Journal of Science and Technology vol. 13
ISSN 1605 – 427X
Engineering and Computer Sciences (E C S No. 1)
www.sustech.edu

June 2012

The Integration of Structural Knowledge in Studio Design Projects: An Assessment Curriculum in: Architecture Course in SUST

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Abstract: This study is concerned with the effective structures curriculum content in architectural department and the teaching methods that lead to a better integration of architectural concepts with structural solutions for architectural students' design application. It aims at identifying a better course content and teaching method to improve the students' design capability to integrate structure principles learned in lecture sessions and architectural design studio, where the principles are being applied. Respondents are B.Sc. (Arch) students from year 1 to year 5 of the academic year 2008/2009 in the Department of Architecture, College of Engineering, Sudan University of Science and Technology. Descriptive statistic and ANOVA test were employed to attain the stated objectives. The study examined the course content, instruction modes and method of teaching structures subject and investigated the learning outcome with design studio through students' performance and perception in integrating structural knowledge in their design project. Semi-structured interviews were conducted with the design studio coordinators and structure lecturers. The results revealed that 77.8% of respondents faced difficulty in integrating structural knowledge into their design of the project in the studio. Although they found that structure subject interesting but the teaching methods used in its classes did not satisfy their learning needs. Furthermore, the subject content is full of mathematical jargons which relate more to engineers than architects.

***Keywords**: architectural education, teaching method, architectural design, structural knowledge, integration.*

مستخلص

يهدف البحث المحتوي في هذه الدراسة لتعيين افضل مكونات وطريقه تدريس لمقرر الانشاءات لتطوير وتحسين التكامل بين مادتي الانشاءات والتصميم المعماري. استخدمت في الدراسه وسيله الاستبيان لاستقراء اراء طلاب السنوات الدراسية من الاولي وحتي الخامسه خلال العام الدراسي 2009\ 2008

في مستوي البكالوريوس لقسم العمارة في جامعة السودان للعلوم والتكنولوجيا بالاضافه للمقابلات الشخصيه مع اساتذة الانشاءات والتصميم المعماري في ذات القسم. وقد استخدمت الاحصاءات الوصفيه وباختيار ANOVA للوصول للاهداف المرجوة. اظهرت نتائج الدراسه ان 77.8% من الطلاب يواجهون صعوبه الاستفادة من المعلومات الانشائية في تصاميمهم المعماريه , كما اظهرت الدراسة " رغم استمتاع الطلاب بمادة الانشاءات " ان الطريقة التي تدرس بها المادة لاتلبي رغباتهم كما يروا ان المقرر يعج بالمعادلات الرياضية ذات الارتباط الوثيق بالهندسه اكثر من العمارة.

افضت الدراسة الي مقترحات عمليه للاستيفاده من مقرر الانشاءات في التصميم المعماري من حيث محتويات المادة وطريقه تدريسها لخلق افضل ارتباط ممكن بين مقرر الانشاءات ومشاريع التصميم المعماري دون تغيير كبير في محتوي المادة.

Introduction

It is commonly known that in all architecture schools, studio is the core and back bone of architectural education. Where design is taught as a domain subject. However, all technical subjects are taught in order to serve and enhance the quality of design with the current industrial growth of building technology, architectural education should advance in parallel and must provide sufficient qualitative knowledge, particularly that one concerning technical knowledge that assist architectural students to meet 21st century expectations for a sustainable environment. As suppliers and transmitters of architectural education, academicians and practitioners in the field are responsible for its advancement.

Universities as a producer of future architects have not developed curriculum for building technology to suit that revolution [(1)]. Sudan University of Science and Technology (SUST) as the largest technological university in Sudan has continuously persuades updating curricula in all fields, and this helped propel SUST to be internationally known in areas of applied and life sciences, accordingly, SUST continuously rises and now its ranks as No 57 among the top universities in Africa.

In line with this wide inspiration, SUST on the steps of achieving an international recognition, the Department of Architecture Faculty of Engineering is on the process of developing and assessing its architectural education and curriculum in terms of instructional mode and methods of teaching in order to achieve these international accreditations.

In general, the main principle of architectural education is the creativity (imagination) that must be controlled and organized according to rules and regulations to achieve the realistic requirements, which may only be obtained through practicality of building structures and construction. Structural correctness is essential to every creative architecture, as stated by Vitruvius, the first Roman architect in ancient Rome that Creativity in architecture design and structural solution seems to have a symbiotic relationship; both are inseparable because each has an effect on the function of the other. *"Architecture should have firmness (structure permanence) commodity (function) and delight (aesthetic)"* [(2).] The flexibility of the modern structural materials should help to inspire architects to invent forms that are more creative and as a result, the building process requires more than drawing and other legal documents such as specifications, construction details and selection of specific structural system which should be suitable to both the building form and the function. In a traditional construction contract, the architect will be the leader of the building consultancy team and therefore he/she shall have some degree of knowledge of other disciplines specially structures subjects to gain the respect from the consultants, contractors and indirectly the clients.

Basically, Structure is a functional element that enables the building to stand up, carry the entire load and transport the load to the ground through the foundation [(3)].

Therefore, understanding structures subjects is absolutely essential to the education of the architect, but the subject contents, methods and teaching tools currently carried out in SUST were developed outside the architecture discipline and borrowed from engineering programs. This has lead to students design project that lean heavily on forms and simple structure solutions or may not express any structure integration at all in their design proposal.

Based on the above issue, the main objective of this study was to suggest a teaching methodology for structures a subject that leads to better integration of structural knowledge within the studio design. That is to suggest a methodology for teaching structural courses to make the structure class more understandable and effective language to architectural students.

A review of the literature proved that, the integration between design and the technical subjects can only be upgraded and emphasised by the collaboration between structures class and the studio design [4]. Architectural students are visual learners, so the visualization enhances their imagination capabilities [5]. Thus, enhances their structural intuition. In order to achieve such collaboration goal, the visual approach in teaching is the appropriate method for architectural students.

In fact, to enhance such intuition, it is vital for them to see or imagine how the building form behave under loads rather than how to calculate their loads. So they can feel when a system is not quite correct or when a structural member is not efficient. Thus architectural students need to understand the structural system. Structural education has been addressed by masters in the field in 1960s - 1970s such as Corkill [6] who emphasized the visual approach and explained structural principles through examples from nature. Therefore, Salvadori [7] had the talent of simplifying not only structure but mathematics as well.

A number of pioneers such as Moore [8], Gauld [9] wrote and published effective books which upgrade the integration level. At the same time a number of computer programmes were created for the same purpose to simplify structures subject for better integration. University of Buffalo (UB) addressed this unwanted phenomenon in research collaboration between a few universities in the USA such as State University of New York and University of Oregon, Utah; led by University of Buffalo's. Vassigh [9] planted the primary seed of the project by developing methods of teaching structures to architectural student. With the association of a number of professors, he developed a project entitled "learning structure through advanced media: A comprehensive approach to teaching structures using multimedia", which exposes the structure topics in an innovative instructional delivery system that utilizes high quality digital graphics, animation and audio narration to demonstrate the structural principles, also supporting it with structures learning centre website which provide a learning venue composed of terms, concepts and the instructional support relevant to structural analysis and design for architecture students [10]. See Figure 1.

A project related to teaching called "Technology Initiative" carried out by Professor Martini [11] from the University of Virginia (UV) also explored similar problems. The project's objective was leaning towards ability to learn about structure through informed observation and to manipulate structure to enhance architectural intent through digital images and online website. See Figure 2.

The SAP 2000 programme is integrated software for structural analysis and design. It provides analysis of three-dimensional static and dynamic finite elements analysis and design of structure [12]. So far, SAP 2000 has proven itself to be the most incorporated, productive and practical program at the studying level. It is powered by SAP FIRE CSI's Blazing New Analytical Engine [13], Figure 3. Other efficient programmes such as Elabs and Stand 3 can be used. The world is developing at an increasingly rapid rate, especially in terms of building construction and structural technology.

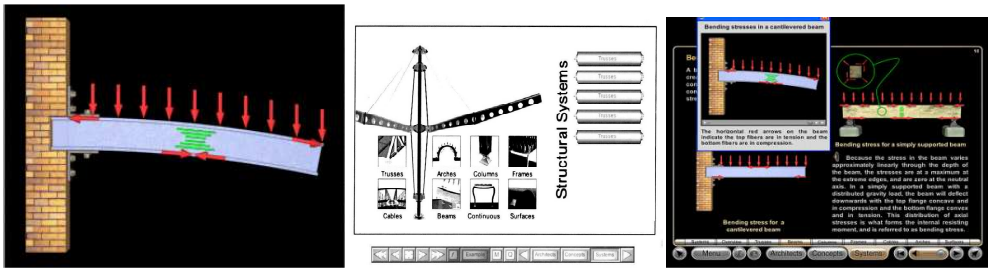

Figure.1: Structural topics in digital graphics, animation and audio narration: Source: UB project 2005.

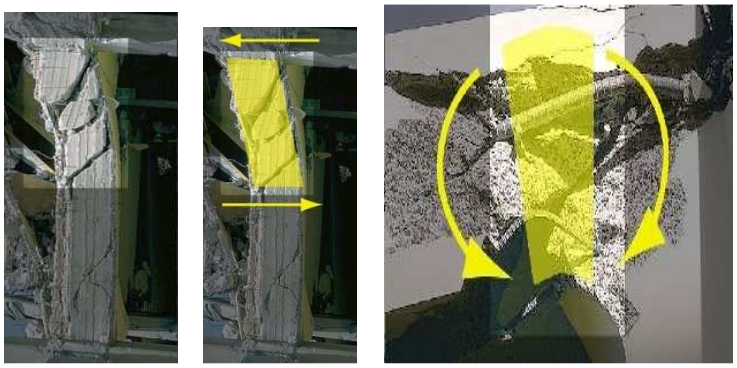

Figure 2: Real life digital images to explain structure behaviour:
Source: UV project 1996.

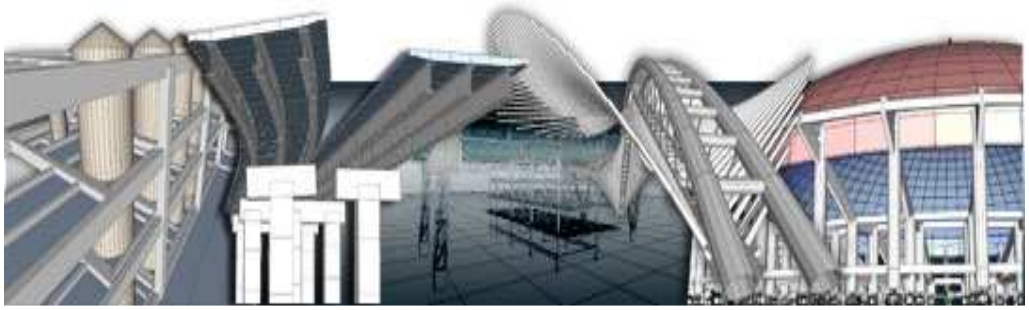

Figure 3: SAP 2000 Software
(Source: SAP 2000 NONLINEAR Version 7.1)

Therefore, the discipline of architecture has an inevitable influence on the creation and development of a humane environment.

Thus, it is vital for the architectural department in SUST as many other architectural schools are facing the same structures teaching problem. From personal observation as SUST architectural teaching staff, the ability to integrate the structural components are not suitably reflected in conceptual design and practice as most of the structural solutions selected are mainly of reinforced concrete cast in-situ of post and beam concept, and any external façade is an added-on feature which is not integrated with the whole building structural design.

The structural solution is complicated and generally confusing and misguided. Many of the proposals failed to establish clear relationship to the total act of architectural design. In fact, few students did not manage to complete the whole architectural course in the 5 years time, due to their failure in the structural subject. Architectural education was recommended by international organizations and objectives of suitably convey the principles and assimilated by students. It is important to equip with teaching methods that provide sufficient qualitative institutions architecture to be properly knowledge regarding technical aspects which imbued the students need. Students would then be able to understand their design in a comprehensive manner which integrates the aesthetic, artistic, humanistic, scientific and technology holistically.

Materials and Methods

An initial survey was done during 2008/2009 to investigate this integration problem. Respondents from the 1st year to the 5th year were not able to integrate structures in their design; the study focused on the course objectives and method of teaching structure courses and integration in the studio design from the 1st year to the 5th year (academic years 2008-09).

The primary source of this study was a case study of the curriculum of department of architecture at SUST. Moreover, the methods of teaching structural subjects in department of architecture were studied for the purpose of finding the appropriate methods which can lead to better integration. The secondary sources for this study were based on literature reviews and materials that were obtained from books, journals, magazines, conferences, and the Internet.

The methodologies used to search for better method of teaching structures courses were questionnaires and interviews gathered from SUST from first to fifth year architectural students. A total number of 140 questionnaires were handed to the students and 125 feedbacks were obtained which was 89% of the total response rate. Respondents were asked to provide definite yes or no answers to part one question which asked about the structures in design projects.

Results are students' awareness on their weakness on the understanding of the structural subjects and also the poor integration of the analysed using the SPSS statistical program.

Results and Discussion

Generally, the strength of the architectural programs lies in the design studios which occupy central component of the curriculum with the emphasis on the design /environment /social/cultural technical aspect and tectonic as well. The department offers less than 15% of structures related classes such as construction and building analysis and design in the curriculum. Design studio as the core subjects occupy 33% of the curriculum. See Table 1.

Many aspects pertaining to the students capabilities' of integrating structural knowledge with design in the study area

were discussed. These include: why architectural students having difficulties in integrating structural knowledge into their design, the students capabilities' of integrating structural knowledge, Tables 2 and 3, chart 1. Tables 4 - 6 show the percentages of the student's ability in integrating structural solutions, statistical parameter and the factors influencing their creativity. Chart 2 also presents the respondents opinions on how structures and design classes can be modified.

Table 1: SUST curriculum for studio design and structure course objectives and learning outcome

Design studio		Structure course	
Objective of course	Learning outcome	Objective of course	Learning outcome
Sem.1, yr 1: Design studio1 –		No structure class	
Introduce basic principles of architectural drawing as tool of communication. Master drafting skills (manually)	ability for observation and understanding the architectural symbol (architectural language) - skill and ability for using graphics as a tool of communication and managing tasks within a given framework.		
Sem.2, yr 1: Design studio11		No structure class	
Introduce student to design and definition of design, the role of concepts in architectural design	Introduction to form and function ,circulation and contex		
Sem.1, yr 2: Design studio11		Structural mechanics1	
Concepts and concepts making and development process. -Presentation of architectural work (manually). Ability to imagine and translate design idea into 3D models.	-Understand the role of form, function, circulation and context in architectural design and acquire ability to manipulate them. Ability to design simple building and demonstrate an understanding of selected issues that clarify interrelationships of cultural aspects, human behaviour, and the built environment. Ability to translate information into visual/and formal media	Introduction to the structural mechanics. Analysis of simple structural elements.	Ability to understand the engineering calculations and analysis simple structural elements.
Sem.2, yr2, Design studio 1		Structural mechanics II	
- Focus on space and form - Use analytical and conceptual approach to design - Introduce site analysis and design Consideration for structure element and material and construction technology in design.	To Improve the ability for analysis and conception in design and demonstrate an ability to translate behavioral information into architectural forms - Improve space and form organization skills in design. Understand site design principles and develop the ability to undertake site design. The role of structure and construction material and technology.	To develop an understanding of the place of structural mechanics in architecture, study the characteristics and uses of principle structural material-timber, steel, concrete and glass	Ability to understand the important place of structure in architectural world, the structural material characteristic.

Sem.1, yr3, Design studio V-		Structural Design 1	
- to develop the candidate capability in connecting the analysis and the general spaces to create good design - to develop the candidate capabilities towards integrated design, design problem solving and decision making process.	-Understand the proficiency in architectural design. - ability to connect the data analysis and the general spaces to create good design - Be able to read integrated design - Ability toward form follow function	-Introduction to structural behavior and stability of structure. -Introduction to reinforce concrete. -Design of simple elements made of R.C	1- Understand the essences of stability in structural system and the analysis and design of different structural systems. 2- Ability to analyse and design masonry walls and appreciate the structural capability of concrete.
Sem.2,yr3, Design StudioV1		No structure class	
- to develop the candidate capability in connecting the analysis and the general spaces to create suitable design -to develop and upgrade the candidate skills towards the correct methods in collecting and analysing scientific data. - to develop the candidate capabilities towards integrated design and good design follow function.	-capability in connecting the analysis and the general spaces to create suitable design -Ability to collect data and analyze it. -Ability to integrate design with other disciplines. -Able to design good design principles of form follow function.		
Sem.1, yr4, Design studio V-		Structural Design II	
- to develop the candidate capability in connecting the analysis and the general spaces to create good design - Proficiency in architectural design problem solving and decision making process. - To develop the candidate capabilities towards integrated design, problem solving & decision making process.	-Understand the proficiency in architectural design. - ability to connect the data analysis and the general spaces to create good design - Be able to read integrated design - Ability toward form follow function	-Introduction to structural behaviour and stability of structure. - Designs of simple elements made of steel	1- Understand the essences of stability in structural system and the analysis and design of different structural systems. 2- Ability to undertake analysis and design of masonry walls and appreciation the structural capability of concrete.

Source: department of architecture (Sudan University) session 2008/2009 [(14)].

Table 2: SUST student's the ability to integrate Structural knowledge into design

SUST GROUP	*SD*	Mean	Percentage
1st Year	0.332	1.88	76%
2nd Year	0.44	1.76	73.1%
3rd Year	0.44	1.76	76%
4th Year	0.47	1.69	69.2%
5th Year	0.73	1.96	80%

N= 126 (1st Year n = 25, 2nd Year n = 25, 3rd Year = 25, 4th Year = 26, 5th Year = 25) SD: Standard Deviation.

Table 3: Ability to integrate structural knowledge into design (ANOVA)

SUST GROUP	P-Value	F	Mean Square	df	Sum of Squares
Between Groups	0.341	1.139	0.287	6	1.149
Within Groups			0.252	120	30.243
Total				126	31.392

N= 126 (1st Year n = 25, 2nd Year n = 25, 3rd Year = 25, 4th Year = 26, 5th Year = 25)

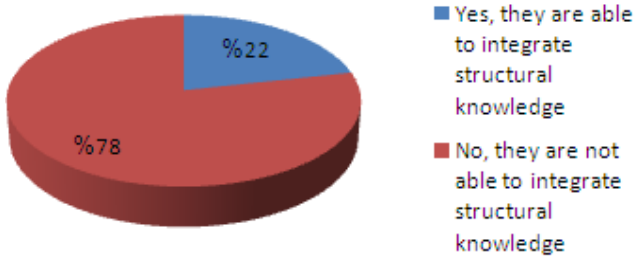

Chart 1: SUST Students' perception towards ability to integrate structural knowledge into design (as shown in Table 3)

Table 4: Ability to integrate structural knowledge in design studio

SUST Group		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		27	21.4	21.4	21.4
		98	77.8	77.8	99.2
		1	0.8	0.8	100.0
	Total	126	100.0	100.0	

The discussion is based mainly on answering the main questions of the questionnaire as follows:

Why architectural students have difficulties in integrating structural knowledge into their design? The answer is due to three basic problems: the structures curriculum, the teaching methods and the instructional tools; which were borrowed from the engineering course and this does not satisfy the architectural students' need.

The methodology in teaching structure is subdivided and dismalness a structure into extremely small subcomponents using an arcane abstract of symbolic notation. The focus is on quantity analysis using mathematical formulae and notations. The lack of integration of structural knowledge in student's design applications during the preliminary stages has become one of the major design concerns should this 'lack of concern attitude' continues when these students later become practicing architects. A good architectural designer should be aware that the structural systems affect the aesthetic part of his/her design. Structure integration should be considered in the preliminary stage of design synthesis because of the influence it will have upon the design (Buffalo, Utah, Florida, Oregon, and Virginia Universities).

What about the Students Capabilities' of Integrating Structural Knowledge.

Table 2 shows the details of the mean for each year of the 5 years architecture curriculum. There was no tangible difference in the mean. Although the logical projected result is a decrease in disability over the years, it did increase in Year 5. Perception levels fell between 1.88 for year 1 and 1.76 for Year 2 and 3 while for Years 4 and 5 it was 1.69 and 1.96, respectively, which was higher than the initial year mean rating. This shows that there is no difference in students' perceptions towards the integration of structural knowledge in design. For year 1 this result was expected because they were architectural novices and has yet to take the structure courses.

In year 2 the structures course only exposes the basics of structural mechanics without any interaction with studio design. In year 3 there is a little bit connection with studio design but not sufficient enough. In year 3 the core lies in the integration of the technical aspects and,

Thus, was expected to be higher than the pervious years, however, the result was similar in year 2.

Based on SUST curriculum analysis, the structures class covers mostly theoretical topics about the basic structural mechanics and analysing very simple structures while the third year studio projects are more complicated. As declared by the third year SUST studio coordinator, there is a gap between the studio assignment projects and structure classes' topic. The assignment project is more advanced than structures class lesson. The mechanical knowledge provided is far from the students' need. They need a kind of structural knowledge that can assist them to develop their design projects. This idea is supported by Ozmen [13], who ascertained the lack of coordination and communication between studio projects and structure classes. The results for Years 4 and 5 are also similar to the previous years. Logically, the students should know more about the integration as they are in their final years. Logically, the students should know more about the integration as they are in their final years. Unfortunately, there is no notable difference between the five groups as shown in Table 2.

What Factors Influence the Student's Creativity in Structural Solutions? with refer to Table 3 it can be Seen that these is no significant differences between the five groups, and the P- value = 0.341, F= 1.139 showed no significant differences, meaning that the respondents did not possess any variety of integration ability.

Hence, 98 (77.8%) of the respondents in this group had difficulties in integrating structural knowledge in design Table 4. Chart 3 below, shows 32% of respondent are not creative in the structure solution due to lack of understanding of structural application. This response revealed that they need to know about the structural application rather than structural calculations.

Similar to studio teaching structure subject should also be taught by learning, doing, observation and critical thinking instead of by listening, computing the mathematical formulae to engage interest, innovation and confident of the student. Architecture is very subjective but the solution to architecture is the reasonableness of decision making based on fiction (concept and aesthetic) and factual (technical knowledge, human behaviour/sociology and psychology) and ability to make reasonable and acceptable argument for the decision made Table 6.

On improvement of teaching and learning method, refer to Chart 2 above, 43% of the respondent suggested that studio project should be integrated with other courses, and 18% of them suggested more case studies on structure of existing building. These responses indirectly suggest how the assignment/s in structure course 3, semester 1 can be carried out. The first assignment may ask the student to analyse a structure of a selected existing building of similar capacity with the design studio assignment.

The analysis may identify the structure elements load and selected members sizing based on rules of thumb and some basic calculation formulae. The second assignment should be related to their design project where they might suggest options for their designed building structure and the aesthetic of structure rather than calculation of members. To raise the level of confidence, the students may need to justify their reasoning behind this selection.

Table 5: Mean and standard deviation for Q6, Q8, Q9 and Q

	SUST Group	When Do You Integrate Structure With Your Design Concepts	How Do You Start Composing The Building Form	Student May Not Be Creative In Structure Solution	In Design Studio Are You Able To Integrate Structural Knowledge Into Design
Valid	N	126	126	126	126
Missing		0	0	0	0
	Mean	1.80	2.66	3.96	1.81
	Std. Deviation	.620	1.69	1.556	0.501
100	Percentiles	3.00	5.00	6.00	5.00

Table 6: Factors affecting students' creativity in integration of structures- ANOVA

SUST GROUPS Year 1 to 5	P-Value	F	Mean Square	df	Sum of Squares
Between Groups	0.158	1.683	4.021	6	16.085
Within Groups			2.389	120	286.715
Total				124	302.800

N= 126 (1st Year n = 25, 2nd Year n = 25, 3rd Year = 25, 4th Year = 26, 5th Year = 25)

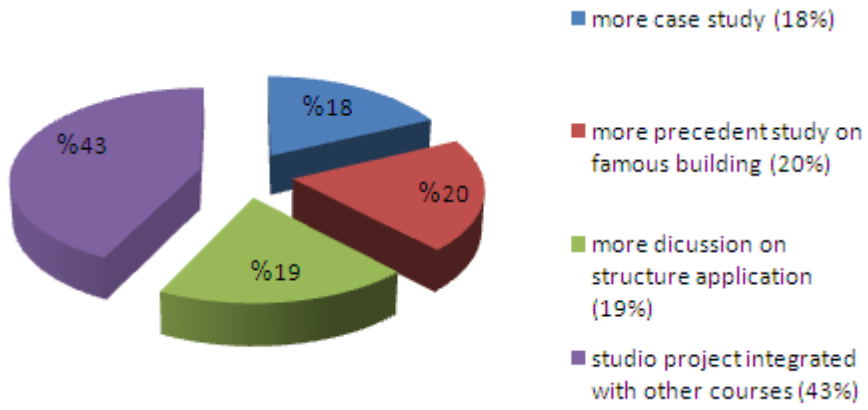

Chart 2: Respondent suggestions to modify structure class

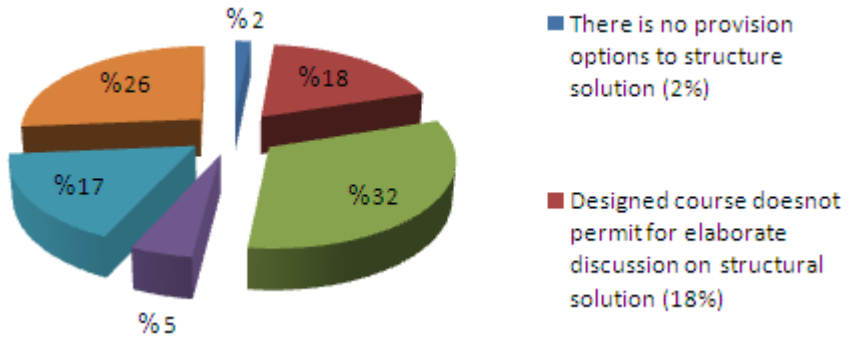

Chart 3: SUST Students perception towards factors influencing creativity in structure solution

In the earlier structure subjects in year 2, 3 and 4 the assignment may take previous design from the studio and analyse the structure component. Built physical models of the structure elements will enable students to view their project based on structures alone. They may be asked to justify the reason for selection of the structure based on rules of thumb and basic calculations as part of the assignment. Thus the structure subjects will always integrate with studio design which will increase the confident level and understanding of structure design.

It may also be suggested that the students' lack of interest in structural subject is due to the traditional method of teaching which may be inappropriate in terms of the advanced structural system. Architecture students may need to visualise how the structure elements work because their understanding ability in the early learning stage is mostly depend on visual and oral communication rather than imagination.

The advancement of computer soft wares has changed the students' approach to learning. Therefore, the educators might also need to look at how to raise interest in structure subject by using virtual soft wares. If 'Barbie' can change dress in the Barbie Doll game may be the buildings should also be given the chance for options of structure to open up the flexibility in choosing types of structure. The structure class content emphasizes more on the structural behaviour rather than the structural mechanics.

Structure systems should be taught as a space defining elements and integrate it with design project where students are required to provide structural actions relative to plans and sections based on their design.

Structural model for the design should be done in proper scale for testing and retesting to enable students to understand the relationship between structural pattern and strength, deformation and ways to resist it, and the effect of member shaping on overall configuration. The numerical and mathematical formula should be addressed minimally to clarify basics of static's.

Issues regarding structural application in design studio should be addressed in structure class rather than leaving them to the studio master to handle in the design studio. A physical model would enable the student to visualise the structure elements clearly rather than in the architectural model that shows more of the space planning and the materials selected. Another method of teaching approach is learning from precedent. Students like to flip through magazine or search the internet for sophisticated looking building without understanding the building system. Structural precedent study of these buildings should also be looked into in the structural class assignment. This will enable students to have better understanding of the building structure system. The explorative nature should not be kerbed because of the disability to calculate the forces and sizes of members but instead the students should be allowed to give rational ideas on how the supportive members may look like based on reasoning derived from their design concept. In actual practice the calculations of structural members will be done by the structural engineers while the architect proposed the image of the structure. The sizes and proportion of the structural elements are a compromise between the actual sizes required by the structural engineer and the aesthetic and proportion of the building through the architect's artistic vision.

The design studio is the main subject of the architectural education, thus, it is fundamentally that the studio assignments should be integrated and taken as cross referencing throughout the other technical classes to enhance the students understanding of a holistic design. By addressing the structure at an early stage of the design the student's would have a better perception on integrating the structure with design but also able to provide proposal to the building construction system. By creating interest in structure and technology of buildings in the students through analytical games and quizzes and options in structure selection will make the students open-up to varieties of design to select and promote them to be more creative. As stated by Mitchell [15], "Architecture is no longer simply the play of masses in light. It now embraces the play of digital information in space", educators may need to look at computer soft wares to bridge the gap. Educators cannot deny the effects the computers have on the new generation, however, while the students appear more sophisticated in their approach to learning devices, the need and desire to understand basic structural-design concepts and theories remain virtually unchanged.

Conclusions:

In conclusion, based on questionnaire analysis, it was found that: 77.8% of the respondents in this study have difficulties in integrating the structural knowledge in the studio design. Moreover, 23.2% of the respondents are not creative in the structure solution due to lack of understanding of structural application. Furthermore, 34.3% of the respondents suggested an improvement methods based, mainly, on

case studies- computer soft wares and physical models and the given assignments.

The study recommends strong emphasis on the importance of structures in architecture-related occupations in all studio sessions, strong emphasis coordination and communication between structures classes and design studios, particularly, among studio projects and structural topics. Special effort should be given to make structures classes and assignments more exciting to attract and retain students' attention and interest by including Multimedia, emphasising the architectural module as guide to the structural module. Furthermore the study suggests regular assessment of structures courses in terms of teaching methods and course content to improve and ensure the integration ability.

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