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Teaching the Principles of Structural Design: Rethinking the Methods for Architecture Students

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Abstract
Structural design requires both knowledge of engineering and architecture. Engineers stick with the principles of physics by estimating the force conditions. However, architects are into the structural design from the aesthetical perspective. There are usually separate courses to teach both areas, but architecture students often fail to understand how they relate in the real life. This paper discusses the methods and the outcomes of two courses that are taught to the second and the third-year architecture students. In both courses, students were delivered lectures and the opportunity to design their unique structural design for a given sized volume. The paper outlines the methods of teaching the contemporary large span structural design and the methods of learning by modelling and sketching on the side of students.
Keywords: Structural Design; Structure for Architecture; Large-Span Buildings; Contemporary Design; Structural Aesthetics.

1. Introduction

With the beginning of 21st century, digitalisation of all kinds of knowledge in any field began to feel more evident. Architecture and construction sector were developed together accordingly and took the process of design and how-to-construct into the digital world. Today, there are unknown numbers of software used for the purpose of architectural design, visualisation, and rendering. Digital tools enable architects to design buildings they long dreamed of. In the professional business world, they know they necessarily cooperate with structural engineers. This is a significant cooperation because both disciplines have a visible impact on buildings, as one decides the conceptual language and the appearance character inside and outside, while the other decides how the building will stand and so how to construct on site phase by phase. In schools, both disciplines have their own education structure, but often taught separately that is lacking consideration of each other's mindset and approach towards design. For engineers, numerical estimations are usually sufficient to decide the structural system and components' sizes once they meet the limitations they are bind to. This is because engineers stick with the principles of physics by estimating the force conditions. However, for architects it is more complicated. It is a start from zero and a journey from inspirations to imaginations to make an idea real. Design process is a gradual development of an idea with a few back and forth; and preliminary structural design of buildings plays a significant role in the entire design. Having said that, architects are into the structural design from the aesthetical perspective. Sometimes, they like to expose the components and sometimes they envelop the system as they tend to diminish the structural effect and enhance the architectural aspects. Ünay and Özmen (2006) highlighted the specialisation of two disciplines as a disadvantage because architects deem structure solely a technical issue, whereas engineers began to see architects as design artists with no bother of principles and economic issues. Guthrie (2012) also wrote "Architecture and construction management students can often graduate with a weak foundation in structural engineering leaving them less than fully prepared to take on their future roles in industry". This problem is across the countries. The accumulation of knowledge increased sharply with the help of technology and professional awareness in the 21st century. Numerous simulation and animation programmes, new materials and new construction technologies, mechanical developments in HVAC systems, ecological concerns dealing with sustainability of buildings etc. are today among the topics taught in the schools of architecture, which makes the curriculum loader than that of two decades ago. Tzonis (2014a, 2014b) criticised the architectural education which he found 'poor quality' and the curriculums drowned in 'global', 'universal', 'core', 'regional' and 'local' titles. Undergraduate curriculum, thus, gathers all topics but often not perfectly that leaves some at a very preliminary level or in a very disintegrated way to the rest. Unfortunately, structural design courses suffer these issues.

Addressing the issue, a degree programme titled "Architectural Engineering" was established in the last years, particularly in the USA (e.g., in the California Polytechnic State University in San Luis Obispo), which is interdepartmental and mirrors the interaction in the industry (Guthrie, 2012). Nonetheless, changing the title of the discipline of architecture should not be the solution. Instead, as educators it is necessary to discuss the conventional methods in today's world. Statics and strength of materials and building analysis are the theoretical courses taught almost in all schools. However, they are often delivered by an engineer (Wetzel, 2012) and leave disintegrated to other departmental courses. Ünay and Özmen (2006) outlined the issues from the perspective of architecture students:

1. Students are unable to relate lecture courses to their design studio,
2. Students show less interest to lecture courses and deem as an independent part of their design education,
3. Students lack knowledge transfer from theoretical courses to design studio.

Similarly, Dhanorkar and Tarar (2017) also highlighted the problems in general:

1. Students struggle to understand formulas and mathematical equations in solving structural problems,
2. Students are often taught only simple beam and column structures, whereas inadequately taught of indeterminate structures, which are more complex,
3. Students separate structural courses from design courses, although instructors make effort to make easier to understand with graphics and illustrations.

Whitehead (2015) argues that the relationship between architecture and structure are inseparable in practice but taught separately in schools in terms of pedagogical approach. Ridgway (2000) also criticised the linear and chronological approach in education. For example, design studio is the skeleton of the whole curriculum, in which students are expected to blend all the knowledge they acquired through diverse theoretical courses. However, structural design often remains as a part that can be left to a later stage and arguably design studio lecturers often do not want to put pressure on students since they do not want to limit the design skills of students. This also returns to another problem that students begin to think structural design is not crucial since the marks are largely depends on their final architectural presentations. The problem of the gap between the theory and the practice also exists in the education of structural engineers that cause the lack of understanding each other's perspective in design when step into the professional world. However, as Ünay and Özmen (2006) wrote, "the architects of tomorrow should accept structural design well within their scope of responsibilities. This is not enough by itself. Architects should also be equipped with the skills and knowledge to carry out the necessary operations required to realize the structural design of their buildings".

In the architectural education, students visit their term project site to conduct their site analyses. In the history of architecture courses, they are usually taken to that specific building or area to view the features it holds and likely asked to sketch some interiors and exteriors. This action aims to build a bridge between their vision, memory, and hand-sketching skills. It is believed that only this way architecture students can fully absorb the knowledge of the course in the matter like a sponge. Despite knowing this, why would the structural courses be left only theoretical? Furthermore, architecture students get used to make models with the beginning of their first semester. It teaches them to see the model made in scale would make it easier for them to grasp the impact of design. Therefore, they tend to imagine and model in three dimensions (3D), unlike any other discipline. Accordingly, tasks of virtual modelling and handmade modelling increase the acquisition capacity of architecture students. Therefore, the argument for the past two decades was to adopt multiple mediums to teach topics to architecture students and the courses of the structural systems were in the stake to see how this multiple method could work, since it was understood that if it remained only theoretical mode, students would not grasp the topics and valued the courses less than other active learning-based courses.

Dhanorkar and Tarar (2017) introduced a model that uses human body postures to explain the states of tension, compression, torsion, cantilever, equilibrium, and centre of gravity. Ridgway (2000) rather established a phenomenological and building specific model with tutorials, workshops, site visits beside lectures. Shareef and Farivarsadri (2020) suggest a model to deliver technical courses. The model is a combination of problem-based learning, game-based learning, challenge-based learning, and constructivist approach. It leaves the course instructor only as a facilitator and students work in small groups (3-5 students), in which they exchange knowledge with each other. Walls (2016) explored the effect of multiple mediums of teaching he experimented with the final year engineering students. He utilised site visits, tutorials, workshops, 3d computer models, Mola systems and web videos along with theoretical lectures. He concluded that the students' capacity of understanding increased considerably, and particularly technology-based mediums had higher effect than hands-on activities and traditional lecturing. In the Iowa State University, structural design courses were reconfigured combining all of building technology related courses together and structured into one umbrella course sequence spread in five semesters, instead of delivering each one separately (Whitehead, 2015). Wetzel (2012) explained that the method of 1:1 scale building of a large span structural design applied in the Materiality course, taught in the second semester of a master programme in the Illinois Institute of Technology, were fruitful for students who participated the course that they achieved greater success in their third design studio. They brought this hands-on building method to the second-year design studio in the master programme as well with the positive outcomes from 188 students and 26 projects they developed. Alakavuk (2016) discussed the lack of integration of construction knowledge into design process for architecture students. She experimented a method to achieve the integration and titled the studio topic of third year students as "Redefining urban public spaces by Housing within the Context of Earthquake". It was aimed to introduce seismic design principles and earthquake resistant buildings. Students were asked to simply test their design through a simulation programme to see how their building analysis work to carry loads or fail. They were able to view how the sizes of columns and beams were crucial to withstand the forces. Öztaş and İpekçi (2015) experimented an integration model within the course of 'Structural Systems and Technology 1', taught to second year students, and the students were assigned to design 'Modelling a structural system – hanging object'. Students worked in groups, 5 in each, and they were asked to build a 1:1 scale model of their design and to write a report on the development process and difficulties in assembling the parts of their model. Öztaş and İpekçi (2015) surveyed the students and revealed that 61% thought function, form and structural system affect each other, and 20% thought that function, form, and structural system were respectively important in design process. Only 9% resulted that structural system affected form and function. On the other hand, visualisation tools should be chosen carefully as Ağırbaş (2020) argued the method of teaching construction knowledge through building information modelling (BIM) tools, and laid the drawbacks of doing such implementations:

1. Utilising BIM in architectural education could bring the lack of flexibility and hinder the creativity.
2. BIM could burden students' design education since it work with excessive technical content.
3. BIM mostly works perfect with standard geometries, but contemporary architecture is a difficult issue for an undergraduate student. In addition, students could skip the design sketching phase since BIM works with only certain objects.

Having said that, the outcomes of teaching BIM recognised Revit programme to the third-year architecture students under the course of computer aided design 2 resulted in the expected way. A survey in the end of the semester revealed that students found Revit helpful at learning construction science as 3,66 out of 5 scored and found useful also at understanding the nature of building components such as beams, floors, and stairs as 3,72 out of 5 scored (Ağırbaş, 2020).

In a four-year long curriculum, material and structural system-related courses take place from the first year to the third year. Unlike design studio in the architecture education, these courses do not have an established or one-size-fits-all structure to teach, unless it is kept only theoretical through semester. It depends on the instructor and how he/she establishes the teaching modes and communication with and between students. As seen in the examples, multiplication of teaching methods clearly increases students' capacity to learn and their interest. In addition, students in architecture gain experience and more skills to display digitally as they learn programmes through semesters. Hence, building an appropriate teaching model should be in line with the students' experience and skills. This is to say, adoption of various architectural graphic communications should be auxiliary, should not be or turn into the main goal if the subject in matter is different. For instance, teaching structural systems should not turn into the goal of teaching a specific software. This should be the practice of another course in line with its purpose. Because using digital tools for communication is different from learning them from zero. The curriculum structure should consider these needs and the number and titles of courses should address the appropriate flow of the development of group courses (e.g., history of architecture, building materials and computer aided design etc.).

In the Bursa Technical University (BTU), the Department of Architecture runs a four-year long curriculum (this applies to the standards of the Council of Higher Education in Turkey – YÖK) with eight semesters in total, two in each year. What differs the curriculum from the other universities' is the 7th semester, which is set up as a Sectoral Practice Training. Students spend their one entire semester in a private company/bureau or a public corporation /municipality. This experience is unique and valuable; but it means to share the courses that would normally take place in the 7th semester between the previous semesters and the ultimate one. As shown in Table 1, the structure-related subjects begin with the 2nd semester of the first year. *Statics and strength of materials* is a course delivered by a lecturer from the department of Civil Engineering. It has three contact hours per week. In the same semester, students start to learn digital tools such as technical drawing in AutoCAD, basic modelling in Sketchup, and board composition in Adobe Photoshop in the *Computer aided Design 1*, which has three contact hours per week as well. *Construction technology and materials 1* is the first structure related course and majority of the content focuses on building materials. This and the following courses have three contact hours per week. In the 3rd semester, students continue to develop their digital skills as they are taught ArchiCAD and basics of rendering in the *Computer aided Design 2, w*hich has also three contact hours. As a continue of Statics and strength of materials, *Structural Analysis* is delivered by the same instructor from the department of Civil Engineering. This course has two contact hours per week. *Construction technology and materials 2* focuses on foundations, walls and detailing of doors and windows. This course has drawing tasks at several stages. The 4th semester continues with *Construction technology and materials 3,* which focuses on architectural roofs and further detailing issues. The buildings physics, including topics of lumination, isolation, acoustics and so on are taught in the *Physical Environment Control*, which has two contact hours per week. *Construction technology and materials 4* is the last in the group and taught in the 5th semester.

Table 1. The curriculum structure – the first three year - of the Department of Architecture in Bursa Technical University (As collected from the Bologna System by Author).

	1.Semester Course Plan			
Course Code	**Course Name**	**T+A+L**	**Compulsory/Elective**	**ECTS**
ENG0101	Advanced English I	2+0+0	Compulsory	2
MAT0101	Mathematics	3+0+0	Compulsory	3
MIM0101	Introduction to Architectural Design and Professional Orientation	2+4+0	Compulsory	6
MIM0103	Architectural Presentation Techniques	2+2+0	Compulsory	4
MIM0105	Introduction to Art History and Culture	2+0+0	Compulsory	2
TUD0101	Turkish Language I	2+0+0	Compulsory	2
MIMTI-I	Technical Elective I (1.Type) (1 Course)	0+0+0	Elective	4
MIMTI-II	Technical Elective II (1.Type) (1 Course)	0+0+0	Elective	4
SOSI	Social Elective Course (1 Course)	0+0+0	Elective	3
			Total ECTS	**30**
	2.Semester Course Plan			
Course Code	**Course Name**	**T+A+L**	**Compulsory/Elective**	**ECTS**
ENG0102	Advanced English 2	2+0+0	Compulsory	2
MIM0100	Architectural Design Studio 1	4+4+0	Compulsory	8
MIM0102	Computer-Aided Design 1	1+2+0	Compulsory	3
MIM0104	History of Architecture 1	2+0+0	Compulsory	2
MIM0106	Statics and Strength of Materials	2+1+0	Compulsory	3
MIM0108	Construction Technology and Materials 1	1+2+0	Compulsory	3
TUD0102	Turkish Language II	2+0+0	Compulsory	2
MIMTII-I	Technical Elective III (1.Type) (1 Course)	0+0+0	Elective	4
SOSII	Social Elective II (1.Type) (1 Course)	0+0+0	Elective	3
			Total ECTS	**30**
	3.Semester Course Plan			
Course Code	**Course Name**	**T+A+L**	**Compulsory/Elective**	**ECTS**
AİT0201	Principles of Atatürk and History of Modern Turkey I	2+0+0	Compulsory	2
MIM0201	Architectural Design Studio 2	4+4+0	Compulsory	8
MIM0203	Professional English	2+0+0	Compulsory	2
MIM0205	Computer-Aided Design 2	1+2+0	Compulsory	3
MIM0207	Structural Analysis	2+0+0	Compulsory	2
MIM0209	History of Architecture 2	2+0+0	Compulsory	2
MIM0211	Construction Technology and Materials 2	1+2+0	Compulsory	3
MIMTIII-I	Technical Elective IV (1.Type) (1 Course)	0+0+0	Elective	4
MIMTIII-II	Technical Elective V (1. Type) (1 Course)	0+0+0	Elective	4
			Total ECTS	**30**
	4.Semester Course Plan			
Course Code	**Course Name**	**T+A+L**	**Compulsory/Elective**	**ECTS**
AİT0202	Principles of Atatürk and History of Modern Turkey 2	2+0+0	Compulsory	2
İSG0201	Occupational Health and Safety I	2+0+0	Compulsory	2
MIM0202	Architectural Design Studio 3	4+4+0	Compulsory	8
MIM0206	Building Typologies	2+0+0	Compulsory	2
MIM0208	History of Architecture 3	2+0+0	Compulsory	2
MIM0210	Construction Technology and Materials 3	1+2+0	Compulsory	3
MIM0212	Physical Environment Control	1+1+0	Compulsory	2
MIMIV-I	Technical Elective VI (1. Type) (1 Course)	0+0+0	Elective	4
MIMIV-II	Technical Elective VII (2. Type) (1 Course)	0+0+0	Elective	5
			Total ECTS	**30**
	5.Semester Course Plan			
Course Code	**Course Name**	**T+A+L**	**Compulsory/Elective**	**ECTS**
MIM0301	Architectural Design Studio 4	4+4+0	Compulsory	8
MIM0303	History of Architecture 4	2+0+0	Compulsory	2
MIM0305	Urban Planning and Urban Development Law	2+0+0	Compulsory	2
MIM0307	Analysing Historical Building	1+2+0	Compulsory	3
MIM0309	Industrial Design Studio	1+1+0	Compulsory	2
MIM0311	Construction Technology and Materials 4	1+2+0	Compulsory	3
MIM0313	Landscape Design	2+0+0	Compulsory	2
MIM0599	Internship I (20 days)	0+0+0	Compulsory	3
MIMTV-I	Technical Elective VIII (2.Type) (1 Course)	0+0+0	Elective	5
			Total ECTS	**30**
	6.Semester Course Plan			
Course Code	**Course Name**	**T+A+L**	**Compulsory/Elective**	**ECTS**
İSG0202	Occupational Health and Safety II	2+0+0	Compulsory	2
MIM0302	Architectural Design 5	4+4+0	Compulsory	8
MIM0304	Application Project 1	0+2+0	Compulsory	2
MIM0306	Conservation and Restoration	2+1+0	Compulsory	3
MIM0308	Urban Design Studio	1+2+0	Compulsory	3
MIM0310	Accessibility and Design for Everyone	2+0+0	Compulsory	2
MIM0312	Sustainable Design	2+0+0	Compulsory	3
MIM0314	Professional Ethics, Legal and Social Responsibility	2+0+0	Compulsory	2
MIMTVI-I	Technical Elective IX (2.Type) (1 Course)	0+0+0	Elective	5
			Total ECTS	**30**

Technical electives have a significant share in the curriculum that each semester students take one or two courses. There are two categories of technical electives. The first category consists more of auxiliary courses such as skecthing and painting, perspective, experimental model making, design methodology, design philosophy, user requirements etc. The courses in this category have two contact hours per week and count 4 credits. The courses in the second category are thematic and each has a detailed content for a specific subject. It includes courses such as room acoustics, fire saftey in buildings, modernism and post-modernism, architecture of republic period and etc. *Contemporary Structural Systems* is in the second category as well. The paper outlines the syllabus development and teaching methods adopted for *Contemporary Structural Systems* and *Construction technology and materials 4*. As the courses were delivered by the author, the paper discusses the outcomes, her experience, and observations, and brings further recommendations to enrich the perspectives in the literature.

2. Material and Methods

The subject courses of this paper are *Contemporary Structural Systems* and *Construction Technology and Materials 4*. The first was delivered to the second-year students in the Spring semester of 2019-2020 and in the Spring semester of 2020-2021. The latter was delivered to the third-year students in the Fall semester of 2020-2021 (Table 2). The academic calendar of each semester consists of 14 weeks and one additional week of mid-term examination. Final examination week and submission dates are exclusive to the calendar and takes place in two weeks.

Table 2. Info of the courses (By Author).

Course name	Year/term	Number of students	Year of students
Contemporary Structural Systems	2019-2020/Spring	42	2nd
Contemporary Structural Systems	2020-2021/Spring	49	2nd
Construction technology and materials 4	2020-2021/Fall	21	3rd

It is a must to report that with the outbreak of coronavirus pandemic in the world, all universities in Turkey went through a three week-long semester break. However, as the circumstances did not change, the Council of Higher Education in Turkey urged the universities to arrange the rest of the semester as online education. Since the architecture education has a studio-based core and hands-on activities even in the theoretical courses, this raised a few issues and hesitations regarding the course of the lectures. This period took place during the Contemporary Structural Systems in the 2019-2020 Spring semester. The issue is detailed under the following title. In this regard, the paper also highlights the input of distance learning or online teaching methods and discusses each course on its own merits. Other than the discussion parts, the evaluation of students' performances and interpretation of their works are from the author's point of view.

3. Contemporary Structural Systems

This course was opened as a technical elective for the first time in the Spring semester of 2019-2020. In total, 42 students enrolled and all of them were 2nd year students. This is because the 4th semester is the one, they start to take Category 2 technical elective courses. The course has no prerequisite. The course is divided into two parts and focused on teaching mainly large span structures and tall buildings and their structural configurations (Table 3). The overall syllabus includes the following subjects respectively in 15 weeks:

Table 3. The syllabus of Contemporary Structural Systems (By Author).

#WEEK	SUBJECT
1	Structural behaviour - Principles
2	Large span – Shell structures
3	Large span – Grid systems
4	Large span – Domes
5	Large span – Suspended structures
6	Large span – Tension (cable) structures
7	Large span – Folded plates
8	Large span – Tensegrity systems
9	Large span – Stadiums
10	Midterm exam
11	Tall buildings – General titles
12	Tall buildings – Structural systems
13	Tall buildings – Exoskeletons
14	Tall buildings – Students' presentations
15	Tall buildings – Students' presentations

3.1 Contemporary Structural Systems: 2019-2020/Spring

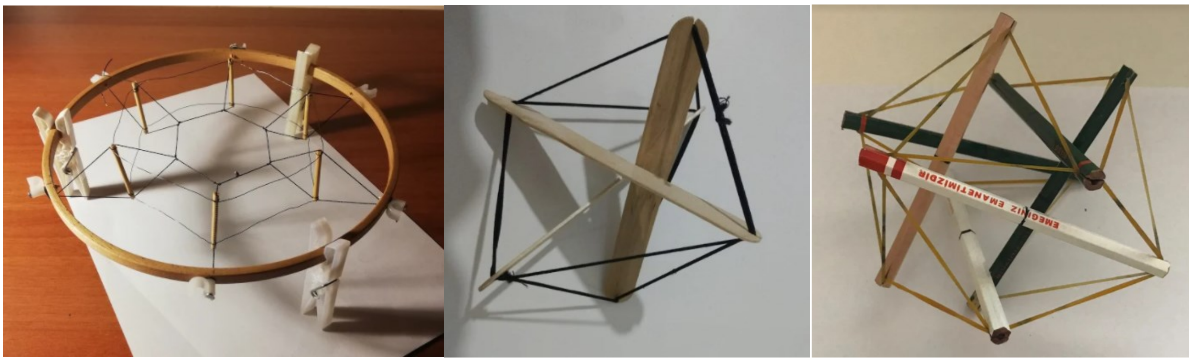
The semester began normally and continued for six weeks until 13th March 2020. From 16th March 2020, the Council declared a three week-long semester break, leaving the final decision at a later stage. During the six weeks, students were delivered theoretical lectures and handouts of semester plan, which included studio-based group works (model making for domes and tension structures) and parametric façade design by learning Rhinoceros. Since the school laboratory did not have the license yet, all students were assisted to set up the programme on their laptops. The students were planned to take two research tasks by working in groups as well. One was to research a specific building and the other was to research an architect who had projects with outstanding structural design. The list of both can be found in Table 4. Students had the opportunity to pick the one they like to research as the groups were assigned in the first few weeks. However, with the suspension of the semester, the weekly plan needed to be updated. The Council declared the education in the universities had to carry on via online platforms for the rest of the semester. Accordingly, the BTU scheduled the semester to continue after 6th April 2020 and finish on 29th May 2020, which covered the eight weeks after the break.

Table 4. The list of to-research given in the Contemporary Structural Systems (By Author).

#	Architect	Building
1	Frei Otto	World Trade Centre (old towers)
2	Felix Candela	Petronas Tower
3	Oscar Niemeyer	Willis Tower, a.k.a. Sears Tower
4	Pier Luigi Nervi	Turning Torso
5	Buckminster Fuller	Beijing National Stadium
6	Shigeru Ban	The Shard
7	Heinz Isler	Shanghai World Financial Centre
8	Eero Saarinen	Bank of China
9	Santiago Calatrava	Absolute Towers
10	Zaha Hadid	CCTV Headquarters
11	Jurgen Mayer	Nakagin Capsule
12	Frank Gehry	Shanghai Tower
13	Thomas Herzog	Pearl River Tower
14	I.M.Pei	Leeza Soho Tower
15	Renzo Piano	HSBC Hong Kong
16	Richard Rogers	Hearst Tower
17	Norman Foster	Morpheus Hotel Tower
18	Ma Yansong	Jin Mao Tower
19	Moshe Safdi	International Commerce Centre
20	Daniel Libeskind	Allianz Arena
21	Rem Koolhaas	Madrid Barajas Terminal 4

The course began to run through Google Classroom platform. All assignments and exams were completed through this platform. Theoretical lectures were recorded via Vidyard and the links were shared in the Classroom page. The students were to submit their research tasks by 14th and 21st April 2020 respectively, considering the semester break of three weeks. They were asked to prepare a board size of A0 (which was aimed to hold an exhibition under normal circumstances) and a MS PowerPoint presentation to share online with their classmates. As the lectures continued online, the students were asked to build a simple model in sizes of 20*20*20 cm to understand tensegrity structures, and upload the photographs taken from clear angles to explain the structure. In fact, model making was a challenge under such circumstances because not all students were able to find appropriate materials considering some lived in rural areas. In this regard, students were given options of materials they could easily reach and not necessarily to buy, such as pencils, fishing lines, short rulers, chopsticks etc. 32 out of 42 submitted their models. Some students were severely influenced by the examples given in the lecture, and some students were able to stabilise a building-like structure as seen in the first image in Figure 1 (a).

Following the week, the students were delivered pneumatic structures, they were assigned to a model making task again to same sizes. This was a more difficult task since it requires blowing air inside the components. The students were advised to use materials such as balloons, fabric cords or plastic cords, sticks and so on. 26 out of 42 submitted their models. It was understood that some students did not understand the structure stood on components which gained stability through air inflation, since some made models only stands with posts and fabric or balloon only hold on it, shown in Figure 1 (b).



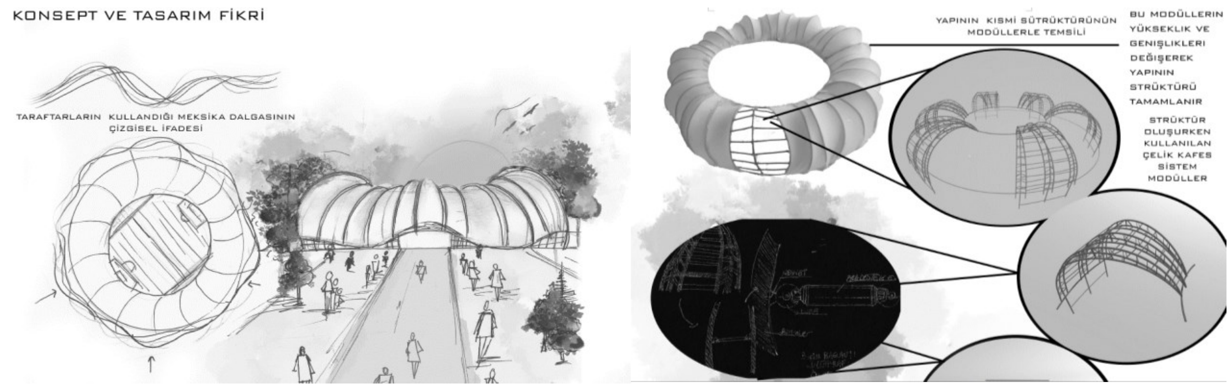
(a)

Figure 1. (a) Examples of student works for tensegrity structures. The first model is design as a structure, whereas the two are very similar to the theoretical displays; (b) Examples of student works for pneumatic structures. The first two models are appropriate, whereas the last one shows misunderstood of the principles (by Author).

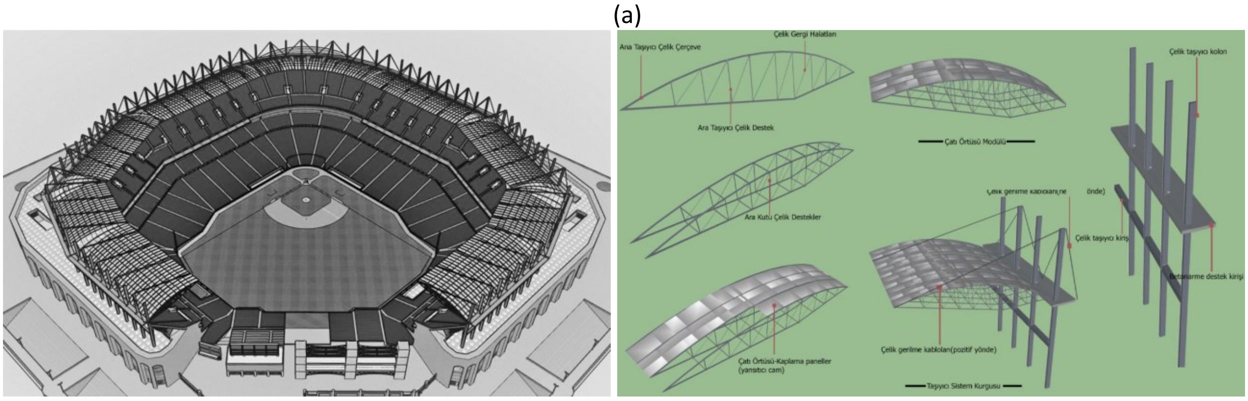
The large span structures were completed with the lecture on stadiums. This is a good closure to the subject because a stadium structure consists of a suspended roof and an outstanding façade. Students were going to design a parametric envelope for a stadium if they were taught Rhinoceros within the course. Normally, it was planned to teach one hour per week in each lecture. However, considering the students had never used the programme before, it would have been less effective to take time from the actual content of the course to teach the programme. Nonetheless, all students completed the Computer Aided Design 1 and 2 by the 4th semester, which meant they knew to use AutoCAD, Sketchup, and ArchiCAD at some level. Hence, the task was switched to these programmes, and they were asked to design a roof structure and a façade for a stadium. They were given ready models, available free online. Two were in DWG format and two were in SKP format. The students were left to choose one of them and to design in any programme they were fluent to use. Hand sketches and possibly a model was also required and to present their work in a board size of A1. The submission date was assigned in two weeks. 36 out of 42 submitted their work (Figure 2).

When the second part of the course began, the students were given a translation task over an article reviewing the high-rise office buildings in Europe. Considering the literature is heavily fed by English sources, students encounter difficulties from time to time. In BTU, the education of architecture is in Turkish, but throughout the course, subjects' keyworks and key terms are given to the students to enable them to access more sources and encourage to better understanding the subject in matter. Accordingly, the article of Pietrzak (2015) was assigned to translate for students. 36 out of 42 submitted it. Following this, a list of ten tall buildings and videos were shared with the students and assigned to watch and take notes on issues regarding their structural design and construction process. The list included Burj Khalifa and Burj Al Arab in Dubai, Las Vegas Complex in USA, Aldar Tower and Capital Gate in Abu Dhabi, Taipei 101 in Taiwan, Khan Chatry in Kazakhstan, Bahrain World Trade Centre in Bahrain, Pearl River Tower in China, and Petronas Tower in Malaysia. This task was measured through a quiz. The students were given two questions for each building and asked to choose only five buildings to answer, which makes each question worth 10 points and 100 in total score. An hour was given to submit the answers. The quiz scores were high, and it was observed that the students were able to answer to very specific questions clearly and with auxiliary sketch drawings.

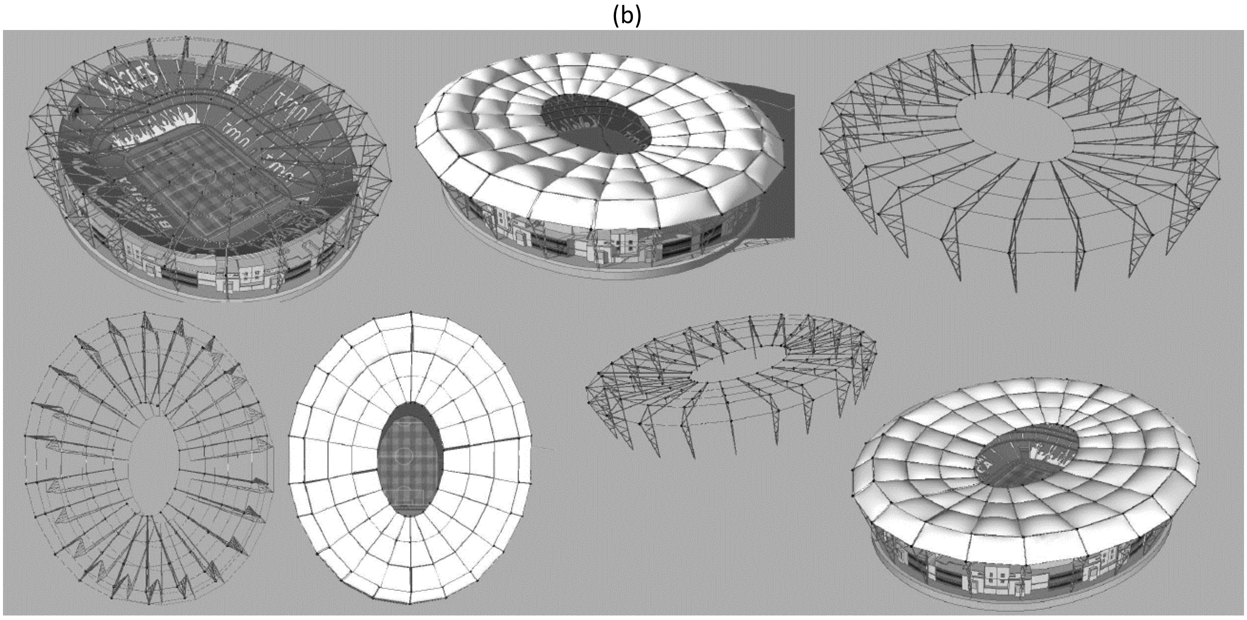
The final examination of the course was conducted in two parts: a written exam and a hand sketching part. The written exam was online and an hour-long and consisted of ten questions, of which only five the students needed to answer, to score 50 points. For the second half of the exam, students were given with the images of a stadium structure, Kiev National Stadium, they did not see either in the lectures or in the research tasks. It was asked to configure the structural system of the stadium envelop and to sketch it and provide further possible details sketching from joints and diagonals. Further links were also shared in case they needed help to solve the configuration. 37 students completed the first part and 38 submitted the second part. Overall, most students were able to configure the structural systems and provided the detail from the suspended roof structure as shown in Figure 3(a).



(a)

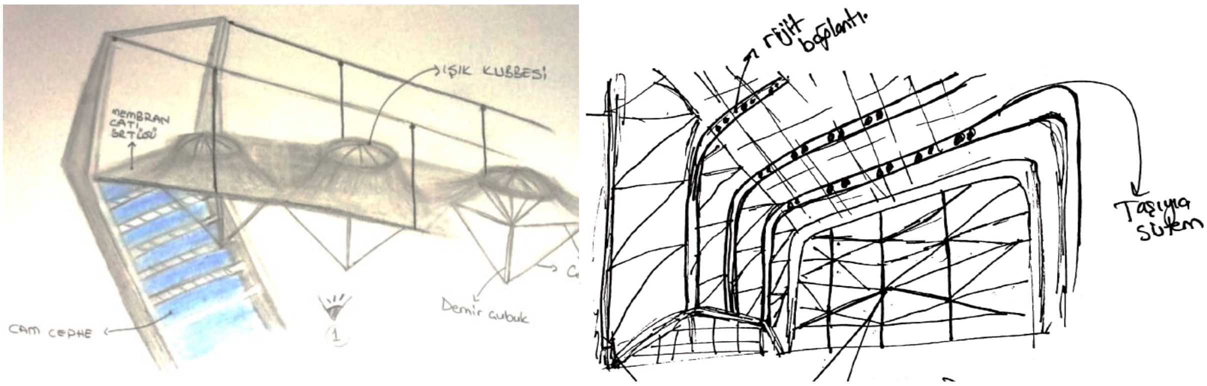


(b)



(c)

Figure 2. Examples of student works for stadium envelop structures. (a) inspires from Mexican waves move in stadiums and arch-like 3d trusses are covered with membrane; (b) is an example of cable structures with suspended 3d trusses covered with membrane and long posts; (c) 2d trusses circulate the stadium and covered with ETFE pillows (by Author).



(a) (b)

Figure 3. The Kiev National Stadium's detail sketches of the students (a); The structural sketching of the Shed by a student, showing the main steel load-carrying frame (b) (by Author).

3.2 Contemporary Structural Systems: 2020-2021/Spring

This course was opened for the second time in the Spring semester of 2019-2020. In total, 49 students enrolled and all of them were 2nd year students, the second cycle of the architecture students. The weekly plan of the course kept as same as in Table 3. Because the pandemic conditions did not change, the BTU announced that the Semester to be conducted online alone. Therefore, slight changes were adopted in the number of tasks and assignments. Instead of lecture recordings, online lectures were delivered, as the school brought back the attendance requirement, unlike the semester of 2019-2020. The number of students increased a few and they had to attend and work on the tasks and assignments alone from their home from the beginning of the semester. The online platform was changed to the MS Teams, which allowed online lecturing and post-lecture automatic recordings, provided attendance output per meeting, and dropped messages of assignments directly to the students' account.

The first assignment was to design a structure in size of 8*18 m and of 5 m height. It was aimed to teach the axes system of structures and the fact that the development of the design bound to this preliminary decision. No preference of material was made. The students allowed to design a timber, steel as well as concrete structure, although none chose the latter. This assignment was announced as a part of mid-term exam with a worth to 40 points. This decision was made so, because the number of students who submitted the work was not satisfactory. Only 24 out of 49 submitted. For three weeks the assignments were given critiques at the beginning of the online lectures, so the students learned how and where to fix their design. This helped the students to understand better the structural system configuration and to learn from each other's work. In the midterm exam, it was asked to submit a board size of A2, and the graphic language was left to the choice of the students, but nearly half of the submissions were based on computer aided graphics. 40 out of 49 submitted their work. It was observed that the majority understood how to form a structure through an axes system. Figure 4 shows two examples of the students' works. One student preferred applying the timber connection detail from the Weald and Downland Museum, which combined with tree columns. The following assignment was to make a model for a tension structure. The students were advised to use materials such as stretchable fabric, sticks, cords, pins, and a stiff base material. The size of the model was limited to 30*30*30 cm. The students were warned about the tension forces born while making the model so to be careful with sticks and pins, and possibly to ask for some help from a family member to give the tension required to the fabric. The photographs from clear angles were to submit by students and 35 out of 49 completed submissions. In the following lecture, the students shared their models on screen and given critiques. The majority completed the task successfully (Figure 5), while only few had misunderstood the structure and the membrane relationship, and the use of not a stretchable fabric led to an unsuccessful model finish as well.

Figure 5. Examples from the assignment of tension structures, the first two has a tent-like structure and the third one has an arch-centre in the middle (by Author).

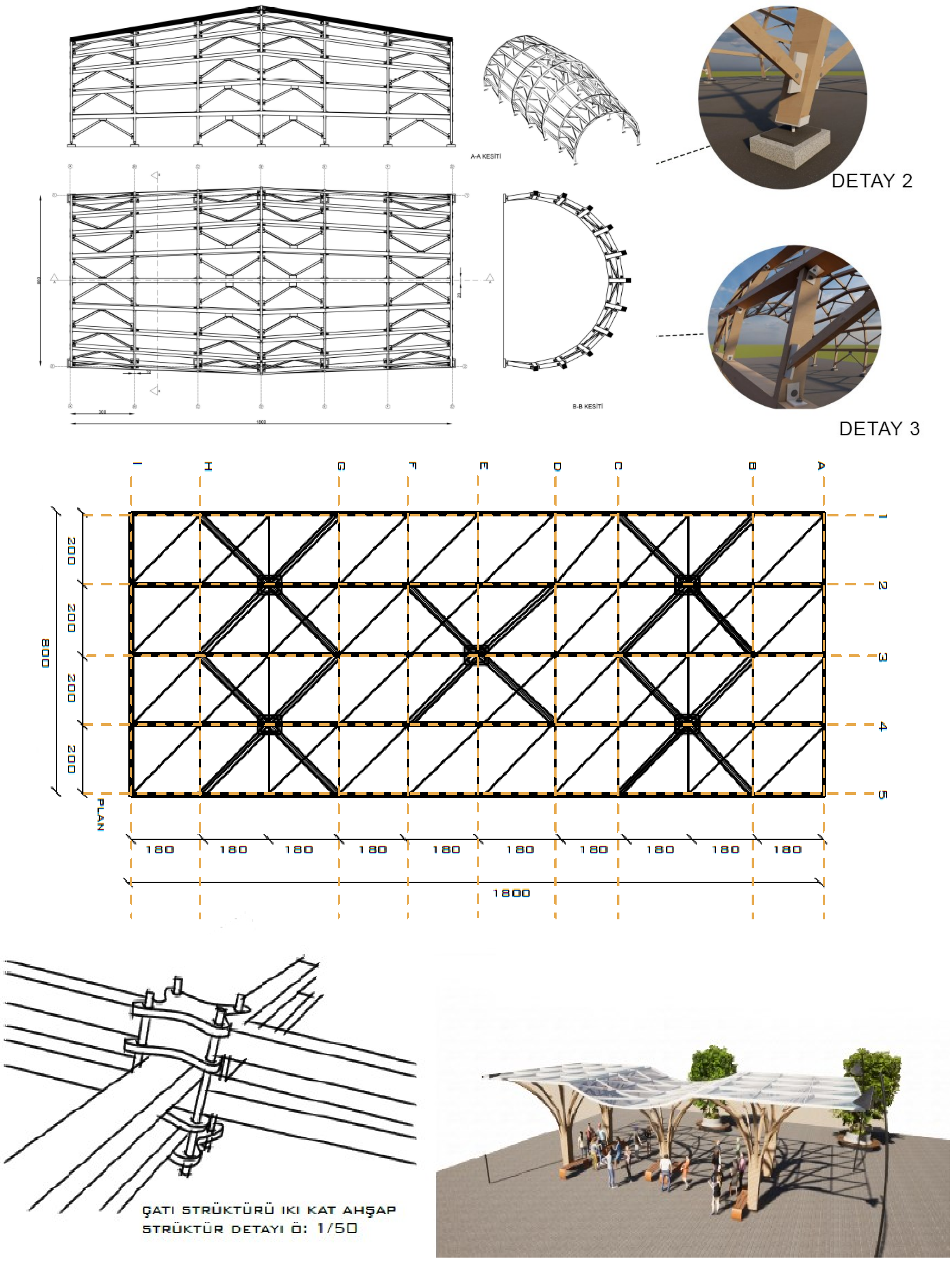


Figure 4. Examples from the students' works for the task of 8*18*5 m structure design and the graphics of how they built axes system (by Author).

The midterm exam was applied in two parts. The first part was the design project worth to 40 points as explained previously. The second part of the exam was online and two-hour long with written questions and hand sketching part. The students were asked five questions to answer and the structure of The Shed in USA, which was design by Diller Scofidio + Renfro, with further links provided, the students were asked to sketch the main and auxiliary structural elements and joint and support details as much as they could, which worth to 25 points in 60 in total. Majority of the students understood the roller support of the structure and the ETFE pillow used for the facade, but many failed to configure the steel structural system. Only a few were able to sketch properly as shown in Figure 3(b). The students were also assigned to research the buildings in the Table 4 with four additional buildings added to the list; Louvre Museum in Abu Dhabi, One Thousand Museum in Miami, One World Trade Centre (New tower) in New York and The Empire State Building also in New York.

3.3 Discussion

In the end of the semester, the school applies an evaluation test for each course, which is measured over 5-scale and competed by students, before they can see their final marks. The overall score of the test was 3,15 for this course, which was completed by 38 students. The test has 17 statements in total, and the content varies from the structure of the course to the online teaching effectiveness. The highest score achieved for the statement “The materials, documents and videos used for the course are up to date”, which scored 3,32. The next highest score is 3,29 and achieved for the statement “Online lectures were uploaded to the platform in a way that student can access anytime”. The third highest score was 3,26 and achieved for two statements: “I can access the weekly plan on the platform” and “The weekly flow of the course is in line with the uploaded plan”. The lowest score was 2,97 and achieved for the statement “The methods of evaluation and the regarding criteria were explained in the beginning of the semester”. The lowest score for this statement can be explained with the changes made in the course particularly after the semester break. Similarly, for the second cycle of the course, the students showed less interest in doing the tasks and assignments other than only participating to the online lectures, in which they were passive listeners only. Hence, some tasks were upgraded to a marked assignment or a part of mid-term and final examinations to keep the interest level satisfactory. The number of tasks and assignments were found ‘overload’ by few students in the first cycle of the course that they dropped emails stating that they had other courses and the deadlines were overlapping in some cases. Have this in mind, for the second cycle, the number of tasks and assignments were kept rather moderate.

4. Construction Technology and Materials 4

This course is the last of its group and to pass the previous three courses is the prerequisite to enrol to this final one. This explains why only 21 students enrolled to the course. The course is taught in the 5th semester and the following semester students need to take Application Project 1. Therefore, this course is structured to prepare students for an advanced level of detail drawing as well as to continue teaching the advanced building production technologies, advanced concrete materials, and contemporary scaffolding systems. It is divided into two parts: theoretical and application. The weekly plan is outlined as in Table 5:

Table 5. The syllabus of Construction Technology and Materials 4 (By Author).

#WEEK	SUBJECT
1	Introduction
2	Advanced building materials -concrete 1
3	Advanced building materials -concrete 2
4	Advanced building materials -steel and timber
5	Advanced building technology -scaffolding systems and formwork
6	Advanced building technology -scaffolding systems and facades
7	Advanced building technology -Prefabrication
8	Midterm exam
9	Application: Structural system and axes
10	Application: Foundation
11	Application: Foundation and Basements
12	Application: Roof and Rainwater drainage
13	Application: Stairs
14	Application: Footbridge, other supported components
15	Application: Detailing

4.1 Construction Technology and Materials 4: 2020-2021/Fall

The course included an amount of technical drawing work, but the attendance of some students was not sufficient. To say, in the midterm exam 17 students submitted their exam paper, whereas in the final exam only 11 out of 21 submitted their application project drawings in requested format. The students got used to do drawing in small scales or partial detailing but working on this kind of large plans was a difficult task for them. The students were asked to work on their own design project which they passed in the previous Spring semester of their 2nd year. This was a rehearsal of the Application Project 1. It was observed that although the students know the partial details in the structure and the building, they had a problem of combining them together in an accordance. For example, the students knew the suspended structures, but could not develop a solution rapidly and had several back and forth in the design. The building had a cantilever axis, for which the student did not want to build on columns and beams. Therefore, the student was advised to suspend the entire axis to the axis with solid frames with posts seen from the roof level. The student solved the issue with steel cantilever floor beams and with tension cords hung to the posts on the roof.

4.2 Discussion

The evaluation test results revealed an overall score of 3,15 on a 5-scale measurement. The highest score was 3,29 and achieved for the statement “I could access the lecture recordings anytime which I could not attended”. The next highest score was 3,24 and achieved for two statements: “Precautions and backups were taken in case to fail to submit files on time”, and “The materials, documents and videos used for the course are up to date”. The third highest score was 3,19 and achieved for six statements including: “The course run encourages student’s active participation”, “Online lectures were uploaded to the platform in a way that student can access anytime” and “The topics taught in the course provided knowledge applicable in the industry”. The lowest score was 2,95 and achieved for the statement “There were not any troubles causing delays and access problems and freezing during the lectures”, which clearly was the result of the problems with internet connection in a home environment.

5. Conclusions

“For an architect, it is necessary to know about building materials, structural designs, site and project and time management. (…) Particularly, an architect needs to understand when and why he/she must compromise his/her design due to the engineering systems” (Yılmaz, 2018). Architecture education is under serious burden of ‘too much to teach’ and the dilemma between ‘quality over quantity’ or ‘quantity over quality’. Having said that, this is not an excuse to get rid of this burden by just leaving the subjects must-to-teach out of the curriculum or teach them in a manner of completing only a procedure. In all schools of architecture, there is a clash or a gap between the subjects of structural design and architectural design. Students should be challenged to work on their full project to upgrade it to an application project level. She/he should understand the problematic locations in her/his design and should develop appropriate solutions to make it possible to build. Besides, students should know contemporary structural systems so that they could imagine and have a foundation of how it would be built on site. Three courses discussed in this paper showed that not all students had the same interest for structural design courses. As educators, it is our duty to build a syllabus combining the active participation of students and a share of tasks and assignments. They should understand that structural design is not a burden that contradicts their architectural design. It is a skeleton that makes their design buildable, and sometimes, it is a coat that makes their design even more outstanding. From solving the structure for a small scale, they can learn the basics. By learning the extraordinary examples of the large-scale structures, they can understand the basics better. In the Contemporary Structural Systems course, the content was established with this in mind and applied with only some adjustments in the second cycle. The final score of the course clearly revealed that the students were keen to learn the contemporary structures and the buildings as they gave the highest score to the “The materials, documents and videos used for the course are up to date”. Online teaching has advantages and disadvantages. Advantages are for the students as they can access the documents anytime and listen to lecture as many times as they need to. So, this reflected the scores as well. Disadvantages are mostly for the lecturers since they were required to update the program they built and follow for face-to-face teaching environment. This was found critical particularly in the evaluation methods by the students.

For the Contemporary Structural Systems course, the number of quizzes, assignments and exams were subject to change based on the performance and the attendance of the students. This was essential to keep concentrated the students throughout the course but did not help to drop a low evaluation score by the students. In the Construction Technology and Materials 4, the syllabus was established to challenge and encourage the students. However, it was observed that the students had serious difficulties in addressing the expected quality of detailing in drawings. It should be noted that the pandemic circumstances required serious updates for the course. Particularly, construction site visits and building materials manufacturer visits were removed from the program, which could have been beneficial to the students. Besides, students are normally expected to take their first internship following the fourth semester, which develops their background prior to the fifth semester, in which Construction Technology and

Materials 4 is delivered. As the pandemic conditions blocked this opportunity from the students, they could not complete the internship. This leaded a disadvantage for them since they kept on learning the detailing and building structures based on paperwork and on simulation models. Despite the fact, the students were required to develop an application project of one of their architectural designs. Drawing such an application project initiated their active participation and thy understood the level of drawing and detailing knowledge they needed to know as an architect better, so they evaluated they got knowledge applicable in the industry. The studio environment is significant for the education of architecture discipline. The paper examined two courses which adopted the methods from the design studio and overall, achieved the teaching goals both on the side of the lecturer and the students as the scores revealed.

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Conflict of Interests
The Authors declare no conflict of interest.

References
Ağırbaş, A. (2020). Teaching construction sciences with the integration of BIM to undergraduate architecture students. Frontiers of Architectural Research (2020) 9, 940-950. https://doi.org/10.1016/j.foar.2020.03.007

Alakavuk, E. (2016). Integration of building construction courses in the architecture education programme. ERPA 2015, SHS Web of Conferences, 26, doi: 10.1051/shsconf/20162601036

Dhanorkar, S. S., and Tarar, A. (2017). A Comprehensive and Integrated Pedagogical Approach for Teaching Structures in Architecture. International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 10, Number 1, 72-86.

Guthrie, J. B. (2012). Structural Engineering for Architecture and Construction management Students: Teaching Methods and Changing Needs. American Society for Engineering Education, Page 25.1181.1

Öztaş, S. K., and İpekçi, C. A. (2015). Innovations for Structural System Education In Architecture. Cbu International Conference on Innovation, Technology Transfer And Education March 25-27, 2015, Prague, Czech Republic. DOI: http://dx.doi.org/10.12955/cbup.v3.610

Pietrzak, J. (2015). Shaping and structuring of high-rise office buildings in Europe. Challenges of Modern Technology, 6.

Ridgway, S. (2000) Building A Site For Thinking: Teaching First Year Building Construction, Architectural Theory Review, 5:2, 14-26, DOI: 10.1080/13264820009478397

Shareef, S. S. and Farivarsadri, G. (2020). An Innovative Framework for Teaching/Learning Technical Courses in Architectural Education. Sustainability 2020, 12, 9514; doi:10.3390/su12229514

Tzonis, A. (2014a). Architectural education at the crossroads. Frontiers of Architectural Research (2014) 3, 76–78. http://dx.doi.org/10.1016/j.foar.2014.01.001

Tzonis, A. (2014b). A framework for architectural education. Frontiers of Architectural Research (2014) 3, 477–479. http://dx.doi.org/10.1016/j.foar.2014.10.001

Ünay, A. İ., Özmen, C. (2006). Building Structure Design as an Integral Part of Architecture: A Teaching Model for Students of Architecture. International Journal of Technology and Design Education (2006) 16:253–271. DOI: 10.1007/s10798-005-5241-z

Wetzel, C. (2012) Integrating Structures and Design in the First-Year Studio, Journal of Architectural Education, 66:1, 107-114, DOI: 10.1080/10464883.2012.715980

Walls, R.S., 2016. Teaching structural analysis and design: Evaluation and student feedback on various techniques and interventions. In A. Zingoni, ed. Insights and Innovations in Structural Engineering, Mechanics and Computation. Cape Town: Taylor & Francis, pp. 2169–74.

Whitehead, R. (2015). Rebuilding a Framework for Learning: Rethinking Structural Design Instruction in an Architectural Curriculum. Architecture Conference Proceedings and Presentations. 111. https://lib.dr.iastate.edu/arch_conf/111

Yılmaz, D. G. (2018). An Introduction to Architecture and Building Construction: A Starter Module for Freshers of Interior Design. Avanti Publishers, International Journal of Architectural Engineering Technology, Volume 5, 10-27. DOI: http://dx.doi.org/10.15377/2409-9821.2018.05.2