and an Organized Process of Design," in National Academy of Sciences, Proceedings of the Building Research Institute (Washington, D.C.: National Academy of Sciences, 1961), 115-24.

GUNEY, D. (2015). "*The importance of computer-aided courses in architectural education*" Procedia-Social and Behavioral Sciences 176: 757.

AL-QWASMI, J., (2005). "*Digital media in architectural design education: Reflections on the e-studio pedagogy*" Art Design & Communication in Higher Education 4, no. 3: 205, 220.

LAWSON, What Designers Know (London: Architectural Press, 2004).

SCHENK, P., (2005). "Reflections on the Teaching of Drawing in the Digital Age: Attitudes of Senior Academics in the United Kingdom to the Place of Drawing Tuition on the Design Curriculum in Higher Education," *Art, Design & Communication in Higher Education* 4, no. 3: 189-203.

SALMAN, H., LAING, R. AND A. CONNIFF (2006). "*CAAD Visualization Techniques Mediate the Conceptual Design Process as a Thinking Tool: Reflection on Action Study*" in Communicating Space(s): 24th eCAADe Conference Proceedings (Volos, Greece): 700-708.

SALMAN, H., LAING, R. AND A. CONNIFF (2008). "The Changing Role of CAAD at the Architectural Design Studio". In *Built & Human Environment Review* 1: 25-39.

Zellner, P., 1999. *Hybrid space: new forms in digital architecture*. London: Thames and Hudson,