Learning by Merging 3D Modeling for CAAD with the Interactive Applications

Bearing walls, Vaults, Domes as Case study

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The development and the innovation of tools, techniques and digital applications represent a challenge for those who are in charge of architectural education to keep up with this development. This is because these techniques provide potentials that are not available in the traditional method of teaching. This raises an important question: can these tools and techniques help to achieve the targeted outcomes of education? This research paper discusses how to integrate both digital 3D models, of CAAD, and interactive applications for the development of architectural education curriculum. To test this, a case study has been conducted on the subject of building construction, for the second year at the faculty of engineering, specifically, the bearing walls construction system. In addition, this study has been divided into three parts. Through the first part, the scientific content of the curriculum, which tackles the bearing walls, has been prepared. The second part shows how to convert the scientific content into an interactive content in which the students learn through the experiment and the simulation of the traditional construction methods as the students acquire construction skills and the ability to imagine different structural complexities. The third part includes the creation of both the application and the software containing the interactive curriculum. Workshop for the students has been held as a case study to test the effectiveness of this development and to recognize the pros and cons. The results confirmed the importance of integrating this applications into architectural education.

Keywords: CAAD, 3D modeling, Building Construction, Interactive applications, Bearing walls systems
INTRODUCTION
Is there a need for the development of the current teaching methods, especially in the light of the development of CAAD programs and the availability of many sites and interactive educational applications? Is it possible that CAAD programs can be assisting programs in education and creativity? Moreover, what is the students’ reaction towards the modern methods of education? What are their advantages and disadvantages? The research, in order to answer these questions, clarifies the importance of the development and the usage of CAAD programs in architectural education as traditional teaching methods depend on the second dimension and, in some cases, such as hand sketches, they show the third dimension. Whereas some CAAD programs depend on 3D, 4D, 5D, 6D, 7D (Czmoch & Pękala, 2014) which are very important dimensions in the study of the effectiveness and the efficiency of the design and constructive elements. However, the study will focus on 3D models, of many of CAAD programs, integrated with an interactive educational application. The research supposes that teaching through these programs and applications will complete what is missing in the traditional methods.

METHODOLOGY
The research depends on three integrated approaches. The first approach is the inductive approach through which the previous studies, dealing with scientific experiments and applications, have been reviewed. These scientific experiments and applications have been conducted to use both 3D models of CAAD and interactive applications in architecture to benefit from their advantages and avoid its disadvantages.

The second approach is the practical approach. This approach completes what has been achieved by the inductive approach. It is divided into three sections. The first section will tackle the presentation of the scientific material, bearing walls systems, depending on the books of architecture history, which include the development of construction using this method. In addition, it depends on the books of architectural construction, which deal with the types, the methods and the materials of construction used in building bearing walls. This forms the database for both the course and interactive application. The objective of the database is that the students learn how to classify all structural elements according to their structural nature and to link them to their architectural function. Whereas the second section depends on the conversion of the prepared scientific content into an interactive content. This section depends on the methods of preparing the interactive materials and their organization to achieve the objectives and learning outcomes, which will be carried out in the third section. The third section includes the preparation of the interactive exercises through which the students learn, using 3D Models, previously prepared with CAAD. The students gain scientific and practical knowledge through trial and error and through providing the right solutions.

The third approach is the case study which will show the extent to which the students take the advantage of the development of the former Course referred to, as the study is related to the students at the faculty of engineering, the university of Al Azhar. The results have been analyzed through observation, questionnaire.

BACKGROUND
Previous studies are divided into two sections: the first one tackles the usage of 3D models of CAAD in the development of curriculums. The second section tackles the usage of interactive applications as being tools, to develop professional practice, and educational tools.

firstly: the usage of 3D models of CAAD in the development of curriculums
Many studies, which were conducted, tackled the development of curriculums, through 3D models of CAAD, according to their technical and informational development. The case study shows some of them, according to the ways of their usage, as follows:
A case study was conducted by professor Maia Engle, in cooperation with Professor Gerhard Schmitt, both of whom are from Swiss Federal Institute of Technology ETH, Zurich. They prepared an interactive approach, for many digital designs, through which they demonstrate the future of design through CAAD. The approach consisted of thirty-three innovative projects and it was divided into four main sections as follows: 1- Design in space and time. 2- Learning and Creative Collaboration. 3- Virtual Environments. 4- IT and design practice.

The idea of the approach depended on how CAAD can be a tool for innovation and creativity in design. It greatly focused on the interaction between the designer and the computer to achieve the aesthetic aspects. The approach was supported with 3D models and animation for each project so that students can learn, through the animation sequences, the ways of exterior and interior digital design, graphic design and Information technology. (Engeli, 2001)

Both Gianluca Cattoli and Simon Garagnani conducted another case study in Italy, at the University of Bologna. They trained the students to make models of many historical buildings, in the form of practical exercises with different levels. This was applied through scientific methodology which aimed at learning by practicing and participating. They divided the students into groups, each of whom was required to simulate a building of architectural and constructional value. At the end of the course, an evaluation of the students work was made. The result was that they all succeeded in learning the basics of designing and simulating many historical buildings (Garagnani & Gianluca, 2015).

Another study was carried out by both Zoja Veide and Veronika Strozheva, from Riga Technical University. They developed the course of construction calculation in the civil engineering department. They used visualization to help students understand the geometrical problems. In this course, they used programs of Archicad, Revit and CAD, associating the used models with augmented reality, which helped the students to gain experience through experiment and practice. The content of the subject was divided into four modules, one of which was to teach geometric modeling. The period of the course was 32 hours, ten of which had been allocated for practical exercises on the previously mentioned programs (Zoja Veide, 2015).

Zhigang Shen and Wayne Jensen, both of whom were from The Durham School of Architectural Engineering and Construction, the university of Nebraska-Lincoln, carried out another study. The two researchers taught students sustainability through BIM programs. They prepared an approach including both sustainability systems and the way of their application on the different types of buildings. Moreover, it included how to apply modeling of buildings, by BIM, and energy simulation, through the programs of energy calculation. It showed how to analyze the rates of its availability and the effectiveness of environmental treatments. The design course has been linked to the environmental control course in order that students could apply ideas and test their impact on the efficiency of their designs (Zhigang Shen, 2012) (P.E., 2014).

many case studies for the development of curriculums were conducted through parametric modeling. One of them was conducted by Joshue Vermillion and Antonieta Angulo. They prepared a new course depending on teaching the strategies of thinking through parametric design integrated with traditional curriculums, at the university of Ball. One of its advantages was that the students were able to associate the elements of the project in a unified model according to the different changes, i.e, material performance, sustainability and structure form. The students were able to evaluate their work with digital ways, through modeling methods, surface, solid, rendering and digital fabrication. The digital culture was reflected on their designs. (Angulo & Vermillion, 2012).

Analyzing the previous studies, we find that they clearly depended on 3D modeling and used it in architectural education in various ways according to
different subjects. The experiments varied widely using digital media, animation augmented reality and other techniques which help to teach. The researcher considers that the usage of these techniques reflects their emergence during the period before which the interactive applications appear. The usage of the interactive applications is a trend that has spread in many educational branches and professional practice.

**Secondly: Using interactive applications to develop professional practice**

In the context of the inductive approach, many interactive applications have been monitored and developed in many professional and educational aspects, including a study by The site, Arch daily www.archdaily.com, which is one of the specialized sites in the presentation of everything related to architectural engineering, such as projects, products and scientific articles. It showed the most important applications from which architects can benefit. These applications have various uses and objectives and five of which were chosen according to their advantages as follows:

1- Auto desk formit application helps architects and students to put the initial ideas of the conceptual masses to be developed easily. It provides multiplicity of tools that facilitate 3D modeling. In this purpose, the tablet devices and mobiles are used and drawing is made only by fingers.

2- Rhino 3D application is used to show ideas that have been implemented through the Rhino program for the parametric design. It has been designed for both architects and clients.

3- Graphsoft BIMX application is used to show the implemented projects by BIM programs to follow the development of designs with the ability to review and identify the clashes that occur in the construction site, through virtual reality. It has been designed for both site engineers and clients.

4- Magic plan application is used to take the dimensions of real spaces through the mobile camera turning them into 2D graphics and drawings in order to be exported later to the various drawing programs.

5- Sketchbook application enables designers to draw sketches on tablet devices anywhere, which many similar applications do. The applications simulate the same traditional methods of drawings. So, interactive applications can be considered as assisting tools for the designer. It is also a means to review and exchange ideas and to measure space dimensions. In addition to the previous applications, there are educational applications which target the undergraduate students. The researcher has monitored many of these applications which tackle many subjects, but he has focused on the applications which deal with both architectural construction of bearing walls and the history of architecture. By monitoring these applications and downloading them from the "google store", they are found to be non-interactive applications, i.e., they only display the scientific content in a simplified form, which resembles the same traditional methods, but the only difference is that they can be loaded on mobile phones and tablets. Therefore, the research seeks to design an interactive educational application as follows:

**INTERACTIVE APPLICATION**

The researcher prepared an interactive application which is called "3D Arch Learning", after he had conducted tests and a questionnaire related to the students’ awareness of the scientific content of architectural construction subject, of second year undergraduate students. It was found that the curriculum and the used teaching aids weren’t sufficient. Depending on that, the idea of interactive applications appeared as a means through which different educational aids and methods can be combined in one place, and linked to each other with the possibility to measure the level of students according to the achievement of different learning outcomes.

**what are the learning outcomes for which the application will be designed?**

The application is designed to achieve the learning outcomes according to the national academic standers (Abd Alwahab & Al Baz, 2009). Learning out-
comes are phrases that describe what the student should know and be able to perform and achieve by the end of studying a particular course or an educational program. Through the case study of the architectural construction subject of the second year, specifically the bearing wall system, it was found that the curriculum doesn’t achieve the required learning outcomes, namely: cognitive domain, the affective domain and the psychomotor domain. It was found that the students drew the structural system according to what they learned. But by testing their ability to understand, compose, apply and analyze, they didn’t meet these cognitive aspects, the matter that has been solved in the preparation of the application and the scientific material, which is to achieve the cognitive, affective, and psychomotor outcomes through the application.

**The Scientific Material of the Application**

The scientific content is divided into three sections: the theoretical section, the practical section and the interactive exercises, which are included in the application interface.

**Firstly, the Theoretical Content.** The scientific content has been prepared according to many scientific classifications as follows: 1- The history of the development of the bearing walls system throughout the previous civilization. 2- The classification of the structural elements of the bearing walls according to their nature and their constructive function. 3- Realistic models of the most famous domes and vaults, throughout history, and their constructive analysis. The theoretical content targets the level of understanding related to the cognitive aspect. But this is one level of this aspect, so a section, which is the practical content, is added.

**Secondly, the Practical Content.** It has been prepared to contain various educational videos containing: 1- Educational videos showing the ways of building the structural elements of the bearing walls, domes, vaults and cross vaults using different building materials. 2- Educational videos illustrating the ways of modeling the structural elements in the CAAD programs, specifically, 3D max program. The practical content targets the levels of understanding and the composition of the cognitive side, but this isn’t sufficient to achieve the rest of the required learning outcomes in the curriculum. Therefore, the third part, which is the interactive exercises, is added.

**The Interactive Exercises.** The interactive exercises are considered as an educational tool that helps the students to learn, through trial and errors, and helps the lecturer to know and determine the level of the students’ understanding of the theoretical and practical content. The aim of the interactive exercises is to deal with all learning outcomes: cognitive, affective and psychomotor domains. The interactive exercises are divided into three separate levels:

Firstly: the skill of arranging different stages of building.

Secondly: the skill of selecting the appropriate structural elements.

Thirdly: the skill of linking the structural elements to the appropriate space shape.

In order to transform the theoretical and practical content into an interactive content, coordination with programmer has been made. The stages, upon which the interactive exercises were created, were as follows:

1- Studying analysis 2- Gather requirements 3- System analysis and design 4- Development(Coding) 5- Testing & debugging

**Firstly: The Exercise Related to the Skills of Arranging Different Stages of Construction.** The aim of this interactive exercise is to teach the students how to build and implement buildings with the bearing walls system. This exercise has been carried out on a model of the most famous historical buildings, which is Mohammed Ali mosque (see Figure 1). A model, consisting of nine stages, has been built. Each stage illustrates how to build the construction elements of the mosque. Tools have been added to help students understand three things: The technique of building walls, vaults and cross vaults.

The students learn how to model them in a three-dimensional image. The students’ ability to un-
Figure 1
A model of an interactive exercises illustrating the stages of building the mosque with the bearing walls system
nderstand the construction stages has been tested by the application interface. Drag and Drop has been done in a logical order until the correct stages of building the mosque have been completed.

This exercise targets both the levels of the cognitive domain (application, analysis, synthesis, evaluation) and the levels of the affective Domain (attention, response, assessment) and the levels of the psychomotor domain (observation and practice) (see Figure 1) illustrate the interactive exercise interface.

**Secondly: the exercise related to the skill of selecting the appropriate structural elements.** The purpose of this exercise is to teach the students to choose the suitable structure elements. The application presents many structural elements as alternatives. The student is to select among them. The structural elements are shown in the form of either architectural columns of different styles or different types of domes and vaults according to both the architectural style and the time period. It's available for the student to choose among the different structural elements. This exercise is associated with the third exercise that represents the first stage (stage 1 structural elements), which is the composition of the structural elements (see Figure 2).

**Thirdly: the exercise related to the skill of linking the structural elements to the appropriate space shape.** This exercise represents the second stage (3D model). It is the stage of linking the structural elements to each other and showing them in two forms:

The first form is the stages of building and the second form is the final composition after meeting the building conditions. The third and fourth stage are implemented through another application which is (Insta VR). It is an interactive application that receives images produced by the system of 360 degrees and turns them into an integrated scene showing the floors, walls and ceiling. The application helps to show the various stages of the development of the construction and associate them with realistic models to add comparison between the final form and the construction stages. (see Figure 2) illustrates the second interactive exercise interface.

**THE APPLICATION TEST**

The application was tested by a workshop for the second-year students at the faculty of engineering, Al Azhar university. The study sample consisted of 85 students. The workshop completes what has been studied in the academic lectures, which consisted of 24 lectures and 42 hours divided into two terms. The workshop has been prepared after the usage of traditional teaching methods, and measuring their results. Then, the workshop has been conducted to measure the targeted learning outcomes achieved through the application. The workshop consisted of three stages:

- The first stage: teaching the students the ways of building using bearing walls system through sketches and educational videos.
- The second stage: teaching the students the methods of modeling domes and vaults through 3D max.
- The third stage: The use of the interactive application by the students. The rubrics which represents the basic rules for judging performance level has been applied. It is a descriptive measurement to determine the level of what the students know and can perform. These measurements tell the lecturer, who is responsible for the evaluation, the characteristics or marks that he is looking for in the students’ work. They also show how to evaluate this work depending on the rubrics. (Abd Alwahab & Al baz, 2009).

The extent, to which the students responded to the three stages of the workshop, has been monitored, through observation and questionnaire, from one hand, and through the availability of evidence, on the other hand. The following questions have been posed as a part of the questionnaire:

1- What is the order of the three learning stages used in the workshop according to the concept of the bearing wall systems?
2- Has the interactive application, as an educational tool, helped to clarify the construction methods of the bearing wall system?
3- What are the advantages and disadvantages of the application?
4- Is the interactive application...
Figure 2
The four stages of the interactive exercises

Stage 4 (Making Application)

Stage 3

Stage 2 (3D Model)

Stage 1 (Structural Elements)

Convert 3D Model to 360 Panoramic View

to Make simple Application

Material	Arch	Dome	Squinch	Space

Exist

Structural System phase 1

Structural System phase 2

Structural System phase 3

Structural System Exterior Arcade
sufficient to learn the structural system? 5- Did learning 3D modeling help understand the structural systems? 6- Did the integration of 3D models with the interactive application and 360-degree display help to understand the construction stages of bearing walls system? 7- Are the previous methods sufficient to understand the structural system?

Table 1

The statistic of the case study

<table>
<thead>
<tr>
<th>No. of enrolled Students</th>
<th>85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours of Lectures</td>
<td>42</td>
</tr>
<tr>
<td>Duration in months</td>
<td>7</td>
</tr>
<tr>
<td>Lecturer</td>
<td>3</td>
</tr>
<tr>
<td>Teaching assistant</td>
<td>4</td>
</tr>
<tr>
<td>Laptops Used</td>
<td>85</td>
</tr>
<tr>
<td>Students who successfully passed the 3D workshop</td>
<td>53</td>
</tr>
<tr>
<td>Student Selection for the best explanation Method in order</td>
<td>1-Application</td>
</tr>
<tr>
<td></td>
<td>2- 3D Models</td>
</tr>
<tr>
<td></td>
<td>3- Traditional methods</td>
</tr>
</tbody>
</table>

**THE RESULTS WERE AS FOLLOWS**

1- After monitoring the results of the questionnaire, after using the application, and comparing them with the results of the first questionnaire, which was conducted before using the application, it was found that the students arranged the means of explanation and education as follows:

The interactive application came in the first place. The results were based on the fact that it is an easy means that doesn't need previous skills. It was found that the interactive exercises helped the students to understand the ways of composing the construction system of the bearing walls. The students were able, through trial and error, to build the structural composition correctly (see Table1).

Teaching 3D modeling came in the second place. However, 85% of the students thought that it needed to be studied and practiced in advance. In comparison with the interactive application, it is considered as an important and complementary element. Its integration with the second application, Insta VR, to show the 360 degree structural elements, helped the students understand structural relationships, especially, when the three-dimensional models of CAAD were linked to the existing structure building.

Traditional methods came in the third place. According to the questionnaire, the reason was that these methods helped to understand drawing methods but didn't help to facilitate the imagination of reciprocal relations among structural elements, as clearly as, in the interactive application and 3D models.

2- the study confirmed the research hypothesis that learning by merging 3D modeling of CAAD with the interactive applications completes what is lacking in the traditional methods. The targeted learning outcomes have been achieved in a varying rate. The scientific content, prepared for the interactive application, helped in achieving the outcomes of the cognitive domain by 70% whereas the knowledge level was achieved by 65%. The comprehension level was 58%, the application level was 70%, the analysis level was 75%, the synthesis level was 80% and finally, the evaluation level was 40% (see Figure 3). The results have come with these rates because the application is in the preliminary stage. The goal, in the future, is to develop the application to allow the students to design and compose according to what they have learnt and to use structural elements that aren't linked to the curriculum. But they may depend on what they have search for, so that the students acquire the skills of knowledge and creativity. The students will be able to upload their work on the application and, consequently, learning is achieved through practice and participation.

3- one of the advantages of the interactive application is that it is continuously scalable and testable, which can achieve more learning outcomes. The used methodology can be applied on the rest of the construction systems, in the same course, and other subjects.
An evaluation of the cognitive learning outcomes

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