COMBINING ARCHITECTURAL-, STRUCTURAL-, AND INDUSTRIAL DESIGN: A NECESSITY FOR HAVING DISASTER PROOF FUTURE BUILDINGS

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ABSTRACT
Although “architectural design”, “structural design”, and “industrial design” each looks at the “product” in a different way, yet they have several aspects in common, which if combined, can lead to the creation of products with much more virtues, of which one is “being disaster-proof”. Actually, by “structural design” alone, it is possible to have a disaster-proof building, but most probably it will be economically unacceptable, particularly if it is to have specific architectural features. However, combining the “industrial design” knowledge with architectural- and structural design makes the most reliable architectural configuration as well as the most economical production procedure achievable. Clearly, to give such a design capability to building designers, it is necessary to develop a specific program in “design education”. This paper explains and discusses the specifications of this program, which can be named “Master of Disaster-Proof Design and Development” as a master degree program in architecture.

Keywords: Architectural, Structural, Industrial, Design, Disaster Proof Buildings

1 INTRODUCTION

Throughout the history, disastrous natural events such as earthquakes and hurricanes have hindered or even destroyed the achievements of human civilization. This means that in order to keep the civilization achievements completely safe against these events, the buildings and urban facilities, which are themselves major products of civilization and at the same time the maintaining factors of other civilization products, should be disaster-proof. The existing knowledge of building engineering is rich enough to easily produce disaster-proof buildings (seismic isolation technique is a good example), however, employing this knowledge without any economic consideration is unacceptable, since no community is wealthy enough to do so. That is why in almost all seismic design codes, a level of seismic hazard as “the most probable earthquake”, or similar to that, is defined, for which ordinary buildings are allowed to experience extensive damage, and just the collapse of these buildings is not accepted, since it may result in casualty and life loss. This implies that the codes provisions do not prevent disasters. For example, it can be imagined that an earthquake happens in a large and populated city, nobody gets injured, but several thousands of ordinary buildings get heavily damaged (as the seismic design code has allowed), and therefore should be replaced by new ones. This of course needs large amounts of money and takes a long time, and as a result hundreds of thousands of people are rendered homeless for several months or even years. Can’t such a case be a disaster? Thus, it can be claimed that the seismic design codes do not guarantee disaster-proof buildings, but they can lead to safe and economical buildings. Instead, the author believes that employing the existing knowledge in various fields of engineering, particularly structural, more specifically, earthquake engineering and wind engineering and industrial engineering in combination with architectural design knowledge in a proper way, can make it possible to have relatively disaster-proof and at the same time economically acceptable buildings. Clearly, this combination-based design needs some specific knowledge which in turn requires some specific program to be included in "architectural design".

Although the improvement of knowledge and information usage with regard to earthquake preparedness was taken into consideration since mid 80s [1], almost a decade later it was claimed in Queen's University, Belfast, that the influence of disasters on engineering thinking and work practice should have a much larger influence on the curriculum development [2]. Also around that time, a discussion was raised in New Zealand on the necessity of inclusion the seismic design in architectural education [3]. Surprisingly, working on the empowerment of architecture and civil engineering students with regard to earthquake engineering education is still under discussion [4]. Accordingly, an attempt was made for the inclusion of earthquake engineering concepts in the curricula of architecture by the author a few years ago[1]. More recently, a similar attempt in a wider perspective has been made for the development of "Hurricane Engineering" course as a new branch of 'Wind Engineering' in Louisiana State University by a team of over 20 faculties from civil, environmental, chemical, mechanical engineering, coastal science, landscape architecture, and environmental fields [5].

The author's experience in teaching earthquake issues to the students of architecture during the past 5 years and his interaction, as an 'Earthquake Engineering' specialist, with the experts of 'Architecture' and 'Urban Planning and Design' led him to develop his idea regarding the important roles of architects and urban designers in disaster mitigation. It also helped him to realize that more education of natural disasters in general, and earthquakes in particular, is required for the students of architecture and urban planning and design to achieve disaster-proof development. On this basis, a new program in architecture is believed to be necessary, which can be a combination of the architecture with parts of structural and industrial engineering as discussed in this paper.

2 A COMPARATIVE INSIGHT INTO ARCHITECTURAL-, STRUCTURAL-, AND INDUSTRIAL DESIGN

To realize the necessity of the proposed program, a comparative insight into the concepts of architectural-, structural-, and industrial design is very useful.

2.1 Architectural Design Concepts and Requirements

It is notable that by definition 'Architecture' is different from 'Architectural Engineering'. Architects are directly responsible for the form and appearance of a building, including the way in which people use the spaces of the building. Architects traditionally acted as the leader of the design team, and are thus known as the 'prime professional'. Architectural engineers, on the other hand, apply the skills of many

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[1] The author initiated and taught a course entitled "Earthquake Considerations in Architectural and Urban Design" in Dept. of Architecture, Cornell University, USA, in 2002. The course is now taught, with some modifications, in Tehran University and some other Iranian universities.

engineering disciplines for the analysis, design, construction, operation, maintenance, and renovation of buildings while paying attention to their impacts on the surrounding environment. In countries such as Canada, the UK and Australia, architectural engineering is more commonly known as 'Building Engineering'. Architectural engineers attempt to integrate buildings' HVAC, plumbing, fire protection, electrical, lighting, transportation, and structural systems with the design. Architectural engineers' roles can overlap with that of the architect and other project engineers. Like architects, they seek to achieve optimal designs within the overall constraints, except using primarily the tools of engineering rather than architecture [6]. To realize the differences between architects and architectural engineers, the required courses in Department of Architecture of Cornell University, as one of the pioneers in the US, are presented in Table 1, and the required course for a four- or five-year B.S. Degree in Architectural Engineering in most American universities are shown in Table 2.

Table 1: The required departmental courses in Department of Architecture of Cornell University, [8]

Semesters	Subject	Course Numbers	Credits
10	Design	ARCH 101-502	62
3	Structures	ARCH 263, 264, 363	10
4	Technology	ARCH 261, 262, 361, 362	12
2	Architectural Theory	ARCH 231, 232	4
2	History of Architecture	ARCH 181, 182	6
1	Architecture, Culture and Society	ARCH 181, 182	3
1	Professional Practice	ARCH 521 (formerly 411)	3
3	Drawing	ARCH 151, 152, 253	6
1	College Introductory Course	AAP 111	1

Table 2: The curricula for B.S. Degree in architectural engineering degree in the US, [6]

Basic Courses	Eng. Science Courses	Eng. Design Courses
An introduction to architectural engineering / Two courses in English / Five courses in mathematics (calculus, differential equations, linear algebra, probability) / Two courses in physics / One course in chemistry / One course in science (e.g., geology, environment, biology) / Several courses in humanities/social sciences (e.g., architectural history, sociology) / Two courses in architectural design / Two courses in building materials and construction	Statics and dynamics / Strength of materials / Structural analysis / Basic circuits / Thermodynamics / Fluid mechanics / Heat transfer / Engineering economics / Computer programming / Computer-aided design and drafting (CADD)	Structures (e.g., steel, concrete, and/or wood design) / Construction / Power and lighting systems / Plumbing and piping systems / Heating, ventilating, and air-conditioning (HVAC) systems / Senior design project / Electives

2.2 Structural Design Concepts and Requirements

In structural engineering, structural design is an iterative process of applying engineering mechanics and past experience to create a functional, economic, and, most importantly, safe structure. Using structural analysis techniques and conforming them to design specifications, the design engineer works to create a solution that is of everyone's benefit. Structural engineers ensure that their design satisfy a given design intent predicated on safety and on serviceability. They are responsible for making efficient use of funds and materials to achieve these goals. Their outcomes also have to fulfil the technical, economic, environmental, aesthetic and social aspects. It is a very creative profession which makes a significant contribution to infrastructure, public facilities, residential housing development and leisure venues essential to modern society [6]. 'Structural Design' can also be defined as the selection of materials and member type, size, and configuration to carry loads in a safe and serviceable fashion. In general, structural design implies the engineering of stationary objects and involves at least five distinct phases of work: project requirements, materials, structural scheme, analysis, and design. For unusual structures or materials, testing, should be added [7].

2.3 Industrial Design Concepts and Requirements

Industrial design, which is the design of products made by large-scale industry for mass distribution, is an applied art whereby the aesthetics and usability of products may be improved for marketability and production. The use of industrial designers in a product development process may lead to added values by improved usability, lowered production costs and more appealing products. In industrial design, the product should be produced in an industrial way, however, some classic industrial designs are considered as much works of art as of engineering [6]. 'Industrial Engineering' is also defined as a branch of engineering dealing with the design, development, and implementation of integrated systems of humans, machines, and information resources to provide products and services. The industrial engineering requires an understanding of the physical, physiological, psychological, and other characteristics that govern and affect the performance of individuals and groups in working environments. The philosophy and motivation of the industrial engineering profession is to find the most efficient and effective methods, procedures, and processes for an operating system, and to seek continuous improvement. Industrial engineers, particularly those involved in manufacturing and related industries, work closely with management. Therefore, some understanding of organizational behaviour, finance, management, and related business principles and practices is needed [7].

As seen, although each of three "design" branches looks at the "product" in a different way, still they have several aspects in common, which if combined, can lead to "disaster-proof products". This idea is developed in the next section of the paper.

3 THE PROPOSED PROGRAM AND ITS DEVELOPMENT

As mentioned in the introduction, in order to have a disaster-proof building, it should be designed and constructed in such a way that can not only resist the forces imposed onto it because of the extreme natural phenomena such as earthquake, etc., but also should remain functional after the event. The minimum performance expected from a disaster-proof building is to be usable again by some, even extensive repairs. In the latter case, some parts of the building should have the capability of placing the residents safely to live or work for the restoration period. In terms of 'design', these features mean that:

1 The architectural form of the building, its orientation and location with respect to other neighbouring buildings, as well as the configuration of buildings' components and contents (non-structural elements, [9]) should be such that the effects of the natural hazardous event on these components and elements become minimal.

2 The weight of the building and its content should be minimal to minimize the structure's weight and construction as well as several other costs (for hurricane the heavy weight might seem helpful, however, it can be shown that there are better ways for making the building safe against hurricanes.)

3 The structural specifications of the building and its components, including type of materials and their specifications, structural system, structural elements and their sizes, connections, etc. should be such to experience no damage, or just limited damage which is repairable in reasonable time period.

4 The non-structural elements of the buildings, including its architectural appendages, mechanical and electrical facilities, and equipments, should be architecturally and structurally designed for the effects of the hazardous event.

In addition to the above four design specifications, which are related to architects (provided that they have 'hazard resistant design' knowledge) and structural engineers, the construction work of the building should also be pre-planned, so the whole process of construction can be done in the minimum possible time to reduce the costs. Additionally, the quality of the construction and its compliance with the design should be assured to maximize the owner's confidence. The latter can benefit best from industrial engineering knowledge.

In the current practice of building projects, particularly in developing countries, at first the architectural design is done by architects, which is not necessarily appropriate for withstanding against the disastrous events. Then the structural design is performed independently by structural engineers, during which the non-structural architectural elements are not designed structurally. Finally, the electrical and mechanical designs are done by the corresponding designers just for the electrical and/or mechanical operation, and not for structural stability against disastrous events. Clearly, this practice results in a building, which may have: a) inappropriate architectural features for disastrous events, b) un-economic structural design, and c) un-safe architectural, electrical, and mechanical elements. Obviously, such a building is not disaster-proof at all. What can make the building a disaster-proof one is a combined design. Clearly, such a design can not be accomplished by one person. However, a person who is quite familiar with all the requirements for achieving the aforementioned building specifications for being disaster-proof, can lead the design team, check the construction plan and supervise the construction process to be optimum. Such an expert should have a multi-disciplinary mind, and possess sufficient knowledge of all design aspects. Based on the above discussion, some graduates of architecture with multi-disciplinary minds, can continue their studies for a 'master degree in architecture', which can be named "Master of Disaster-Proof Design and Development". In this program, a combination of courses, selected form the three aforementioned branches of design and engineering, enriched by some new courses for 'hazard resistant design', shown in Table 3, are taught.

Table 3: Proposed courses for "Master of Disaster-Proof Design and Development"

Courses From Architectural and Structural Engineering	**Courses From Industrial Engineering**	**Proposed Additional Courses**
Mathematics (calculus, linear algebra, probability and statistics) / Building materials / HVAC systems / Power and lighting systems / Plumbing and piping systems /	Financial Engineering / Warehousing and Material Handling / Process engineering / Quality control / Leadership in engineering / Ergonomics	Fundamentals of earthquake-, hurricane- , etc. resistant design / Construction technologies / Project Management / **Senior Design Project** / Electives

Descriptions of courses listed in Table 3 are available in various academic sources, however, in case of ‘hazard resistant design’ courses, more explanations are necessary. The fundamentals of ‘earthquake resistant design’ can be found in the authors’ hand-outs for the course presently being taught in Tehran University. The senior design project indicated by bold letters in the third column of Table 3 can be the most important course of the program, in which all the gained knowledge should be employed by students in a comprehensive and multi-aspect design work.

4 CONCLUSIONS AND RECOMMENDATIONS

Based on the presented issues and proposed courses, it can be stated that holding the suggested Master Degrees Program in Architecture is quite feasible in many universities, and regarding the necessity of having disaster-proof and economic buildings, particularly in developing countries, these programs should be initiated and developed as soon as possible. Furthermore, planning to hold such an academic program can lead to some professional developments in design, such as earthquake- and hurricane resistant design and so on in architecture as well as urban planning and design. Inclusion of other disastrous events, such as heavy snow fall, big size hails, etc., can be considered in the proposed program as the supplementary part of the work. The graduates of the proposed program can be employed in large scale civil development programs as well as projects which includes important or special buildings. Finally, the suggested combination of three design fields may result in some innovative design approaches, which may be beneficial to all these three fields.

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