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IMPACT OF 3D SIMULATION MODELING ON ARCHITECTURAL DESIGN EDUCATION

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Abstract

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ABSTRACT

Throughout the last few decades, architectural design education has witnessed several changes. One of these changes was using 3D Simulation modeling technology into design process. With the rise of environmental approach in design, new 3D simulation applications started to invade studios and laboratories of design. These applications proved an obvious efficiency for the architectural form concerning thermal adaptation, ideal lighting, and most appropriate ventilation. Lately, Arabic countries imported this technology into its schools of architecture, but unfortunately students faced obstacles in applying it in their design projects. Although there are certain courses, such as; 'Environmental Design', 'Indoor Environmental Control', and 'Digital Fabrication Modeling', that already give students a good knowledge with 3D simulation modeling and environment aspects, but in fact students still find difficulties in applying it into their 'Architectural Design' course. This paper investigates the real reasons standing behind this problem trying to produce new suggestions that can be followed into design studio. That aims to improve the student's architectural product to be closer to reality. As an effective case study, the paper will examine the impact of using 3D simulation modeling on a selection of design projects from 'the fourth year students, Faculty of Architectural Engineering, Beirut Arab University, Lebanon'. One of the important findings is: 'Students consider the 3D simulation modeling a constrain reducing their conceptual creativity'.

KEYWORDS

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1. INTRODUCTION

By returning a flash back certainly to 1980s, several trials were made to invent computer aided design programs. The first version of AutoCAD was released by Autodesk at December, 1982, which was compatible with DOS system. After launching 'Windows' and 'Macintosh' systems, tens of computer companies started to compete with each other producing their software programs. Function of these programs was supporting designers and architects in creating digital 2D and 3D models instead of an alternative to the traditional physical model. The ultimate aim of any design aid is to provide valuable information in an efficient manner. (Mills, 2000)

Computer simulation in architecture has a relatively brief history. As a rule, computer simulation is classified with computing and applied mathematics, while the technical development of its visualization methods is nonetheless inseparable from certain architectural aspects. Even early on, architects were involved in the development of computer-based methods of representation. More than twenty years ago, Horst Rittel, a former lecturer in design science at the Hochschule fur Gestaltung in Ulm, referred to computer simulation as one of the most important areas where architects interacted with the computer. With the rapid development of hardware and software, the advanced numerical simulation finally became a new practice in science and research,

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in architecture and design. Having now established itself as a ubiquitous cultural technology, it increasingly alters our interactions with the world. Simulation, then, is a fundamental concept in whose definitions repeated demands for trans-disciplinarity make themselves felt. This is true not only for arts, but perhaps even more so for a dialogue between architecture, technology, and the sciences. With this background, it becomes clear that a discussion of such basic concepts goes beyond the traditional discursive boundaries of architectural discourse, and is characterized increasingly by an intensive dialogue with the theory and philosophy of technology and with the history of science. (Gleiniger & Vrachliotis, 2008) On parallel of applying 3D simulation technology in the professional practice, the architectural education has applied it too, particularly with the beginning of 1990s. Design studios started to use computer modeling programs for the following reasons: 2D graphics, 3D modeling, rendering, simulation, and animation. No doubt, this software has invaded the architectural education. Design studio around the world witnessed a radical change concerning design strategy, methods of teaching, and even furnishing. Since 1990s, students became familiar with computer modeling programs employing them into 'Architectural Design' course. (Perrella & Pang, 1998)

This paper sheds a light on a specific problem focusing on the way that schools of architecture in Arabic countries are dealing with simulation modeling, which unfortunately imported this technology with an obvious mishandling. This software became taught to students, as independent courses such as; 'Environmental Design', 'Indoor Environmental Control', and 'Digital Fabrication modeling' without injecting its applications in the 'Architectural Design Course'. As a result, student's design process misses, in a way or another, the right strategy to use this software concerning, when to use it, which type of program should be used in each design phase, and how to reflect this application on powerful schematic drawings. To solve this problem, the paper aims to reach new criteria that can be followed into design studio to improve the student's architectural product and let it be closer to reality. This paper, therefore, hypothesizes that introducing basic knowledge of the 3D simulation modeling and making a detailed questionnaire on a sample of 4th year students in the Faculty of Architectural Engineering, Beirut Arab University, Lebanon, may lead to this new strategy.

2. KNOWLEDGE IN THE AGE OF SIMULATION:

Over the past decade, software architecture research has emerged as the principled study of the overall structure of software systems, especially the relations among subsystems and components. From its roots in qualitative descriptions of useful system organizations, software architecture has matured to encompass broad explorations of notations, tools, and analysis techniques. Whereas initially the research area interpreted software practice, it now offers concrete guidance for complex software design and development. (Shaw, 2001)

2.1 Definition of Simulation Modeling

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behavior of the actual system or its subsystem can be inferred. In its broadest sense, simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time. Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance. For instance, simulation can be used to answer questions like: What is the best design for a new telecommunications network? What are the associated resource requirements? How will a telecommunication network perform when the traffic load increases by 50%? How will a new routing algorithm affect its performance? What will be the impact of a link failure? (Maria, 1997) Simulation modeling is the process of creating and analyzing a digital prototype of a physical model to

predict its performance in the real world. It is used to help architects and engineers in predicting fluid flow and heat transfer patterns. (Law, 2014) Researchers in the University of Central Florida, USA, define the 'computer model' as a mathematical representation of an object; a person, a building, a vehicle, a tree, - any object. It can be a process like; a weather pattern, traffic flow, air flowing over a wing. In their point of view, models are created from a mass of data, equations, and computations that mimic actions of things represented. Models can be simple images of things or can be complex carrying all characteristics of an object or process they represent. (UCF, 2014) Therefore, it can be concluded that 'Simulation Modeling' is: The process that makes a model behaves the way it would act in the real life.

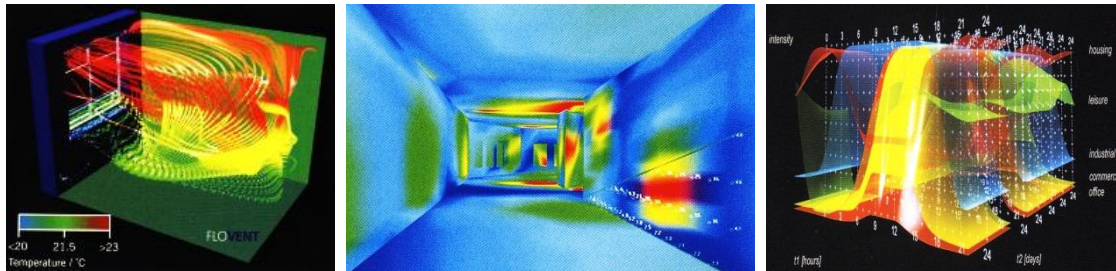


Fig. 1 Different simulation modeling applications; the left represents air flow and temperature simulation, the middle represents light contour rays simulation in a museum competition, and the right represents circulation simulation made by UN Studio in designing Penn Station, New York, USA, 1999.

Reference: (Lally & Young, 2007), p.49

2.2 Functions of Simulation Modeling

After mentioning reasons of using computer modeling programs, the essential functions for 3D simulation modeling applications (Winsberg, 2003):

- Assessing extreme environmental conditions such as; strong winds, hurricanes, high temperature, immense sunlight, or even full darkness.
- Testing light flux into spaces.
- Examining efficiency of circulation flow inside and outside building.
- Examining technical installations such as; sanitary, electrical, and mechanical installations.
- Choosing the appropriate materials that match with function, budget, and aesthetic value.
- Optimizing design form for loads, weights, and safe structure.

2.3 Mathematical background of Simulation Modeling

There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. This confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes. Confidence in model estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). Over several decades of development, models have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases. Climate models are mathematical representations of the climate system, expressed as computer codes and run on powerful computers. One source of confidence in models comes from the fact that model fundamentals are based on established physical laws, such as conservation of mass, energy and momentum, along with a wealth of observations. A second source of confidence comes from the ability of models to simulate important aspects of the current climate. Models are routinely and extensively assessed by comparing their simulations with observations of the atmosphere, ocean, cryosphere and land surface. A third source of confidence comes from the ability of models to reproduce features of past climates and climate changes. (Randall, 2007)

2.4 Simulation Modeling Applications

The speed and sophistication of computer modeling applications have increased rapidly over the last few decades, but debate persists over its ability to match the intuitive nature of physical modeling. Moreover, because of the extrusional logic used by most programs, XYZ coordinates points must be used to create diagonals and warped planes and can be cumbersome as compared with directness of angling cardboard planes. This limitation is compensated for by the ease with which forms can be manipulated. In addition, inherently common operations for a computer, such as duplication, distortion, and overlay, can become powerful tools for discovery. (Mills, 2000) Simulation modeling applications are divided into two types: software applications and hardware applications.

2.4.1 Software simulation modeling applications:

According to the interview with the expert Samer El-Sayary the Egyptian Autodesk certified instructor, computer companies distributed the aided programs on groups, titled 'candy groups'. The shown table presents five different candy groups as follows:

Table 1. Candy groups of the 3D modeling and simulation programs
Reference: Based on an interview with Samer El-Sayary

CAD-CADD	Digital Modeling	BIM	2D & 3D Simulation	Parametric Generative
AUTOCAD SKETCHUP RHINO	3D MAX MAYA CINEMA 4D LIGHT WAVE SOFT IMAGE AUG. REALITY	ARCHICAD	DESIGN BUIDER ECOTECT E-QUEST VASARI	GRASSHOPPER

The shown figure 2 presents the most used software programs in 3D modeling. Each program has its own function, interface, and hardware requirements. Some of these programs have been developed to make simulations.



Fig. 2 Interface of fifteen modeling programs.
Reference: Collection by the authors

The next generation of graphic modeling was the 3D simulation programs. In the shown figure 3, samples of these programs are presented.



Fig. 3 Interface of five 3D simulation modeling programs.
Reference: Collection by the authors

By focusing closer on the most used simulation programs, it can be figured out that its main function is analyzing and simulating the environmental performance of a building. These programs contribute also in designing the building's outer form. Many users are relying on a single simulation program when they might be more productive having a suite of tools from which to choose. Early design decisions may not require a detailed simulation program to deal with massing or other early design problems. It is encouraged that users consider adopting a suite of tools which would support the range of simulation needs they usually see in their practice. (Crawley, 2005) The shown table explores the potentials of fourteen simulation programs in light of forty different architectural and environmental criteria.

Table 2. Comparison between the potentials of 14 Simulation Programs
Reference: (Attia, 2012), p.109 - Modified by the PhD student Yathreb Sabsaby

Criteria	HEED	eQUEST	ENERGY 10	Vasari	Solar Shoebox	Openstudio	IES VE- Ware	ECOTECT	DesignBuilder	BeOpt	BLAST	DeST	DOE-2-1E	TRNSYS
Metrics	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Energy	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Environmental (CO2)	•	•	•				•		•	•	•		•	•
Economic	•	•	•					•	•	•		•	•	•
Embodied Energy														
Urban Scale NZEBs														
Comfort & Climate	•	•	•		•		•	•	•	•	•		•	•
Climate Analysis	•	•	•	•			•	•	•		•		•	•
Static	•	•	•	•			•	•	•	•				
Adaptive					•									
Comfort Visualization					•			•	•					
Passive Solar	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Geometry, Massing				•	•	•	•			•				
Day-lighting	•	•	•				•		•			•	•	•
Natural Ventilation	•		•				•		•	•				
WWR		•	•				•		•	•		•	•	•
Thermal Mass	•		•				•		•	•	•			
Shading Devices	•	•	•			•	•	•	•	•	•	•	•	•
Energy Efficiency	•	•	•	•	•	•	•	•	•	•	•			•
Envelope insulation	•	•	•	•	•	•	•	•	•	•	•			
Glazing Performance	•	•	•	•	•		•	•	•	•				
Envelope Air Tightness	•	•	•				•	•	•	•	•			
Artificial Lighting	•	•	•				•		•	•				
Plug Loads	•	•	•				•		•	•			•	•
Infiltration rate	•	•	•		•				•	•	•	•	•	•
Mechanical Ventilation	•		•						•	•		•		
Cooling system	•	•	•	•			•		•	•	•		•	•
Heating System	•	•	•	•			•		•	•	•		•	•
Renewable ES	•		•		•		•			•				•
Photovoltaic (PV)	•		•		•		•			•				•
Building integrated PV														
Solar Therm. Collectors			•				•			•		•		•
Innovative Solution & Technologies					•		•			•				
Mixed Mode Ventilation					•							•		•
Advanced Fenestration							•		•					
Green Roofs							•							
Cool Roofs	•													
Double Skin Façade									•					
Solar Tubes														
Phase change materials												•		•
Validation: IEA SHC Task 12 Envelope BESTEST	•		•				•		•		•	•	•	•

2.4.2 Hardware simulation modeling applications:

Throughout history of visual modeling products, it can be seen that models were made by simple techniques and traditional materials. After the digital revolution in 1990s, new machines have appeared supported in producing physical models with new characteristics. Equipment such as; CNC machines, 3D printers, 3D plotters, 3D scanners, robots, virtual digital pens, and others, contributed in making a radical change in the modeling industry; not only in architecture but also in sculpture, car-design, Space-vehicles, and military stuff.



Fig. 4 Samples of five modeling machines using different materials
Reference: Collection by the authors

Each machine has its own function and works on specific materials. The outcome models differentiate in accuracy, hardness, flexibility, and cost. On parallel to the modeling equipment, engineers invented simulation modeling hardware as; thermal cameras, digital glasses, digital helmets, virtual simulators, and environmental simulation equipment. The sky dome is one of the important environmental simulation hardware that became usable in architectural education. In the middle of this dome, a study model is put and became a center of environmental studies; sunlight and temperature experiments.



Fig. 5 Exterior and interior shots for the Sky Dome in the Welsh School of Architecture, Cardiff University, UK, present that dome's surface is covered by fluorescent lamps simulating daylight performance. Students, with cooperation of a technician, put their study-model in the middle of the dome activating environmental experiments.

Reference: Photographed by the author, M. Youssef, August, 2015

Simulation hardware is compatible with software programs translating all results to be visualized on computer screens and can be modified manually. Beside the environmental simulation applications, the technology of simulation became also used

in the field of planning and urban design. Other tools are used to simulate the process of planning. City-building simulators became known worldwide such as; AnyLogic which is a large scale urban simulator designed for urban planners. (Borshchev, 2013)

3. EXPERIENCING A CASE STUDY

After giving information about definitions, functions, mathematical background and applications of simulation modeling, the paper will examine a case study of students, belong to a specific Arabic school of architecture, trying to investigate the problems facing them during phases of design process regarding when, how, and which type of simulation program has to be used to reach the intended design goals.

The case study will be 'the 4th year students, Faculty of Architectural Engineering, Beirut Arab University, Lebanon', in the Fall Semester - academic year 2015/2016, to be the main case study of this research trying to determine their using of simulation modeling applications. Some important parameters have to be introduced firstly as follows:

- Total number of students = 60
- In the course of 'Architectural Design', number of projects per semester = 2
- In the course of 'Architectural Design', number of teaching staff = 6
- In the course of 'Architectural Design', number of weeks = 15
- Average number of courses that each student learns per semester = 7
- Available facilities for students = a design studio, a workshop of making models, a digital fabrication laboratory, and an environmental laboratory.
- Weekly, number of days in attending 'Architectural Design' studio = 2
- Weekly, duration of 'Architectural Design' studio = 10 hours
- Duration of a learning day = 8 hours - from 8.00 am to 4.00 pm
- Average duration to build a model using 3D printer = 7 to 8 hours
- Types of the two projects given in the Fall Semester were 'Museum of Knowledge - proceeding in the international Indian competition of Chandigarh' and 'Google Office Building in Beirut'.

3.1 Problems facing students in design studio regarding 3D Simulation Modeling

In teaching the courses of 'Architectural Design', it can be noticed that students pass a systematic process in designing their projects. The shown table outlines this process.

Table 3. Phases of design process for students

Reference: The authors

Phase I – Research	- Research groups analyzing site context, regulations, components of design program, and similar projects, - executing a site model - Individual research in (architectural theories, philosophies, myths, arts, science, history, building technologies) to select an inspiration source - Individual research in the appropriate structure system
Phase II – Concept	- First conceptual sketch - Abstraction - Design alternatives through sketches and study models - Settling on a single design proposal - Developing idea to solve functions within a deliberate form
Phase III – Schematic Drawings	- Translating the conceptual sketches and models into schematic drawings of (plans, sections, elevations, site plan, and perspectives) - Analytical and structural drawings
Phase IV – Presentation	- Submitting the project fully presented - Final model / animation / computer presentation / manual presentation - Oral presentation
Phase V – Final Jury	- Final oral exam – examining all aspects covering the ILO's, Intended Learning Outcomes, of the course.

According to this table, students made physical and graphic models during their design process. In phase I (Research), teamwork groups can erect a physical model for the chosen

site. In phase II (Concept), each student is asked to build a physical study model expressing his/her own concept. In phase III (Schematic Drawings), student may need to develop the study model and is welcomed to present graphic models such as; perspectives, interior shots, or even 3D details. In phase IV (Presentation), each student is asked to submit study models and the final model. In the final phase, jury members are often building their impressions from the first sight toward student's models.

Throughout their study, students learn other courses beside 'Architectural Design' like 'Environmental Design', 'Indoor Environmental Control', and 'Digital Fabrication Modeling'. In these courses, students took concentrated information about simulation of environmental issues and parametric applications, but unfortunately they do not apply it into the 'Architectural Design' course for the following reasons:

- o Student's tight time
- o Unawareness of the student him/herself
- o Separation between the conceptual design and reality
- o Some students find the traditional methods, as manual sketching, enough to cover the whole design phases
- o Jury members do not focus on these applications in particular
- o Although the environmental factors in Lebanon are not stable, it can be found that students do not pay much attention to simulate these factors into their design projects

As a serious attempt to solve most of these problems, a questionnaire was designed and distributed on the whole group of 4th year students. The main target of this questionnaire is to investigate the awareness of students to use simulation modeling applications in design projects. A copy of this questionnaire is attached at the end of the paper in the appendix part.

3.2 Analysis and Statistics of the Questionnaire

A single page questionnaire was distributed over 60 students, the total number of students in the 4th year level. 21 of them did not show interest and 39 answered it. SPSS was the statics program that has been used in analyzing the students' results. Firstly, the questionnaire asked students to fill personal information; (name, GPA, number of credit hours taken in the Fall Semester, 2015/2016), then it was divided into three parts:

- Part I: Applications of students on 3D simulation modeling
- Part II: Impact of 3D simulation modeling on design core
- Part III: Students suggestions

Results of students' answers can be explained as follows:

Answers of the first part: (Applications of students on 3D simulation modeling)

1- Answer of first Question, "In which phases do you use the modeling application?"

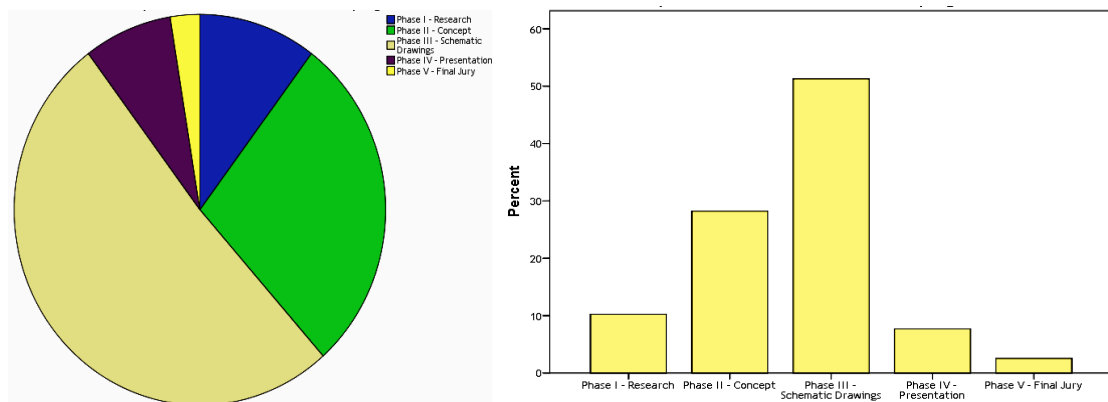


Fig. 6 Analysis and statistics for the first question in the questionnaire indicating that students use 3D modeling applications mostly in the phase of 'Schematic Drawings'

Reference: Statistics of authors

2- Answer of the second question, “Highlight the programs you use in your design process?”

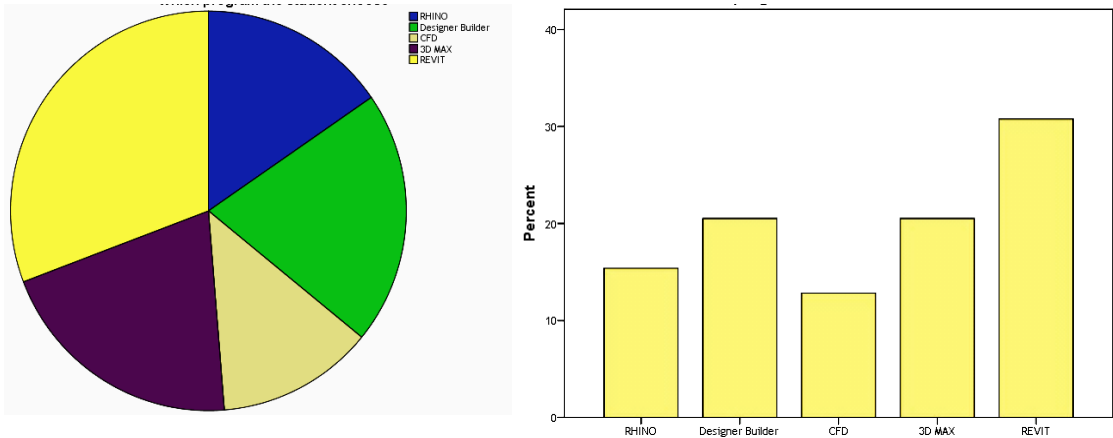


Fig. 7 Analysis and statistics for the second question in the questionnaire indicating that students use REVIT program mostly in the design process

Reference: Statistics of authors

3- Answer of the third question, “Highlight the source you recognized the programs?”

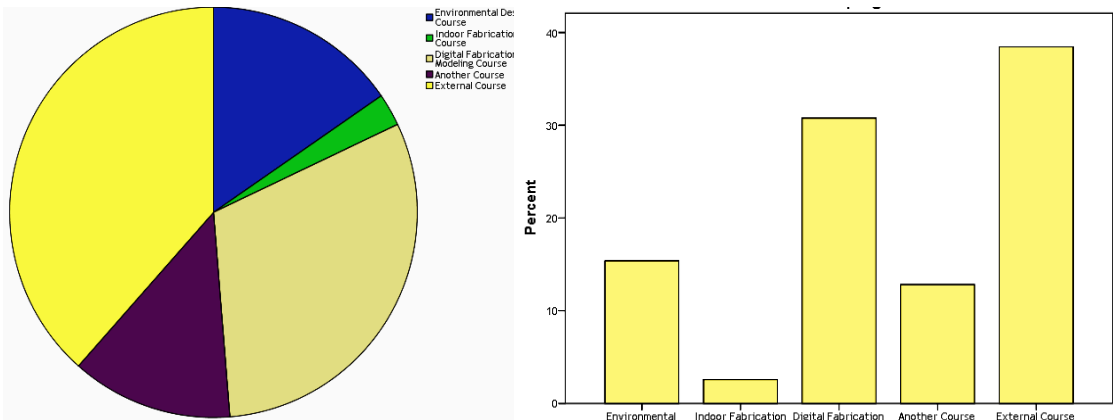


Fig.8 Analysis and statistics for the third question in the questionnaire indicating that students depended on external sources mostly to recognize using the modeling programs

Reference: Statistics of authors

4- Answer of the fourth question, “Highlight on the problems you faced during using these programs?”

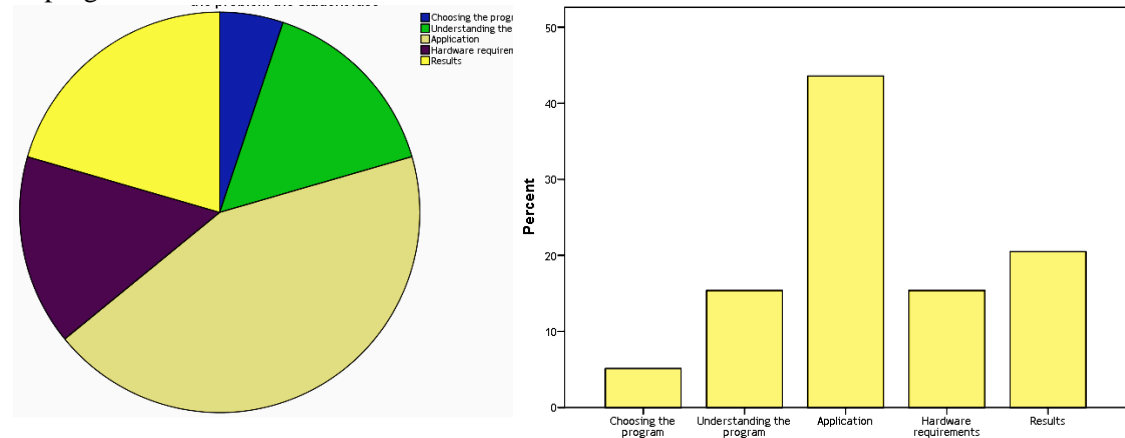


Fig.9 Analysis and statistics for the fourth question in the questionnaire indicating that the most problem facing students was the using the application itself

Reference: Statistics of authors

Answers of the second part: (Impact of 3D simulation modeling on design core)

5- Answer of the fifth question, “Do you think that using 3D simulation modeling effect positively on your design project?”

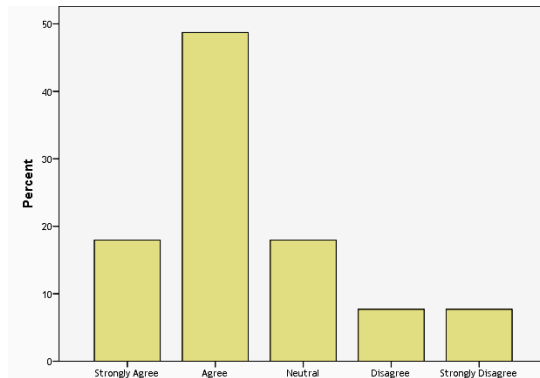


Fig.10 Analysis and statistics for the fifth question in the questionnaire indicating that most students are agreeing on the positive effect of using 3D simulation on design project

Reference: Statistics of authors

6- Answer of the sixth question, “From your point of view, are you satisfied with efficiency of the simulation modeling in serving your design concept?”

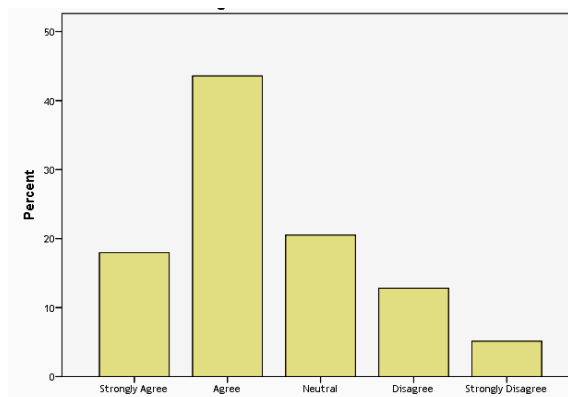


Fig.11 Analysis and statistics for the sixth question in the questionnaire indicating that most students are satisfying with efficiency of simulation modeling in serving design concept

Reference: Statistics of authors

7- Answer of the seventh question, “Do you think that using 3D simulation modeling in your design process reduce your conceptual creativity?”

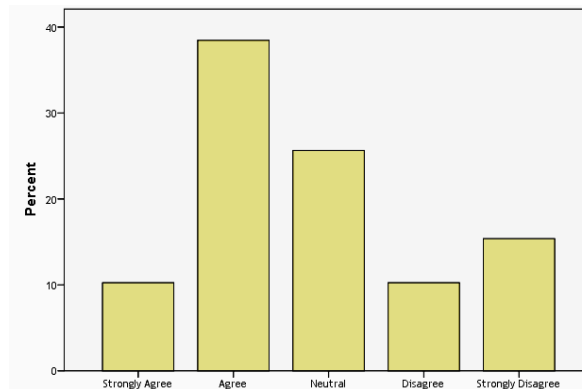


Fig.12 Analysis and statistics for the seventh question in the questionnaire indicating that most students viewing that the conceptual creativity has been reduced due to use the 3D simulation modeling . Reference: Statistics of authors

8- Answer of the eighth question, “Do you think that more integration between 3D simulation modeling and design process will help you more?”

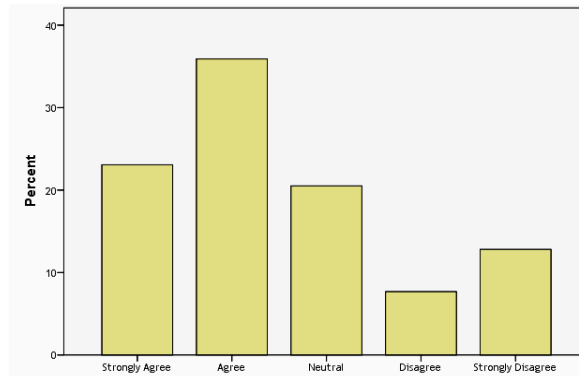


Fig.13 Analysis and statistics for the eighth question in the questionnaire indicating that most students agree on the integration between 3D simulation modeling and design process and that will help them more.

Reference: Statistics of authors

Answers of the third part: (Students suggestions): None

4. CONCLUSIONS

Finally, the paper may reach a set of conclusions as follows:

- a- There is an obvious gap between students' understanding of the main objectives of environmental simulation programs and their ability to reflect this application in design process. This research tried to shed the light on this problem suggesting four recommendations that can be applied in the schools of architecture, particularly in the Arabic countries:
 - First: Curriculum of environmental courses should be upgraded adding more advanced technology of using the environmental simulation programs.
 - Second: There should be an encouragement for the faculty members to attend and participate in the environmental workshops to gain more knowledge about the 3D environmental simulation programs. This participation aims to reflect this knowledge into the design studio.
 - Third: In design studio, there should be orientation for students to use the 3D simulation applications in the earlier phases of design process. These applications can be useful tools supporting their design decisions.
 - Fourth: Tutors of the 'Architectural Design' course should give more concern to the environmental issues and focus more on the importance of using simulation which adds the reality dimension to the project.
- b- Clearly, many students do not pay attention to use simulation programs in design process of their projects because they know it will not be a part of jury's questions.
- c- According to the questionnaire, most of students consider the 3D simulation modeling a constrain reducing their conceptual creativity because they thought it enforce them in shaping, orienting, and functioning the project's components.

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APPENDIX

Template of students Questionnaire

Personal Information

Name:

GPA:

Number of Credit Hours for the Fall Semester, Academic Year 2015/2016:

First Part: Applications of students on 3D simulation modeling

❖ From the shown five cells, Please highlight the suitable choice:

No.	Questions	1	2	3	4	5
Q1	In which phases do you use the modeling applications?	Phase I – Research	Phase II – Concept	Phase III – Schematic Drawings	Phase IV – Presentation	Phase V – Final Jury
Q2	Please, highlight the programs you use in your design process:	RHINO	Design Builder	CFD	3D MAX	REVIT
Q3	Highlight the source you recognized the programs	Environmental Design course	Indoor Environmental Control course	Digital Fabrication Modeling course	Another course	External Source
Q4	Highlight on the problems you faced during using these programs:	Choosing the program	Understanding the program	Application	Hardware requirements	Results

Second Part: Impact of 3D simulation modeling on design core

❖ Please select the best choice from among these choices:

Strongly Agree (1)	Agree (2)	Neutral (3)	Disagree (4)	Strongly Disagree (5)
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No.	Questions	1	2	3	4	5
Q5	Do you think that using 3D simulation modeling effect positively on your design project?					
Q6	From your point of view, are you satisfied with efficiency of the simulation modeling in serving your design concept?					
Q7	Do you think that using 3D simulation modeling in your design process reduce your conceptual creativity?					
Q8	Do you think that more integration between 3D simulation modeling and design process will help you more?					

Third Part: Students Suggestions

❖ Please state your suggestions if any:

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Thank you for your cooperation