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THE METHODOLOGY OF DESIGN BY GEOMETRIC CODE IN TRADITIONAL ARCHITECTURE

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ABASTRACT
The role of geometric code as a design generator in architecture design throughout history had not demonstrated in any specialized study. The most concern for this research understands how some historical buildings may have been designed in the first place by the aid of geometry. The research started a process of geometric decoding for these buildings beginning with understanding the geometric methodology of design which were used. Geometrical analyses of various designs of historical buildings from Greek, Roman and Islamic architecture , are presented to illustrate how design idea and the building design have been derived geometrically by depending on the geometric code, which remain the backbone of the process of "designing" of all buildings, and it played the role of design generator which control all the design process. The outcome of research analysis were listed in a set of observations which show a certain relationship between building design and geometry, arising from the use of geometric code as the core of the process of architecture design, not only in these selected buildings but generally in the architecture of the different historical periods.

Key words: Geometric Code – Architecture Principles – Design Methodology – Traditional Architecture - Theories of Proportions.

الملخص :-
دور الشفرة الهندسية كمولد للتصميم المعمارى لم يتم تناوله فى دراسة متخصصة على مدار التاريخ. يركز هذا البحث فى المقام الاول على فهم كيف يتم انتاج التصميم المعمارى لبعض المبانى التاريخية بمساعدة علم الهندسة. يبدا البحث بفك الشفرة الهندسية لهذه المبانى من خلال فهم منهجية التصميم الهندسية التى استخدمت فى تصميم تلك المبانى. تم اجراء عملية تحليل هندسى للعديد من المبانى التاريخية من العمارة اليونانية والرومانية والإسلامية وشرح كيف تم صياغة الفكرة التصميمية والتصميم المعمارى للمبنى بالاعتماد على الشفرة الهندسية والتى ظلت تمثل العمود الفقرى للعملية التصميمية للمبنى وتلعب دور المولد التصميمي الذى يسيطر على كل محاور العملية التصميمية. والنتائج النهائية لعملية التحليل الهندسى تم صياغته فى صورة مجموعة ملاحظات توضح العلاقة الوثيقة بين تصميم المبنى وعلم الهندسة والتى تظهر بوضوح من خلال استخدام الشفرة الهندسية كمحور أساسى لعملية تصميم المبانى ليس فقط فى هذه العينة المختارة من المبانى ولكن عموماً فى عملية التصميم المعمارى فى العديد من الحقب التاريخية المختلفة وبذلك تم صياغة منهجية للتصميم المعمارى باستخدام الشفرة الهندسية فى العمارة المعاصرة الحديثة.المختلفة.

الكلمات الدالة : كود هندسي - مبادئ العمارة - منهجية التصميم - العمارة التقليدية - رمز – نظريات النسب

1. INTRODUCTION

Architects in ancient cultures believed that, architectural geometries could be enjoyed both intellectually and sensually. The guidance for many ancient architects came from geometry. Perhaps based on the belief that orderly geometry reflects the order of the divine world, they established precise geometric systems with which to generate forms [Gelernter,1995]p.40. So they aimed to capture the best sequence of geometric operations underlying the generation of the building design.

1.1. Research Problem

From studying and researching traditional architecture the research observes that, there is no study dedicated to the field of geometric code in building design in traditional architecture which provides the basis to discover some of the profound knowledge used in these buildings architectural design, according to that the research problem emerges as a question that this research will try to answer: "What is the Geometric Code that Controls the Design of Buildings during the Traditional Architecture Eras?"

1.2. Research Importance:

This research shade light on the geometric code that control the design of buildings in traditional architecture and it gains its importance due to the following reasons:

- A study of geometric methodology of architecture design is surely of great use, since there are only few specialists who have an overview about the role of geometric code in space design of multi-functional buildings in traditional architecture.
- The information that is produced in this research will form a historical background to help in the process of re-creating or re-designing or reservation of the traditional architecture buildings in the modern society.
- Studying design methods in traditional architecture helps us find various methods for making new environments less alienating and therefore more satisfactory to use.

1.3. Research Objectives:

The research attempts to reach one main objective which is: discovering the geometric code which control the design of buildings in traditional architecture

In order to achieve this main objective two sub-objectives have been formulated:

- **The first**: Shows through many examples that geometry can be employed in various ways in architectural design to provide solutions to the design problems.
- **The second**: Reveals that the geometric aspects of traditional architectural designs have not been adequately described in the architectural or design process literature.

1.4. Research hypothesis:

The research has three main hypothesises

- Learning from the built environment of the past is one of the legitimate approaches and is important way to respond with sensitivity to the existing world to improve the modern theories of design and to set new design criteria.
- By using the geometrical codes the designer could enforce desired spatial configurations of building components and spaces because it offers a qualitatively different way to explore shape and form in architecture design.
- The geometrical analysis of historical buildings is an alternative tool for understanding how the traditional master-builders was forming the building design.

1.5. Research Questions

The research attempts to answer one main question which is: what is the geometric code which control the design of the buildings in traditional architecture?

In order to answer this main question the research must answer the following sub-questions

- What is the role of geometry in the design of buildings in traditional architecture?

- How is geometry become an essential tool in the hand of architects for designing buildings in traditional architecture?
- What were the geometrical methods of design used by traditional architects in the design of buildings?

1.6. Research Skeleton

The research skeleton is divided into five main parts. The first part is the introduction, which demonstrates the roots of the research problem and the research methodology for dealing with the research problem. The second part is the theoretical study, which begins with a close look at the design method throughout history and demonstrates the role of geometry in architecture design. Then it sheds light on the role of geometry in the design methods which were used in traditional architecture. The third part is the analytical study which begins by analysing the case-study buildings presenting the role of the geometry in its design before going on focus on the role of geometry in the general theories of proportions. The fourth part presents the suggested methodology of design by geometric code, and finally the fifth part is the applied study which demonstrates the applying of the suggested methodology in one modern building. Finally the research ending with the conclusion and recommendations. The following figure present the research methodology.

1.7. Research Methodology

The research attempted to develop analytic approach to understanding the geometry that inspires the traditional architecture. At the heart of this approach lies the consideration of the relationship between geometry and architecture design, and its application to provide a practical method for form making and developing systems of composition. The research aim is “outline a new method of design depends mainly on geometry and its applications in different steps of architecture design process, so the research name it "Geometric Code Design Method". This is being essential not only to the process of traditional architecture but also to the understanding it. The research attempts to answer many questions as: how can geometry play a role in design process? How designer in modern architecture can benefits from geometry in their design of different buildings?. The following figure present the research methodology.

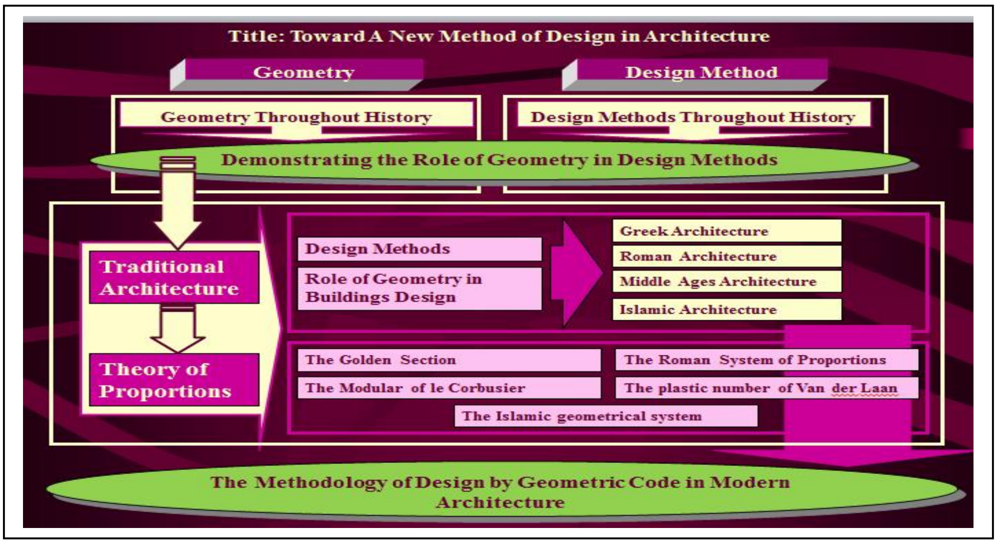

Fig. (1) The research methodology (authors)

2. HISTORICAL BACKGROUND

2.1. Design Methods throughtout History

Design is a process, a dynamic interaction between the concept and contingency between the generic and the specific; it evolves progressively as multiple individual decisions are assimilated into the whole [Gelernter,1995]p.49. The process of architectural design is an intellectual and imagination activity, based on an continuing internal dialogue between the designer and himself bout the nature of the design problem which he faced. This dialogue aims to understand all the conditions and dimensions of the design's problem components and the impact on each other, and he try to find a solution takes all these into account and achieve the goals, objectives and tasks required by the nature of the design problem [Hassan,1997].

The use of geometrical systems in architectural design builds the bridges between principles, practicality and beauty in design that explains the longevity of the traditional buildings design, offers a meaningful insight into the architecture of the time, and makes it easy for the designer to understand the nature of the design problem. So all classical architectures were bound up with arithmetical and geometrical proportions, and geometrical harmony was considered an axiom of good design. For the Modernism arguably, have brought an ideology which focused on function and aesthetic into architecture, but the notion also resulting in a far less empathic architectural. The building becomes apathetic, as function and aesthetic pushed aside the liveliness context. Designs are becoming less authentic, as architects prefer to use existing data to save their time. In short, it can be said that the presence of empathy has far been less acknowledged as an essential aspect of architecture. [Patria, 2018]

2.1.1. The Role of Geometry in Design Method

Design Methods encompass a wide variety of subjects, from describing the design problem to asserting the social and political consequence of the building layouts. A particular issue that lies at the core of design method was focused on: what is the role of geometry in creating the architect's design idea, besides explaining the geometrical relationships between the design vocabularies. At the beginning of the design process the architect possesses only a random collection of information, requirements, intentions and assumptions, and then suddenly on the drawing board appears a proposal for a building design idea. How is this idea generated? Is geometry an important factor influencing its shape? What is the role of geometry in the process of the design idea derivation in particular?.

These are central questions for a design method for a number of reasons. For architects, the key issue at the heart of their practice is the task of developing a building design, because during all stages of architectural design Geometry has a set of normative principles that could guide architects design activities. So architects should first study the functional requirements and secondly manipulate geometrical systems to obtain a good expression or good results for the design idea. Taking into consideration that the architects did not invent their design methods in a vacuum, but rather inherited them from their cultures a number of factors and even specific philosophies shaped their ideas about the architecture design. Geometry is the major and important factor among them which shaped the architects' design idea activities.

2.1.2. The Origins of Design Method

It is difficult to determine when builders began to reflect on the source of their design methods, or when the first methods of design were proposed. For many millennia, the earlier builders in our prehistoric past most certainly worked without theory or design method. Through a trial and error over generations they developed building forms and design that were suited to the material at hand, the climate in which they lived and their social system. If a form or design method failed, they tried variations; if the variations worked, they passed it on to the next generation as a set of specific rules. Any rules passed down from generation to the next about the important arrangements for divine or cosmological reasons would have constituted an embryonic or primary method of design.

Design methods were developed automatically through time, and in all traditional cultures design methods principles were originated in a divinity. Geometrical systems were the best tools which can interpret the divine source of design, so the geometrical systems became a set of rules which governed the design and shaped the methodology of the architects' design methods. According to that, the architects in different cultures could directing builders according to divine instructions by using these geometrical systems.

2.1.3. The First Design Method

In all the ancient cultures people began to settle in one place and establish permanent homes for themselves. They felt obliged also to provide a home for their Gods. These homes had to please the Gods and the design of the temples had to be God-given. That is how the divine order became related to the building design method. According to that many cosmological systems were developed and many settlements and buildings remained from the Stone Age acquired additional cosmological symbolic or religious meaning. This early symbolic system eventually gave rise to the first theories of design and design method.

From the architects’ point of view, this divine conception of the source of design had to present a dilemma: they were expected to direct the construction of buildings according to the divine designs order, but they themselves did not have direct access to those sources. In response the architects looked for some guidance, some rules or some procedures, which would ensure that the buildings they designed secularly would accord with the divine original. For many ancient architects, the guidance came from geometry, which used as a good tool provided architects with guidance rules to reflect the divine design order. They established precise geometrical system with which to generate buildings design.

The ancient Egyptian theory of architectural design and design method was seemingly empirical and only minimally indebted to mathematics. The architect employed simultaneously a modular system and a geometric system. The module would be derived from a major dimension in the building under design, the width of the inner room in a temple for example. Multiples and fractions of the module would then determine all the other dimensions of the building, as well as the placement of the columns and piers. The geometric system depended on a few simple figures, mainly the square and a few triangle with specific ratios of base to height (1:1, 1:2, 1:8, 3:4, and 5:8, a ratio which is close to the golden section). Relying on a set module and combination of two or more of these basic geometrical figures, the Egyptian architect prepared a ground plan and a set of outline elevations for all parts of the building in question [Kostof,1977]p.8-9. Nature is one of the basis for resolving building design challenges. For example the incorporation of biomimicry idea in architectural design is believed to be more sustainable and efficient for reduction of energy usage. The idea of inspiration from nature has developed the intention to explore how the geometric code could be applied to overcome the challenges through design strategies. [Dash, 2018]. The formulation of a geometric design guideline with evident biomimetic principles that could be applied to any building design with reference to different contexts to achieve function performance efficiency in building design continues to discuss the application of possible design strategies for establishment of an geometrical design methods compatible to modern architecture. .

2.2. Geometry throughtout History

The Greek civilization was followed by the Roman civilization; Christianity appeared in Roman times, the Roman civilization thus straddling both sides of the Christian calendar: BC and A.D. Following the fall of the Roman Empire began what are generally known as the dark ages, which elapsed from roughly the late fifth century to the late fifteen century.

In the midst of Europe’s darkness, almost immediately after the fall of the Roman Empire, the Muslim civilization came into being. It was in the year 622 that the Prophet’s Hijra (travelling) from Mecaa to Medina took place. Following the death of the Prophet (pbuh), Islam spread to the neighbouring lands, embraced rapidly by the various local populations. By the year 750, the Muslim lands stretched from Spain to the borders of China. Unlike Europe gripped by the darkness, the Muslim scientific revolution took place exactly during the apogee of Islam, from roughly the late 8^{th} century to the thirteenth [Zaimeche,2002]p.3, especially the science of geometry, which became a very important tool in the hand of builders for designing.

2.2.1. History of Geometry and the Geometry Time-Line

Geometry, which comes from the Greek words *geo*, “earth,” and *metrein*, “to measure”, is a part of mathematics concerned with questions of size, shape, and relative position or spatial relationship of geometric figures and with properties of space. Ancient scientists paid special attention to constructing geometric objects, and the classical instruments allowed in geometric constructions are those with compass and straightedge. The mathematician who works in the field of geometry is called a geometer [WIKIPEDIA].

Since geometry is encountered in the first written records of mankind and was developed extensively by ancient Egyptians, Babylonians, and the Greeks, one might suppose it had been exhausted of discoveries long ago. Not so! The subject is slow to reveal its secrets. There are still geometric principles to be uncovered and new applications to architecture that can improve the state of the art. There are also principles that have been long forgotten or ignored that have strong relevance to architecture today [Blackwell,1983]preface.

The geometry time line had begun in ancient Egyptians civilization, they had used a practical knowledge of geometry through surveying and construction projects, then Babylonians (c. 2000 - 500 B.C.) left clay tablets which reveal that they knew the Pythagorean relationships, then Ancient Greeks, between c. 750-250 B.C., practiced centuries of experimental geometry. After the fall of the Greek and Roman civilizations Europe entered the dark ages, Most of the works of Greek mathematics were scattered or lost. Some of these were translated and studied by the Muslims and Hindus. The Modern Geometry: Representing geometric figures within a coordinate system came into being.

2.2.2. The Role of Geometry in Architecture Design

Geometry according to the Encyclopaedia Britanica, is the study of space, and architecture, in the broadest sense of the word, is the creation of space by construction or subdivision. The two disciplines are virtually inseparable with one distinction. Geometry can exist without architecture but architecture cannot exist without geometry. Geometry is not all of architecture but it is an essential part of it [Blackwell,1983]p.3.

Architecture space must serve the needs of humans with some exactness: floors must be levelled, stairs must be straightened, building must be buildable, and there are always functional requirements and conditions in the arrangement of architectural space. Geometry is the secret effective factors which help the architects make the building architecture suits to the purpose of the building beside the human needs.

Architecture and Geometry are virtually inseparable. Architecture and geometry together form a powerful union of creativity. One is the instrument for the other. Geometry creates the balance between the imagination and exacting realism in architectural work. It also helps the architect understand the properties and relationships of lines, patterns, surfaces, and solids. This understanding is almost essential to an architect as breathing, whether one is designing a coffee table or a fifty-story building. So geometry is everywhere in architecture, at the same time, without architecture, geometry would be a “dead language”.

Architecture is in dire need of solid foundation and orientation, which can be found in the principles and applications of geometry. So a successful architectural space design depends on clear spatial arrangements. In this regard, the visual harmony between different forms and shapes used for different function in the building is an essential part of an effective design [Blackwell,1983] p.49. When we look back in the history of architecture, we can find the background of geometric structures as important fundaments for design, for example in symmetry concepts or using transformations like perspective transformations. [Leopold, 2014]

2.3. Geometry and Design Methods in Traditional Architecture

Architecture and Geometry are virtually inseparable. Architecture and geometry together form a powerful union of creativity; one is the instrument for the other. Geometry creates the balance between the imagination and exacting realism in architectural work. It also helps the architect understand the properties and relationships of lines, patterns, surfaces, and solids. This understanding is almost as essential to an architect as breathing, So geometry is everywhere in architecture; at the same time, without architecture, geometry would be a “dead language”. Architectural space must serve the needs of humans with some exactness: floors must be levelled, stairs must be straightened, buildings must be buildable, and there are always functional requirements and conditions in the arrangement of architectural space [Blackwell,1983]p.49.

Geometry is the secret effective factor which helps architects make the architecture of the building suit its purpose besides fulfilling the required human needs.

Architects were not the only people who shaped space. In many ancient societies the basic form of cult buildings was imposed by religious authorities, and under an extreme view the architect-mother carried out an essentially executive function, administering building contracts and resolving technical issues [Jones,2003]p.28. This section will demonstrate the principles of design methods in classical and Islamic architecture. This is done be by concentrating on the role of geometry in architectural design process in these different design methods.

2.3.1. Design Method in Greek Architecture

Greek architects attempted to built temples that would suit their divinities' expectations and continued to search for rules that would help them generate what they believed were divinely determined forms. They found these rules in geometry.

The Greeks started with a basic module found within the building itself- for example, the lower diameter of column in a Doric temple - and then derived all of the other dimensions in the building from this unit. Over time standard temple types emerged which specified the number of columns and their locations, the ratios of plan width to length and column diameter to height, the design and location of mouldings, and so on. Eventually, these evolved into the orders upon which most subsequent classical architecture is based [Gelernter,1995]p. 57.

Greek architectural treaties until the fourth century BC, apparently, concentrated on explaining the accepted properties and proportions of the Orders. The Greeks believed that their codified rules captured the rational order of the divine so they were written in order to codify the rules and help with the training of young architects [Gelernter,1995]p.57-59. Fig (2) present the Doric order, one of five types that codified forms, structure, proportions and details. The Greek rules derive every size from the lower diameter of the column, from a module (one half of a diameter) or from a part (one twelfth of a module).

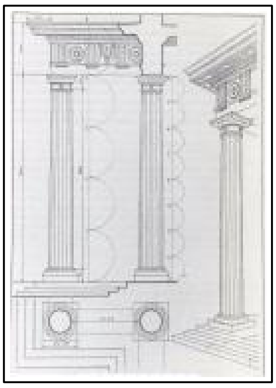

Figure (2) The Doric Order
http://www.doric-column.com

2.3.2. Design Method in Roman Architecture

In Roman architecture there are two distinct compositional stra component and generated the whole by aggregation; the other assigned a specific proportion to the whole, and adjusted its components to suit [Jones,2003]p.120. Aggregative design gave no guarantee of proportional simplicity to the whole, which was a major aim for many architects through the Roman period.

In Roman architecture the shape of building derives ultimately from elemental geometrical form; their overall size or another critical dimension is frequently a simple dimension; the part tends to relate one to another in either an arithmetical or geometrical sense. The critical dimension locates the interior space design if it is more important than the building exterior organization and vice versa.

Like so many manifestations of traditional architecture, Roman buildings derive ultimately from elemental geometrical forms like circle, regular polygons, rectangle and their three dimensional counterparts [Jones,2003]p.87. The geometrical harmony between the design vocabularies is the main and important aspect of design, while geometry certainly provided the discipline with the generation of certain types of plan. The Roman architects were less likely to use geometrical procedures in composing elevations than plans. Vitruvius makes this distinction clear: he used geometry to set out the plan of the theatre buildings, but arithmetic alone to its elevation [Jones,2003]p126-127.

2.3.3. Design Method in Middle Ages Architecture

Artists and architects in the medieval period attempted to capture the mathematical harmony, proportion and number that they believed expresses and celebrates God's divine order in their work [Gelernter,1995]p.75. The importance of the role of geometry in architectural design has remained a constant throughout all history; what changes is whether this geometry is considered to reflect the order of the Divine or the order of nature.

The geometry, the medieval architects believed, not only assured the structural fitness of the building, but also guaranteed that the building would necessarily embody the Divine [Gelernter,1995]p.75.

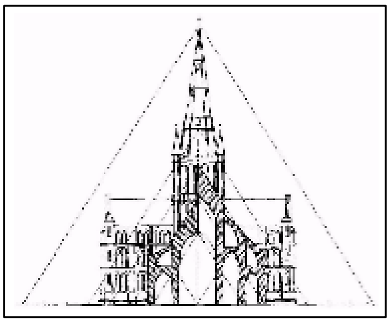

Figure (3) Medieval cathedral geometry **https://en.wikipedia.org/wiki/Architecture_of_the_medieval_cathedrals_of_England**

In building design Medieval architects started with simple g equilateral triangles and squares, and then through a series of pre geometrical forms that organized the building both in section and in plan. As shown in fig (3) the equilateral triangles determine all of the major proportions, although medieval buildings also employed complex combinations of squares, non-equilateral triangles and circles.

The important thing in designing buildings was not the individual creative perception or expression, but rather pre-established knowledge and information which linked architectural design with the Divine. In this sense the medieval architects were like the Egyptian and early Greek architects who sought objectively true, divinely inspired building design.

In the Medieval ages the young craftsman served an apprenticeship under a master. Through his membership in the guild and from his master, he learned trade secrets including how to generate a plan and elevations through geometrical manipulations, how to design important construction details, and how to design facades. Many of these secrets were transmitted by means of guarded pattern books, which set out exemplars of good practice. Distinguished practitioners in each generation add to these books, drawing upon their own experiences and innovations, that is how the guild’s design traditions naturally evolved over time [Gelernter,1995]p.87-89. The main target for students in the mason’s guild is to learn and gain skills for manipulating the divine geometries of the cathedrals.

2.3.4. Design Method in Islamic architecture

Islamic architecture exists because of the existence of Islam. Therefore, it can be seen as a special kind of architecture, as a cultural phenomenon determined by special qualities inherent in Islamic legislations. For this reason it encompasses a wide range of both secular and religious styles influencing the design and construction of buildings. The process of building design is not only concerned with the form of buildings but also of equal importance are all the phases and aspects of design. It is almost impossible to identify one phase or aspect in the design process and consider it more important than others. This means that there are no strict rules applied to governing Islamic architecture. The architects used local geometry, local materials, local building methods to express in their own ways the order and unity of Islamic architecture. According to that, when the religious monuments of Islamic architecture examined they reveal complex geometric relationships and great depths of symbolic meaning.

The approach to architecture design in Islamic architecture depends mainly on Quran and Sunnah of the Prophet Muhammad (p.b.u.h.). They contain a fixed Islamic content and fixed rules on building and planning, from which the Muslim architect can extract and derive design basic principles, design fundamental idea, design rules and design values. This content and rules are transferred to different generations and between different places during the long ages of Islamic architecture with the Quran texts and the Prophet Sunna, Thus, Muslim architects should be obligated to the Quran and the Sunnah of the Prophet Muhammad (p.b.u.h.) since they are the main sources which determine the fundamentals ideas of the Islamic society’s architecture.

2.3.5. Remarks about the four architectural design methods

Architects in all ancient cultures desired to base their design on timeless principles behind appearance. Therefore, they wished to base architectural design on more than the contingencies of a particular site, climate or individual designer. Much of their efforts attempts to set out the 'fundamental principles of architecture' and obtain the timeless characteristic of design which would help practising architects to achieve an universal validity and beauty in their work. So, all the ancient architects' attempts had tried to capture the underlying principles of design and discover the true principles of timeless design.

The architects in the three ancient cultures (Greek, Roman, Medieval) believe that, architectural geometries were enjoyed both intellectually and sensually so they aimed to capture the sequence of geometrical operations underlying the generation of the building design. For example if a diagram was used to design a building, the important and main space was located and then geometry came into play to offer a means of organizing vistas of sight.

3. The Analytical study

Architects in ancient cultures believed that, architectural geometries could be enjoyed both intellectually and sensually. The guidance for many ancient architects came from geometry. Perhaps based on the belief that orderly geometry reflects the order of the divine world, they established precise geometric systems with which to generate forms [Gelernter,1995]p.40. Much of their efforts attempted to set out the 'fundamental principles of architecture' and obtain the timeless characteristic of design which would help practising architects achieve a universal validity and beauty in their work [Gelernter,1995]p.62.

3.1. The Role of Geometry in the Design Methods in Traditional Architecture

By means of geometrical analysis it is possible to find a proportional key, which indicates how the elements are arranged in the work of architecture design, and what roles they have. The advantage of demonstrating the geometrical analysis is to provide architects with an explicit or clear method not only for the understanding of architectural composition of sophisticated design, but also to give architects insight for the construction of new design idea by using geometrical schemes. So a geometrical analysis for three historical buildings is introduced to set out the fundamental geometrical principles of their architectural composition as follows:-

3.1.1. Parthenon Geometrical analysis (Athena, constructed between 447-438 B.C.)

Parthenon is the culminating masterpiece of Greek architecture. The body of the building comprised a cella and behind it an inner chamber (the Parthenon proper), which gave the temple its name. In the 6th cent. the Parthenon became a Christian church, with the addition of an apse at the east end. It next served as a mosque, and a minaret was added to it. In 1687, in the Venetian attack on Athens, it was used as a powder shop by the Turks and the entire centre portion was destroyed by an explosion [Questia,2004]. Numerous attempts have been made to establish the mathematical o ly employed in producing the building design. Figs (5) and (6) shows two attempts of the building geometrical analysis, where it can be seen that the architecture is governed by the relationship between side and diagonal in a series of squares.

Parthenon of Athens
https://www.google.com.eg/search?tbm=isch&q=Parthenon

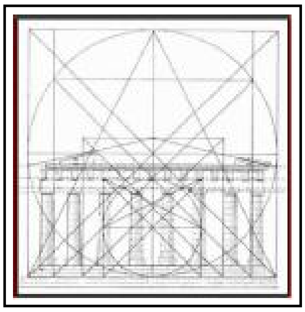

Figure (5) The building geometric analysis [Brunes,1967].

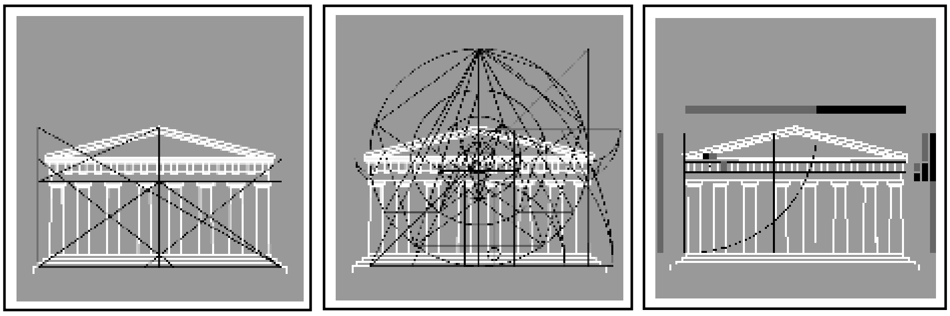

Figure (6) Building analysis inscribe different rectangles in a given drawing [Huylebrouck and Labarque,2002]p.48.

3.1.2. Amphitheatre Geometrical analysis (Verona, early 1st century AD)

In amphitheatre design the starting-point for laying out was one of just two geometrical schemes. These schemes located the focal points of an oval at the vertices of two 'focal triangles', one being the 3:4:5 or Pythagorean triangle, the other the bisected equilateral triangle (figs.8,9) [Jones,2003]p.88. Using either of these methods it was possible to generate the basic outline of an amphitheatre arena with but a few sweeps of the compass.

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https://www.google.com.eg/search?q=amphitheatre&source

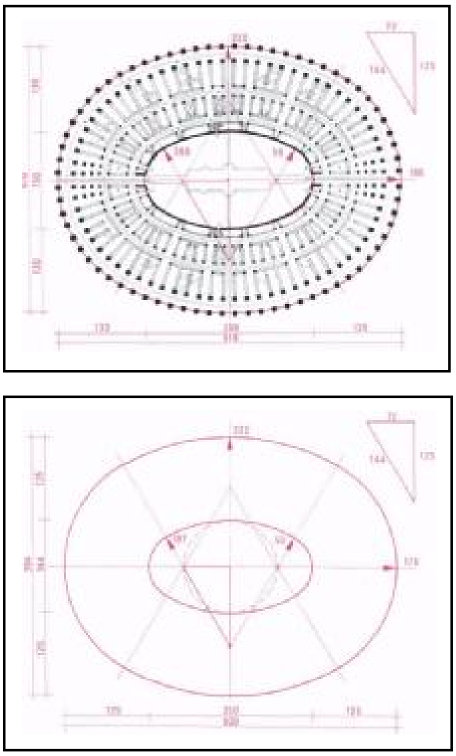


Figure (8) Outline layout of the amphitheatre at Verona [Jones,2003]p.88

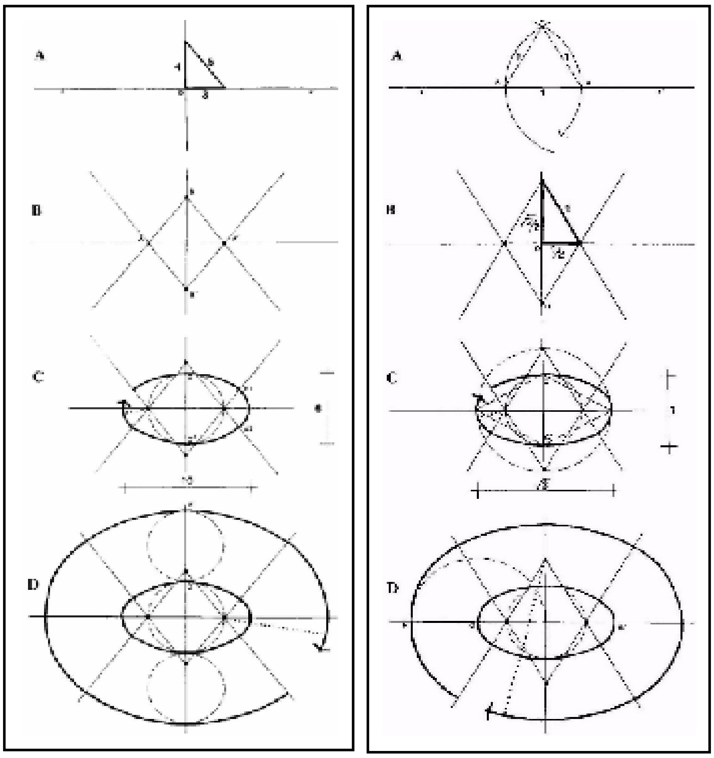


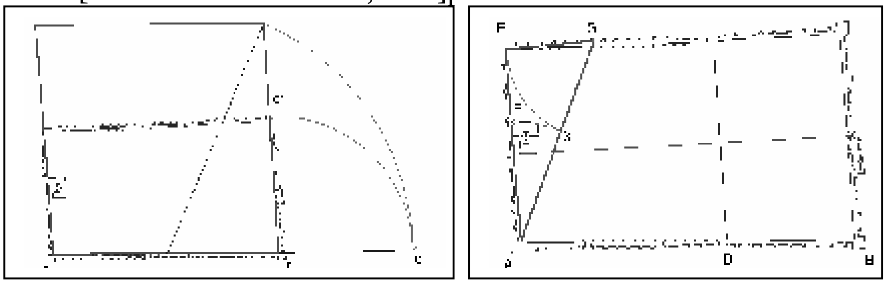
Figure (9) Methods for laying out the Amphitheater using the Pythagorean-triangle-and-inscribed-circle scheme : [Jones,2003]p.88

3.1.3. The Great Mosque at Kairouan, Tunisia 670 A.D.

The mosque is composed of two parts: the court and the prayer space. The dimensions of this space are less than that of the court. It has seventeen naves perpendicular to the Qibla wall. The axial aisle and the one parallel to the Qibla wall are larger than the others, forming a T-shaped plan. The minaret is the dominating feature in this composition. Its elevation is divided into three levels. The mosque has an irregular plan. Its form is nearly a rectangle, with its four sides not perfectly parallel. This deformation is due to the site conditions.

Taking into account the fact that many traditional buildings have used the golden section, it has to be mentioned that the golden section is used as proportioning system in the mosque. The following figures show the use of the golden section in determining the dimensions of the plan and the height of the Minaret [Boussora and Mazouz,2004]p.12-15.

Figure (10) The geometrical construction of the golden section in the plan and minaret [Boussora and Mazouz,2004]p.12-15



3.2. The Role of Geometry in the Design Method in the General Theories of Proportions

Throughout history, proportion has been a significant concept in architectural design. The Greek transcribed the ancient knowledge of proportional techniques. This knowledge was traced back centuries earlier at the times of Moses and Solomo [MARCH, LIONEL. 1998]. The concept of proportion is based on ratio defined by Euclid as “a relation in respect of size between two magnitudes of the same kind”. Ratio is expressed as a:b or represented by a function a/b; a and b can be any number. A proportion involves equality of two or more ratios, and potentially between four magnitudes a:b::c:d [MARCH, LIONEL. 1998]. The research will discuss five of general theories of proportion. These include the golden section, the roman system of proportions, the modular of le Corbusier, the plastic number of Van der laan and the Islamic geometry system.

The general principle of the system of proportion is to resolve the problem of how to punctuate the interval between 1 and 2, by a series of measures that are not only additive and multiplicative, but also, productive of both order and complexity [*PADOVAN, RICHARD 1999*]. In architecture, the role of the proportioning system is to create a set of visual relationships between all the different parts of a building, and between the parts and their whole. The aim is to provide a sense of order in the overall structure. The visual order created is sensed and recognized through different experiences [CHING, FRANCIS D.K. 1943].

3.2.1. The Golden Section

For a long time the Golden Section does not occur in architectural theory. It first appears in 19th century, through Adolf Zeising and Fechner, and then rises to a certain fashion in the third and fourth decade of the 20th century, where Neufert and Le Corbusier get to know it. In the time of the beginning of Historicism and of the great scientific discoveries and theories, Adolf Zeising (1810-76) began his researches on proportions in nature and art. In the book "Neue Lehre von den Proportionen des menschlichen Korpers" (1854) Zeising formulates the law of proportionality as: "The division of the whole on the unequal parts looked proportional when the ratio of parts of the whole between themselves is the same that the ratio of them to the whole, i.e. that, the ratio, which gives the golden section".

In this theory the Golden Section plays an important role as the perfect balance between absolute unity and absolute variety. Zeising is convinced that in the Golden Section "is contained the fundamental principle of all formation striving to beauty and totality in the realm of nature and in the field of the pictorial arts, and that it from the very first beginning was the highest aim and ideal of all figurations and formal relations,

Passing to a significance of the law of proportionality in architecture Zeisung shows that the architecture in the field of arts takes the same place as well as the organic world in the nature. Systematization, symmetry and proportionality thus are its indispensable attributes; it follows from here that the problem on the proportionality laws stands considerably more acute in architecture, than in sculpture or in painting.

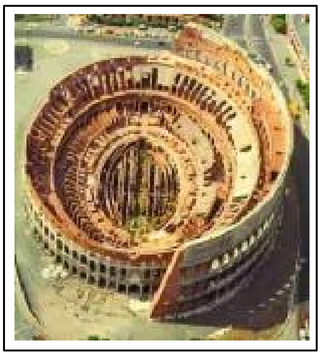
The golden section is considered to be among the most used principles of the architectural proportion [PADOVAN, RICHARD 1999] . The application of the golden section in architecture enables the overall structure of the building to be integrated, from the site to the smallest detail. Euclid describes the golden section as "division in extreme and mean ratio". During the Renaissance, it was known as the "Divine proportion", and later, in the nineteenth century it was called the "Golden section" [El-Said and Parman,1976].

3.2.2. The roman system of proportions

Proportion in geometry, architecture, music and art can be said to be ''an harmonious relationship between the parts, with and within the whole''. Vitruvius (70?–25 BC), a Roman architect and engineer, writes in his Ten Books on Architecture [Vitruvius,1914], De Architectura, that is the oldest surviving work on the subject, ''symmetry is a proper agreement between the members of the work itself, and relation between the different parts and the whole general scheme, in accordance with a certain part selected as standard''. And later, ''therefore since nature has proportioned the human body so that its members are duly proportioned to the frame as a whole, ...in perfect buildings the different members must be in exact symmetrical relations to the whole general scheme''. It is through the system of proportions that all parts are harmoniously interrelated with and within the whole; therefore providing functioning design.

By studying the measurements of the Roman monuments, a large number of monuments use the Roman foot (as far as it can be approximated with individual monuments) reveals some very clear patterns, or preferences, namely the strong preference for Roman designers to design, wherever possible, with major dimensions in simple whole numbers of feet, usually multiples of 10 or 12, or to a lesser extent 16 [Jones,2003]. This also gives a clue to design process since wherever the dimensions of a monument can be imputed to be such simple dimensions these may represent the initial design assumptions of the building. For instance, with the design of centralized monuments, Roman architect has distinguished between externally oriented centrally planned buildings, such as the tombs of Munatius Plancus or Caecilia Metella, which have entrances that thrust inward and maintain a geometrically pure exterior, and internally oriented buildings, like the Mausoleum of Maxentius or the Pantheon, which have entrances which thrust outward, maintaining geometrically regular interiors [Jones,2003].

Fig (11) The Roman Colosseum or Coliseum (The Flavian Amphitheatre (lat. Amphitheatrum Flavium), https://www.google.com.eg/search?q=Amphitheatrum&source



The simple whole number dimensions occur on the exterior of the externally oriented buildings and on the interior of internally oriented ones. There is also a tendency to prefer dimensions of a hundred (Munatius Plancus, Caecilia Metella) or a hundred and fifty feet (Pantheon, San Stefano Rotondo). This existence of the "ideal" dimensions in one location or the other deals with the simple fact that in actual executed architecture simple numbers or proportions can usually occur in only in a limited number of dimensions; as soon as one has to deal with wall thicknesses one has to accept the existence of certain less elegant dimensions. As Vitruvius says, with the usual lack of concrete illustrative clarity: "Now it is not possible to have the symmetries for every theater carried out according to every principle and to every effect.

Instead it is up to the architect to note in which it will be necessary to pursue symmetry to make adjustments according to the nature of the site.' [b.c.d, trans. I.D. Rowland 1999].

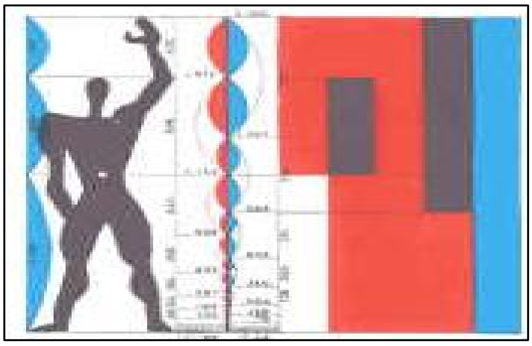
3.2.3. The Modular of Le Corbusier

In the twentieth century the Golden Section attracted two architects : Ernst Neufert and Le Corbusier. More efficacious for architecture probably was Neufert's decision to embrace the Golden Section in his famous Bauentwurfslehre from 1936. He propagates the Golden Ratio as this architectural principle of proportion, that together with his own normed measures leads to a "spiritual permeation" and a renewal of architectural formation by "an inner law" in the spirit of Antique, Gothic, Renaissance, and Classicism of Palladio and Schinkel. In fact Neufert does not really join Zeising's human "golden" proportions and his own anthropometric normed measures, because he chooses distances very pragmatically by looking at interior architecture

On the other hand we see planning in proportions caused by aesthetic reasons in the other great system of the 20th century, Le Corbusier's (1887-1965) Modulor. He works up to this later treatise with different proportional systems in his early years - employment at Behrens and study of Lauweriks's designs - in the manifesto Vers une architecture. Written in a prophetic tone like all of his books, it already presents the Golden Section as natural rhythm, inborn to every human organism. However Le Corbusier does not yet recommend concrete proportions, but only to use measure-rulers, to control the geometrical organization of design.

Le Corbusier developed a scale of proportions which he called Le Modulor, based on a human body whose height is divided in golden section commencing at the navel.The Modulor in Le Corbusier's story combines square and Golden Section, but as a result it does not offer anything else than a modular system. From a blue series of numbers (Golden Section of the total height) and a red series (height of the navel) results a sequence of measures from 27 cm to 226 cm (and then much more) in steps of 27 and 16.

Figure (12) Modulor by Le Corbusier. he created this schema about proportions based in the golden section, that you can find in the human body. For example the ratio between the distance of the head and navel to the ground is approximately Phi (1.618...) [Juan C. Dürsteler 2007].
https://www.google.com.eg/search?q=Modulor+by+Le+Corbusier&source



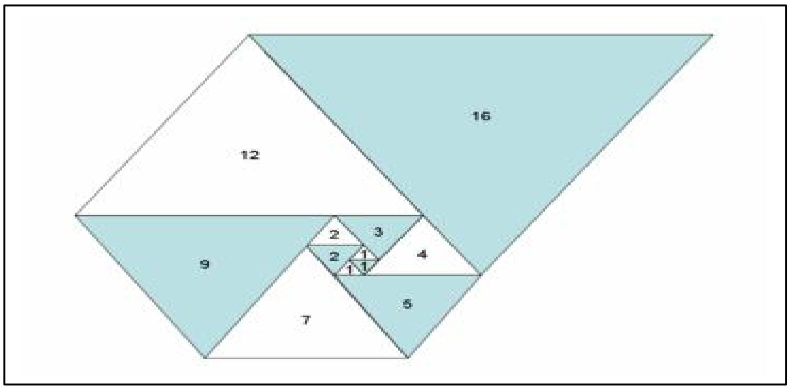
3.2.4. The plastic number of Van der Laan

A little-known number that has much in common with the golden ratio in that it is closely linked to architecture and to aesthetics. The concept of the plastic number was first described by the Dutchman Hans van der Laan (1904-1991) in 1928, shortly after he had abandoned his architectural studies and become a novice monk, and has subsequently been explored by the English architect Richard Padovan (1935). It is derived from a cubic equation, rather than a quadratic in the case of the golden ratio, and is intimately linked to two ratios, approximately 3:4 and 1:7, which van der Laan considered fundamental in the relationship between human perception and shape and form. These ratios, he believed, express the lower and upper limits of our normal ability to perceive differences of size among three-dimensional objects. The lower limit is that at which things differ just enough to be of distinct types of size. The mutual proportion of three-dimensional things first becomes perceptible when the largest dimension of one thing equals the sum of the two smaller dimensions of the other.

The plastic number is also sometimes called the silver number, but that name is more commonly used for the silver ratio $1+\sqrt{2}$. The plastic number is the limiting ratio of successive terms of the Padovan sequence and the Perrin sequence, and bears the same relationship to these sequences as the golden ratio does to the Fibonacci sequence [WIKIPEDIA].

The name plastic number (originally in Dutch plastische getal) was given to this number in 1928 by Dom Hans van der Laan. Unlike the names of the golden ratio and silver number, the word plastic was not intended to refer to a specific substance, but rather in its adjectival sense, meaning something that can be given a three-dimensional shape [Shannon, A. G.; Anderson, P. G. & Horadam, A. F. 2006].

Fig (13) Spiral of equilateral triangles with side lengths which follow the Padovan sequence [Padovan, Richard 2002] https://www.google.com.eg/search?q=Padovan+sequence&source



3.2.5. The Islamic geometrical system

In making any architectural statement, the designer calls upon a formal vocabulary drawn from his or her previous experience and from the background tradition or culture in which the design is being executed [SERAGELDIN, R. 1988], so the morphological structure that underlies the forms of religious buildings can be mathematically analyzed and syntactically systematized to formulate a powerful compositional language that may help in the understanding of the architectonic style and the aesthetic principles of Islamic architecture.

In the Islamic perspective, the method of deriving all the organizational proportions of a building form from the harmonious recursive division of a basic shape is a symbolic way of expressing the oneness of God and his presence everywhere [HIMMO, B.1995]. Compositions in the Islamic architecture have been transformed into highly abstracted shapes on which principles of rhythmic repetitions, unity, symmetry, and variation in scale were applied to create ordered yet dynamic effects. Shape in Islamic architecture is strongly related to the study of mathematics and other sciences.

In Islamic architecture geometric patterns as spatial concepts (Fig 14) are used to fill surfaces; patterns or motifs grow side by side to cover a surface.

Fig (14) Geometric Patterns in Islamic Art [metromuseum.org]
https://www.google.com.eg/search?q=Geometric+Patterns+in+Islamic+Art&source

4. The Methodology of Design by Geometric Code

4.1. The methodology description

The importance of the geometrical systems and orders in architecture design cannot be overstated: they are the DNA of classical architecture, the core of numerous systems by which its design evolved and transmitted. The character of the design revolves around the choice of the order and the geometrical system and the way they are treated. Where more elaborated designs use two or more geometrical systems and orders, the effect depends on the dialogue between them. So, a fundamental characteristic of classical architecture is the interdependence of building design (plan and elevation) and the geometrical system. Taking into consideration the impact of each one on the other very much depends on the type of building in question, and the function of using geometrical systems in design is to weld a heterogeneous collage into a harmoniously integrated whole.

The geometric code design method illustrates how design idea and the building design is deriving geometrically by depending on the geometric schemes, which remain the backbone of the process of "designing" of all buildings, and it plays the role of design generator which control all the design process. The geometric code demonstrates the geometric steps to derive floor plans and these geometric steps establish a basis for a geometric method of design for the automatic derivation of buildings design.

4.2. Relation between geometric code and architecture design layers

Architecture design consists of many different layers, all layer are integrated and the geometric code is the secret factor which control this process of integration and insure it. The geometric code play the role of DNA which controll all the design process and all design layers. If we assume that the architectural design consists of ten consecutive layers as shown in the following table, the geometric code comes as a hidden layer between all these layers, so it control all the architecture design characteristic and it come in aspeparation layer precedes all design layers and in the same time it controlls and affects the performance of all these layers

1- Site analysis layer.	6- Spatial dsign layer.
2- Owner requirements layer.	7- Form composition layer.
3- User demands layer.	8- Avliable technologyical tools layers.
4- Functio relationships layer.	9- Structural system layer.
5- Visual aspects layer	10- Construction techniques layer.

Table (1) the architecture design process's layers (authors)

The geometric code is a hidden layer between design layers, so it controll all the architecture design characteristic and it come in aspeparation layer precedes all design layers and in the same time it controlls and affects the performance of all these layers

The geometric code demonstrates the geometric steps to derive floor plans, this process can be described as s a geometric method of design for the automatic derivation of buildings floor plans. To form the geometric code layer the designer must begins with the suggesting of the idea of the geometric code which mainly will be a geometric scheme. This geometric scheme must be differ from project to project in order to suit the diversity of buildings type, then he ending with the finall form or shape of geometric code. The geometric scheme is founded in the hinterground of design controlling its geometric features

4.3. The methodology scheme

The following figure illustrates the steps of the suggessttedd methodology.

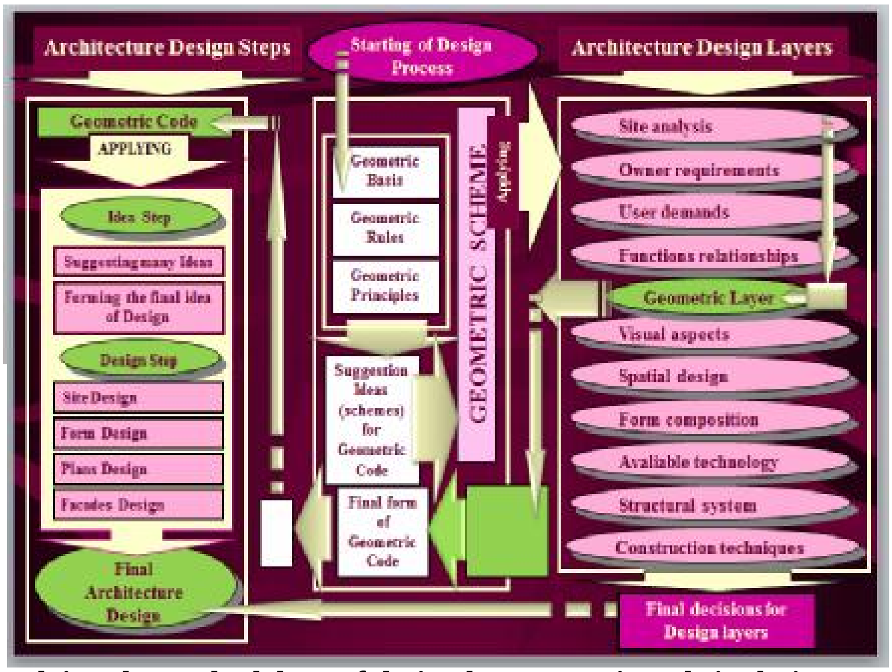


Fig (15) the methodology of designing by geometric code. (authors)

4.4. Steps of applying the methodology of design by geometric code in design process

To apply the methodology of design by geometric code in the design process of buildings, the designer must go on the following steps:

1- Studying and analyzing geometric basis, geometric rules and geometric principles from architecture point of view.
2- Putting a suggestion ideas for geometric code scheme.
3- Studying the first four layers between the architecture design layers which are the site analysis layer, the user requirements layer, the owner demand layer and the function relationships layer.
4- Forming the geometric layer of the architectural design.
5- From step 1 and 4 the designer can formulate the final form of geometric code.
6- Applying the geometric code on architecture design ideas.
7- Reaching to the final idea of the building design.
8- Applying the geometric code in the functional relationships layer.
9- Applying the geometric code to generate the final architectural design.
10- Goining on steps to reach the final architectural form and composition of the building (plan and facades design).

5. The Applied Study

In this study we will demonstrate how to use the suggestted methodology in the design of a complex buildings.

5.1. The first project: (Social- Culture Bulding)

The building have many different functions distributed in three floors as follows: The building in the first floor introduce a service functions but in the second floor introduce an entertainment functions and the accomodation function come in the third floor.

5.1.1. Project description

The project site adress: The project is loacated at the Arab Republic of Egypt in El-Minia city, in Abo Flaw area beside the Nile Language school, facing the river nile..

The project owner: this project is for Administrative Prosecution Authority.

Thr project function: it is social, culture and entertainment club.

The project architectural component: the building have many different architectural functions distributed in three floors as follows:

The ground floor contain the service functions as follow:: reception halls, the main resrurant, praying hall, clinic rooms, main kitschen, open courtyard and the main entrance loopy.

The first floor contain the entertainment functions as follows: the departement of the chairman of board director (it contains meeting hahh, waiting hall, secretariate room and official rooms), computer games hall, GYM hall, the library, employers rooms and official rooms.

The second floor containt the accomodation function as follows: this floor is the hotel floor and it contain a many hotel accommodation rooms, open roof and hotel reception hall.

5.1.2. The components of the geometric code

According to the type of the building and by studying the first four layers between all design layers (as shown previously in the geometric code scheme) and by studying the geometric rules, principles and basis in regard to the building type the designer can formulate the finall shape of the geometric code.

In our case the geometric code consists of four main componenets as follows:

The main triangle: its corners is the position of the main functions in the building and in the extension of its main side will locate the main entrance

The second main triangle: in its main side will be the position of the functions whichhave the modular characterestic.

The modular unit: the modular unit servie the production of the service functions as bathrooms and corridors

The generator factor: the designer must take a decision about the geometric shape for the generator factor, in our case the rectangle will be the suitable shape, this generator factor is moving from place to place in the form composition and change its dimension to generate all functions form in the building whole form.

The following figure present the finall geometric code scheme and its four main components:

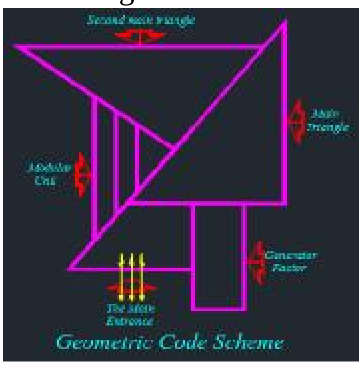


Figure (16) the geomeyric code scheme. (authors)

5.1.3. How to apply the methodology

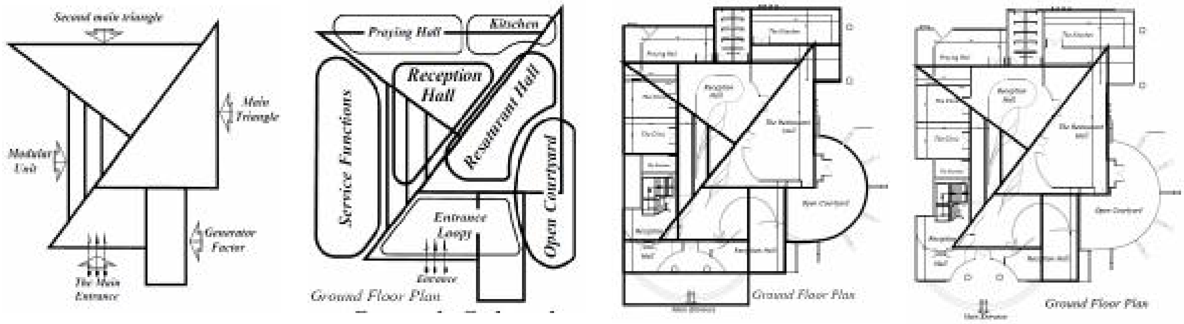
The methodology of designing by geometric code had applied in the design as follows:

- Studying the geometric principles, rules to generate the idea of the geometric code.
- Studying the architecture design layers generate the geometric layer in building design.
- The geometric layer and the idea of the geometric code combined together and generate the final geometric code scheme.
- The geometric code scheme and the functions relationships combined together and generate the architectural spaces.
- Goining on steps the designer reach the finall architectural form and composition.

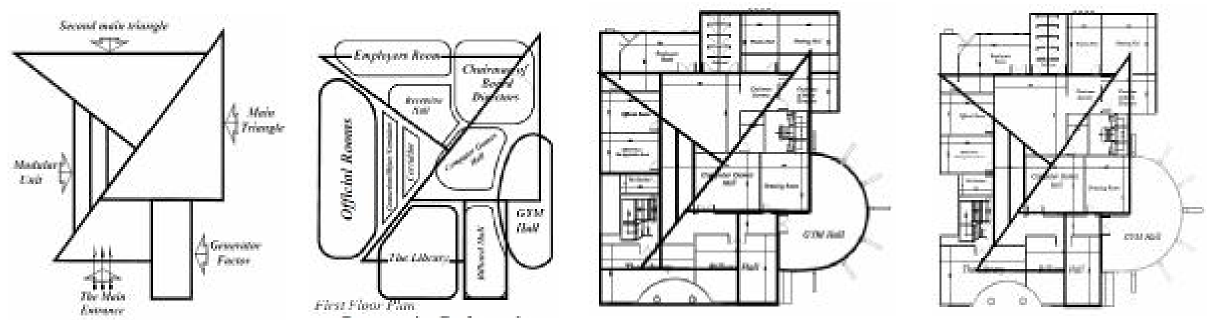
5.1.4. Design of floor plan and form composition

The following drawings present how to generate the floor plans of the building.

The ground floor design



The first floor design



The second floor design

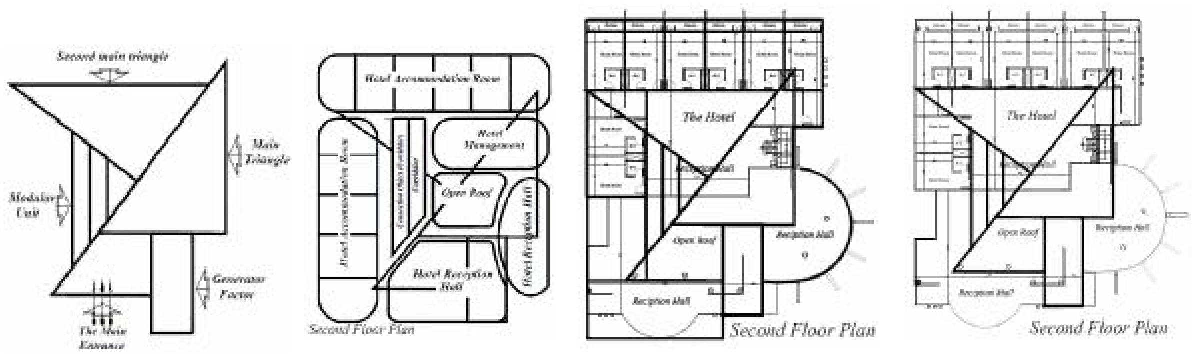


Fig (17) The building different floors steps (left to right) (authors)

Fig (18) The building different floors (left to right: the ground, the first and the second floor). (authors)

The form and facades design

Fig (19) The building different composition (authors)

5.2. The second project: (Multi-function Building)

The building have many different functions distributed in six floors as follows: The building in the basement floor introduce a service functions but in the ground and first floor introduce the commercial functions, the second floor is the adminstration floor functions, the third floor is the hotel floor and the roof floor introduce the entertainment functions (cafe, resturants, ...etc).

5.2.1. Project description

The project site adress: The project is loacated at the Arab Republic of Egypt in New Cairo-city.
The project owner: ARABIAN GROUP DEVELOPMENT.
Thr project function: multi functional building (commercial, adminstration, hotel, entertainment).
The project architectural component: the building have many different architectural functions distributed in six floors as follows: service functions, commercial functions, adminstration functions, accommodation functions and entertainment functions.

5.2.2. The components of the geometric code

According to the type of the building and by studying the first four layers between all design layers (as shown previously) and by studying the geometric rules, principles and basis in regard to the building type the designer can formulate the finall shape of the geometric code scheme.
In our case the geometric code consists of four main componenets as follows:
The three main rays: These three rays play the role of container to the different functions.
The main arc: This arc controll the functions placed in one side of the building, the functions which have the radii modular character. **The main rectangle**: This rectangle controll the functions placed in second side of the building, the functions which have the repeat modular character.**The generator factor**: the designer must take a decision about the geometric element for the generator factor, in this case the centre point will be the suitable element, this generator factor is controlling the generation of all functions form in the building whole form.
The following figure present the finall geometric code scheme and its four main components:

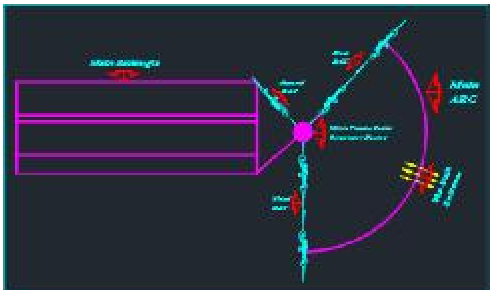


Figure (20) the geomeyric code scheme. (authors)

5.2.3. How to apply the methodology

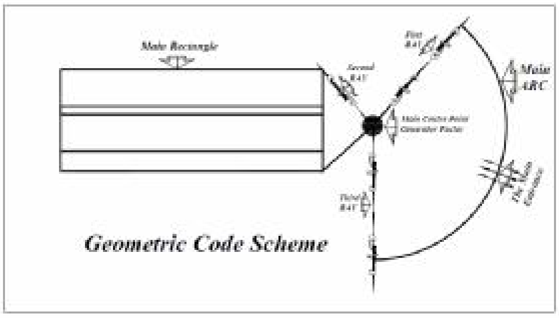
The methodology of designing by geometric code had applied in the design as follows:

- Studying the geometric principles, rules to generate the idea of the geometric code.
- Studying the architecture design layers generate the geometric layer in building design.
- The geometric layer and the idea of the geometric code combined together and generate the final geometric code scheme.
- The geometric code scheme and the functions relationships combined together and generate the architectural spaces.
- Goining on steps the designer reach the finall architectural form and composition.

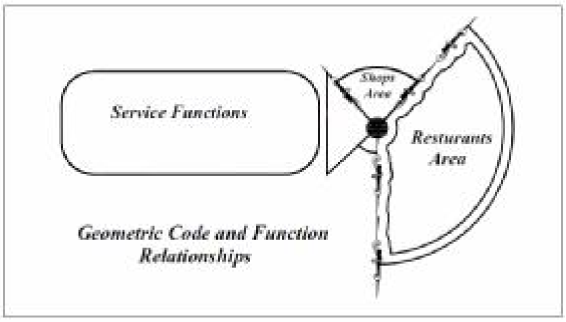
5.2.4. Design of floor plan and form composition

The following drawings present how to generate the floor plans of the building.

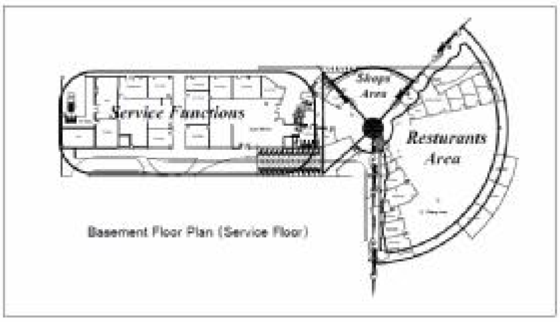
The Basement floor design



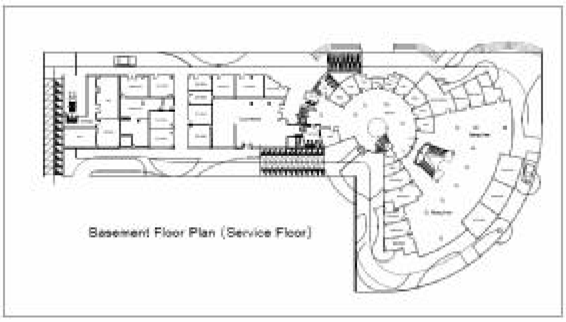
1- The geometric code scheme



2- The geometric code and the function relationships

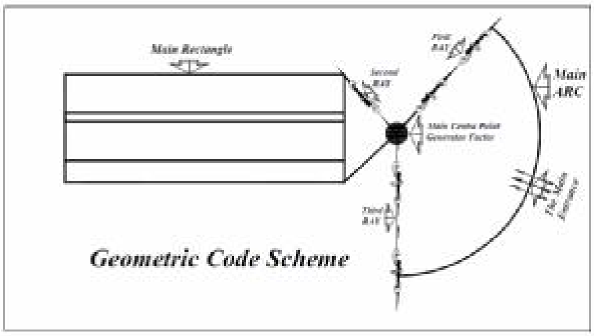


3- The geometric code and generating the architectural spaces

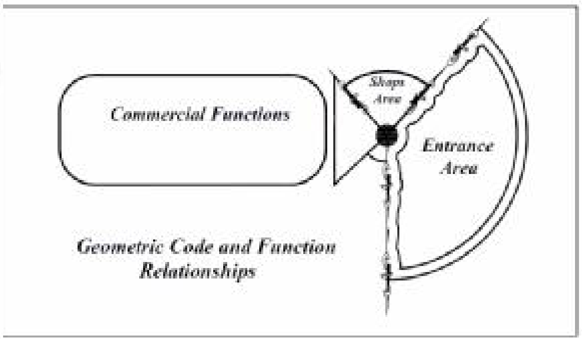


4- the final floor design

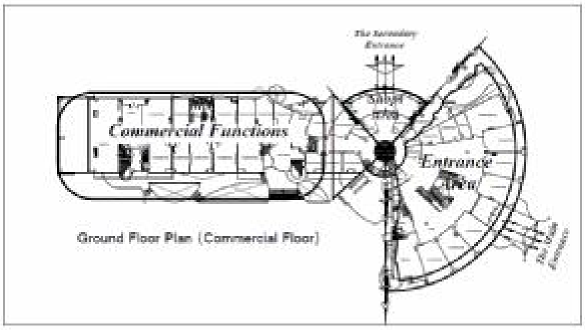
The Ground floor design



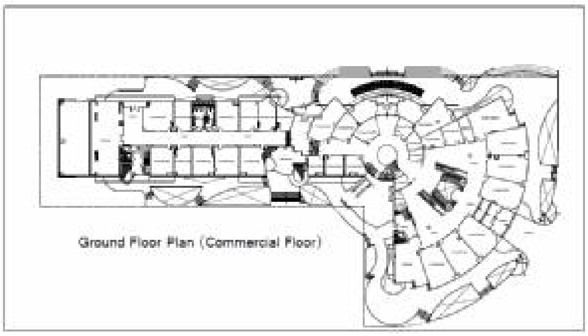
1- The geometric code scheme



2- The geometric code and the function relationships

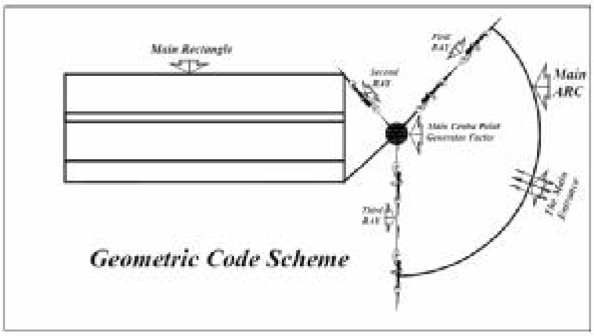


3- The geometric code and generating the architectural spaces

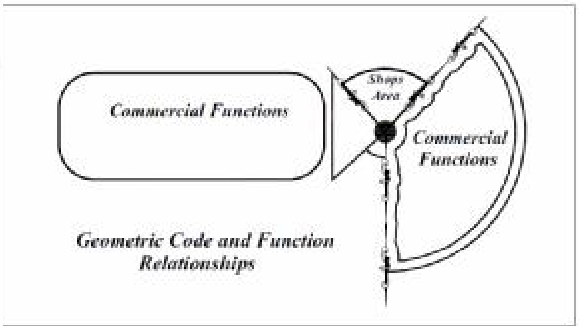


4- the final floor design

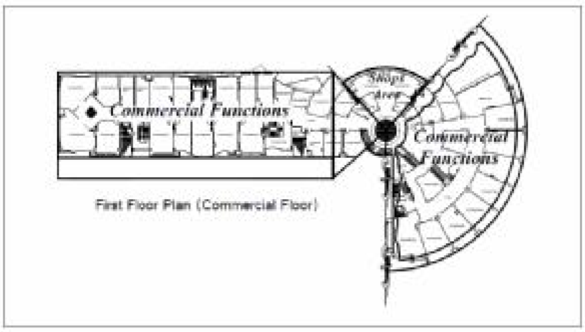
The First floor design



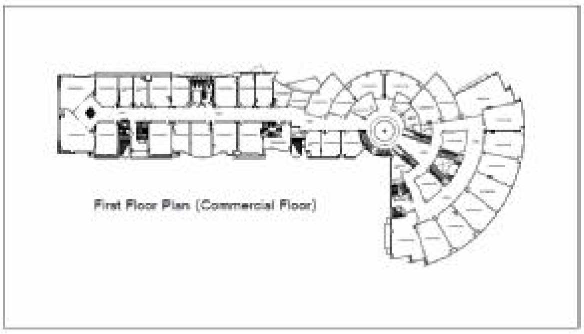
1- The geometric code scheme



2- The geometric code and the function relationships

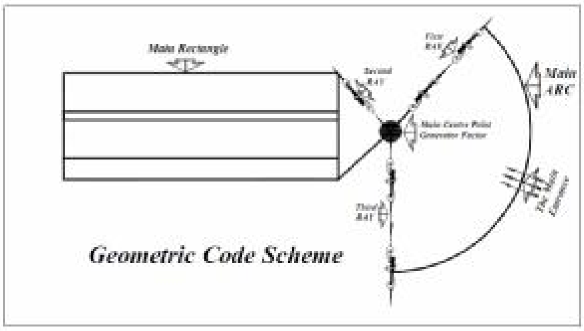


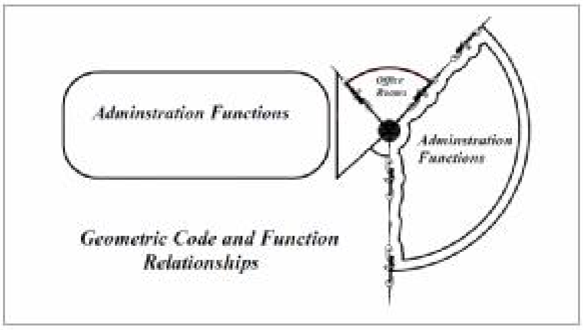
3- The geometric code and generating the architectural spaces



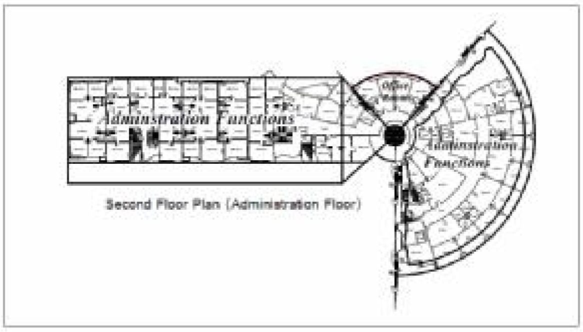
4- the final floor design

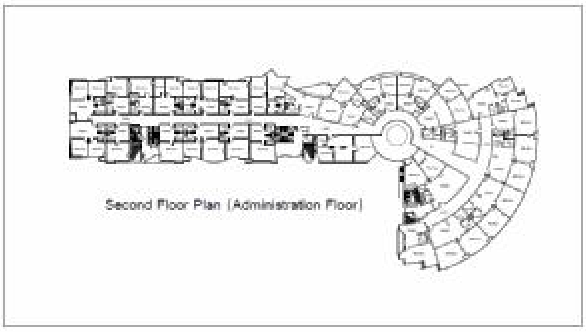
The Second floor design





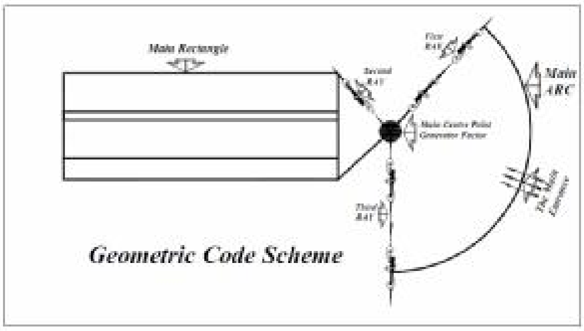
1- The geometric code scheme **2- The geometric code and the function relationships**

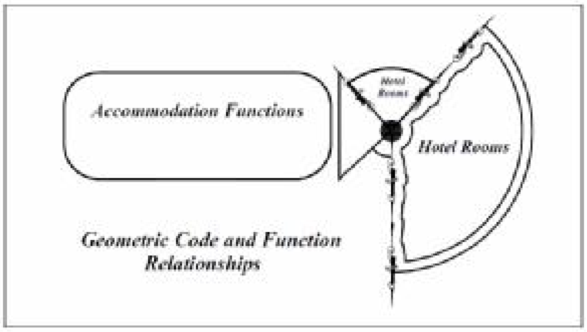




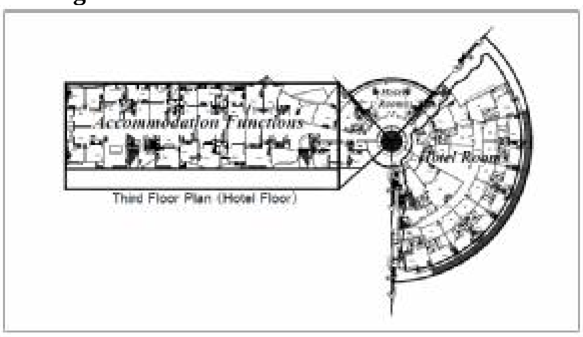
3- The geometric code and generating the architectural spaces **4- the final floor design**

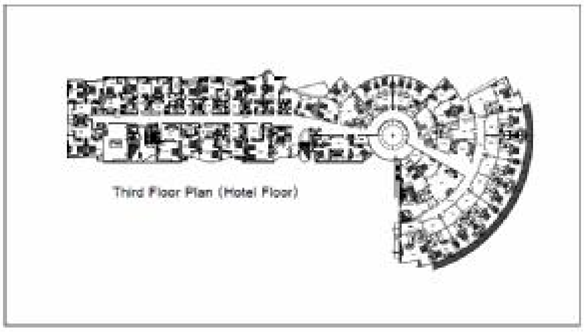
The Third floor design





1- The geometric code scheme **2- The geometric code and the function relationships**





3- The geometric code and generating the architectural spaces **4- the final floor design**

Fig (21) The building different floors steps (left to right) (authors)

The form and facades design

Fig (22) The building different composition (authors)

5.3. The third project: (Administration – Entertainment building)

The building have tow main function (adminstration and entertainment functions) in two floors

5.3.1. Project description

The project site adress: The project is loacated at the Arab Republic of Egypt in 6 October city.
Architecture designer: Authors with co-operation with e. Asmaa Emad El Din.
Thr project function: it is adminstration and entertainment building.
The project architectural component: the building have two main architectural functions.

5.3.2. The components of the geometric code

According to the type of the building and by studying the first four layers between all design layers (as shown previously) and by studying the geometric rules, principles and basis in regard to the building type the designer can formulate the finall shape of the geometric code scheme.
In our case the geometric code consists of four main componenets as follows:
The main arcs: These arcs controll the functions placed in all sides of the building, the functions which have the radii modular character.
The arc heads: Every main arc the designer generate a head to it, his head lead to place the boundary of the building.
The generator factor: the designer must take a decision about the geometric element for the generator factor, in this case the centre point will be the suitable element, this generator factor is controlling the generation of all functions form in the building whole form.
The following figure present the finall geometric code scheme and its four main components:

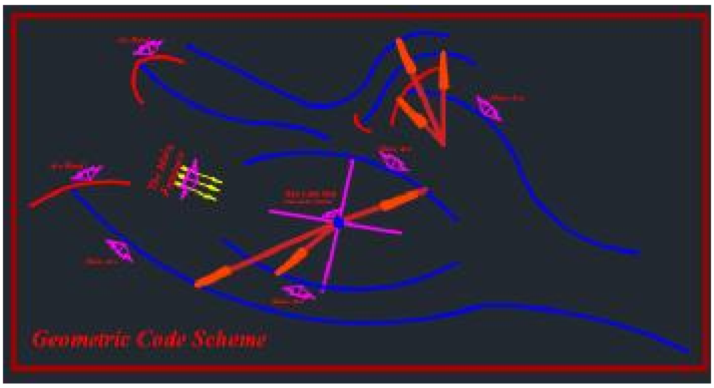


Figure (23) the geomeyric code scheme. (authors)

5.3.3. How to apply the methodology

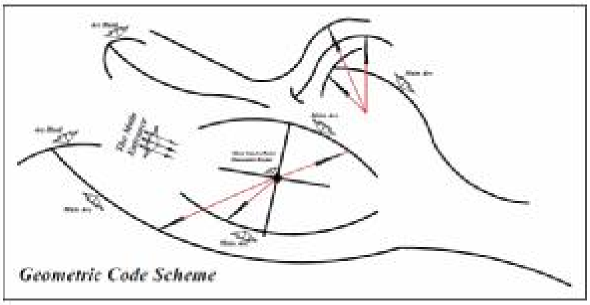
The methodology of designing by geometric code had applied in the design as follows:

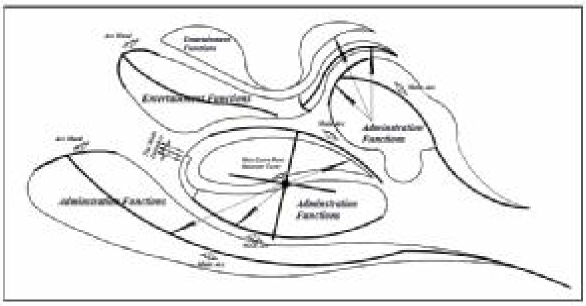
- Studying the geometric principles, rules to generate the idea of the geometric code.
- Studying the architecture design layers generate the geometric layer in building design.
- The geometric layer and the idea of the geometric code combined together and generate the final geometric code scheme.
- The geometric code scheme and the functions relationships combined together and generate the architectural spaces.
- Goining on steps the designer reach the finall architectural form and composition.

5.3.4. Design of floor plan and form composition

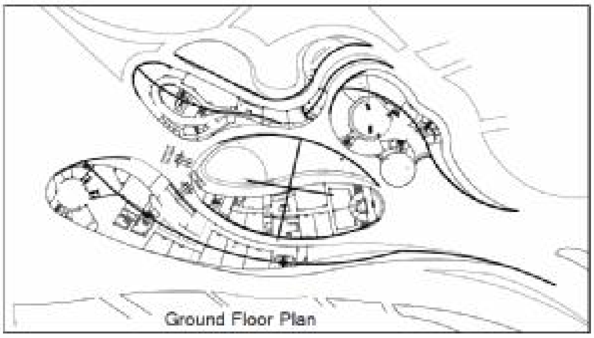
The following drawings present how to generate the floor plans of the building and its form composition

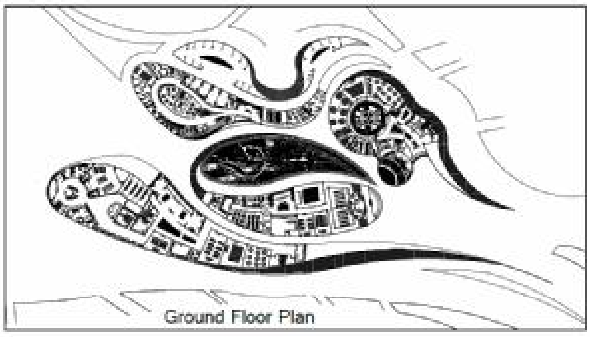
The ground floor design





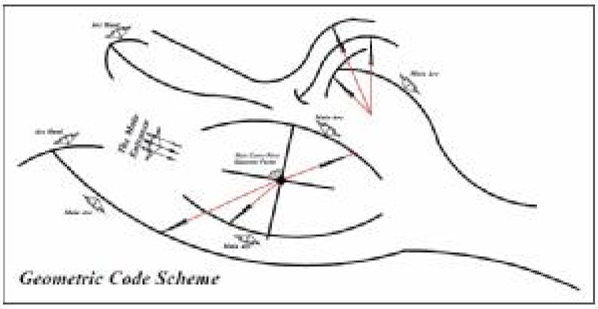
1- The geometric code scheme **2- The geometric code and the function relationships**

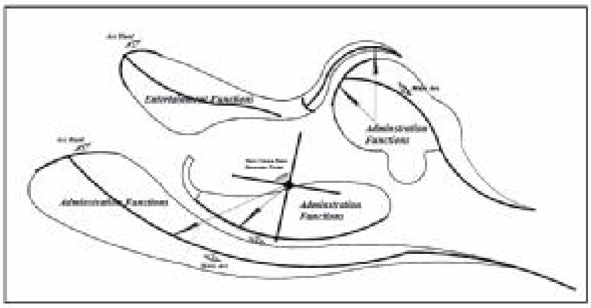




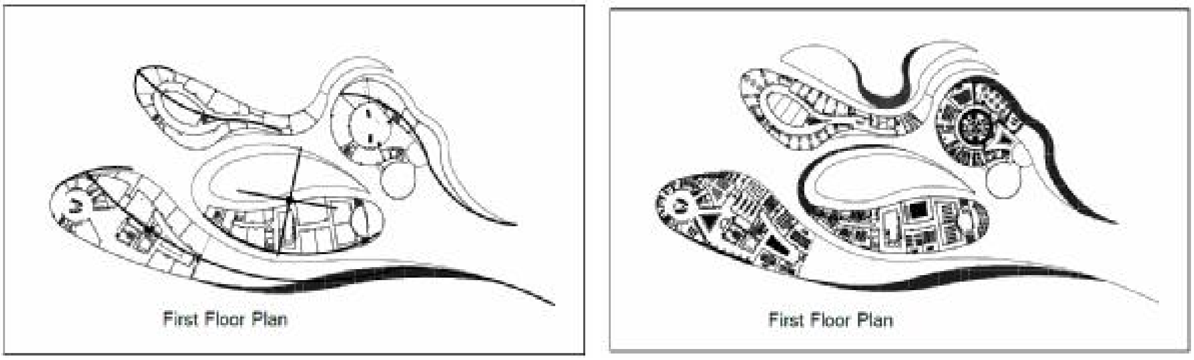
3- The geometric code and generating the architectural spaces **4- the final floor design**

The first floor design





1- The geometric code scheme **2- The geometric code and the function relationships**



3- The geometric code and generating the architectural spaces **4- the final floor design**

Fig (24) The building different floors steps (left to right) (authors)

<u>The form and facades design</u>

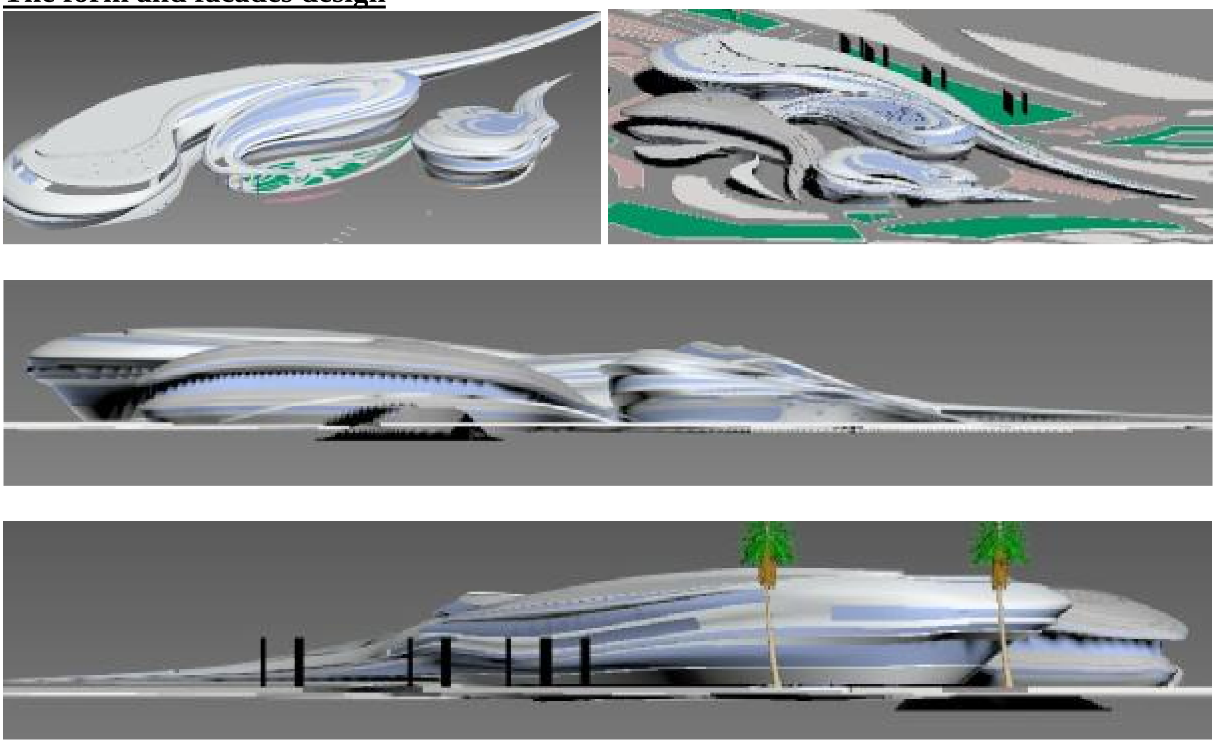


Fig (25) The building different floors composition (authors)

6. CONCLUSION

- Design by geometric code is an important step ahead towards the architecture of the Future
- The research believe in the “geometric design method” as a historical reality and as the basis of architectural design.
- It is now possible to see the design methods reviewed here as steps towards a greatly expanded design process that is becoming necessary to the continued development of the man-made world.

- The research here aske researchers and architects to search for new design methods capable of reviving the roots of traditional architecture in our contemporary architecture beside gain the great benefits from the advanced modern technology.
- This non-mathematical technique the research have labelled design-constructive geometry, to indicate the architects' concern with the construction and manipulation of geometrical forms (There were in his thinking process about the design process always a link between the design in 2D and constructive in 3D). It becomes evident that the "art of geometry" meant the ability to perceive design and building problems in terms of a few basic geometrical figures which could be manipulated through a series of carefully prescribed steps to produce the points, lines and curves needed for the solution.
- The nature of that geometric design method suggests that these design procedures, will be universal laws which will provide the key to contemporary architecture; rather, they will be particular procedures used by particular architects at particular times and places. The sugessted geometric design method is to show how modern architects used step-by- step.
- Namely, it is always possible to tell where the modern architect can starts in suggesting the geometric codes scheme. Sometimes it is clear how certain lines were drawn specially the main spaces' axes, and sometimes it appears that several points may have been the starting point.
- The benefits of geometry in design methods in contemporary architecture can be presented in three methods by which geometry expressed in architectural design
    - Using inherent geometric scheme plays in the background of the design.
    - Using mathematical calculations to determine the functions' positions in design,
    - Using geometric drawing methods or graphic drawing methods.
    -

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A CONCEPTUAL FRAMEWORK FOR ENRICHING ARCHITECTURAL CLASSROOM WITH MOBILE AUGMENTED REALITY

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ABSTRACT
Due to the emergence of digital technology and its necessity in their lives, students of architecture are facing many challenges in this digital era. Unfortunately, it did not succeed the same way in their education as in architectural practice. By away or another, traditional architectural classrooms still depend on obsolete visualization methods and traditional approaches. On the other hand, many architectural students are complaining of lack of interaction and real engagement with the learning environment. Many studies have revealed that architects are “digital natives "and "visual learners", for that; they are in need of an innovative visualization tool to support their style of learning. This study utilizes Mobile Augmented Reality (MAR), technology as an innovative tool for enriching architectural education. Although, engaging MAR technology in architectural classroom is not a new idea, yet it is still not widely applied due to many different reasons. Educators still insist on using the same traditional methods, they still do not know how MAR should be integrated in their teaching strategies. For this purpose, this study is presenting, a conceptual model for integrating the basic concepts of MAR technology in architectural education based on one of the Instructional Design (ID) models and Student-Centered Learning, (SCL) approach. The mod el works as a key guide for architectural educators to design a successful instructional environment that is planned with ID models. This paper presents the key concepts of the framework and the related learning theories, its potential applications, current challenges and future directions. Experiences and lessons learned and presented in this paper could help architectural educators to plan, design and develop their MAR educational experiences.

Keywords : Architectural Education, Student-Centered Learning (SCL), Visual Learning, Edutainment, Mobile Augmented Reality (MAR), Instructional Design (ID.)

ملخص البحث
يواجه معماريو المستقبل العديد من التحديات في عصر التكنولوجيا ؛ وأهمها تدخل التكنولوجيا الرقمية والمنافع العديدة التي تقدمها لهم في حياتهم العلمية والعملية.الا انها لم تحرز نجاحا في مجال التعليم المعماري كما أحرزته في الممارسة المهنية حيث انه لاتزال الفصول المعمارية في الوقت الحالي تتبنى أساليب التعليم التقليدية .ومن ناحية أخرى ؛ يشكو العديد من طلاب العمارة من قصور التفاعل والمشاركة الحقيقية مع بيئة التعلم الحقيقية .فلقد أثبتت الدراسات أن المعماري هو مفكر مرئي يحتاج الى أدوات تعزز أسلوب التعلم التصوري وتقترن باساليب التعلم الذاتي و نتيجة لذلك؛ اقترحت هذه الدراسة أداة تعليمية مبتكرة وهي تكنولوجيا الواقع المعزز النقال . حيث تعمل على نقل مسار العملية التعليمية من المعلم الى الطالب بالتكامل و الدمج لعدة مفاهيم تربوية حديثة أهمها التعلم الذاتي والتعلم النقال بهدف زيادة دافعية التعلم والادراك. وعلى الرغم من الأثر الايجابي لتقنيات الواقع المعزز على طلاب العمارة وانجذابهم لها كاداة مبتكرة لتعزيز التعلم المرئي ,الا أن عدم انتشار أساليب

واستراتيجيات تعليمية واضحة لدمجها في سياق التعليم المعماري وتجنب المعلمين والمؤسسة التعليمية لهذه التقنيات؛ أدى الى تقليص فرص استخدامها في الفصل المعماري. وحتى مع تقبل هذه الفكرة، فانه لا توجد خبرات كافية للتعامل تقنيا وتربويا مع هذه الادوات.لهذا هدفت الدراسة الى تقديم تصورمقترح يعمل كدليل ومرشد رئيسي للمعلم والمصمم التعليمي في تصميم بيئة تعليمية ناجحة للتعليم المعماري تقوم على أساس استراتجية التعلم الذاتي ومدعمة باحد تطبيقات الواقع المعزز النقال والمتوفرة في التطبيقات المتاحة حاليا في الهواتف الذكية.وقد بني هذا التصور على أساس أحد نماذج التصميم التعليمي بهدف ان يمثل اطار نظري ليدعم كلا من احتياجات طالب العمارة المعاصر و امكانيات تكنولوجيا الواقع المعزز النقال .

1. Utilizing Mobile Augmented Reality in Architectural Education

Some researchers consider future architects as "digital natives" and "visual learners", (Shirazi, et al. 2014). They need a powerful digital visualization tool to develop their architectural learning process to go beyond the traditional Teacher-Centered Learning (TCL) and the conventional learning tools. Nowadays, free digital applications, web and mobile computing technologies combined with "Mobile Learning", (M-learning) concept has widely spread. Broadly speaking, M-learning is the next innovative level of E-learning (Anshari, et al. 2017). According to (Parhizkar, et al. 2012), it is the delivery of learning content to learners utilizing mobile computing devices.

This study assume that with the success obtained in various educational areas as military, art, urban planning and different architectural fields in using mobile augmented reality as an educational tool for teaching architecture based a " Student Centered" teaching approach. Research reveals that MAR has a positive potential for architectural students in experiences with regard to different evaluation criteria such as (increasing motivation, social skills, feasibility and overall improvement their academic performance), (Redondo, et al. 2013), (Abdullah, et al. 2017), (Kassim, et al. 2016) and (Domínguez, et al. 2014).

Recently AR techniques begin to be applied in our Egyptian universities, in a study by experiment, in Shebin El-kom University three different architectural case studies was performed for examining MAR's approach on architectural students regarding different case studies in different architectural disciplines such: the building construction, architectural design and landscape design courses .The study showed that students was satisfied regarding using MAR techniques, they had a positive impact on their academic performance based a self learning experience, their learning motivation, spatial skills and perception was improved. (El-Sayed, M., 2016). In Addition, in a study by (El-Sayed, N., 2011) performed in Banha University, MAR had a great acceptance among students, they were satisfied by the efficiency of this tool for learning history, art, science and biology.

Multiple innovative learning opportunities may be generated in the field of architectural education due to the integration of mobile devices with AR as MAR can potentially be used in photographing buildings, construction elements, serve as a means for sharing interests with friends and promoting direct interaction among students anywhere and anytime (Wolpers, et al. 2011). Although, earlier researches have proven the benefits of MAR in education and architectural education fields, they are still not implemented on a large scale due to the educators' limited programming skills that are essential for 3D modeling and multimedia development (Abdullah, et al. 2017). In addition, when educators accepted the idea of integrating these technologies in their teaching strategies, "they really do not know how it should be embedded" (Redondo, et al. 2012). *Consequently, this study is not aiming to prove the effect of MAR on architectural students; rather the study is emphasizing the lack of clear instruction strategies regarding this tool in architectural education from the educator's perspective. For that purpose, a conceptual model is presented to answer the main question posed by the architectural educators: What steps should I follow while designing a MAR learning experience?*

1.1. Architectural Education towards a Shift in Pedagogy Directions

MAR techniques have an innovative impact upon student learning and potential in transforming learning environments from a physical to virtual environment. These techniques allow for the SCL experience with regard to all students at their own personal mobile devices.

Each student has his own rhythm of thinking so he should have his own learning environment. Hence, this study proposes a pedagogical vision shift via MAR capabilities. There are three shifting axis connect to "Constructivism", "Mobility" and "Virtual Learning Environment" concepts as illustrated in Figure. (1)

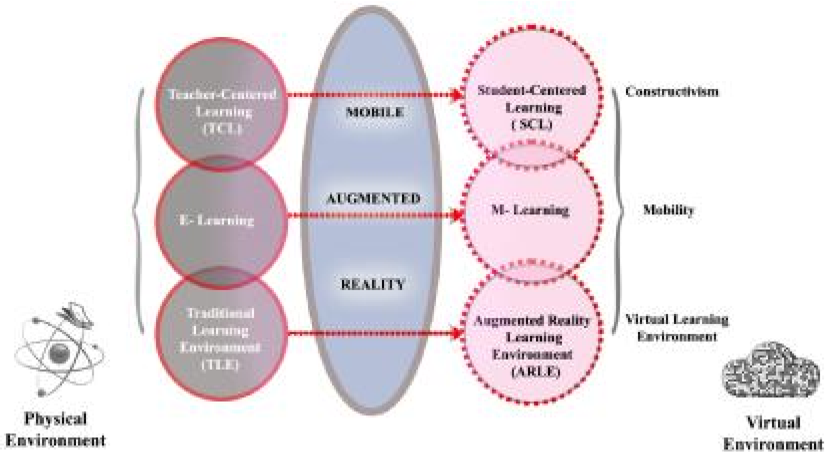


Fig.(1) : The Pedagogic Three Shifting Axis Enhanced by Mobile Augmented Reality (as interpreted by the authors)

From TCL to SCL: MAR will allow for more potential for "*Student-Centered Learning" SCL* or "*Constructivism*" concept in a broader way. Students construct their knowledge through direct interaction with the 3D learning content and supportive online information, by building on MAR's ability of linking with GPS and internet. This new approach is giving an opportunity for transferring from the "*Teacher-Centered Learning"* (TCL) strategies, which provide a verbal knowledge, to a facilitator through mobile platforms' capabilities, such: messaging, annotations, online sharing, cloud storage and various supportive multimedia and feedback strategies

From E-Learning to M-Learning: with M-learning, the MAR's environments can facilitate the learning process. According to, (Stanton, et al. 2013) mobile learning is different from face to face and "*E-learning"* with the "*Mobility*" concept. Being able to move around is a unique feature that differentiates mobile learning from other learning environments; it is seen as freeing the learner from the classroom disk, As students are given the opportunity to explore projects, buildings and masses physically on site through the use of handheld devices with user friendly Graphical User Interfaces (GUI). Thus, shifting from Human-Computer-Interaction (HCI), to Human-Mobile-Interaction (HMI), allowing for further pedagogic flexibility (Redondo, et al. 2013).

From TLE to ARLE: with MAR integration, architectural educators can develop their new pedagogic approaches enhanced by MAR applications via innovative Augmented Reality Learning Environments ARLE characteristics' potentials among students. Broadly, according to (Cubillo, et al. 2015), ARLE as a part of " Virtual Environments" gives a room for educators to test with low cost their teaching materials and without real consequences which is a privilege when compared with traditional learning environments or the "Physical Environment" in a broad way.

2. Paper's Intent and Methodology

This study aims at testing a theoretical model for integrating MAR application in architectural education adapting a SCL approach since both ARLE and M-learning are considered constructive environments, (Berking, et al. 2012). This framework is meant to inject concepts, considerations, and specific guidelines to M-learning, and AR into appropriate points based on one of the generic ID models, the ADDIE model. While ADDIE is an acronym, referring to the five major phases of the generic Instructional System Design (ISD): **A**nalysis, **D**esign, **D**evelopment, **I**mplementation and **E**valuation phases (Schlegel, et al. 1995,p.10).

The paper adopts the ADDIE model adding to it an additional layer of M-learning ID considerations with respect to ARLE characteristics that was conducted by (Cubillo, et al. 2015), such as: ensuring immersion, enabling exploration, incorporating description of virtual resources and designing non-linear content for improving motivation. We have integrated our idea with collected ID mobile learning considerations from the literature and mostly adopted from "Mobile Learning Handbook" 1 to inject these considerations into each of the ADDIE phases. Regarding the final stage of ADDIE; the "Evaluation" phase, it is generally interpreted. However, not assessed since the application was not tested in a real environment with students. A validation assessment has been conducted by gathering some architectural educators on an open questionnaire. In the conclusion, they presented ideas for developing and improving our framework. Moreover, lessons learned are presented and guidelines are given in order to help educators plan, design and develop their learning contents with existing free MAR applications while saving time in the overall development process. The study ends with a vision for generic design characteristics to implement an "Architectural Mobile Augmented Classroom" (AMAC) that was coined by the authors.

3. Augmenting the ADDIE Model with MAR in Architectural Education Context: "Parquet Wooden Floor" Building Construction Details, Case Study

This section of the study proposes a theoretical framework by implementing the ADDIE instruction design (ID) model on MAR application (AR-media™). A Sub User Interface (UI) was adapted from (AR-Media™ plug-in) on desktop was designed for juniors' level one to facilitate the SCL teaching approach of one of the basics building construction courses for "Parquet Wooden Floor" architectural details. In addition, we have added some developed features for AR-media™ application, in order to enhance our SCL approach to provide a deeper understanding of the architectural content. For the aim of this study, the ADDIE model is utilized as a guide and a "Basic model" to combine the ARLE and the instructional design for m-learning considerations within the architectural education context. According to (Saidin, et al. 2016), ADDIE is widely used in system development for teaching methods, particularly in E-learning systems, educational games and M-learning. The study is not trying to create a new ID model rather it has suggested an augmentation for ADDIE with an additional layer by ID for m-learning considerations in each phase. The following are examples of a few questions that are

(1) https://sites.google.com/a1/adlnet.gov/mobile-learning-guide/best-practices . Accessed in 12/7/2017

addressed during each phase, and adopted from Mobile Learning Handbook to incorporate in

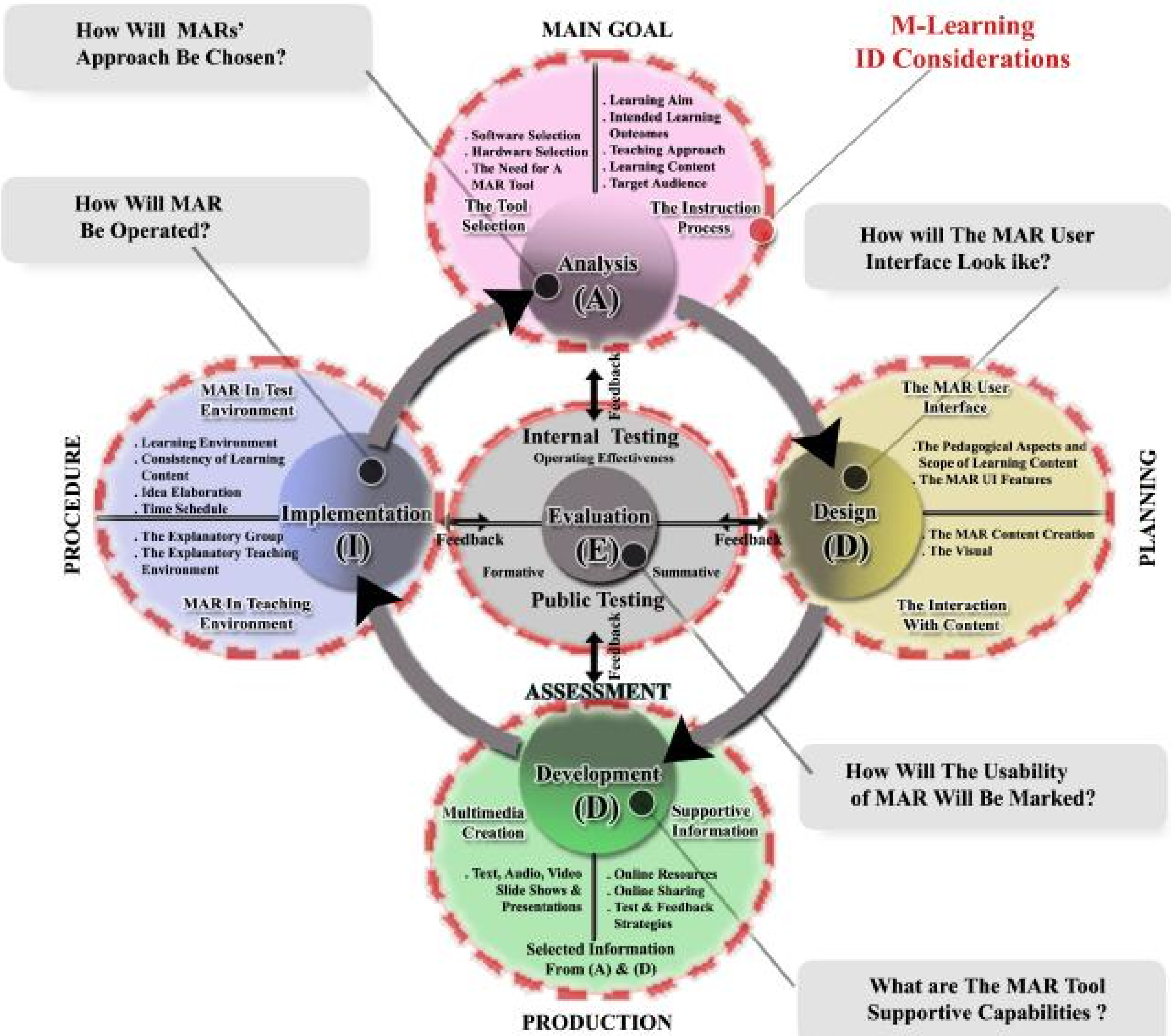


Fig. (2): Augmenting the Main ADDIE Phases After (Gustafson, et.al. 2002) With Instructional Design for M-Learning Considerations

every step of ADDIE, as illustrated in Figure.(2)

3.1. Focus on Analysis

The analysis phase is mainly about "Goal setting stage" (Kurt, 2018), that planning for gathering information and decisions about instructional strategies (Norashikin, 2007). The focus of the architectural educator is on learning goals and objectives, characteristics of target audience and the circumstances of the instruction process. For this purpose, the study has broken-down the analysis phase into two main tasks, "The Tool Selection" and "The Instruction Process ":

<u>1. The Tool Selection:</u> the analysis phase starts with selection of MAR tool that would allow the educator to create the AR educational content. For that, the choice of the tool depends on three factors:

- *Software selection*: an evaluation survey was conducted for three known successful MAR applications in architectural education been used, were evaluated and studied for developing the proposed building construction content, which they are "AR-media™ ", "Aurasma" and "Augment". AR-media™ was chosen based on the selection criteria proposed by (Yilmaz, et al. 2015), such: usability, system features, cost and multimedia creation. In addition, according to a study conducted by (Broschart, et al. 2013), interaction with AR-media™ application is easy and do not require prior knowledge to complete the learning experience to use it only simple gestures and finger touches to complete a learning experience. The software used for modeling was 3Ds Max 2014 and AR-media™ V2.3 plug-in and AR Media Player from Google Play on mobile device.

- *Hardware selection*: it is important for the educator consider the mobile platform capabilities while creating and supporting the learning experience such camera, document viewer, touch screen interaction, cloud storage and other important capabilities, that been addressed in "Advanced Distributed Learning" (ADL) by (Pimmer, et al. 2014). Our device of choice was Samsung Galaxy S6 Edge cell phone as shown in figure 3 , equipped with 16MP camera and Android 5.0.2 Lollipop software. This device is suitable to use with applications on multiple platforms such PC, MAC, Android and IOS as it can accept exported models from renowned architectural modeling software such as 3D Max, Maya and Google Sketch up.

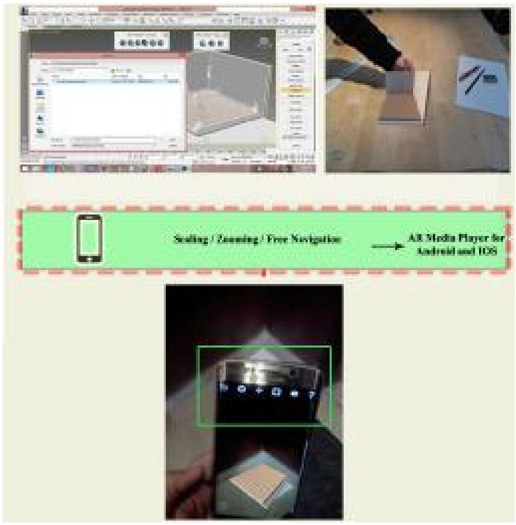


Fig. (3): Displaying the Model on Galaxy S6 Edge Android Platform After Exported From 3D Max

- *The need for a MAR Tool:* which represents the instructional problem. On other words, the need for MAR, which concerns issues, related to the difficulties of Building construction learning in a broad way. It is a subject, which students often complain about missing contact with reality, which lowers their motivation and academic performance (Shirazi, et al. 2015). Beside it is a subject that needs site visits and practical learning side. According to the case of study, the type of "interior flooring "(Parquet Wooden Floor) course, has caused some confusion to students who were trying to imagine the relation between the parquet floor and the subfloor layers. It is a hard task for traditional approaches to illustrate these relations through white board and 2D sketches.

2. The Instruction Process: after the tool has been selected, an instruction process analysis is established to identify all pedagogic approaches and learning environment needs, the instructional goals, objectives, the learning environment, learner's existing knowledge and skills. The instruction process analysis depends on five factors:

- *Learning aim:* the main objective is to increase the students' motivation and enhance their levels of thinking. There are six levels by Bloom's in (Stanton, et al. 2013); knowledge, comprehension, application, analysis, synthesis and evaluation, in order to provide an important framework for educators to use to focus on higher order thinking in a broad way. The main aim here is to learn the basic "Parquet Wooden Floor "contents, basic scales and integration of different materials in a self-edutainment (Education+ Entrainment) experience. For that purpose, we have pointed out a set of objectives regarding our topic as represented in three main points:

    - To introduce the "Parquet Wooden Floor".
    - To analyze the basic "Parquet Wooden Parquet Floor "components.
    - To explore the main execution stages of" Parquet Wooden Floor".

- *Intended learning outcomes:* by allowing students to explore various interactions with the 3D model of Parquet wooden floor through different scenarios, at the end of this experience, the student is supposed to be able to define the wooden parquet execution stages, its standard dimensions and the wooden details of each layer. In addition, to explore construction details, such as: steel spring clips, spacing distribution regarding different wall directions, wooden blanks, Arashalli, timber and parquet board connection, parquet grove connection and parquet board connection. Moreover, to identify the execution stages of the concrete slab, wooden panels, (sub floor) perpendicular wooden panels on the wooden frame, ventilation void, sand immersion, wooden parquet floor and baseboard molding.

- *Educational approach:* a SCL approach was assumed as a foundation and pedagogic approach. Students gain knowledge through direct interaction with the 3D learning content and supportive online information and able to share their experiences online with their colleagues and receive their educators' feedback for guidance upon their request.

- *Learning content:* broadly, it is important for educators to study the nature of learning content and to study the diversity of introducing this content. The learning content represented as an online resource and a 3D model, that considers the learning objectives and AR-media features. In order to, facilitate the educational approach by showing the 3D "Wooden Parquet Floor" as built of three basic layers; layer one: Concrete Slab, layer two: wooden panels, Perpendicular Wooden Panels, Wooden Frame+ Sand Immersion (Sub Floor), layer three: the final finish of Parquet and Wooden Shoe mold.

- *Target audience:* according to (Pantelić, et.al. 2017) characteristic of target audience should be analyzed when designing a MAR experience. For our case the learning content was designed to suite the characteristics of first year architecture junior student's academic level, in other words, to consider their level of skills, prior knowledge, their digital profiles, their goals and motivations to engage with instruction process and their style of learning.

3.2. Focus on Design

The Design phase is about "Planning". In this phase, the study determines all learning goals and identifies the learning tools used to gauge performance, feedback, tests, subject matter analysis, planning of resources (Kurt, 2018). However, according to studies conducted by (Saidin, et.al. 2016) and (Pantelić, et.al. 2017) some specific considerations should be taken into account regarding designing for MAR applications such the User Interface (UI) design, and the visual when pointing on the marker. In addition, the limitations and capabilities of the technologies involved to serve the pedagogic approach and the use of supportive tools to serve the scope of learning content. For that purpose, the design phase was broke-down into two main tasks, "The MAR User Interface" and "The Interaction with Content" as follows.

<u>1. The MAR User Interface :</u> the UI is about how and what are the enhancement tools for enabling the interaction with the learning content, it represent it two factors the pedagogical aspects scope of learning content and the developed MAR user interface features, as illustrated below.

- *The Pedagogical Aspects and Scope of Learning Content*: the considered UI design guides the students to gain further knowledge with clear, simple and non-linear content presentation for enriching their self-learning experience and increasing their motivation through different media .Students with AR Media UI features are free to begin their learning process anytime with any step they prefer. In addition, they may have the opportunity to complete their learning task on the fly as AR media storage enables downloading full 3D content. The AR Media UI has served the designed educational content to reproduce multiple learning scenarios such as (descriptive text, online information, specific level of details required, audio and 3D animation).

- *The MAR UI Features:* while designing for MAR, it is important to consider some technical aspects for the UI. The screen size and RAM capacity of the mobile device (Elias, 2011). UI features should be simple and concise. Hence, the study has divided the UI into "AR media original Tools" by "Inglobetechnologies", and "AR Media Player Sub UI". The Main page displays an upper tool bar of the “Parquet Wooden Floor”; The Original UI" with six main features. Moreover, a lower slider bar for the Sub UI comprised of ten proposed features. Seven of them are involved for interaction with the 3D model while, three of them represents an Additional Information options for producing a further support to the SCL approach as shown in Figure(4).

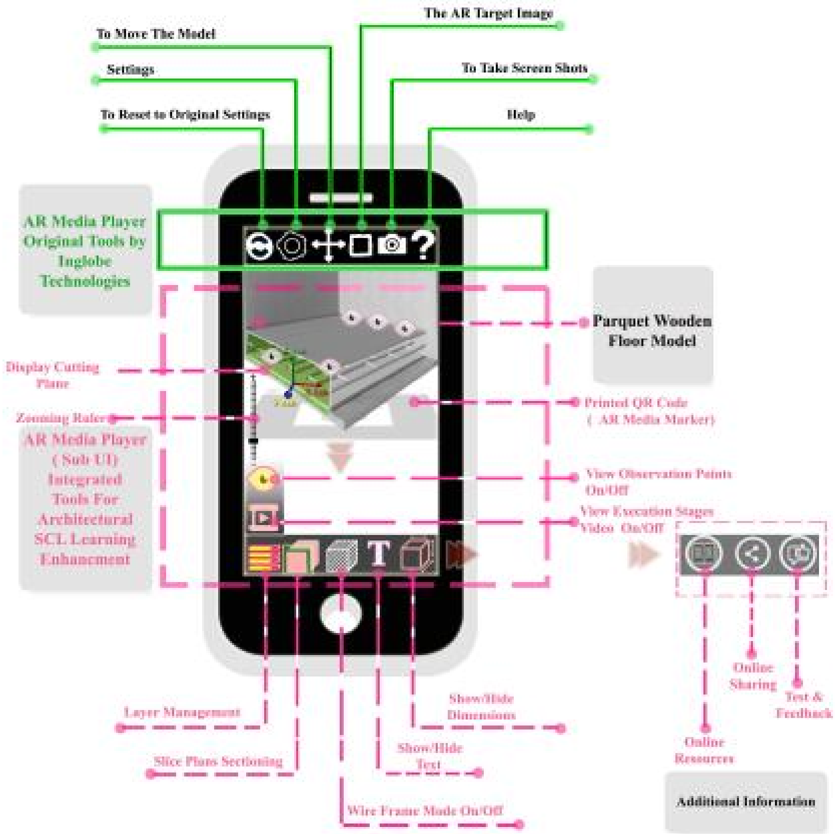


Fig. (4) Integrated SUB UI Based SCL Approach for Learning "Parquet Wooden Floor" Details on Android Mobile by AR-media™ Application (as interpreted by the authors)

<u>2. The Interaction with Content:</u> the interaction with content design comprised of two main factors the " The MAR Content Creation" and "The Visual". MAR's content creation has sketched in four main steps, which describes the link between the modeling programs and the MAR's application. After the content being created, it is important to design the visual when student points on the marker, as follows.

- *The MAR Content Creation:* is represents by four main sequential and procedural steps. Begins with step1 (Modeling +Setup on the Selected Mobile Device), the process of designing the "Parquet Wooden Flooring" model on an hp laptop by Autodesk 3D Max modeling program. Then, "AR-media™ plug-in" is installed on 3DMax to create "woodenfloor.armediafile" .The next is step2 (Printing the Marker + Exporting for the Mobile Device), where the AR player is installed on the mobile device, the marker image is printed from the Inglobetechnologies website, then "woodenfloor.armediafile" is exported to the mobile device. In addition, step3 (Marker Recognition + Generating the Model as a Learning Content), which appears in tracking the marker QR Code and the loading the model. An additional feature is available that allows uploading other files on AR Media web library for multiple markers experience which, requires a licensed version of AR Media. Finally, step4 (MAR Learning Experience at the Architectural Classroom) which clarify the student's navigating the model with mobile through body movements, start interacting with AR Media and ends with possibility to add another marker (which refers to another flooring model) by returning back to step2 and generating another ".armediafile".

- *The Visual:* is what the user will see, hear and experience when pointing on the marker. Various learning scenarios enhanced by the AR media UI such as: recorded video of the execution stages of wooden floor, free navigation, zoom in/out, scaling, moving, layer management, specific observation points beforehand created by the instructor, sectioning, wireframe views and additional information.

3.3. Focus on Development

Broadly speaking, if previous "Analysis" and "Design" phases are about "Goals and Planning" respectively, then the development stage is about "production", "that collects all these aspects and puts them into action (Kurt, 2018). In other words, the developing stage of MAR will be based on selected information as represented in the previous phases of analysis and design. According to a mobile learning ID study conducted by (Berking, et.al. 2012), this phase addresses how the application will look like and what are its (web or native application) capabilities. For that purpose, this phase was broken-down into two main sections, "Multimedia Creation" and "Supportive Information".

<u>1. Multimedia Creation:</u> while scanning the marker image using AR-Media application installed on mobile device, it is important to consider the multimedia creation in this phase. The study poses one of the different scenarios of how could the MAR application enhance the visualizing of "Parquet Wooden Floor "based on SCL approach by integrating multimedia as illustrated below.

- *Text, Audio, Video and Slideshows Presentations:* through the integration of different Multimedia is presented by the educator in *360^{o}Video / Audio* model navigation that enables view of the wooden floor model execution phases. The learning process is enhanced with helpful text for layers descriptions and standard dimensions represents by *text and dimension tabs*. Students are free to begin their learning experiences and navigate the layers of their choice. The *layer management* feature (isolates and builds each layer respectively also is available. There are other additional developed features such as; *observation points,* that are previously designed by the teacher in order to be able to focus on a certain details of the educational topic. Students are free to focus on these points and visualize them moving from one point to another via different perspectives. The *wireframe rendering is also available* with retention to allow for zooming. Moreover, the students may *take cross sections* of the whole model (x, y & z) axis, which is accessible by *slice plans sectioning* tab.

<u>2. Supportive Information:</u> students may also tab for *additional information* for a deeper content delivery and social interaction, which represents by "Online Resources", "Online Sharing" and "Test and Feedback Strategies" that illustrates as follow:

- *Online Recourses:* additional learning scenarios are available when selecting *additional information* tab, online recourses such: eBooks, stored shared web data. These have benefits to serve the SCL approach, accessible anytime/anywhere and lower cost source of knowledge.
- *Online Sharing:* One of the important academic objectives enhanced by MAR is online sharing of information, allowing for further collaboration and interaction among students and their educators. We are suggesting a web-sharing site (to be accessed via Sub UI) that supports our topic and offline scenarios.
- *Test and Feedback Strategies:* according to ARLE characteristics, the role of feedback strategies has been emphasized. Feedback strategies as mini books (Saidin, et al. 2016), online chartrooms and web platforms enable the educators achieve quantifiable results in order to measure the level of achievement. The study suggested MCQs designed specifically for our topic as addressed in details in (Sharkway, 2018).

3.4. Focus on Implementation

This phase of the process describes the first use of the instruction or materials with learners and educators reflects the continuous modification and updates on the application to make sure of the new tools effectiveness in reaching the learning outcomes and to examine them from both educators' and students' perspectives. Since the analysis phase represents "Goal setting" while Design reflects "Planning", and Development reflects "Production" then the Implementation phase is all about "Procedure". In other words, implementation is the phase where the MAR application is initially tested and redesigned in teaching and learning environments to ensure the course is delivered effectively. The implementation phase represents the examination of the MAR tool from different perspectives that were broken-down to two main points, "MAR in Test Environment" and "MAR in Teaching Environment".

<u>1. MAR in Test Environment:</u> the application is tested among educators to discover the possible errors or bugs in order to ensure that the proposed navigation, interaction and communication tools, fulfill the learning objectives that depend on four factors as illustrated below.

- *The Learning Environment:* the circumstances of the educational environment whereas is (outdoor/indoor) which goes with their context, learning goals and learning content). In our case, we have adopted MAR based indoor use. As conducted by (Redondo, et al. 2012), the indoor use is more widely spread for educational purposes than the outdoor use as it requires specific technologies and essential cameras tracking capabilities
- *Consistency of learning content:* the degree of required details (must consider the device limitations; battery, platforms, capacity, screen size) (Elias, 2011).
- *Idea elaboration:* for non-programmer, it took us approximately seven working days to elaborate the whole idea and two days to create the 3D model.
- *Time schedule:* it is important to plan and keep track of issues such as: feedback tests, Number of lectures and their durations, the pre-test and the post lecture on MAR technology. Moreover, the time taken for building cumulative knowledge should be considered in order to minimize bugs and errors in order to fulfill students' need without distraction them too long or less than they deserve.

<u>2. MAR in Teaching Environment:</u> the application is tested by students to ensure its validation (refers to how well a test measures what it is purported to measure) and reliability (is the degree

to which an assessment tool produces stable and consistent results) test for the MAR application (Colin, et al. 2005). In addition, it is important to check if the students understand the different components of the model to ensure that MAR has provided them with the required knowledge.

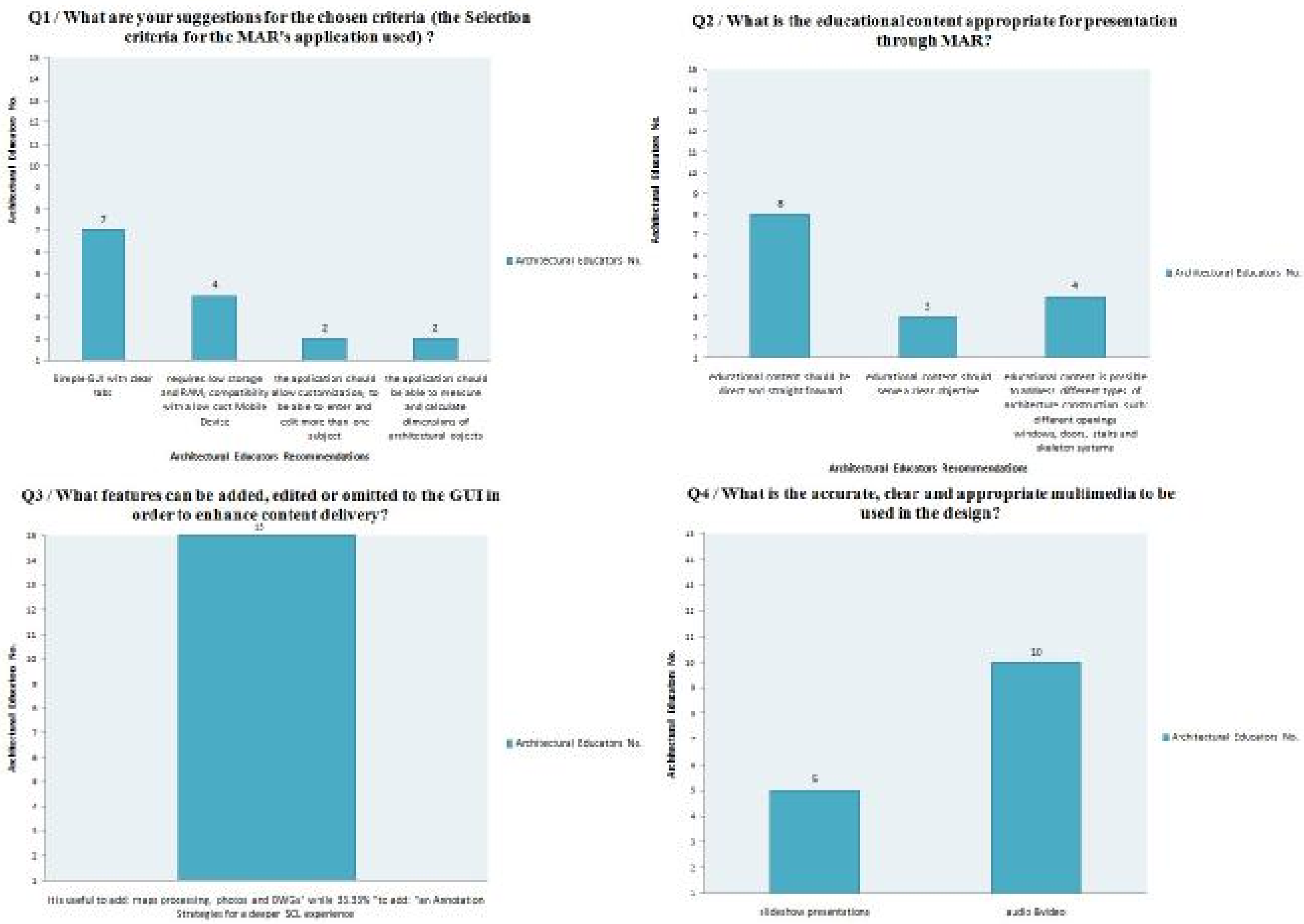
- *The Explanatory Group:* first, the application is tested on the "Explanatory Group" of students who were chosen with the same characteristics of the actual "Test Group" in order to determine the problems and modifications in the same circumstances.
- *The Explanatory Teaching Environment:* begins by selecting the AR media player installed on the students' devices so that they can automatically choose the "woodenparquet.armediafile" as exported from AR media library, which was previously uploaded earlier via email. Once mobile devices' cameras tracked the marker image, the AR experiences will commence. When "Layer Management" is tapped, students will be able to view or hide the model layers one by one or randomly with available description text. Finally, via certain tabs, the whole model can undergo sectioning, zooming or changing its mode from solid to wire frame rendering. At any time, students may explore observation points in the model .In addition; educators may need to return to previous ADDIE phases in sequence to track the tools, system, feedback strategies and other criteria in order to eliminate errors and to ensure that the learning approach is effective.

3.5. Focus on Evaluation

This phase represents the final and actual test results of applying the application. The evaluation process is done via gathering educators and students' feedback. The application is subjected to final testing regarding the what, how, why and when of the things that were accomplished (or not accomplished) of the entire project. The study broken-down this phase into two main tasks "Internal" and "Public "testing

- *The Internal Testing*: represents the "Operating Effectiveness" that occurs inside the system on issues regarding the operation of the application: testing feedback strategies, UI efficiency, and devices 'compatibility.
- *The Public Testing*: comprises the "Formative" and "Summative" tasks (Kurt, 2018): the "Formative" determines the students' learning outcomes while the "Summative" occurs at the end of the program. The evaluation answers whether the students were more motivated to continue using MAR in their learning experience or thought that the MAR approach is effective while learning about "Wooden Parquet Floor" details more than the traditional approach, or if there were more modifications to be made regarding the MAR user interface. Broadly, evaluation is for the application and for students' performance. By one way or another, it assesses whether the main goals have been met to move forward towards a further efficient and successful learning experience.

The Framework Validation: at the end of the study, the researchers held interviews with 15 architectural educators who teach building construction courses. They were chosen with long educational experiences (more than 10 years teaching experience), and are familiar with digital technology in general. By the end of the interviews, *they recommended in order to design a successful mobile AR environment by architectural educators, to follow one of ID models and our augmented ADDIE framework in particular, also to submit it to implementation.* Where, the aim of these interviews was to check the validation of the suggested model and MAR application, through an open questionnaire in different aspects. Educators were asked about their opinion on the MAR application's selection criteria, the appropriate learning content, the proposed UI features, multimedia accuracy, number of objective questions, model's strengths and weaknesses, the MAR's learning environment constraints, and architectural educators' training in order to develop the proposed framework as shown is figure (5).



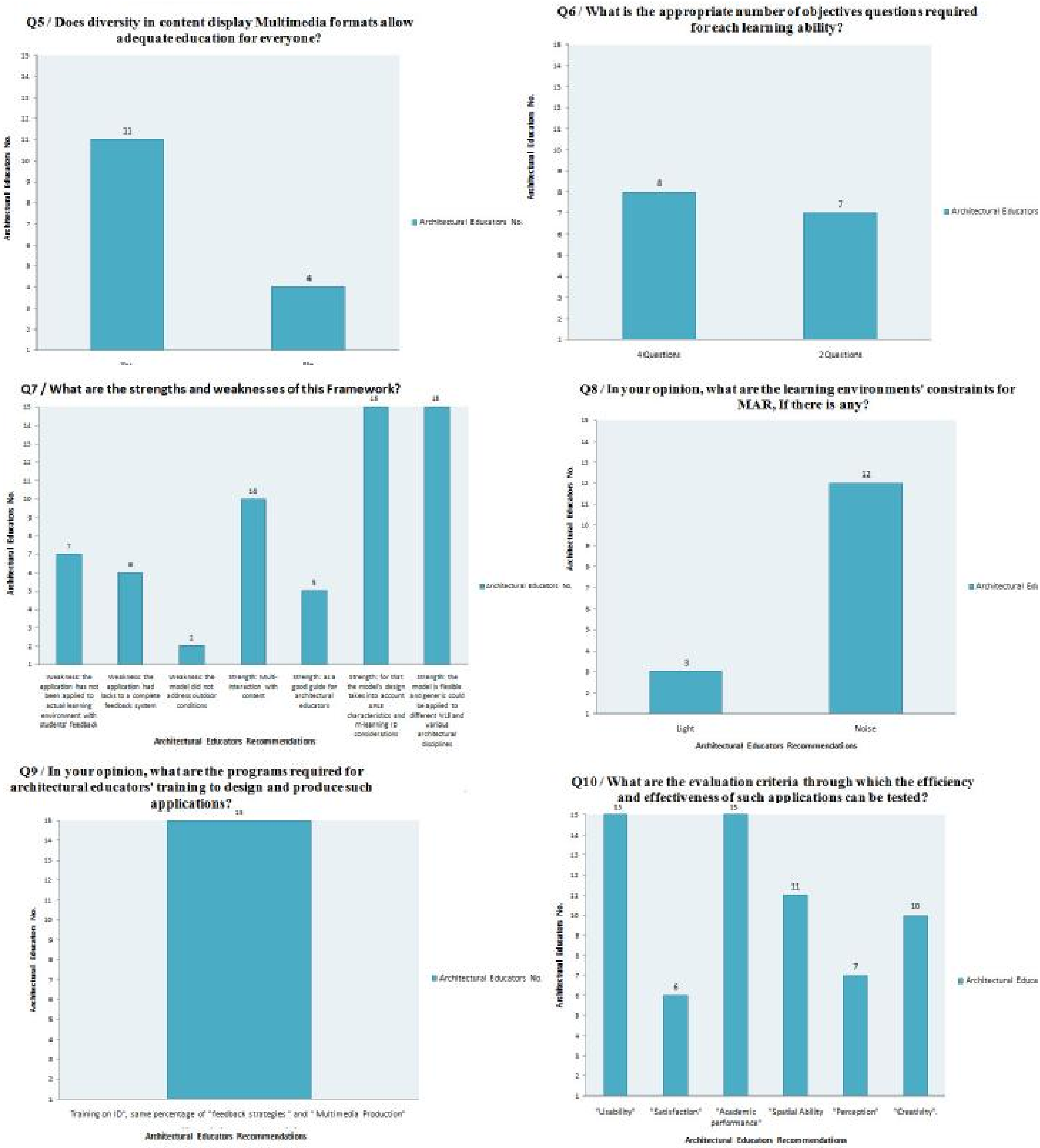


Fig. (5): Architectural Educators Questionnaires and Recommendations

4. Discussion and Conclusions

In this study, the ADDIE model was used as a foundation for a based SCL strategy for learning parquet wooden floor details by AR- Media™ application. This approach enables multiple paths for the students to interact with the educational topic through images, recorded videos, 3D model presentations and text. Functionalities of AR-Media™ have enabled the authors to develop the learning content and to integrate the prepared multimedia elements required to complete the vision, and the additional features that have been added to the mobile learning experience. The study found that it is essential to consider the problem and the requirements of the learning environment prior to the design. The study also found that it is useful during the analysis phase while choosing the AR-media™ tool to study the tools' configurations, description and to learn how to use AR-media™ features through useful tutorials[1].During the implementation, it was found that issues such as the clarity of the printed image could affect the camera tracking feature. Therefore, it is recommended to have a clear printed marker image. As for the software modeling compatibility with MAR application, we have found that Google sketch up 2013, was easier for designing learning content while 3D max design 2014 was more simple in exporting and installing the compatible AR-media™ Plug-in v2.3. Broadly speaking, while developing the MAR educational content, architectural educators should consider assessing the available resources (software, hardware, editing tools, additional equipment) and ensure that the educational content is appropriate for integration into AR context. In addition, it is recommended for architectural educators to evaluate the quality of designed educational content.

This is important for minimizing the probability of students' cognitive overload and misunderstanding. The best way to assess the quality of learning content is to have students use it, then collect their feedback in order to make improvements for MAR application. However, these feedback strategies should not be considered as a substitute to the feedback of the human tutor, nevertheless, they are considered a good and an interesting method to guide the learning process. Moreover, the students might find these strategies helpful, flexible and able to interact with as many times as they want. Educators and instruction designers need to work closely to incorporate better technology for possible transformation from traditional curriculums to MAR's curriculums. They should also pay more attention to consistency in the content creation, organization and interface since mobile screen limits the users' view to only few elements at a time. The multi-layered aspect of MAR's user interface reflects what the student sees and thus, it dictates that it should be more users friendly to navigate for a deeper level of information. *In this research*, we *believe classroom, as a space for learning in the digital era is nothing but a concept. In every space, we move in with the aid of the right tools and methods, learning could become a never-ending journey that could happen independently anywhere and anytime. Taking into consideration the technology presented in this current framework according to mobile learning ID relation with ARLE characteristics in an architectural education context, we have proposed the characteristics for designing an* ***Architectural Mobile Augmented Classroom (AMAC)*** that encompasses the following characteristics:

- ***Constructive Approaches*****:** new innovative technologies such AR and mobile computing provide students with SCL learning opportunities. As it allows them to learn, build knowledge during their learning experiences, provide access to information (through search functions and carefully designed navigation, with opportunities for communication and collaboration with peers).
- ***Experiential Learning****:* MAR learning experiences enhance SCL by adopting notions concerned with "learning by doing" techniques and methods.
- ***Adaptive to Social and personal modes*****:** this technology based human-mobile interaction, support diverse modes of communication and collaboration.

(2) The AR media "Quick Start Guide" at www.armedia.it/showcase.php?sid=3dsmax_tutorials. Accessed at 21/7/2018

- ***Flexibility:*** learning should always take place even if students did not have enough time during their academic schedule. Students have the opportunity to take offline moments or on the fly data and review it anytime / anywhere. Moreover, the flexible nature of AR also appears in the capability to integrate with many technologies such: Intelligent Augmented Reality systems (IARs), AR based BIM (Building Information Modeling), systems and Cloud computing.
- ***Motivation:*** these tools attract the attention of the digital natives to explore and gain knowledge. Hence, one of the main advantages of ARLE is increasing the students' learning motivation.
- ***Edutainment:*** provides potential for memorizing knowledge, as it provides enjoyment while learning through deep inquiry and social engagement with real problem situations.
- ***Immediacy*:** mobile devices may contain supportive tools and capabilities that provide immediate feedback and information delivery.
- ***Accessibility*:** learning environment should be easily accessed and learner's requirements should be fulfilled through; cloud storage, MAR libraries and similar means.
- ***User Friendly GUI:*** offers visual context of environment and other prospects. It appears through a representation that illustrates the key elements of the educational context, which are necessary to create a sense of satisfaction, control and richness.

5. Challenges and Future Directions

- There are several MAR tools for non-programmers' authorization it is necessary for architectural educators to get informed with functionalities of these tools, as well as with the tools that will be used to create or modify the required multimedia elements.

- The applicability of linking AR to various technologies is one of the future directions in architectural education. Because of its special nature, AR is not limited to a specific type of technology as it could be reconsidered from broader views as Building Information Modeling (BIM) and Cloud. Besides, the distinguished advantage of mobility, when linked to cloud, it is possible that architectural classroom may go beyond M-Learning, to Ubiquities learning (U-Learning), "where the data are stored in the cloud and are consulted on any place by all kinds of educational programs and social networks" (Redondo, et.al.2013) .On the other hand, the effectiveness of BIM and AR system integration to enhance task efficiency through improving the information retrieval process enhanced by AR visualization technologies is a valuable combination. Thus, the capabilities of linking Mobile-BIM-AR systems (Chu, et al. 2018) and cloud-based storage could give new horizons of pedagogic potentials for educators and researchers to improve architectural learning not only as visualization but also as information tools.

- Despite potentials of the proposed MAR framework for using digital technology in architectural education, there is still a need to investigate physical, mental and psychological impacts.

- This study has focused on the positive impact of one of the AR techniques, which is MAR techniques on the development of architectural learning space from a pedagogic perspective. On the other hand, it is possible to study the impact of MAR on the design of the physical learning space and their impact on changing architectural classroom design.

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A CONCEPTUAL FRAMEWORK FOR ENRICHING ARCHITECTURAL CLASSROOM WITH MOBILE AUGMENTED REALITY

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ABSTRACT
Due to the emergence of digital technology and its necessity in their lives, students of architecture are facing many challenges in this digital era. Unfortunately, it did not succeed the same way in their education as in architectural practice. By away or another, traditional architectural classrooms still depend on obsolete visualization methods and traditional approaches. On the other hand, many architectural students are complaining of lack of interaction and real engagement with the learning environment. Many studies have revealed that architects are “digital natives "and "visual learners", for that; they are in need of an innovative visualization tool to support their style of learning. This study utilizes Mobile Augmented Reality (MAR), technology as an innovative tool for enriching architectural education. Although, engaging MAR technology in architectural classroom is not a new idea, yet it is still not widely applied due to many different reasons. Educators still insist on using the same traditional methods, they still do not know how MAR should be integrated in their teaching strategies. For this purpose, this study is presenting, a conceptual model for integrating the basic concepts of MAR technology in architectural education based on one of the Instructional Design (ID) models and Student-Centered Learning, (SCL) approach. The mod el works as a key guide for architectural educators to design a successful instructional environment that is planned with ID models. This paper presents the key concepts of the framework and the related learning theories, its potential applications, current challenges and future directions. Experiences and lessons learned and presented in this paper could help architectural educators to plan, design and develop their MAR educational experiences.

Keywords : Architectural Education, Student-Centered Learning (SCL), Visual Learning, Edutainment, Mobile Augmented Reality (MAR), Instructional Design (ID.)

ملخص البحث
يواجه معماريو المستقبل العديد من التحديات في عصر التكنولوجيا ؛ وأهمها تدخل التكنولوجيا الرقمية والمنافع العديدة التي تقدمها لهم في حياتهم العلمية والعملية.الا انها لم تحرز نجاحا في مجال التعليم المعماري كما أحرزته في الممارسة المهنية حيث انه لاتزال الفصول المعمارية في الوقت الحالي تتبنى أساليب التعليم التقليدية .ومن ناحية أخرى ؛ يشكو العديد من طلاب العمارة من قصور التفاعل والمشاركة الحقيقية مع بيئة التعلم الحقيقية .فلقد أثبتت الدراسات أن المعماري هو مفكر مرئي يحتاج الى أدوات تعزز أسلوب التعلم التصوري وتقترن باساليب التعلم الذاتي و نتيجة لذلك؛ اقترحت هذه الدراسة أداة تعليمية مبتكرة وهي تكنولوجيا الواقع المعزز النقال . حيث تعمل على نقل مسار العملية التعليمية من المعلم الى الطالب بالتكامل و الدمج لعدة مفاهيم تربوية حديثة أهمها التعلم الذاتي والتعلم النقال بهدف زيادة دافعية التعلم والادراك. وعلى الرغم من الأثر الايجابي لتقنيات الواقع المعزز على طلاب العمارة وانجذابهم لها كاداة مبتكرة لتعزيز التعلم المرئي ,الا أن عدم انتشار أساليب

واستراتيجيات تعليمية واضحة لدمجها في سياق التعليم المعماري وتجنب المعلمين والمؤسسة التعليمية لهذه التقنيات؛ أدى الى تقليص فرص استخدامها في الفصل المعماري. وحتى مع تقبل هذه الفكرة، فانه لا توجد خبرات كافية للتعامل تقنيا وتربويا مع هذه الادوات.لهذا هدفت الدراسة الى تقديم تصورمقترح يعمل كدليل ومرشد رئيسي للمعلم والمصمم التعليمي في تصميم بيئة تعليمية ناجحة للتعليم المعماري تقوم على أساس استراتجية التعلم الذاتي ومدعمة باحد تطبيقات الواقع المعزز النقال والمتوفرة في التطبيقات المتاحة حاليا في الهواتف الذكية.وقد بني هذا التصور على أساس أحد نماذج التصميم التعليمي بهدف ان يمثل اطار نظري ليدعم كلا من احتياجات طالب العمارة المعاصر و امكانيات تكنولوجيا الواقع المعزز النقال .

1. Utilizing Mobile Augmented Reality in Architectural Education

Some researchers consider future architects as "digital natives" and "visual learners", (Shirazi, et al. 2014). They need a powerful digital visualization tool to develop their architectural learning process to go beyond the traditional Teacher-Centered Learning (TCL) and the conventional learning tools. Nowadays, free digital applications, web and mobile computing technologies combined with "Mobile Learning", (M-learning) concept has widely spread. Broadly speaking, M-learning is the next innovative level of E-learning (Anshari, et al. 2017). According to (Parhizkar, et al. 2012), it is the delivery of learning content to learners utilizing mobile computing devices.

This study assume that with the success obtained in various educational areas as military, art, urban planning and different architectural fields in using mobile augmented reality as an educational tool for teaching architecture based a " Student Centered" teaching approach. Research reveals that MAR has a positive potential for architectural students in experiences with regard to different evaluation criteria such as (increasing motivation, social skills, feasibility and overall improvement their academic performance), (Redondo, et al. 2013), (Abdullah, et al. 2017), (Kassim, et al. 2016) and (Domínguez, et al. 2014).

Recently AR techniques begin to be applied in our Egyptian universities, in a study by experiment, in Shebin El-kom University three different architectural case studies was performed for examining MAR's approach on architectural students regarding different case studies in different architectural disciplines such: the building construction, architectural design and landscape design courses .The study showed that students was satisfied regarding using MAR techniques, they had a positive impact on their academic performance based a self learning experience, their learning motivation, spatial skills and perception was improved. (El-Sayed, M., 2016). In Addition, in a study by (El-Sayed, N., 2011) performed in Banha University, MAR had a great acceptance among students, they were satisfied by the efficiency of this tool for learning history, art, science and biology.

Multiple innovative learning opportunities may be generated in the field of architectural education due to the integration of mobile devices with AR as MAR can potentially be used in photographing buildings, construction elements, serve as a means for sharing interests with friends and promoting direct interaction among students anywhere and anytime (Wolpers, et al. 2011). Although, earlier researches have proven the benefits of MAR in education and architectural education fields, they are still not implemented on a large scale due to the educators' limited programming skills that are essential for 3D modeling and multimedia development (Abdullah, et al. 2017). In addition, when educators accepted the idea of integrating these technologies in their teaching strategies, "they really do not know how it should be embedded" (Redondo, et al. 2012). *Consequently, this study is not aiming to prove the effect of MAR on architectural students; rather the study is emphasizing the lack of clear instruction strategies regarding this tool in architectural education from the educator's perspective*. *For that purpose, a conceptual model is presented to answer the main question posed by the architectural educators: What steps should I follow while designing a MAR learning experience?*

1.1. Architectural Education towards a Shift in Pedagogy Directions

MAR techniques have an innovative impact upon student learning and potential in transforming learning environments from a physical to virtual environment. These techniques allow for the SCL experience with regard to all students at their own personal mobile devices.

Each student has his own rhythm of thinking so he should have his own learning environment. Hence, this study proposes a pedagogical vision shift via MAR capabilities. There are three shifting axis connect to "Constructivism", "Mobility" and "Virtual Learning Environment" concepts as illustrated in Figure. (1)

From TCL to SCL: MAR will allow for more potential for "*Student-Centered Learning" SCL* or "*Constructivism*" concept in a broader way. Students construct their knowledge through direct interaction with the 3D learning content and supportive online information, by building on MAR's ability of linking with GPS and internet. This new approach is giving an opportunity for transferring from the "*Teacher-Centered Learning"* (TCL) strategies, which provide a verbal knowledge, to a facilitator through mobile platforms' capabilities, such: messaging, annotations, online sharing, cloud storage and various supportive multimedia and feedback strategies

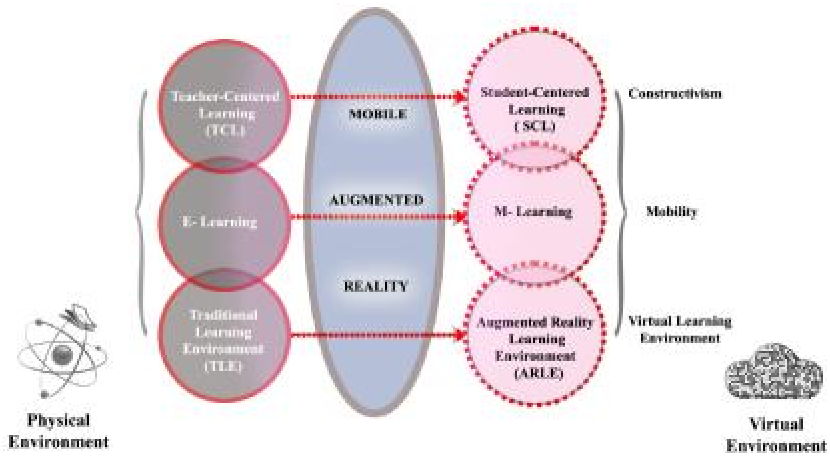

Fig.(1) : The Pedagogic Three Shifting Axis Enhanced by Mobile Augmented Reality (as interpreted by the authors)

From E-Learning to M-Learning: with M-learning, the MAR's environments can facilitate the learning process. According to, (Stanton, et al. 2013) mobile learning is different from face to face and "*E-learning"* with the "*Mobility*" concept. Being able to move around is a unique feature that differentiates mobile learning from other learning environments; it is seen as freeing the learner from the classroom disk, As students are given the opportunity to explore projects, buildings and masses physically on site through the use of handheld devices with user friendly Graphical User Interfaces (GUI). Thus, shifting from Human-Computer-Interaction (HCI), to Human-Mobile-Interaction (HMI), allowing for further pedagogic flexibility (Redondo, et al. 2013).

From TLE to ARLE: with MAR integration, architectural educators can develop their new pedagogic approaches enhanced by MAR applications via innovative Augmented Reality Learning Environments ARLE characteristics' potentials among students. Broadly, according to (Cubillo, et al. 2015), ARLE as a part of " Virtual Environments" gives a room for educators to test with low cost their teaching materials and without real consequences which is a privilege when compared with traditional learning environments or the "Physical Environment" in a broad way.

2. Paper's Intent and Methodology

This study aims at testing a theoretical model for integrating MAR application in architectural education adapting a SCL approach since both ARLE and M-learning are considered constructive environments, (Berking, et al. 2012). This framework is meant to inject concepts, considerations, and specific guidelines to M-learning, and AR into appropriate points based on one of the generic ID models, the ADDIE model. While ADDIE is an acronym, referring to the five major phases of the generic Instructional System Design (ISD): **A**nalysis, **D**esign, **D**evelopment, **I**mplementation and **E**valuation phases (Schlegel, et al. 1995,p.10).

The paper adopts the ADDIE model adding to it an additional layer of M-learning ID considerations with respect to ARLE characteristics that was conducted by (Cubillo, et al. 2015), such as: ensuring immersion, enabling exploration, incorporating description of virtual resources and designing non-linear content for improving motivation. We have integrated our idea with collected ID mobile learning considerations from the literature and mostly adopted from "Mobile Learning Handbook" 1 to inject these considerations into each of the ADDIE phases. Regarding the final stage of ADDIE; the "Evaluation" phase, it is generally interpreted. However, not assessed since the application was not tested in a real environment with students. A validation assessment has been conducted by gathering some architectural educators on an open questionnaire. In the conclusion, they presented ideas for developing and improving our framework. Moreover, lessons learned are presented and guidelines are given in order to help educators plan, design and develop their learning contents with existing free MAR applications while saving time in the overall development process. The study ends with a vision for generic design characteristics to implement an "Architectural Mobile Augmented Classroom" (AMAC) that was coined by the authors.

3. Augmenting the ADDIE Model with MAR in Architectural Education Context: "Parquet Wooden Floor" Building Construction Details, Case Study

This section of the study proposes a theoretical framework by implementing the ADDIE instruction design (ID) model on MAR application (AR-media™). A Sub User Interface (UI) was adapted from (AR-Media™ plug-in) on desktop was designed for juniors' level one to facilitate the SCL teaching approach of one of the basics building construction courses for "Parquet Wooden Floor" architectural details. In addition, we have added some developed features for AR-media™ application, in order to enhance our SCL approach to provide a deeper understanding of the architectural content. For the aim of this study, the ADDIE model is utilized as a guide and a "Basic model" to combine the ARLE and the instructional design for m-learning considerations within the architectural education context. According to (Saidin, et al. 2016), ADDIE is widely used in system development for teaching methods, particularly in E-learning systems, educational games and M-learning. The study is not trying to create a new ID model rather it has suggested an augmentation for ADDIE with an additional layer by ID for m-learning considerations in each phase. The following are examples of a few questions that are

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(1) https://sites.google.com/a1/adlnet.gov/mobile-learning-guide/best-practices . Accessed in 12/7/2017

addressed during each phase, and adopted from Mobile Learning Handbook to incorporate in

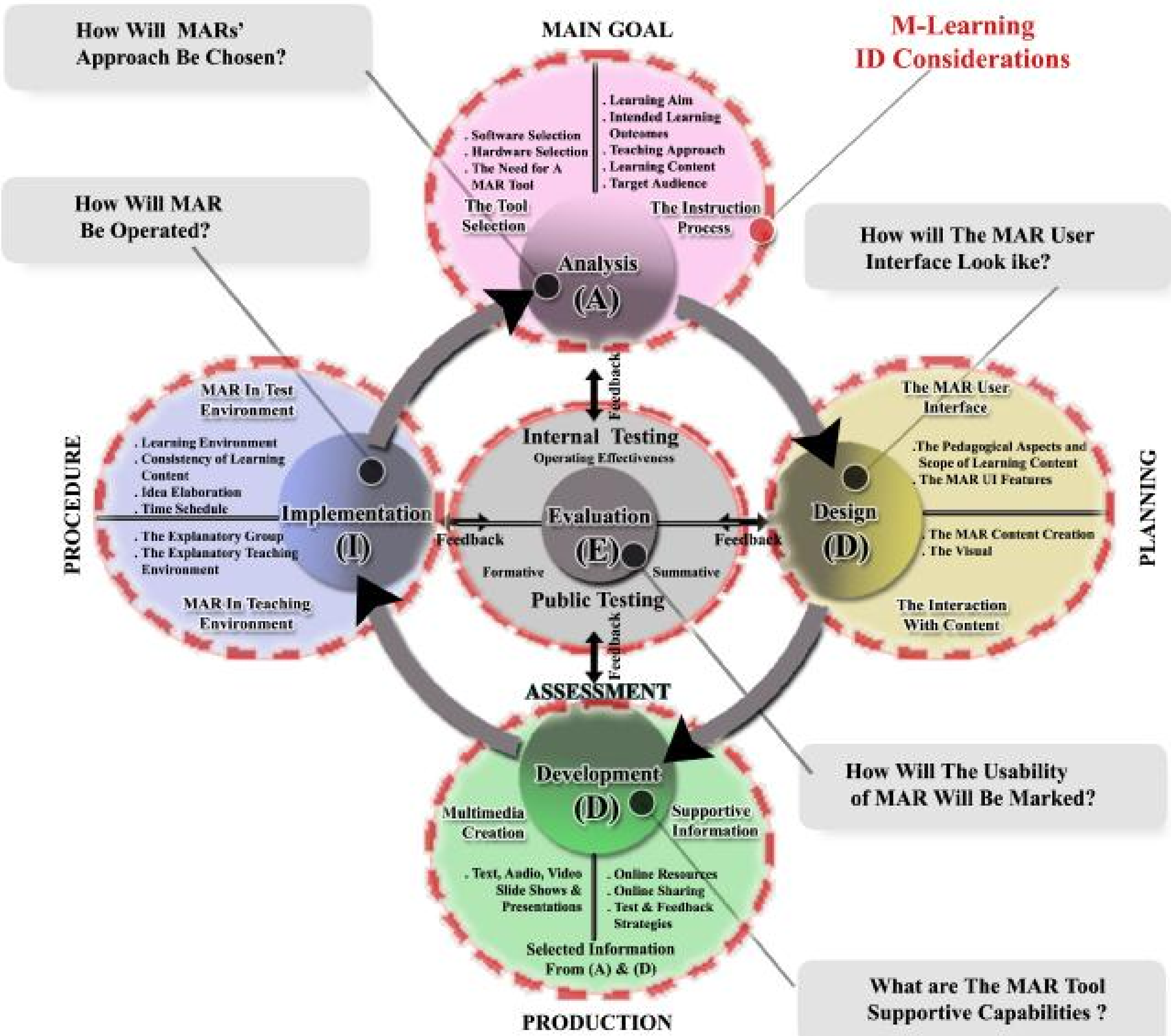


Fig. (2): Augmenting the Main ADDIE Phases After (Gustafson, et.al. 2002) With Instructional Design for M-Learning Considerations

every step of ADDIE, as illustrated in Figure.(2)

3.1. Focus on Analysis

The analysis phase is mainly about "Goal setting stage" (Kurt, 2018), that planning for gathering information and decisions about instructional strategies (Norashikin, 2007). The focus of the architectural educator is on learning goals and objectives, characteristics of target audience and the circumstances of the instruction process. For this purpose, the study has broken-down the analysis phase into two main tasks, "The Tool Selection" and "The Instruction Process ":

1. The Tool Selection: the analysis phase starts with selection of MAR tool that would allow the educator to create the AR educational content. For that, the choice of the tool depends on three factors:

- *Software selection*: an evaluation survey was conducted for three known successful MAR applications in architectural education been used, were evaluated and studied for developing the proposed building construction content, which they are "AR-media™ ", "Aurasma" and "Augment". AR-media™ was chosen based on the selection criteria proposed by (Yilmaz, et al. 2015), such: usability, system features, cost and multimedia creation. In addition, according to a study conducted by (Broschart, et al. 2013), interaction with AR-media™ application is easy and do not require prior knowledge to complete the learning experience to use it only simple gestures and finger touches to complete a learning experience. The software used for modeling was 3Ds Max 2014 and AR-media™ V2.3 plug-in and AR Media Player from Google Play on mobile device.

- *Hardware selection*: it is important for the educator consider the mobile platform capabilities while creating and supporting the learning experience such camera, document viewer, touch screen interaction, cloud storage and other important capabilities, that been addressed in "Advanced Distributed Learning" (ADL) by (Pimmer, et al. 2014). Our device of choice was Samsung Galaxy S6 Edge cell phone as shown in figure 3 , equipped with 16MP camera and Android 5.0.2 Lollipop software. This device is suitable to use with applications on multiple platforms such PC, MAC, Android and IOS as it can accept exported models from renowned architectural modeling software such as 3D Max, Maya and Google Sketch up.

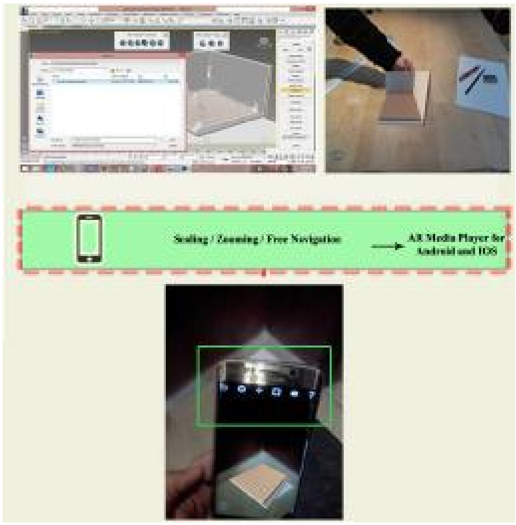


Fig. (3): Displaying the Model on Galaxy S6 Edge Android Platform After Exported From 3D Max

- *The need for a MAR Tool:* which represents the instructional problem. On other words, the need for MAR, which concerns issues, related to the difficulties of Building construction learning in a broad way. It is a subject, which students often complain about missing contact with reality, which lowers their motivation and academic performance (Shirazi, et al. 2015). Beside it is a subject that needs site visits and practical learning side. According to the case of study, the type of "interior flooring "(Parquet Wooden Floor) course, has caused some confusion to students who were trying to imagine the relation between the parquet floor and the subfloor layers. It is a hard task for traditional approaches to illustrate these relations through white board and 2D sketches.

2. The Instruction Process: after the tool has been selected, an instruction process analysis is established to identify all pedagogic approaches and learning environment needs, the instructional goals, objectives, the learning environment, learner's existing knowledge and skills. The instruction process analysis depends on five factors:

- *Learning aim:* the main objective is to increase the students' motivation and enhance their levels of thinking. There are six levels by Bloom's in (Stanton, et al. 2013); knowledge, comprehension, application, analysis, synthesis and evaluation, in order to provide an important framework for educators to use to focus on higher order thinking in a broad way. The main aim here is to learn the basic "Parquet Wooden Floor "contents, basic scales and integration of different materials in a self-edutainment (Education+ Entrainment) experience. For that purpose, we have pointed out a set of objectives regarding our topic as represented in three main points:

    - ü To introduce the "Parquet Wooden Floor".
    - ü To analyze the basic "Parquet Wooden Parquet Floor "components.
    - ü To explore the main execution stages of" Parquet Wooden Floor".

- *Intended learning outcomes:* by allowing students to explore various interactions with the 3D model of Parquet wooden floor through different scenarios, at the end of this experience, the student is supposed to be able to define the wooden parquet execution stages, its standard dimensions and the wooden details of each layer. In addition, to explore construction details, such as: steel spring clips, spacing distribution regarding different wall directions, wooden blanks, Arashalli, timber and parquet board connection, parquet grove connection and parquet board connection. Moreover, to identify the execution stages of the concrete slab, wooden panels, (sub floor) perpendicular wooden panels on the wooden frame, ventilation void, sand immersion, wooden parquet floor and baseboard molding.

- *Educational approach:* a SCL approach was assumed as a foundation and pedagogic approach. Students gain knowledge through direct interaction with the 3D learning content and supportive online information and able to share their experiences online with their colleagues and receive their educators' feedback for guidance upon their request.

- *Learning content:* broadly, it is important for educators to study the nature of learning content and to study the diversity of introducing this content. The learning content represented as an online resource and a 3D model, that considers the learning objectives and AR-media features. In order to, facilitate the educational approach by showing the 3D "Wooden Parquet Floor" as built of three basic layers; layer one: Concrete Slab, layer two: wooden panels, Perpendicular Wooden Panels, Wooden Frame+ Sand Immersion (Sub Floor), layer three: the final finish of Parquet and Wooden Shoe mold.

- *Target audience:* according to (Pantelić, et.al. 2017) characteristic of target audience should be analyzed when designing a MAR experience. For our case the learning content was designed to suite the characteristics of first year architecture junior student's academic level, in other words, to consider their level of skills, prior knowledge, their digital profiles, their goals and motivations to engage with instruction process and their style of learning.

3.2. Focus on Design

The Design phase is about "Planning". In this phase, the study determines all learning goals and identifies the learning tools used to gauge performance, feedback, tests, subject matter analysis, planning of resources (Kurt, 2018). However, according to studies conducted by (Saidin, et.al. 2016) and (Pantelić, et.al. 2017) some specific considerations should be taken into account regarding designing for MAR applications such the User Interface (UI) design, and the visual when pointing on the marker. In addition, the limitations and capabilities of the technologies involved to serve the pedagogic approach and the use of supportive tools to serve the scope of learning content. For that purpose, the design phase was broke-down into two main tasks, "The MAR User Interface" and "The Interaction with Content" as follows.

<u>1. The MAR User Interface :</u> the UI is about how and what are the enhancement tools for enabling the interaction with the learning content, it represent it two factors the pedagogical aspects scope of learning content and the developed MAR user interface features, as illustrated below.

- *The Pedagogical Aspects and Scope of Learning Content*: the considered UI design guides the students to gain further knowledge with clear, simple and non-linear content presentation for enriching their self-learning experience and increasing their motivation through different media .Students with AR Media UI features are free to begin their learning process anytime with any step they prefer. In addition, they may have the opportunity to complete their learning task on the fly as AR media storage enables downloading full 3D content. The AR Media UI has served the designed educational content to reproduce multiple learning scenarios such as (descriptive text, online information, specific level of details required, audio and 3D animation).

- *The MAR UI Features:* while designing for MAR, it is important to consider some technical aspects for the UI. The screen size and RAM capacity of the mobile device (Elias, 2011). UI features should be simple and concise. Hence, the study has divided the UI into "AR media original Tools" by "Inglobetechnologies", and "AR Media Player Sub UI". The Main page displays an upper tool bar of the “Parquet Wooden Floor”; The Original UI" with six main features. Moreover, a lower slider bar for the Sub UI comprised of ten proposed features. Seven of them are involved for interaction with the 3D model while, three of them represents an Additional Information options for producing a further support to the SCL approach as shown in Figure(4).

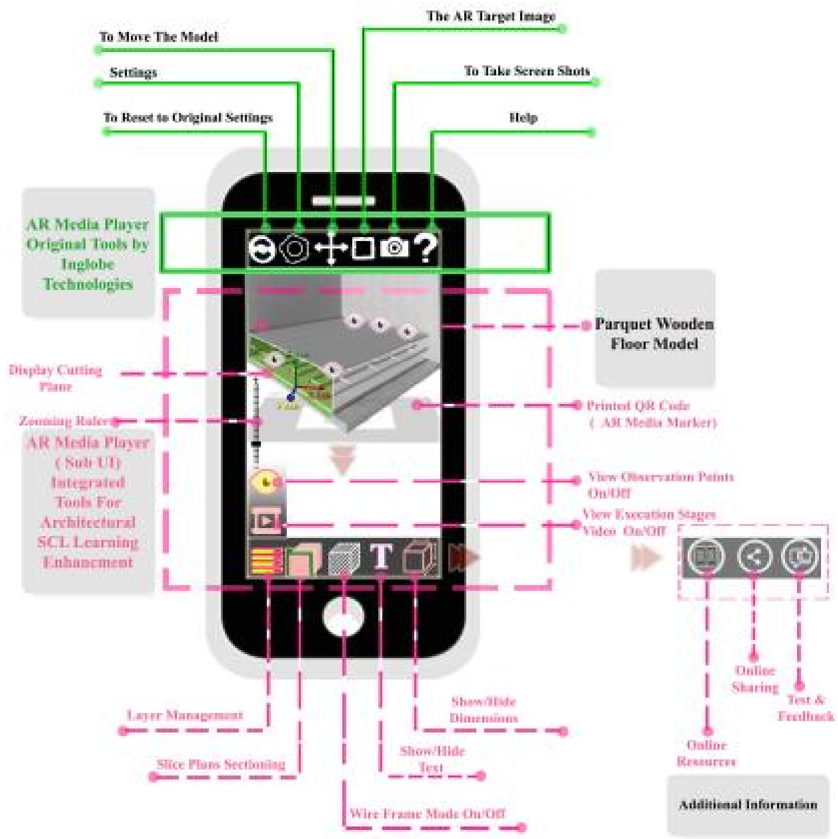


Fig. (4) Integrated SUB UI Based SCL Approach for Learning "Parquet Wooden Floor" Details on Android Mobile by AR-media™ Application (as interpreted by the authors)

<u>2. The Interaction with Content:</u> the interaction with content design comprised of two main factors the " The MAR Content Creation" and "The Visual". MAR's content creation has sketched in four main steps, which describes the link between the modeling programs and the MAR's application. After the content being created, it is important to design the visual when student points on the marker, as follows.

- *The MAR Content Creation:* is represents by four main sequential and procedural steps. Begins with step1 (Modeling +Setup on the Selected Mobile Device), the process of designing the "Parquet Wooden Flooring" model on an hp laptop by Autodesk 3D Max modeling program. Then, "AR-media™ plug-in" is installed on 3DMax to create "woodenfloor.armediafile" .The next is step2 (Printing the Marker + Exporting for the Mobile Device), where the AR player is installed on the mobile device, the marker image is printed from the Inglobetechnologies website, then "woodenfloor.armediafile" is exported to the mobile device. In addition, step3 (Marker Recognition + Generating the Model as a Learning Content), which appears in tracking the marker QR Code and the loading the model. An additional feature is available that allows uploading other files on AR Media web library for multiple markers experience which, requires a licensed version of AR Media. Finally, step4 (MAR Learning Experience at the Architectural Classroom) which clarify the student's navigating the model with mobile through body movements, start interacting with AR Media and ends with possibility to add another marker (which refers to another flooring model) by returning back to step2 and generating another ".armediafile".

- *The Visual:* is what the user will see, hear and experience when pointing on the marker. Various learning scenarios enhanced by the AR media UI such as: recorded video of the execution stages of wooden floor, free navigation, zoom in/out, scaling, moving, layer management, specific observation points beforehand created by the instructor, sectioning, wireframe views and additional information.

3.3. Focus on Development

Broadly speaking, if previous "Analysis" and "Design" phases are about "Goals and Planning" respectively, then the development stage is about "production", "that collects all these aspects and puts them into action (Kurt, 2018). In other words, the developing stage of MAR will be based on selected information as represented in the previous phases of analysis and design. According to a mobile learning ID study conducted by (Berking, et.al. 2012), this phase addresses how the application will look like and what are its (web or native application) capabilities. For that purpose, this phase was broken-down into two main sections, "Multimedia Creation" and "Supportive Information".

1. Multimedia Creation: while scanning the marker image using AR-Media application installed on mobile device, it is important to consider the multimedia creation in this phase. The study poses one of the different scenarios of how could the MAR application enhance the visualizing of "Parquet Wooden Floor "based on SCL approach by integrating multimedia as illustrated below.

- *Text, Audio, Video and Slideshows Presentations:* through the integration of different Multimedia is presented by the educator in *360^{o}Video / Audio* model navigation that enables view of the wooden floor model execution phases. The learning process is enhanced with helpful text for layers descriptions and standard dimensions represents by *text and dimension tabs*. Students are free to begin their learning experiences and navigate the layers of their choice. The *layer management* feature (isolates and builds each layer respectively also is available. There are other additional developed features such as; *observation points,* that are previously designed by the teacher in order to be able to focus on a certain details of the educational topic. Students are free to focus on these points and visualize them moving from one point to another via different perspectives. The *wireframe rendering is also available* with retention to allow for zooming. Moreover, the students may *take cross sections* of the whole model (x, y & z) axis, which is accessible by *slice plans sectioning* tab.

2. Supportive Information: students may also tab for *additional information* for a deeper content delivery and social interaction, which represents by "Online Resources", "Online Sharing" and "Test and Feedback Strategies" that illustrates as follow:

- *Online Recourses:* additional learning scenarios are available when selecting *additional information* tab, online recourses such: eBooks, stored shared web data. These have benefits to serve the SCL approach, accessible anytime/anywhere and lower cost source of knowledge.
- *Online Sharing:* One of the important academic objectives enhanced by MAR is online sharing of information, allowing for further collaboration and interaction among students and their educators. We are suggesting a web-sharing site (to be accessed via Sub UI) that supports our topic and offline scenarios.
- *Test and Feedback Strategies:* according to ARLE characteristics, the role of feedback strategies has been emphasized. Feedback strategies as mini books (Saidin, et al. 2016), online chartrooms and web platforms enable the educators achieve quantifiable results in order to measure the level of achievement. The study suggested MCQs designed specifically for our topic as addressed in details in (Sharkway, 2018).

3.4. Focus on Implementation

This phase of the process describes the first use of the instruction or materials with learners and educators reflects the continuous modification and updates on the application to make sure of the new tools effectiveness in reaching the learning outcomes and to examine them from both educators' and students' perspectives. Since the analysis phase represents "Goal setting" while Design reflects "Planning", and Development reflects "Production" then the Implementation phase is all about "Procedure". In other words, implementation is the phase where the MAR application is initially tested and redesigned in teaching and learning environments to ensure the course is delivered effectively. The implementation phase represents the examination of the MAR tool from different perspectives that were broken-down to two main points, "MAR in Test Environment" and "MAR in Teaching Environment".

<u>1. MAR in Test Environment:</u> the application is tested among educators to discover the possible errors or bugs in order to ensure that the proposed navigation, interaction and communication tools, fulfill the learning objectives that depend on four factors as illustrated below.

- *The Learning Environment:* the circumstances of the educational environment whereas is (outdoor/indoor) which goes with their context, learning goals and learning content). In our case, we have adopted MAR based indoor use. As conducted by (Redondo, et al. 2012), the indoor use is more widely spread for educational purposes than the outdoor use as it requires specific technologies and essential cameras tracking capabilities
- *Consistency of learning content:* the degree of required details (must consider the device limitations; battery, platforms, capacity, screen size) (Elias, 2011).
- *Idea elaboration:* for non-programmer, it took us approximately seven working days to elaborate the whole idea and two days to create the 3D model.
- *Time schedule:* it is important to plan and keep track of issues such as: feedback tests, Number of lectures and their durations, the pre-test and the post lecture on MAR technology. Moreover, the time taken for building cumulative knowledge should be considered in order to minimize bugs and errors in order to fulfill students' need without distraction them too long or less than they deserve.

<u>2. MAR in Teaching Environment:</u> the application is tested by students to ensure its validation (refers to how well a test measures what it is purported to measure) and reliability (is the degree

to which an assessment tool produces stable and consistent results) test for the MAR application (Colin, et al. 2005). In addition, it is important to check if the students understand the different components of the model to ensure that MAR has provided them with the required knowledge.

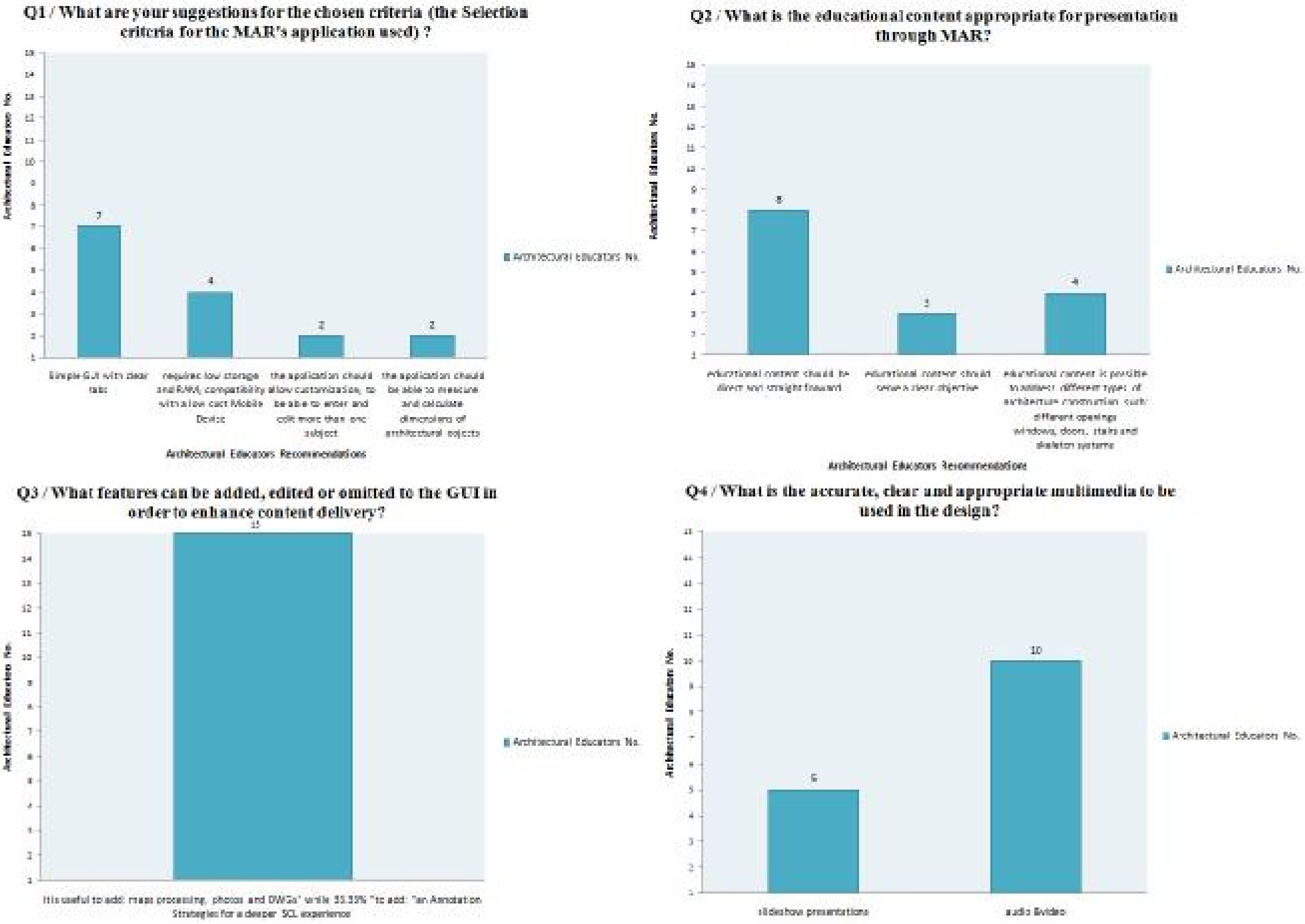
- *The Explanatory Group:* first, the application is tested on the "Explanatory Group" of students who were chosen with the same characteristics of the actual "Test Group" in order to determine the problems and modifications in the same circumstances.
- *The Explanatory Teaching Environment:* begins by selecting the AR media player installed on the students' devices so that they can automatically choose the "woodenparquet.armediafile" as exported from AR media library, which was previously uploaded earlier via email. Once mobile devices' cameras tracked the marker image, the AR experiences will commence. When "Layer Management" is tapped, students will be able to view or hide the model layers one by one or randomly with available description text. Finally, via certain tabs, the whole model can undergo sectioning, zooming or changing its mode from solid to wire frame rendering. At any time, students may explore observation points in the model .In addition; educators may need to return to previous ADDIE phases in sequence to track the tools, system, feedback strategies and other criteria in order to eliminate errors and to ensure that the learning approach is effective.

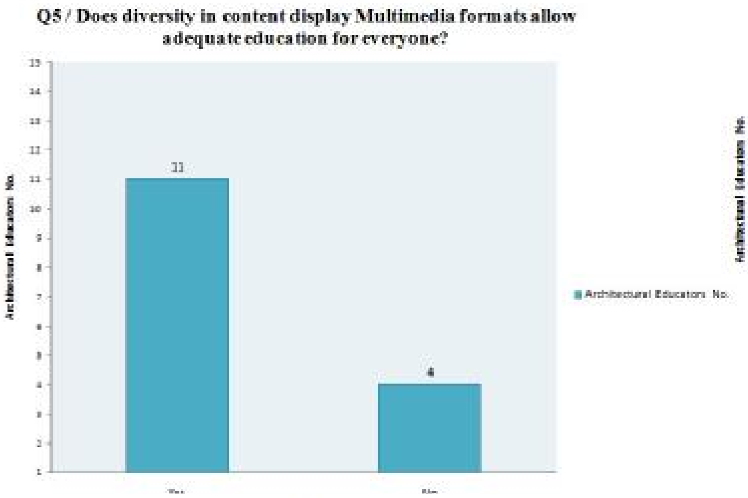
3.5. Focus on Evaluation

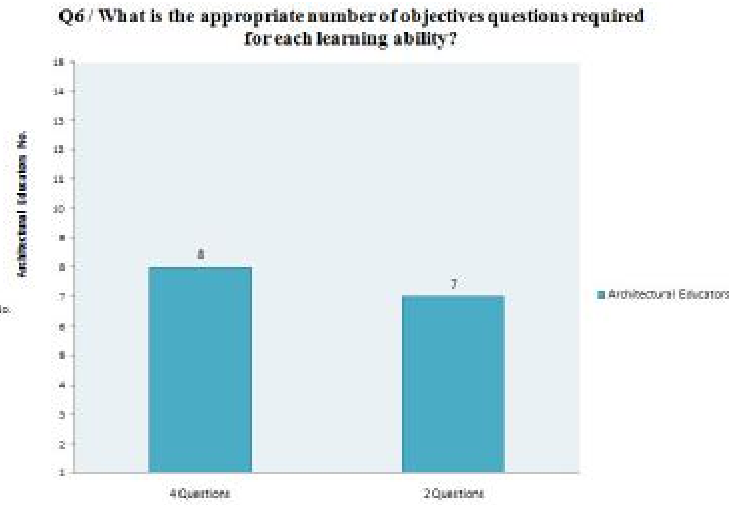
This phase represents the final and actual test results of applying the application. The evaluation process is done via gathering educators and students' feedback. The application is subjected to final testing regarding the what, how, why and when of the things that were accomplished (or not accomplished) of the entire project. The study broken-down this phase into two main tasks "Internal" and "Public "testing

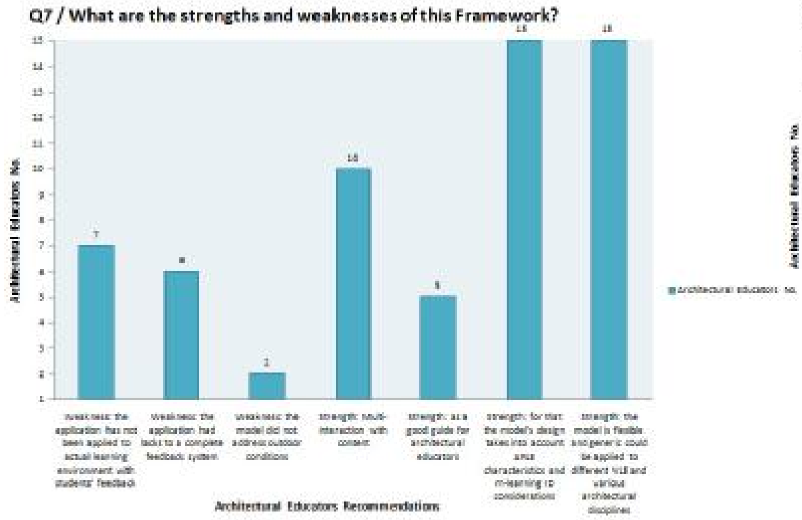
- *The Internal Testing*: represents the "Operating Effectiveness" that occurs inside the system on issues regarding the operation of the application: testing feedback strategies, UI efficiency, and devices 'compatibility.
- *The Public Testing*: comprises the "Formative" and "Summative" tasks (Kurt, 2018): the "Formative" determines the students' learning outcomes while the "Summative" occurs at the end of the program. The evaluation answers whether the students were more motivated to continue using MAR in their learning experience or thought that the MAR approach is effective while learning about "Wooden Parquet Floor" details more than the traditional approach, or if there were more modifications to be made regarding the MAR user interface. Broadly, evaluation is for the application and for students' performance. By one way or another, it assesses whether the main goals have been met to move forward towards a further efficient and successful learning experience.

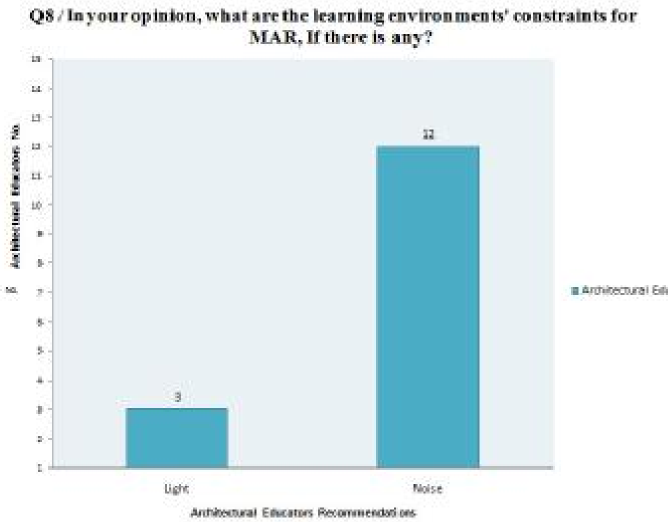
The Framework Validation: at the end of the study, the researchers held interviews with 15 architectural educators who teach building construction courses. They were chosen with long educational experiences (more than 10 years teaching experience), and are familiar with digital technology in general. By the end of the interviews, *they recommended in order to design a successful mobile AR environment by architectural educators, to follow one of ID models and our augmented ADDIE framework in particular, also to submit it to implementation.* Where, the aim of these interviews was to check the validation of the suggested model and MAR application, through an open questionnaire in different aspects. Educators were asked about their opinion on the MAR application's selection criteria, the appropriate learning content, the proposed UI features, multimedia accuracy, number of objective questions, model's strengths and weaknesses, the MAR's learning environment constraints, and architectural educators' training in order to develop the proposed framework as shown is figure (5).

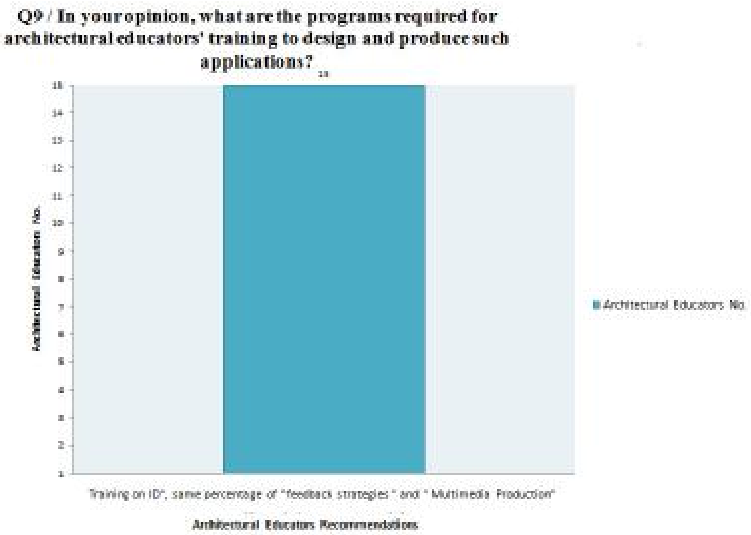












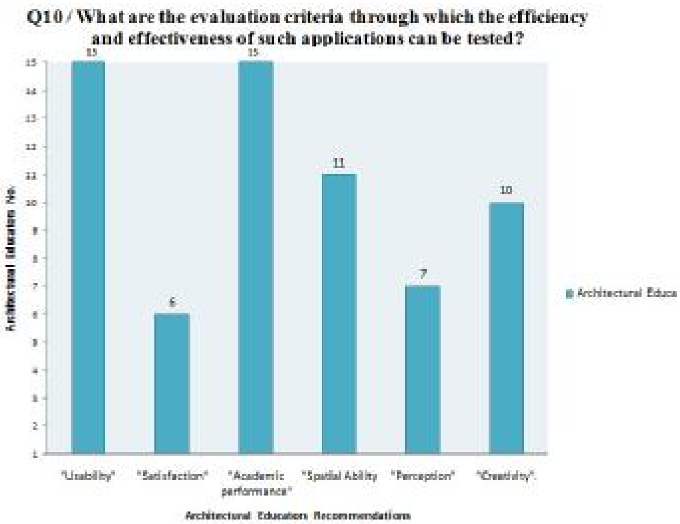


Fig. (5): Architectural Educators Questionnaires and Recommendations

4. Discussion and Conclusions

In this study, the ADDIE model was used as a foundation for a based SCL strategy for learning parquet wooden floor details by AR- Media™ application. This approach enables multiple paths for the students to interact with the educational topic through images, recorded videos, 3D model presentations and text. Functionalities of AR-Media™ have enabled the authors to develop the learning content and to integrate the prepared multimedia elements required to complete the vision, and the additional features that have been added to the mobile learning experience. The study found that it is essential to consider the problem and the requirements of the learning environment prior to the design. The study also found that it is useful during the analysis phase while choosing the AR-media™ tool to study the tools' configurations, description and to learn how to use AR-media™ features through useful tutorials[1].During the implementation, it was found that issues such as the clarity of the printed image could affect the camera tracking feature. Therefore, it is recommended to have a clear printed marker image. As for the software modeling compatibility with MAR application, we have found that Google sketch up 2013, was easier for designing learning content while 3D max design 2014 was more simple in exporting and installing the compatible AR-media™ Plug-in v2.3. Broadly speaking, while developing the MAR educational content, architectural educators should consider assessing the available resources (software, hardware, editing tools, additional equipment) and ensure that the educational content is appropriate for integration into AR context. In addition, it is recommended for architectural educators to evaluate the quality of designed educational content.

This is important for minimizing the probability of students' cognitive overload and misunderstanding. The best way to assess the quality of learning content is to have students use it, then collect their feedback in order to make improvements for MAR application. However, these feedback strategies should not be considered as a substitute to the feedback of the human tutor, nevertheless, they are considered a good and an interesting method to guide the learning process. Moreover, the students might find these strategies helpful, flexible and able to interact with as many times as they want. Educators and instruction designers need to work closely to incorporate better technology for possible transformation from traditional curriculums to MAR's curriculums. They should also pay more attention to consistency in the content creation, organization and interface since mobile screen limits the users' view to only few elements at a time. The multi-layered aspect of MAR's user interface reflects what the student sees and thus, it dictates that it should be more users friendly to navigate for a deeper level of information. *In this research*, we *believe classroom, as a space for learning in the digital era is nothing but a concept. In every space, we move in with the aid of the right tools and methods, learning could become a never-ending journey that could happen independently anywhere and anytime. Taking into consideration the technology presented in this current framework according to mobile learning ID relation with ARLE characteristics in an architectural education context*, *we have proposed the characteristics for designing an* ***Architectural Mobile Augmented Classroom (AMAC)*** that encompasses the following characteristics:

- ***Constructive Approaches*****:** new innovative technologies such AR and mobile computing provide students with SCL learning opportunities. As it allows them to learn, build knowledge during their learning experiences, provide access to information (through search functions and carefully designed navigation, with opportunities for communication and collaboration with peers).
- ***Experiential Learning****:* MAR learning experiences enhance SCL by adopting notions concerned with "learning by doing" techniques and methods.
- ***Adaptive to Social and personal modes*****:** this technology based human-mobile interaction, support diverse modes of communication and collaboration.

(2) The AR media "Quick Start Guide" at www.armedia.it/showcase.php?sid=3dsmax_tutorials. Accessed at 21/7/2018

- ***Flexibility:*** learning should always take place even if students did not have enough time during their academic schedule. Students have the opportunity to take offline moments or on the fly data and review it anytime / anywhere. Moreover, the flexible nature of AR also appears in the capability to integrate with many technologies such: Intelligent Augmented Reality systems (IARs), AR based BIM (Building Information Modeling), systems and Cloud computing.
- ***Motivation:*** these tools attract the attention of the digital natives to explore and gain knowledge. Hence, one of the main advantages of ARLE is increasing the students' learning motivation.
- ***Edutainment:*** provides potential for memorizing knowledge, as it provides enjoyment while learning through deep inquiry and social engagement with real problem situations.
- ***Immediacy*:** mobile devices may contain supportive tools and capabilities that provide immediate feedback and information delivery.
- ***Accessibility*:** learning environment should be easily accessed and learner's requirements should be fulfilled through; cloud storage, MAR libraries and similar means.
- ***User Friendly GUI:*** offers visual context of environment and other prospects. It appears through a representation that illustrates the key elements of the educational context, which are necessary to create a sense of satisfaction, control and richness.

5. Challenges and Future Directions

- There are several MAR tools for non-programmers' authorization it is necessary for architectural educators to get informed with functionalities of these tools, as well as with the tools that will be used to create or modify the required multimedia elements.

- The applicability of linking AR to various technologies is one of the future directions in architectural education. Because of its special nature, AR is not limited to a specific type of technology as it could be reconsidered from broader views as Building Information Modeling (BIM) and Cloud. Besides, the distinguished advantage of mobility, when linked to cloud, it is possible that architectural classroom may go beyond M-Learning, to Ubiquities learning (U-Learning), "where the data are stored in the cloud and are consulted on any place by all kinds of educational programs and social networks" (Redondo, et.al.2013) .On the other hand, the effectiveness of BIM and AR system integration to enhance task efficiency through improving the information retrieval process enhanced by AR visualization technologies is a valuable combination. Thus, the capabilities of linking Mobile-BIM-AR systems (Chu, et al. 2018) and cloud-based storage could give new horizons of pedagogic potentials for educators and researchers to improve architectural learning not only as visualization but also as information tools.

- Despite potentials of the proposed MAR framework for using digital technology in architectural education, there is still a need to investigate physical, mental and psychological impacts.

- This study has focused on the positive impact of one of the AR techniques, which is MAR techniques on the development of architectural learning space from a pedagogic perspective. On the other hand, it is possible to study the impact of MAR on the design of the physical learning space and their impact on changing architectural classroom design.

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