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Unconventional formulations in architectural curricula: An atelier on design for outer space architecture

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Abstract

Theories and methods of integrating digital tools into the architectural curriculum cannot be conceptualized as simply the merging of computerized tools with conventional formulations of design. This paper focuses on a case study of a workshop entitled "Mission Mars 2024: A Biomimetic Structural Organism", as part of the studio course ARCH 202 in the spring semester of 2017 at Izmir University of Economics. It explores the use of digital architectural design tools in the context of outer space architecture, and the use of biomimicry as a design approach. We encouraged students to explore various stages of Oxman's digital design ontology at the design level, and to employ various CAD/CAM tools as well as Virtual Reality (VR) and 3D representation methods. It is important to emphasise that the curriculum is a studio-based education with limited access to additional technical classes. Part of our aim was to integrate this content into the studio and allow students to explore new methods of design development. In order to free the students from conventional architectural preoccupations, we particularly chose on the surface of Mars. The paper presents a critical approach to understanding the impact of digital tools and methods on the learning outcomes of the students, which are discussed and demonstrated based on four studio outcomes.

Keywords
Architectural curricula, Biomimicry, Digital tools, Integrated studio model, Space design.

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1. Introduction and background

Design educators are facing the challenge of integrating computational tools into architectural education. The ability of these tools to work at a parametric, algorithmic and representational level necessitates an update in traditional methods of architectural education (Kotnik, 2010). Since the adoption of CAD/CAM technologies by other industries during the 1970s (Corser, 2010), emerging technologies in design and fabrication became increasingly prominent in architectural education and practice, particularly during the last two decades. As a result, computational approaches in architectural design education (Oxman 2006, Oxman 2008; Oxman and Gu, 2015; Özkar, 2007) and the insertion of digital fabrication tools in architectural curricula (Celani 2012; Duarte et al., 2011; Gül and Simisic, 2014) have been investigated in many architecture schools from multiple points of view. In many cases, the availability of tools, methods and resources in digital design setups are flexible, and open to change. In traditional design schools however, with less emphasis on digital tools, the matter of how these skills are introduced is important. A more traditional view taken by some schools is that too much emphasis on digital tools may somehow lead to a disconnection with existential space during the design process. Therefore, spatial design in extra-terrestrial environments are considered premature at second year studio level. This paper challenges some of these traditional views and investigates how digital fabrication tools are changing the design process that the students traditionally taught. How can students merge the conventions of architectural regulations with unconventional design contexts using new digital tools? How can a biomimetic design approach be combined with digital tools? This paper describes a two-week digital fabrication workshop in which students were asked to use digital tools to design a biomimetic organism on Mars.

As a teaching group, the project allowed us to investigate the extent to which digital design and fabrication tools contributed to students' design thinking. Considering that there are minimum architectural constraints and contextual references in such an extraterrestrial space, we aim to find out whether students can freely explore the digital tools to come up with unconventional, creative and innovative design solutions. To evaluate our approach for integrating digital thinking, application, and experience in architectural education, we follow a comparative case study method in which Computer Aided Manufacturing (CAM) as fabrication method, Virtual Reality (VR) as a representation tool and biomimicry as a design approach played an integral part of the two-week workshop.

2. Digital architectural design (DAD)

Oxman (2008: 106) makes a distinction between Computer Aided Design (CAD) and Digital Architectural Design (DAD). CAD methods, its principles and theory utilise paper-based design methods, whereas digital architectural design methods suggest new types of a form, grammar and concept. This reflects a shift in conventional architectural design processes because rather than being just a tool, digital architectural design methods have the potential to become the whole process itself. Principles, theories, and methods of CAD were based on imitating paper-based approaches. The new relationship between digital form and digital processes have contributed today to the emergence of a new conceptual vocabulary and domain knowledge which has led to a paradigm shift in design. It is important to note that Oxman (2006: 39) indicated the emergence of a new ideology by emphasising the conceptual conflicts between traditional and digital design. Oxman (2008) proposed five paradigmatic classes of digital design models, based on the various relationships between the designer, the conceptual content, the design process applied, and the design object itself:

- CAD models: descriptive by employing various geometrical modelling and rendering software, but have little qualitative effect on design thinking, and are essentially isomorphic with paper-based design models (representational computability).

- Formation models: structured geometric or formal digital processes providing designers with a high level of digital interaction and control, a threshold between digital/non-digital models
- Generative models: a computational mechanism for formalized generation process.
- Performance models: a process of formation or generation that is driven by a desired performance.
- Integrated compound models: a complex mixture of the above.

Oxman's ontology emphasises the abandonment of typological and deterministic approaches in favour of the creation of generative and performance models. Still, at the representation and manufacturing level of computing, digital tools are widely used. Affordable CAM and low-budget VR devices are reshaping architectural curricula. While the first numerically controlled tools can be dated back to early 1950s, the first digital fabrication laboratory called Center of Bits and Atoms (CBA) was established at Massachusetts Institute of Technology (MIT) in 2001 (Gershenfeld, 2012). Since the year 2000, digital fabrication tools and methods have begun to appear in architecture and engineering education (Blikstein, 2013). Celani (2012) discusses the role of the new digital fabrication laboratories in architectural education. Along with scientific content, she claims that these labs create an opportunity for practical explorations for students. For the integration of VR, Horne and Thompson (2008) present research on the integration of VR within the built environment curriculum, and aim to investigate the role of VR and 3D modelling on the architectural curriculum. This study reports on the integration process and considers how CAM and VR technologies can combine with the existing range of teaching and learning methods.

3. Updating architectural curricula in a digital age

Architectural education should produce well-qualified and well-prepared professionals who are familiar with recent technologies. Employers demand that graduates not only have the required knowledge, but also the appropriate skills to be effective and productive in the workplace. To adapt to these challenges, universities constantly need to review their academic processes, in particular how best to integrate digital technologies, rather than teaching them as supporting technical skills courses, which restricts their creative use as part of the design process.

The design studio is still at the core of curricular structure of the schools of architecture and is considered as the norm for architectural design practice. In some architecture programs drawing and representation courses are separated; while in others these courses are integrated into the design studio (Gökmen et al., 2007). Either way students' need the ability to use these tools creatively. Our intention at Izmir University of Economics is to incorporate digital technology not merely as a tool but as a way of thinking.

The first course to introduce CAD/CAM to students at Izmir University of Economics is "FFD 104 - Computer Aided Technical Drawing" (Varinlioglu et al., 2016). Similar to the first year core Basic Design Studio, this computational course reflects the pedagogy of teaching architectural elements, human scale, and abstract forms without functional requirements. This interdisciplinary approach introduces a discrete studio model, while requiring independent professional courses for each discipline (Duarte et al., 2011). However, an important disadvantage of this pedagogical model is the separation/dissociation of CAD/CAM courses from the main design studio.

In the second year, "FFD 201 Computer Aided Architectural Graphics" covers the basics of 3D modelling, architectural graphics, and professional conventions in a one-semester course (Varinlioglu et al., 2017). As this is the second and last of the required CAD courses, it was necessary to incorporate several topics. The course introduces the essential techniques of architectural graphics in two and three dimensions, and stresses their incorporation and application within the virtual technology. Information constituting the initial design created by way of primitive forms exists at the core of the course. Students are not expected to develop their designs any further than the minimum initial requirements. Instead, they are repeatedly encouraged to re-elaborate the initial design within a variety of media, thus remodelling the same information with different tools.

4. Outer space architecture

Explorations in outer space have shown significant progress in technological and architectural terms since the 1960s. The first attempts to enable humans to exist and survive in outer space, corresponding to the first wave of outer space development extending to the late 1990s, aimed to create small-scale habitable spaces in the form of a shuttle or a capsule for the specific missions of exploring other celestial bodies, building telecommunication satellites as well as scientific research and photographic data collection. Upgrading the applicable missions in outer space from small-scale scientific research to commercial public scale, the second wave of outer space development opened a new path for space colonisation attracting not only scientists but also private entrepreneurs and ordinary people.

Scientific research during the first wave outer space development brought forward a new spatial term called "cabin ecology", which was used by scholars in astronautics in the late 1950s to describe the environment inside a space vehicle. "The best way to build space cabins", as the science historian Peder Anker mentions, "was to make their environment as close as possible to the environment found on the surface of the earth" (Anker, 2005: 240). In this context, research on cabin ecology did not initially aim to solve environmental and architectural problems regarding outer space habitats and to build closed liveable environments in space for astronauts, but to construct self-sufficient artificial ecosystems for the use of military forces or as models to handle the ecological crisis on Earth.

The Mars One project, which aims to send the first human colonists to Mars in 2032 and establish a permanent human settlement, is an example of the gradual transformation of outer space architecture from the orbital cabin ecology to on-land outpost architecture. Although the architectural design will primarily be based on adjusting the interiors in accordance with the physiological and functional requirements of the inhabitants, the challenging environmental conditions on Mars as compared to those of Earth may lead to the emergence of new life forms, growth, behaviour and sociability patterns. On Mars, the outpost will expand as more astronauts arrive, creating more living space and ever changing environments for the permanent settlement (Mars One, 2017).

In this paper, we consider outer space architecture not as a "cabin ecology" in which outer space habitats are reduced to an interior design problem, but as an outpost architecture of unconventional living forms. In an extra-terrestrial environment where time flow, solar orientation, bodily stimulation and ergonomics as well as microclimatic context is quite different from those on Earth, new forms of human existence and behaviour patterns are likely to occur in and out of the living unit. Such an approach allowed the students to explore a number of unconventional design solutions. Primarily this entailed the use of biomimicry in exploring how these biomimetic organisms could transform themselves.

5. Biomimetic approaches in outer space architecture

The British architect Michael Pawlyn defines biomimicry as "mimicking the functional basis of biological forms, processes and systems to produce sustainable solutions" (Pawlyn, 2011: 2). In outer space architecture, biomimicry has rarely been referred to as a design approach. The major reason is that the mainstream approach in designing outer space habitats has always aimed to provide isolated and self-sufficient enclosures for human survival that will resist the challenging unexpected conditions of a relatively unknown environment. In almost all of the architectural solutions for outer space habitats discussed in the previous section, ranging from "cabin ecology" to "outpost design", the designers have worked within the limited opportunities provided by engineering technologies. Although the Earth, as the only known natural ground where the human species can survive, provides a large variety of biomimetic resources and references for extraterrestrial colonisation, the functional, formal, physical and chemical features of organic life forms on Earth has often been ignored during the design process of outer space habitats.

Among various architects who became aware of the importance of space research to ecological design in the 1950s, Buckminster Fuller was one of the key figures who used biomimicry as a model for understanding life on Earth and adapted it into his domes, some of which were designed for military purposes. Based on his geometrical research of spherical trigonometry, he developed and constructed a dome structure with students at the Institute of Design in Chicago in 1949, which later became as "the standard of living package […] for the use of civilians fleeing cities to 'decentralized communities' in the event of a nuclear war" (Anker, 2007: 424). In the following years, Fuller constructed a number of domes, a large scale version of a space shuttle interior adapted to human's bodily features. A complex system of shades was used to control its internal temperature. The sun-shading system was an attempt by the architect to reflect the same biological processes that the human body relies on to maintain its internal temperature. Even more ambitious, Fuller's original idea for the geodesic dome was to incorporate pores into the enclosed system, further likening it to the sensitivity of human skin (Massey, 2012).

6. The Mars Workshop

In order to understand how second year students of architecture at Izmir University of Economics, who developed basic computer skills in their first year, refer to, interpret and utilize digital design tools in the fabrication and representation of an unconventional design context, we conducted a two-week workshop entitled "Mission Mars 2024: A Biomimetic Structural Organism", as part of the studio course ARCH 202 in the spring semester of 2017 (Mission Mars, 2017). Originating from the Mars One project initiated by Bas Lansdorp and Arno Wieldersas, students were asked to design a biomimetic structural organism that will function as a habitat for the first colonisers on Mars. The final design was expected to be a standalone organism which can not only structurally withstand the geographical and climatological conditions of Mars, but also grow, move freely, reproduce and/or exterminate itself. As part of the structural organism, the students were also asked to design habitable spaces that will respond to basic human needs such as eating, sleeping, working and socializing. Even though the primary objective of the workshop was to advance their digital design skills in creating unconventional design formations, we considered that in order to propose new growth and living patterns in an extra-terrestrial context, the students also needed a conceptual departure point, and this led to the introduction of "biomimicry" as a supplementary design approach which would initiate their draft proposals.

The students worked in teams of six to seven, each of which was assigned in cross-combinations one of four plants: banyan tree, lithops, romanesco and pine cone; one of four animal features: beetle exoskeleton, dragonfly wing, snail shell and moth eyes; and one of the four specific sites on Mars' surface: Radau, Conches, Maunder and Mistretta (Figure 1). After introductory sessions on advanced digital design tools and biomimicry in architecture as well as Mars' geography and climate, each team of students was asked to research and analyse their particular plant or animal feature and to build both a digital and a physical model of their given site. In terms of a biomimetic approach, they were asked to design a unique organism that does not simply resemble the plant or the animal feature but mimics and interprets its structural formation.

In the initial stage, students presented their design ideas through sketches, diagrams and concept models before they start interacting with the digital tools. Later, students with basic

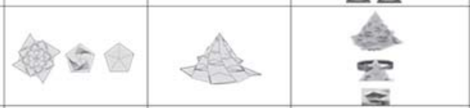
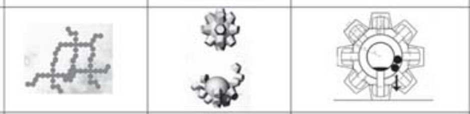
	Growth Pattern / Unit Design / Structural Design	Biomimicry	Digital Tools
Team 1		Banyan Tree	VR/3D print
Team 2		Romanesco	VR/3D print
Team 3		Lithops	VR/3D print/ VSE/Video mapping
Team 4		Beetle Exoskeleton	VR/3D print
Team 5		Pine Cone	VR/3D print
Team 6		Dragonfly Wing	VR/3D print
Team 7		Snail Shell	VR/3D print
Team 8		Moth Eyes	VR/3D print
Team 9		Banyan Tree	VR/3D print
Team 10		Moth Eyes	VR/3D print
Team 11		Lithops	VR/3D print
Team 12		Romanesco	VR/3D print/VSE
Team 13		Pine Cone	VR/3D print
Team 14		Dragonfly Wing	VR/3D print/VSE
Team 15		Snail Shell	VR/3D print

Figure 1. *Chart of workshop teams (Halıcı et al. 2017).*

Grasshopper Visual Scripting Environment (VSE) skills are encouraged to search for pre-cooked algorithms/ definitions representing their spatial and functional scenarios of the Mars organism, thus gaining the skills to read and understand the algorithms, to guess the potential outcomes generated by these algorithms, to change parameters to generate more results and also to compound two algorithms for creating their own models. Referring to Oxman's ontology, teams used digital tools at three different levels: the CAD models, replacement of the physical models with digital ones; the formation models, models showing various stages of the forms/formation;

Table 1. Analysis of the design outcomes (GP, growth pattern, UD, unit design, S, structure). The number of dots in each cell refer to the frequency of the biomimetic approach and the digital tools in the design outcomes.

	Digital Tools					Biomimetic Design Approach				
	GP	UD	S	Computability		GP	UD	S	Biomimetic Organism	
Team 1	•	•	•	CAD model	GP/UD/S	•	••	••	Banyan tree	UD/S
Team 2	•••	•	•	CAD model	GP	•	••	••	Romanesco	UD/S
Team 3	**•••**	**•**	**•**	**Generative model**	**GP**	**•••**	**••**	**•••**	**Lithops**	**GP/S**
Team 4	••	••	••	Formation model	GP/UD/S	•	•••	••	Beetle exoskeleton	UD
Team 5	-	•	••	Formation model	S	-	••	•	Pine cone	UD
Team 6	**••**	**••**	**••**	**CAD model**	**GP/UD/S**	**•••**	**•••**	**•••**	**Dragonfly**	**GP/UD/S**
Team 7	-	-	•	Paper-based	S	•	-	••	Snail shell	S
Team 8	-	•	•	Formation model	UD/S	•	•••	••	Moth eyes	UD
Team 9	••	••	•	CAD model	GP/UD	••	•	••	Banyan tree	GP/S
Team 10	•	•	•	CAD model	GP/UD/S	••	•••	•••	Moth eyes	UD/S
Team 11	-	••	•	CAD model	UD	-	•••	••	Lithops	UD
Team 12	**•••**	**•••**	**•••**	**Generative model**	**GP/UD/S**	**••**	**•••**	**•••**	**Romanesco**	**UD/S**
Team 13	-	••	•	Formation model	UD	•	•••	••	Pine cone	UD/S
Team 14	**•••**	**••**	**•••**	**Generative model**	**GP/S**	**•••**	**••**	**••**	**Dragonfly**	**GP**
Team 15	•	•	•	CAD model	GP/UD/S	••	•	•	Snail Shell	GP

and the generative models, parametric models that can generate new results based on the rules. Four selected examples will be examined in the next section.

At the manufacturing phase, the students considered various potential outcomes of the digital fabrication. The 1/5000 site models were produced with laser cuts and 1/200 unit models with 3D printers. But the digital fabrication is not limited to the production of the models. Discovering the potential of 3D manufacturing, they are encouraged to think about the real one-to-one construction of their organisms on Mars. This allowed them to reconsider their concept sketches and ideas, in particular building their colonisation scenarios on Mars, where they frequently utilised digital fabrication. At the representation phase of their design for unconventional environments, students were encouraged to go further than conventional architectural drawings. Using basic VR tools, they were able to simulate the experiential aspects of their work. The finalized 3D digital models were post-processed in an online 3D display and VR display system, with an internal render/ visualisation engine.

7. Analyses of the workshop outcomes

We followed a comparative case study method in which we analysed the digital tools and biomimetic approaches of each design team in relation to parameters of growth patterns, unit design and structure particular for the workshop (Table 1) (Halıcı et al. 2017). The initial results show that the use of digital tools is equally distributed among the parameters at different levels of computability, while biomimicry is referred to mostly for parameters of unit design and structure. We consider that the teams which design the same parameters both by means of digital tools and through a biomimetic approach show consistency in their design process in terms of creating an unconventional solution with reference to a conventional living organism.

The results have shown that the use of digital tools varies according to the level of design computability. Based on Oxman's ontology (2008: 106), on the first level are CAD models, which utilize paper-based design methods. Teams 1, 2, 6, 9, 10, 11, 15 utilized digital tools merely as a modelling tool and, team 7 used a paper-based model only, despite digital architectural design methods suggesting a new type of vocabulary. The other teams employed digital architectural design methods which had the potential to become the whole process itself, and also present infinite iterations which can be manipulated many times throughout interactive processes. Teams 4, 5, 8 and 13 used parametric tools to create a model capable of showing several forms of their design. However, three examples that particularly stood out are teams 3, 12 and 14, as they showed consistency in their digital design process in terms of creating an unconventional solution with reference to a conventional living organism. They created generative models to create the unit, and to display the growth pattern of the colonisation in Mars. The findings in Table 1 below explain the selected four projects: Teams 3, 12, and 14 all make significant use of digital tools and a biomimetic approach. Although team 6 used biomimicry efficiently without creating generative models, at conceptual level it is worth a mention. It also provides a comparison with team 14, which used the same biomimetic organism.

Next, we aimed to establish the extent to which digital tools and biomimicry were reflected in the student's work, based on the grades awarded, and the personal observations of jury members. There follows an analysis of four successful projects based on the efficiency of using digital tools as a design aid, an appropriate understanding of biomimicry and the exploration of a colonisation program in outer space. Each team was evaluated on the success of using growth patterns, unit design and structural design. While each team of students analysed and interpreted the structural formation of their plant or animal feature as required, the end products varied in terms of the biomimetic approaches that they followed. Some teams focused on the biological structure without directly copying its form but utilizing it to find a functional solution for the long-term survival of users, while some teams transformed the structural form in a more literal way into a living unit.

Team 12: Team 12 analysed the extraordinary biological formation of the romanesco which is composed of thousands of smaller fractal romanescos. The team adapted this formation into a mobile structural organism which can move, rotate, scroll and change its form and place in accordance with sunlight and moonlight. Their structure is an abstracted large scale version of the romanesco, a spiral central module surrounded by conic sub-modules, functioning as living capsules, which enable the whole structure to move and change its position and overall form. In using the growth pattern of romanes-

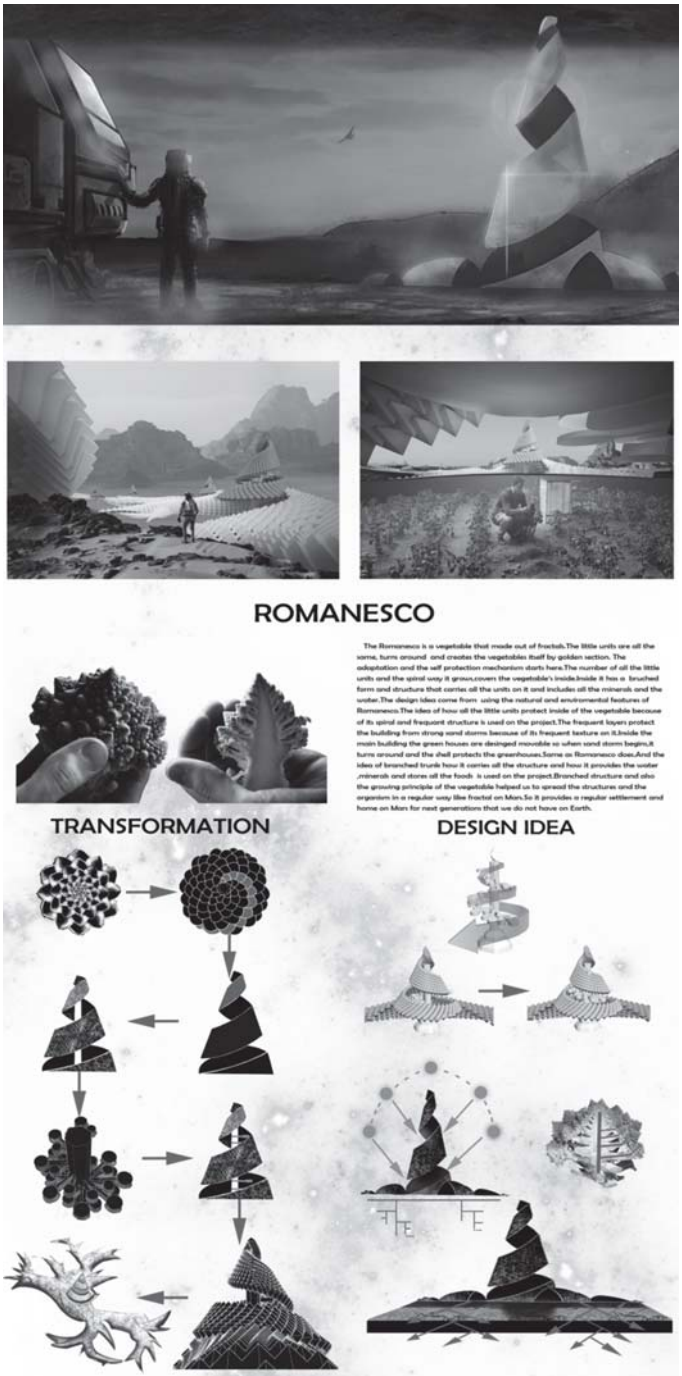


Figure 2(a). *Presentation boards of Team 12 and 3.*

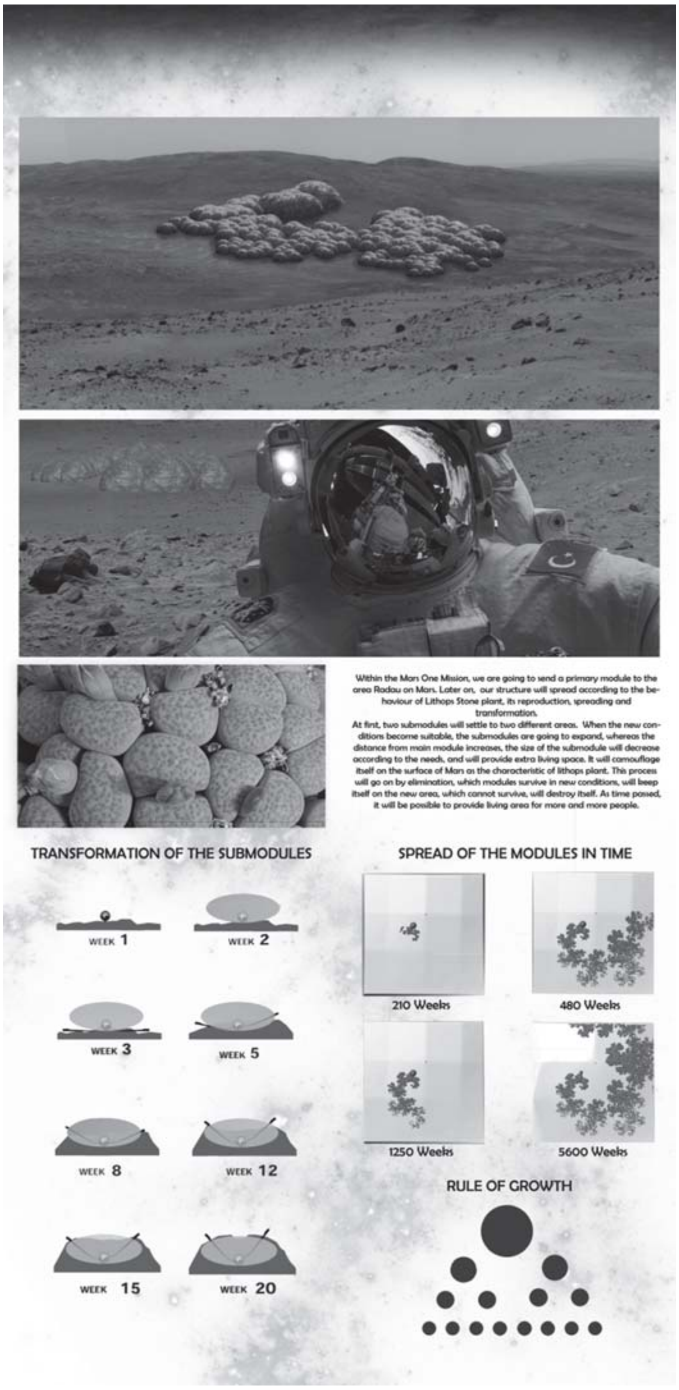


Figure 2(b). *Presentation boards of Team 12 and 3.*

co, they used the generative design approach of L-systems, the algorithm of the spiral. The core is growing in spirals until it reaches its maximum number of units. The fractals of the romanesco plant generated similar sets whose patterns are composed of smaller-scale copies of themselves, processing self-similarity across scales (Lu et al., 2012), and this is reflected in the VSE environment, carrying the biomimetic parameters at a digital level. Thus, they conveyed efficiently the biomimetic parameters into the form-finding process, by generating alternatives based on the same rules.

Team 3: Apart from these biomimetic approaches, there were other teams which did not only integrate the functional and formal characteristics of their reference plant or animal feature, but further proposed unique structural organisms which can exist, grow, reproduce and survive in alternative ways to those of the typical life forms on Earth. In doing so, they gave particular emphasis on the challenging site conditions of Mars. They analysed the lithops plant, which can grow inwards and camouflage itself after extending to a certain degree in accordance with changing degrees of temperature and water vapour level. Taking these characteristics as their starting point, they proposed a structure that provides an organic link between Earth and Mars. According to their scenario, a modular organism created on Earth is sent to Mars and separates into sub-modules that will settle on different areas of the site Radau. As the site conditions allow, the main module will expand, reproduce and spread into smaller modules. The modules which can adapt to site conditions can survive while the others exterminate themselves by growing inwards in weekly periods.

The team analysed carefully several characteristics of the plant such as the growth pattern and unit design. The capsules of the plant opening and leading to the new plants led students to develop an algorithm of the fractal geometry for the growth pattern. Each unit, in the form of a sphere, as inspired by Ozdemir and Halici (2016), spreads within the Mars environment using the cellular automata, a generative design approach to define a self-organizing system for managing complex structures within its neighbourhoods (Dinçer at. Al. 2014). Once one survives, more colonies may spread next to it. If one dies, there is no colonisation around this unit. During construction the fractal joints would help to ease the manufacturing process, where robots will make the camouflage covering under the regolith at the surface of Mars. VR, as a representation tool was expected from each team. For Team 3, at the representation level, the conventional physical static models were not enough to reflect their ever changing and growing mechanism. They therefore made a video of the growth pattern and reflected to video mapping to the Mars environment.

Teams 6 and 14: Teams 6 and 14 analysed the dragonfly wing as their reference animal feature. The Dragonfly is a flying insect with a centralized body and four equal wings, which can absorb energy from another dragonfly by hitting them. As a unique characteristic, the veins on the wings of the dragonfly are arranged in accordance with the Fibonacci sequence with voronoi pattern, creating a slightly hexagonal pattern growing towards the edges of the wing (Rokicki and Gawell, 2016).

Team 6 did not directly copy the form and the pattern of the wing but designed vertical structures which are enveloped by spiral tubes functioning as wind turbines which resist and utilize the strong winds on Mars' surface. Inside each spiral tube, there are spherical cells continuously moving by wind force. Analogous to the energy absorption characteristic of the dragonfly wing, each cell charges itself as it moves forward and touches another cell. Furthermore, the vertical structures are connected to each other with horizontal tubes, functioning as greenhouses, and arranged in a growing pattern based on the Fibonacci series. Team 14 also analysed the same growth pattern but only in formal terms. They designed a single bowl-like structure that resembles the pattern of the wing and fits onto the volcanic crater in their site Mistretta.

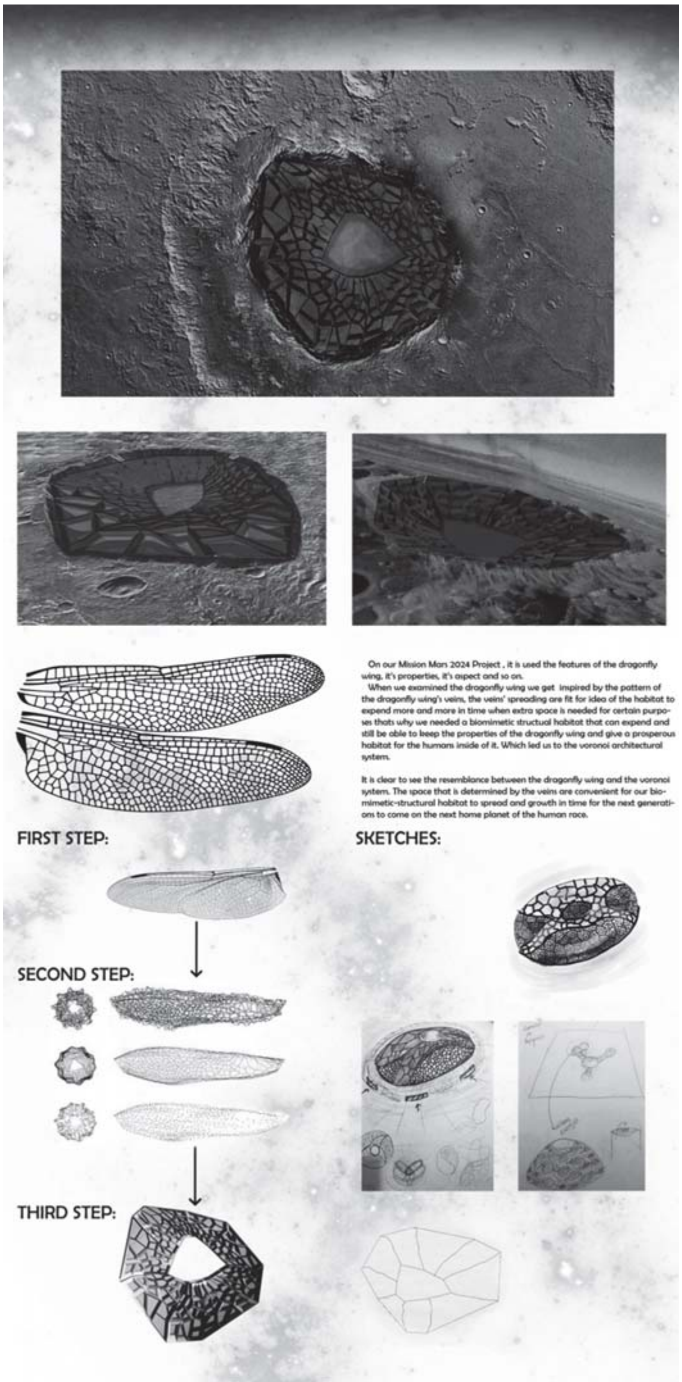


Figure 3(a). *Presentation boards of Team 6 and 14.*

Although the two teams differ in their use of digital tools, have both generated promising generative models. Although team 14 achieved a generative model, the algorithmic thinking could not be reflected in the final digital model. Team 6 planned a performance model, where the spiral form would act like a wing of the dragonfly in a vertical direction, but ended up with a simple spiral CAD model. At the growth pattern level, the spiral units would produce energy, using the wind. Although Team 14 took a very literal view of biomimicry, they created a growth pattern from the voronoi and ended up with a generative model. The Voronoi pattern divides the space into a number of regions according to the shortest distance to corresponding points in the neighbouring cells (Reinhardt, 2015). Using Delaunay triangulation, the straight line in between the voronoi cells represents the centers of the living units. Similar to the application of voronoi diagrams in contemporary architecture and town planning

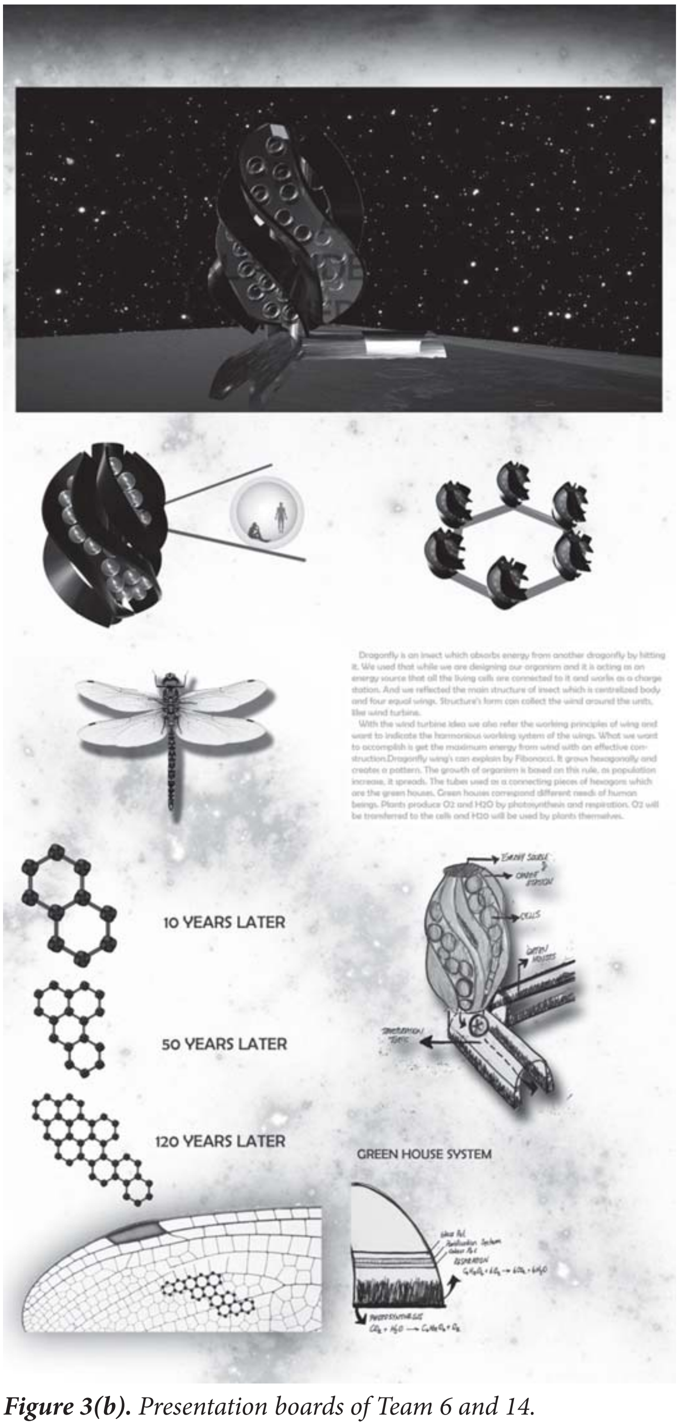


Figure 3(b). *Presentation boards of Team 6 and 14.*

presented by Nowak (2015), the vessels of the dragonfly would turn into the circulation axes in their colony. The proposals were well adapted to the geography, growth patterns and topographic parameters, and they were successful in terms of using digital tools.

8. Concluding Remarks

The outcomes of the workshop have not only shown that the students follow various approaches in designing outer space habitats, ranging from biomimicry to digital tools, but also that they tend to reflect certain preconceptions in their cognitive design process both in formal and functional terms. First of all, even though their design approaches may be unconventional, the actual living units as part of their structural organism mostly take elliptical or spherical forms fully or partially resembling a typical space shuttle. This may be due to the fact that they utilised digital tools to develop growth patterns rather than generating the unit designs in this way. Second, none of the teams developed a proposal for the human life cycle inside, outside or in-between these units, considering this functional issue an interior architecture or engineering problem. The ways in which basic human needs and habitation can differ on Mars from those on Earth and how it reflects on the design of habitable spaces are the two key questions which remain unanswered.

The high level of enthusiasm displayed for the projects by the students is worth mentioning as it exceeded our expectations. The presentations were expanded to form part of a public exhibition in collaboration with the Space Camp Turkey in Izmir, and the students were greatly motivated by the positive responses they have received.

Most of the architecture schools in Turkey teach digital representation tools in the classroom due to the insufficiency of the technical infrastructure and/or lack of experience of the design studio tutors. In this study, we observed that a more integrated approach had the potential to provide novice architecture students with the adaptability which is necessary to understand digital fabrication, virtual reality and digital architectural design processes. Therefore, this study may be considered an attempt to develop integrated pedagogical models for future architecture curricula.

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