Towards Math-Based Architectural Education in Egyptian Engineering Faculties

Abstract. This paper introduces and discusses the current developments in architectural education through the debates about integrating mathematics courses to fulfill the accreditation requirements in the Egyptian faculties of engineering. The analysis and conclusions shed light on the math-based architectural education not only as a hope towards the accreditation of architectural education in Egypt, but also as a method to introduce the algorithmic thinking that helps students to examine the design process from a broad perspective.

Introduction

The importance of mathematics in architecture, as a scientific issue, is indubitable. Architecture can be considered, in a way or another, a graphical interpretation of mathematics. Historically, the link between math and architecture goes back to ancient times, when the two disciplines were virtually indistinguishable. In the ancient world, the architects who constructed the pyramids, ziggurats and temples were originally mathematicians. In Classical Greece and ancient Rome, architects were required to be mathematicians as well. When the Byzantine emperor Justinian decided to construct Hagia Sophia, the building that surpassed everything ever built, he turned to professors of mathematics to do this job. This tradition continued in the Islamic civilization, which created an enormous number of tiling patterns centuries before Western mathematicians devised a complete classification [Connor and Robertson 2002; Nastasi 2012].

The first attempts to establish architectural education as a separate discipline began in France by the year 1671 and continued through the twentieth century, with the Bauhaus and similar schools [Cikis 2010; Seraji-Bozorgzad 2004]. The nineteenth century saw a change of attitude that led to a gap in people's views about science and art. This doesn't mean that the connections between mathematics and architecture vanished, but it was believed that the scientific and artistic aspects can't be found in the same person [Connor and Robertson 2002].

The modern schools of architecture developed from the educational movement of the nineteenth century, which was influenced by the desire to broaden the objectives of higher education, the increase in the complexity of building systems and the new knowledge acquired from related fields. Since then, architectural programs have flourished in a wide range of academic settings [Raouf 2001].

The main questions

There is much national and international debate about the interaction/integration of mathematics in architectural education. This debate leads to the questions posed in this present paper:

- Should architecture students take a mathematics course? If so,
- Should mathematics courses taught alone or integrated directly or indirectly within other courses in architectural program? If so,
- Should these courses belong to mathematics and basic science, architectural or structural departments; from coding to teaching? If so,
- Could these courses improve the architectural education or they just a way to the accreditation in the Egyptian faculties of engineering?
- Finally, what are the effects or benefits of NARS (National Academic Reference Standards) in architectural education with the desire to obtain the accreditation?

These are some of the questions that are raised by all those involved with teaching mathematics in architectural departments. The answer to these questions are closely linked to each other, and are still the topic of national and international debates.

Objectives

Starting from the notion that mathematical education could influence the way in which one conducts his life and views about the world [Brown 2002], this research aims to:

- Explain the humanistic mathematics in architectural education between beauty and power;
- Analyze the current state of architectural engineering departments in Egypt in terms of their mathematical courses;
- Highlight the mathematical approaches along with describing the suggested mathematical courses in architectural education.

Methodology

Data has been collected from a survey that was completed either through the Internet or by consulting the available literature resources in order to draw a clear vision about the mathematical education in both the Egyptian departments of architecture and some other equivalent international departments/schools of architecture that adopted mathematical courses.

To begin, the study reviews the origin and development of mathematical education in architecture. Next, it reviews the current situation of architectural education in Egypt, starting from the first academic institution to the recent accreditation guidelines. Finally, the collected data was classified, organized and compared utilizing descriptive analysis to conclude the results.

The origin and development of mathematical education: a review

It is evident that math-based education is rooted in the Age of Enlightenment; this may answer the first question. However; this relationship is troubled by rising social interest during the 1960s rather than building construction. The 1970s saw a revival of interest in architectural history and also in the design of everyday buildings with beautifully rendered drawings. Taken together with the rising individualism of the 1990s, all such changes impose a new set of relations between mathematics and architecture. The need for these mathematical–architectural relationships to adapt to new development in digital tools is another dimension of this subject [Cikis 2010].

Recently, technological advances transformed mathematics into a creative tool that can help architects in the design of the multidimensional and virtual spaces through various types of drafting and modeling software [Burry 2007; Burry and Burry 2010]. Students also use mathematics as tools to express their ideas, to develop their abilities in the evaluation and to optimize their choices. In this paradigm, mathematics still plays a distinctive role in providing a common language shared by all fields, looking at the universe with a new point of view, thinking in n -dimensional space with algorithmic thinking, and allowing flexibility in the design process [Gönenç Sorguç 2005].

The mutual contributions of architectural and mathematical thinking emphasized and illustrated by the geometrical analysis of architectural objects, from the calculation of dimensions to performing spatial transformations [Verner and Maor 2005].

This section displays and analyzes math-based architectural education, showing the relevance of the beauty and power of mathematics for achieving the objectives of humanistic sciences. To do this, it reviews a number of related mathematical topics in the architectural world.

Fig. 1. The beauty of mathematics: from geometric patterns to fractal geometry.
 Drawing by the author

The beauty based on mathematics

For thousands of years, civilized people have used mathematics to investigate sizes, shapes, and the relationships among physical objects. Geometry was carefully organized in about 300 B.C., when Euclid gathered what known at the time, added original work of his own, and arranged 465 propositions into thirteen books, entitled *The Elements*. Now Euclidean geometry is well known as the study of flat space based on point, line and plane [Gantert 2008]. Mathematics also speaks through numbers; drawing is the essential language of architecture. Thus, a close relationship has developed between geometry and architecture [Rossi 2006], as the matrix of ideas contained the creation of shapes, symmetry, patterns and proportions. More novel is the encouragement of creativity through appreciation of mathematics with computer-aided design software, topological and fractal architecture, which provide a variety of tools for the efficient design, analysis, and imagines of complex shapes (fig. 1) [Burry 2007; Hejazi 2005; Indraprastha 2008; Kappraff 1986; Pottmann et al. 2007].

Geometric patterns and Platonic solids

Geometric patterns are spatial concepts used to fill surfaces; leaving no spaces between the meeting-points of the vertices. The basic filling patterns are also known as mosaics, grids, lattices, or tessellations that fill two-dimensional surfaces or three-dimensional spaces [Hejazi 2005]. For filling two-dimensional surfaces, it has been shown that only three regular polygons are used to fill surface areas, but combinations of these three regular polygons form eight semi-regular polygons in which the vertices are similar on all occasions.

Fig. 2. Islamic decorative concept with regular and semi-regular patterns: a) the Sacred Mosque; b) the Prophet's Mosque; c) Topkapi Palace; and d) the Blue Mosque. Photographs by the author

For filling three-dimensional spaces, there is another filling pattern by regular solids. There are five regular polyhedra that are called the Platonic solids; these solids are a rich subject in connections to the worlds of arts, architecture, chemistry and biology. They provide a source of the interesting structures to study in architectural engineering [Hejazi 2005; Kappraff 1986]. Geometric patterns and Platonic solids are used widely in Islamic architecture by various designs and scales (fig. 2).

Systems of proportions and symmetrical relations

Proportions in geometry, architecture, music and art express the harmonious relationships between the whole and its parts, and within a whole system. The selection and use of systems of proportions has always been a vital issue for artists and architects. The recognition that beautiful harmonious sounds depended on ratios of small integers led architects to design buildings using a module [Connor and Robertson 2002; Hejazi 2005]. However, architects have fine senses of symmetry of visual forms without considering a precise definition of this concept from the mathematical point of view [Kappraff 1986].

The golden ratio is the most pleasing aesthetic proportion. This seems to be a good point to introduce mathematical courses to architecture students, by giving various examples of structures and golden ratio. Throughout the history of art and architecture, classical artists adopted the golden ratio as a sacred measure and aesthetic proportion in order to embody the spirit in the matter [Hejazi 2005; Fischler 1976]. Mathematically, the golden ratio (*phi* or Φ) can be calculated as:

$$\Phi = (1 + \sqrt{5}) / 2 = 1.6180339887....$$

The angle based on this number equals ($51^\circ 50'$, or $\text{arc-sec } \Phi$).

Fig. 3. Golden section and related proportions: a) line segment divided according to the golden ratio; b) golden spiral in rectangles; c) golden triangle; and d) golden ratio in pyramids. Drawings by the author

Fig. 3 illustrates the golden section and its related proportions. There are relationships among golden section, Fibonacci series and spirals that can be found in many instances in nature where self-generating patterns are in effect [Rossi 2006]. Finally, any treatment of the golden section in architecture must include a discussion of Le Corbusier and the Modulor [Kappraff 1986].

From Euclidean to topological and fractal geometry

Traditionally, architectural elements are composed of shapes constituted by Euclidean geometry. Recently, however, different shapes have appeared, and the ways these are explored has totally changed with the development of topology [Delgado Cepeda 2005; Consiglieri and Consiglieri 2003].

Topology is defined as a study of intrinsic, qualitative properties of geometric forms that are not affected by changes in size or shape. The study of topology is more general than Euclidean geometry, and allows the study of the transformations and deformation of an object. Continuous deformation of a surface can lead to the intersections of exterior and interior planes in a continuous morphological change. A good example for such geometry is the new Guggenheim Museum in Bilbao, Spain by Frank Gehry [Consiglieri and Consiglieri 2003; Emmer 2005].

Topological architecture leads the architectural design to a renewed and often spectacular plasticity, in the wake of the Baroque and of organic Expressionism. Architectural topology is influenced by the inherent temporalities of animation software, augmented reality and computer-aided software [Emmer 2005]. Sophisticated software frees today's architects from endless calculations, making topological models of objects such as Möbius strips and Klein bottles almost as easily achieved as straight-line forms, something that was unimaginable a decade ago [Burry 2007; Burry and Burry 2010]. However, the importance of learning the equations behind these models remains a fundamental issue for architectural students, because mathematical realization and awareness strengthens visual creativity. Understanding topological models allows architects to incorporate differentiated ideas of space and time into their designs, combining art, form and mathematics into a plastic piece of imagination [Emmer 2005]. It is significant to point out that mathematics is also a tool for biomimetics as well as an appropriate objective reference for thinking with a broader perspective [Gönenç Sorguç 2005] by recalling the fractals and self-similarity of living forms.

Fractals are not found only in mathematics, but also in every corner of nature. With the advance of fractal geometry and computer-aided design software, it is now possible to model and create the organic, self-similar forms of nature in a way never realized before [Harris 2012]. From a mathematician's point of view, the origins of this modern imagination can be traced to 1952 when Hermann Weyl published his book *Symmetry* [1952], which included many examples taken from nature, art, and architecture. The artworks of M. C. Escher also embody a variety of mathematical concepts, such as symmetry, self-similarity and topological equivalence. Buckminster Fuller's geodesic domes also emphasize this approach. All of these works show the potential for narrowing the gap between art and science [Wassell 1998].

The power of mathematics: algorithmic thinking

Mathematicians have tried to find attractive applications for many scientific branches especially for engineers, such as graph theory and parametric modeling. This approach makes math not only a powerful tool for design but also for thinking, one may help

students examine, analyze and integrate an amazing array of constraints in order to find optimal solutions from a broad perspective.

Graph theory

Graph theory was introduced in 1736 by Leonhard Euler to solve the famous Königsberg Bridge and the utilities problems. Mathematically, connectivity is one of the basic concepts of graph theory, in which each graph is defined in terms of its connectivity rather than its length, angle or other familiar geometric properties [Fischler 1976; Kappraff 1986]. There are some enjoyable examples with graph theory's applications to architecture and urban design (fig. 4), thus allowing architects, mathematicians and computer scientists to begin to explore areas of common interests. Computer scientists saw architecture students as potential users of computers, in particular, of computer graphics. Besides, architects look more and more frequently to other disciplines and industrial processes for inspiration [Cikis 2010; Emmer 2005; Kappraff 1986]. In this concern, the future of this theory in architecture will be boundless and pleasant.

Fig. 4. Graph theory and connectivity relationships. Drawing by the author

Parametric modeling

Parametric modeling appeared in the 1960s, but only now architects are fully exploiting its power. Every aspect of a building can be modeled, from its physics to its appearance. Parametric models make it possible to change some of the geometrical features while keeping others fixed. With the use of computers, advanced digital tools can analyze and integrate the amazing array of constraints to find optimal solutions based on complicated mathematical languages, allowing them to create groundbreaking models. All the information obtained from these models can be pulled together in what is probably the most notable innovation in architectural CAD tools in recent years, in particular CATIA (Computer-Aided Three-Dimensional Interactive Application). The models allow the designer to play around with certain features of a building without having to re-calculate all the other features that are affected by the changes. Rather than describing a structure by a large number of individually stored coordinates, designers only need save an equation. This opportunity helps architects to shape building models and make changes using a step-by-step procedure [Freiberger 2007; Nastasi 2012].

The architectural education in the Egyptian higher education system: review

Historically, architectural education in Egypt perhaps date back to the era of Muhammad Ali Pasha. In those days higher education adopted the French curriculum. In December 1908 Cairo University was founded, and was greatly influenced by the

German technology-oriented way of teaching architecture. Growing out of these roots, architectural education in Egypt still follows the Western model in theories started with both the French and German systems, but has ended up closer to the British system of teaching rather than other Western ones [Al-Hassan and Dudek 2008].

Currently, in order to obtain a Bachelor of Science in architecture (B.Sc.), architecture students must complete four years of study in a department of architecture (which is a part of an engineering faculty) in addition to one year (known as the preparatory year) of general studies in engineering. As a part of engineering faculties, it is obligatory for the students to study mathematics and other basic science courses, especially in the preparatory year. In this year, the mathematical courses address general subjects not usually related to architectural courses or the applied mathematics required in practice. These general courses comprise the greatest number of mathematics hours studied by architecture students in all of their five years. Given that the accreditation rules require better distribution of basic science, the future of engineering faculties relies on rethinking how to teach architecture students and accredit their architectural departments.

A. Standard-based education. National Authority for Quality Assurance and Accreditation of Education (NAQAAE) is the body responsible for the accreditation of the Egyptian educational programs by establishing specific standards and requirements. These standards are informed by external references and include the minimum knowledge and skills that must be gained. Standard-based education assists staff in planning and performing the educational activities in the classroom and evaluating the results. It also assists the institutions in developing an institutional improvement plan, developing curriculums, and using different practical teaching, learning and assessment methods. NAQAAE established a method to manage an academic program in which clearly defined National Academic Reference Standards (NARS), performance indicators and standard operating procedures are aligned. In this regard, qualitative and quantitative measures were used to track the performance over time to check if the agreed performance levels have been met [NAQAAE 2007; 2009]. The NARS for Engineering set out generic statements that represent general expectations about standards for the B.Sc. degree in Engineering. According to NARS, from 20% to 26% of total semester hours must be devoted to mathematics and basic sciences, which includes math, physics, and chemistry. This part of the curriculum may be taught in separate courses or included in several courses and its hours are to be indicated in the course specification [NAQAAE 2009].

Until recently, in most of the architectural departments, the effort and time of students are devoted to architectural courses such as freehand sketching, rendering and other visual activities. Although these courses are essential, students tend to neglect thinking on the conceptual level if they are engaged early in such architectural courses [Raouf 2001]. A few years ago, calls for teaching mathematics courses for architecture students were raised during various academic debates. Because of the nature of these students and their future profession, one could argue that the hoped mathematics subjects/courses will be challenged issues and still in its early stage. Therefore, in this paper I have tried to explore the effects or benefits of NARS requirements in architectural education with the desire to increase mathematics subject area. This study does not argue for the integration of pure mathematics courses, but looks for the suitable integration of such subjects/courses within the current curricula along with upgrading their contents, and considering their role in both present academic and professional necessities.

B. The current math education in the departments of architecture. There is a total of twenty-two architectural engineering departments in the public sector (rather than the private one). An analysis of these departments showed that to obtain the degree, after completing two semesters in preparatory year, a full-time study lasting eight semesters, either normal or credit hours systems, is required. Based on this survey, which included all of the Egyptian engineering faculties (public sector) as of March 2013, it was noted that beside general mathematics courses of the preparatory year, only five departments (22.7%) offer separate mathematics courses during these eight semesters. The analysis of these departments reveals that of the total hours, mathematics courses constitute 4-5 credits mostly in the first years, or 3% of the total. Such courses include probability and statistics. The remaining seventeen departments (77.3%) do not provide any separate mathematics course in any of these eight semesters. This condition can be explained by the fact that mathematics as a subject was embedded indirectly with other courses, such as environmental, structural or computer science. Finally, based on this view, this study starts from the accepted fact that there is a gap between the architectural education and NARS requirements. Consequently, there is a need to develop an educational curriculum that will emphasize math-based education to raise its subject area in basic science.

Analysis of the current math courses in the Egyptian departments of architecture

The general classification of math courses

Although architecture students might find the interaction with mathematics of little concern, mathematics is in fact a universal code that every discipline can use. Architecture from ancient times was considered a mathematical topic and the two disciplines have, up to the present time, retained a close connection [Connor and Robertson 2002; Indraprastha 2008; Gönenç Sorguç 2005]. Architecture as an engineering discipline and a scientific art relied on the following groups of mathematics courses; a) basic mathematics courses that identify and solve fundamental engineering problems; b) applied mathematics courses that emphasis structural analysis and environmental issues; c) design-oriented mathematics courses that achieve visual harmony along with imagination and creativity; and d) technology-oriented mathematics courses that highlight the use of a wide range of analytical tools and software packages relating to the discipline. These various and related mathematics groups are fundamental for designing robust architectural projects with creativity and technical mastery. The following sections illustrate these four groups in brief.

A. Basic mathematics course. The composition of these mathematics lessons are adapted to create a scientific foundation in the early years of higher education along with other basic scientific courses such as physics or chemistry. These courses are compulsory for all Egyptian engineering faculties and take place in the preparatory year. The contents of such courses are limited to general topics to serve other engineering departments after specialization. These courses were designed to enhance students' ability to solve engineering problems. They are provided under headings like calculus, linear algebra, trigonometry and analytical geometry.

B. Applied mathematics courses. The main aim of the applied mathematics is to prepare students for analytical and practical activities. Architecture students need such courses in architectural education to understand how to construct buildings [Cikis 2010]. Applied mathematics courses are considered as a correlative part of the early years, including subjects related to the study of building construction, environmental and structural

analysis. These courses also should have laboratory hours and must be connected to the other courses in the architectural program.

C. Design-oriented mathematics. The idea of mathematics as an art raises many challenges and is still a major concern in preparing the architect. In addition to basic and applied mathematics, architecture students also need distinctive courses that emphasis architectural design or to help them to think of mathematicians as artists. Developments in this role were first expressed at the French Royal Academy and followed by Beaux-Arts system, where the geometrical analysis of the classical buildings of ancient Greece, Rome, the Renaissance and the Baroque was used to support work in the design studios. Descriptive geometry is important to be taught in the context of architectural presentation, with topics such as proportion, balance, symmetry and laws of harmony. In this way, strong links are formed between architectural history, design and mathematics [Burry 2007; Cikis 2010; Fjelstad 1999].

D. Technology-oriented mathematics. The adaptation of mathematics courses to develop digital technologies is a fundamental concern [Cikis 2010; Gönenç Sorguç 2005]. The need for mathematics in learning the software required in design processes is certain, as the use of computers in all the design processes will increase in the near future. The motivation to learn CAD and information technology seemed of high importance among the architectural schools [Indraprastha 2008]. In this way, can the computer extend the potential for relevant application of mathematics in design process? In the era of digital design, architects can apply mathematical concepts to build structures never seen before and imagine complex geometrical forms with efficient solutions [Burry 2007; Burry and Burry 2010; Maor and Verner 2007].

Fig. 5. Math-based architectural education in Egyptian engineering faculties.

Digital technologies have transformed the design process in various degrees, putting into question the traditional techniques of the profession. In the architectural offices, this has led to an increasing demand for digital skills, and in the schools of architecture the use of software programs has provoked recent debates [Cikis 2010]. Technology-oriented mathematics also includes courses concerning geographical information systems and other tools for analysis that should be activated to enhance architecture and urban design.

This situation is already in place in some architectural departments in Egyptian engineering faculties. According to the previous classification of mathematics, it appears that most of these four groups, already have a place in the architectural curriculum of the Egyptian engineering faculties (fig. 5). However, there is a gap in the separate mathematics courses (stage 2). This stage plays a major role in bridging the gap between art and science, thus enhancing the mathematical base in architectural education.

Evaluation of the current separate math courses

It appears that architects must have a solid background in mathematics, so they can successfully design and construct structures. As mentioned previously, to acquire the B.Sc. in architecture students must attend several mathematics courses (Math code). First, all students who attend the faculty of engineering have to pass the preparatory year with all of its separate mathematics courses (stage 1). Second, after the preparatory year there are five architectural departments in Egyptian engineering faculties that adopted to teach other mathematics courses (stage 2). This section analyzes the current separate mathematics courses in these five architectural departments.

Course content / available description	Course name	Hours/week	Level/Year	Department / program	University
Multivariable calculus and linear algebra: Double integrals, double integrals in polar coordinates, triple integrals, triple integrals in spherical and cylindrical coordinates, applications of double and triple integrals, line and surface integrals, vector analysis, gradient of a scalar function, divergence of a vector, curl of a vector, divergence and Stokes' theorems, vector identities, LU-factorization, vector spaces, inner product spaces, eigenvalues and eigenvectors, diagonalization of matrices, functions of matrices.	Multivariable calculus and linear algebra	5	1 st	Architectural Engineering and Technology (AET) Credit Hours System	Cairo
	Probability and statistics	5	2 nd		
	Mathematics, statistics and computers	5	1 st	Architectural Engineering	
Probability and statistics: Probability axioms and laws, conditional and continuous probability, random variables, discrete and continuous distributions, joint distribution, computer simulation, sampling, measures of location and variability, parameter estimation, testing of hypothesis, presenting and classifying, statistic data, central tendency, dispersion measures.	Mathematics and statistics	5	1 st	Architectural Engineering	Fayoum
	Mathematics, statistics and programming	4	1 st	Department of architecture	Mansoura
	Mathematics and statistics	4	2 nd	Department of architecture	Zagazig
Linear programming: Objective function, the chart solution to linear programming problem, the mathematical solution to linear programming problem (simplex method).	Engineering statistics and numerical analysis	4	3 rd	Architectural Engineering	Minia

Table 1. Analysis of the current separate mathematics courses in the Egyptian departments of architecture

Course content / available description	Course name	Department / school	University
<ul style="list-style-type: none"> Real numbers, equations and inequalities, Cartesian coordinate systems, coordinates of points and vectors in two and three dimensional space. Operations with vectors. Equations of lines and line graphs in two dimensions, line segments and ratios of division. Convexity and convex polygons and smooth polygons. Matrices, determinants and matrix operations. Linear transformations in the plane; Symmetry, rotation, translation, stretching, shrinking and scaling. Similarity and rates of similarities, Pythagorean and Thales' theorems. Projections. Plane figures and their areas. Solid bodies and their surface areas and volumes. 	Architectural Geometry	Faculty of Engineering Architecture	Beykent University
<ul style="list-style-type: none"> Aesthetics, structural aspects, and related mathematics in great buildings. Sensing form and conceiving number. Problems involve basic algebra and geometry in geometric forms. Dealing with forces. Mathematical study of symmetry. Remarkable curves and remarkable maps Line of numbers, the coordinate plane and system in 3D. Integral calculus, rotation and lengths of curves, volumes of spherical domes. 	Mathematical Excursions to the World's Great Buildings	School of Architecture	University of Notre Dame
<ul style="list-style-type: none"> Vectors, lines in two dimensions, circles, conics, transformation of coordinates, polar coordinates. Parametric equations and the solid analytic geometry of vectors, lines, planes, cylinders, spherical and cylindrical coordinate. 	Analytic geometry	The School of Architecture	The University of Texas at Arlington
<ul style="list-style-type: none"> Topics from previous calculus courses that are related to architecture. 	Architectural calculus	The School of Architecture	The University of Texas at Arlington

Table 2. Analysis of the separate-mathematics courses in architectural education around the world

Table 1 summarizes the situation after the preparatory year (stage 2); this includes the name of the university, the department, course name, and its location in the four years of architectural study, its hours and the available data about its contents.

The analysis of the contents of these courses points out the similarities between their subjects, which depend mainly on probability and statistics. It also mentions the absence of geometry courses. The contents of these separate mathematics courses can be divided into three common subjects, they are:

- Calculus and linear algebra. These courses help students to calculate structural issues, so they can design buildings stand safely and resist their live and dead loads;

- Probability and statistics. These courses help students to analyze data such as geological and geographical information, structural specifications and construction optimization;
- Linear programming. Such courses help students to learn how to evaluate the variable factors that affect design and construction. For example, linear programming enables architects to determine whether the cost of a specific design element will pay off in the long run, or if it's too expensive for the function and purpose it provides [Tucker 2013].

Internationally, the analysis of the other, equivalent departments of architecture around the world indicates that the situation in Egypt does not generally differ very much. However, there is a gap in geometric courses nationally and in some cases internationally. Table 2 summarizes the available data about the departments/schools of architecture that adopted to teach different math subjects compared to Egyptian education. All mathematics courses in these institutions take place in the early years of architectural study.

Suggested separate mathematics courses in Egyptian departments of architecture

There is no doubt that mathematical education can produce positive results in architectural students. It will increase their capabilities to understand complex ideas and prepare them to solve practical problems in design. It seems that architecture students prefer oral discussion; if they are interested in a particular topic or problem they will ask questions, argue and work. Given this situation, the important issue is to teach those students how to think in order to improve their future flexibility [Cikis 2010; Consiglieri and Consiglieri 2003; Fischler 1976; Kappraff 1986].

The search for appropriate math-based architectural education must include reviewing the literature of other international attempts. Pedemonte [2001] suggested more emphasis on descriptive geometry; the study of solids, surfaces, topology and their applications in morphogenetic models. In addition, Cikis [2010] reveals that among the members of the European Association of Architectural Education (EAAE), the least importance is given to general mathematics in the form of algebra and trigonometry [Cikis 2010].

Nowadays descriptive geometry is no longer taught generally in architectural departments, thus it is usually poorly known by younger architects [Putz 2000]. However, descriptive geometry is one of the design-oriented mathematics courses that offers decent point of intersection between the history of architecture, mathematics and the science of construction [Migliari 2012]. If mathematics courses were integrated in the constructive models, the ability of the student to invent forms will be developed [Pedemonte 2001]. In addition, descriptive geometry expresses the practical part of the process of representation as well as the analysis and generation of objects in the three-dimensional space by drawings, which assist the student directly or indirectly in developing his fundamental skills in design [Putz 2000]. Due to the decreasing role played by descriptive geometry in the Egyptian curricula for architectural education, the study suggests the course of “descriptive geometry for architects” as a first attempt to bridge the gap in separate mathematics courses (stage 2). This course relates the science of graphical/visual representation of three-dimensional objects (with an emphasis on the development of drawing and drafting skills) to math equations and theorems. In this regard, the suggested mathematics course will make students more interactive with

mathematical education, understand how to relate the graphical illustrations to the mathematical theorems and equations, understand how graphical and construction information represented in CAD programs and the nature of the overlap between the two subjects. Table 3 presents the course contents, objectives and activities.

Learning activities	Operative objectives	Course content	Course name
<ul style="list-style-type: none"> • Examples found in nature and solve complex problems related to mathematics in architecture design. • Presentations on of the world's great historic buildings in terms of structure and geometric relations. • Drawing basic geometrical modules and their possible combinations. • Discussions of problems of n-dimensionality and the resulting structural stability. • Applications of integrals in design, architecture and building engineering. 	<ul style="list-style-type: none"> • Present the principles of Golden Ratio to Le Corbusier's modular. • Acquire basic skills in solving mathematical problems related to geometric models. • Obtain basic skills in analysis of proportions, symmetry, harmonic dimensions, and drawing tessellations. • Understand the rules of transformations and topological models. • Recognizing algebraic geometry and complex manifolds. • Practice in solving mathematical problems related to spherical and fractal architecture. 	<ul style="list-style-type: none"> • Mathematical concepts related to nature, art and architecture. • Cartesian coordinate system. • Mathematical optimization and the concept of algorithmic thinking. • Mathematics equations with tiling, patterns and symmetry. • Transformations and deformation theorems of object. • Notions from algebraic topology. • Fractals, self-similarity and then concept of fractal architecture. • Design project with mathematical base. 	Descriptive Geometry (DG) for architects

Table 3. Suggested separate mathematical course

Discussion

The answers to the questions posed early in this work are, and will remain, key issues in shaping the different approaches and trends in math-based architectural education. These issues seek to answer how architects rethink their ambitions and goals in the twenty-first century. The vision towards the code of practice depends on the overall response to these questions and highlights the importance of the creative integration of mathematics as a method for enhancing form creation and algorithmic thinking.

The debate over what should be taught in architectural departments is on-going and will continue in the future, but it is agreed that in order to maintain architectural design as a central discipline, it is necessary to integrate mathematics with it so that architects can maintain a dialogue with experts and know how to exchange ideas with electrical, mechanical and structural engineers [Pedemonte 2001]. In the Egyptian universities, all architecture students must study separate mathematics courses along with other engineering majors in the preparatory year. In the following years, only a small percentage of all Egyptian faculties (22.7%) study separate mathematics courses while in other faculties, the architecture curriculum does not include any separate mathematics

courses. However all architecture students study mathematical subjects that were integrated with other courses from the first to the last year of study. Mathematics courses (Math code) that are taught in the preparatory year or the other years mainly concern with calculus, algebra, statistics and computer courses. When grouped according to scope, the highest percentage is within the basic mathematics courses. Unfortunately, these courses have the least direct impact on the architectural specification while the specific mathematics courses that are designed particularly for architects seem to be neglected. Recently, a number of departments have developed mathematics courses to recall the international education movements and accreditation criteria. However, only slight information is available about the educational aspects or the results of these courses in the development of creation and thinking. This may shed light on the expected answers for the last two questions posed in this work. There is a need for a comprehensive study of mathematics curricula for architectural education, updating and renewing the old standards. If one considers that the advanced countries investigated provide at least one or two different mathematics courses that are designed specifically for architects, it will be a vital consideration when updating the curricula and standards in Egypt.

As mentioned above, mathematics courses for architects still follow different models and directions, and ideal/standard courses do not yet exist either nationally or internationally. In Egypt now, the educational environment encourages an increase in the percentage of the basic science in the engineering curriculum and thus an increase in the mathematical subjects. This recent situation also requires the accurate selection for the appropriate mathematics courses that will be taught to develop students' capabilities. Finally, architecture students should study the four mathematics groups mentioned earlier, either in separate courses or integrated with other courses in the architecture curriculum. The balance between these groups is required to improve student's skills.

Concluding remarks

Until recently, math-based education in architectural engineering in Egypt is less than expected. However, this situation is now transforming and the new criteria suggested by NARS require further advances. Mathematics as a general requirement for engineering student remains necessary and at the same time provides an opportunity for boosting architectural education. This point relies on the Western experience, in which many architectural institutions nowadays provide additional courses in mathematics for architecture students. It is hoped that this direction will prepare these students to design, think and analyze using the new available tools based on information technology.

It has become clear that the need for math-based architectural education in the architectural engineering education is a critical issue. We must appraise the content of mathematics courses and update the Egyptian standards to follow the international criteria. The present paper does not call for standard courses of mathematics for architecture, but briefly describes the most relevant aspects and provides an insight into some issues that maybe already known. The aim of the suggested courses is to clarify to students the concrete and strong relationships between mathematics, art and architecture through familiar examples and practical models. Mathematics is not a theoretical discipline full of equations, but can also explain patterns, symmetry, shape and beauty. Conceived in this way, the math based architectural education utilizes mathematics as both a creative art and a method of algorithmic thinking. Thus, when mathematical awareness increases, architecture students will be able to look at the world with new eyes.

Furthermore, their capabilities to analyze mathematically the structures around them will improve.

Acknowledgment

The author gratefully acknowledges the constructive comments provided by the referee, Dr. Ahmed Elkahateeb, a member of the Editorial Board of the *Nexus Network Journal*, whose helpful comments and interesting criticisms helped to improve the quality of the paper.

References

- AL-HASSAN, Ameera, and Steve DUDEK. 2008. Promoting Sustainable Development in Arabia through Initiating an Arab Architecture Accrediting Board. *CEBE Transactions* **5**, 1: 71-89.
- BROWN, Stephen. 2002. Humanistic Mathematics: Personal Evolution and Excavations, *Humanistic Mathematics Network Journal*. http://www2.hmc.edu/www_common/hmnj/brown.pdf (accessed 23 July 2013).
- BURRY, Jane. 2007. Mathematical Relations in Architecture and Spatial Design, *Proceedings of the Ninth International Conference: Mathematics Education in a Global Community*, 7-12 September 2007, Charlotte, USA.
- BURRY, Jane and Mark BURRY. 2010. *The New Mathematics of Architecture*. London: Thames and Hudson.
- CIKIS, Seniz. 2010. A critical evaluation of mathematics courses in architectural education and practice. Mathematics courses in architectural education and practice. *International Journal of Technology & Design Education* **20**, 1: 95-107.
- CONNOR, John and Edmund ROBERTSON. 2002. Mathematics and Architecture. University of St Andrews. <http://www-history.mcs.st-andrews.ac.uk/HistTopics/Architecture.html> (accessed 22 February 2013).
- CONSIGLIERI, Luisa and Victor CONSIGLIERI. 2003. A Proposed Two-Semester Program for Mathematics in the Architecture Curriculum. *Nexus Network Journal* **5**, 1 (Spring 2003): 127-134.
- DELGADO CEPEDA, Francisco Javier. 2005. Designing a Problem-Based Learning Course of Mathematics for Architects. *Nexus Network Journal* **7**, 1 (Spring 2005): 42-47.
- EMMER, Michele. 2005. Mathland: The Role of Mathematics in Virtual Architecture. *Nexus Network Journal* **7**, 2 (Autumn 2005): 73-88.
- FJELSTAD, Paul. 1999. Mathematics Is an Art: The Story of a One-Time Course. *Humanistic Mathematics Network Journal* **21**: 18-26.
- FISCHLER, Roger Herz. 1976. A mathematics course for architecture students. *International Journal of Mathematical Education in Science and Technology* **7**, 2: 221-232.
- FREIBERGER, Marianne. 2007. Perfect buildings: the maths of modern architecture. *Plus Magazine* (Millennium Mathematics Project, University of Cambridge). Available at: <http://plus.maths.org/content/perfect-buildings-maths-modern-architecture>. Accessed 27 February 2013.
- GANTERT, Ann Xavier. 2008. *Amsco's Geometry*. Amsco School Publications, Inc. ISBN 978-1-56765-596-4.
- GÖNENÇ SORGUCU, Arzu. 2005. Teaching Mathematics in Architecture. *Nexus Network Journal* **7**, 1 (Spring 2005): 119-124.
- HARRIS, James. 2012. *Fractal architecture: organic design philosophy in theory and practice*. Albuquerque, NM: University of New Mexico Press.
- HEJAZI, Mehrdad. 2005. Geometry in nature and Persian architecture. *Building and Environment* **40**: 1413-1427.
- INDRAPRASTHA, Aswin. 2008. Mathematics courses and new emerging design tool: an overview of architectural education in Indonesia. *DIMENSI, Journal of Architecture and Built Environment* **36**, 2: 107-114.
- KAPPAFF, Jay. 1986. A course in the mathematics of design. *Computers & Mathematics with Applications* **12B**, 3-4: 913-948.

- MAOR, Sarah and Igor VERNER. 2007. Mathematical Aspects in an Architectural Design Course: The Concept, Design Assignments, and Follow-up. *Nexus Network Journal* 9, 2 (Autumn 2005): 363-376.
- MIGLIARI, Riccardo. 2012. Descriptive Geometry: From its Past to its Future. *Nexus Network Journal* 14, 3 (Winter 2012): 555-571.
- NASTASI, Alison. 2012. 10 Amazing Examples of Architecture Inspired by Mathematics. <http://flavorwire.com/330293/10-amazing-examples-of-architecture-inspired-by-mathematics>. Accessed 13 April 2013.
- [NAQAAE] National Authority for Quality Assurance and Accreditation of Education. 2007. Guidelines for developing national academic reference standards (NARS) for higher education in Egypt.
- . 2009. National academic reference standards (NARS) for engineering. 2nd Edition.
- PEDEMONTE, Orietta. 2001. Mathematics for Architecture: Some European Experiences. *Nexus Network Journal* 3, 1 (Spring 2007):129-135.
- POTTMANN, H., A. ASPERL, M. HOFER and A. KILLAN. 2007. *Architectural Geometry*. Bentley Institute Press, ISBN 978-1-934493-04-5.
- PUTZ, Claus. 2000. Descriptive Geometry Courses for Students of Architecture: On the Selection of Topics. *Journal for Geometry and Graphics* 4, 2: 209-222.
- RAOUF, Ali. 2001. *Towards a new Paradigm in Educating Egyptian Architects: Issues and New Concepts in Contemporary Architectural Education*. Turkey: Union of Mediterranean Architects (UMAR).
- ROSSI, Michela. 2006. Natural Architecture and Constructed Forms: Structure and Surfaces from Idea to Drawing. *Nexus Network Journal* 8: 112-122.
- SERAJI-BOZORGZAD, Nasrine. 2004. Redefining Education in the 21st Century: Pedagogies of Architecture Beyond the Beaux-Arts: Theories, Methods, Structures and Forms. <http://www.aaschool.ac.uk/VIDEO/lecture.php?ID=1054>. Accessed 27 February 2013.
- TUCKER, Kristine. 2013. What Math Classes Do Architects Take in College? <http://education.seattlepi.com/math-classes-architects-college-1107.html>. Accessed 9 July 2013.
- VERNER, Igor and Sarah MAOR. 2005. Mathematical aspects of educating architecture designers: a college study. *International Journal of Mathematical Education in Science and Technology* 36, 6: 655-671.
- WASSELL, Stephen. 1998. Mathematics in architecture. <http://www.dean.sbc.edu/wassell.html>. Accessed 27 February 2013.
- WEYL, Hermann. 1952. *Symmetry*. Princeton: Princeton University Press.

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