

International Conference for
**Sustainable Design of the
Built Environment**
SDBE 2018

Proceedings



Editors

Heba Elsharkawy

Sahar Zahiri

Jack Clough



SDBE
Sustainable Development
of the Built Environment



New Territories: Digital Materiality from Natural systems to Environmental Impact

Carla Aramouny

Assistant Professor, Department of Architecture and Design, American University of Beirut, ca38@aub.edu.lb

Abstract: Digital fabrication, between advancements in software, simulation, and machinery, is pushing practice today towards more complexity in design, allowing for unparalleled explorations. Yet at no time have questions of material knowledge become more relevant and crucial, as technological advancements approach a radical re-invention of the design process. As more designers look towards tactile crafts for material know-how, a parallel interest in natural behaviors has emerged trying to embed environmental performance into the designed objects. New Territories, a yearly architecture and design course on digital design and materiality, allows students to explore processes of digital fabrication in intersection with environmental behaviors and hands-on material experiments. The aim throughout the course is to explore the design of building systems, such as modular facades, intelligent cladding, or adaptable seating, by embedding current digital technologies with an understanding of the environment and physical material behavior. This paper will highlight the importance of learning from nature and physical material explorations to design these active and sustainable systems. It will detail the work done over the course of three years, on themes of building behaviors, environmental responsiveness, concrete plasticity, and material composites. Through the work, the paper will elaborate on the design process, describing the different material experimentations, digital and analog methodologies, and the final results. It will shed light on the persisting importance of material knowledge in intersection with advanced digital fabrication, and the significance of learning from natural systems and bio-properties to embed an active performance in today's design process.

Keywords: digital design, digital fabrication, materiality, environmental behavior, building materials

Introduction

In today's digital age, the proliferation of advanced technologies, namely those associated with prototyping and three-dimensional fabrication, has allowed unparalleled investigations of form, material, and making, right from the individual designer's desktop. This has democratized the production of physical prototypes, allowing any individual to easily access the technology and grasp its process. This has also had a major impact on architecture and the production of space, as designers move towards more computerized production techniques.

Digital fabrication, or the process of making via a digital interface, is however necessitating a clear understanding of material behavior and technological constraints, and thus informing the design process along the way. In addition, it is generating for many designers an aim to produce active and productive prototypes, and compelling them to look at natural systems as a reference to generate environmentally relevant outcomes. In the advent of a digital world, an inherent interest in the 'analog' and the 'organic' is somehow embedding itself in the work of many designers. This paper will address these different notions informing the practice, from materials and crafts, to natural references and digital fabrication methods, presented through the work of the New Territories seminar course, and its student projects' outcomes.

Learning from Nature for the environment

The natural environment has evidently been the essential model upon which architecture, the man-made environment, has long been shaped and formed. According to Petra Gruber (Gruber et al, 2011), biomimetic design, or design modeled from natural systems, has existed as long as architecture existed itself, from the cave dwellings to early translations of natural systems to form the built environment. However, she differentiates between bio-inspired design and biomimetic design, where the latter differs through its concern with the embedded systems and inherent logic within nature, rather than its formal or aesthetical aspects. Such a relationship in biomimetics between architecture and nature is crucial, and in the current digital world, a renewed consideration for nature, its systems, and their complexities, seem almost evident.

With the advancements in intelligent technologies, a deep understanding of natural systems and their inherent behaviors is fundamental to design environmentally active and conscious products. Brownwell and Swackhamer in *Hypernatural's* book introduction (Brownwell et al, 2015), talk about a changing paradigm in today's design world, where a shift is happening from understanding nature as a binary opposite to the man-made world - as an environment that needs to be controlled and that opposes technology - to recognizing it as an extension of the built habitat and with a mutual influence from and on technology. They go on to state that *"The ultimate aim of technology is not anti natural; it is hypernatural. It involves working directly with natural forces and processes- rather than against them-in order to amplify, extend, or exceed natural capacities. This approach characterizes many fields of human industry today, including science, engineering, architecture, and art, which are infused with a growing enthusiasm and reverence for nature."* Furthermore, the accessibility to advanced software and fabrication techniques has given architecture the capacity to model complexities and behaviors found in nature, whether formally or as digital simulations. According to Branko Kolarevic (Kolarevic, 2003, p.1-16), *"digital technologies are changing architectural practices in ways that few were able to anticipate just a decade ago ... Digitally-driven design processes, characterized by dynamic, open-ended and unpredictable but consistent transformations of three-dimensional structures, are giving rise to new architectonic possibilities"*.

Accordingly, and in considering the design disciplines today as having the responsibility to produce outcomes with positive environmental impact, and given the allowances digital technologies are giving the designer today, it remains imperative to look at nature for reference, not only to enable us to maintain it, but also to learn from it to produce intelligent, productive, and environmentally relevant prototypes.

Digital fabrication and Digital craft

Digital fabrication today has become a crucial means of production, allowing the direct application of a three-dimensional digital file into a physical prototype. Through various technologies, such as CNC routers (computer numerically controlled machines) or 3D printers, it has transformed the ways in which designers, or individuals at large, produce physical objects, moving the means of production from the factory or the specialized workshop, right into the designers' desktop, more so with the proliferation of low cost technologies. The open source digital world has enabled a worldwide sharing of knowledge and material know-how, allowing the quick advancement of digital fabrication within and outside of the design field. Furthermore, digital fabrication today is necessitating the role of the designer as both the thinker and the maker, enforcing an understanding of the technology and the material constraints within the design process. Dimitris Papanikolaou (Papanikolaou, 2012) links such

technological constraints to design conception and states *“Digital design and fabrication have significantly affected professional practices, as the designers of complex geometric assemblies must holistically take into account the machine, material, and computational constraints during the design process.”*

This hybrid of the designer/maker has brought forth the notion of the digital craft, linking that digitalized design forming process to a crafts inspired process of making. In his text ‘The Risky Craft of Digital Making’, Branko Kolarevic (Kolarevic, 2008) gives significance to this notion of the ‘digital craft’, by referring to Malcolm McCullough’s (McCullough, 1996) definition of the term as *“an emerging set of material practices based on digital media that engage both the eye and the hand, albeit in an indirect way.”* He proceeds to define several key attributes to this new craft, such as the embedding of material understanding in the digital design process, the linking of the hand and the mind in the fluid form making workflow, the iterative process of testing prototypes in various models, and the circular feedback between the physical prototype and the digital file. In that, he relates the traditional understanding of crafts as an art relying on a hand-mind relationship, on material know-how, and varied iterations, to the current digital design and fabrication process. Kolarevic (Kolarevic, 2003, p.46-87) furthermore proposes that a new materiality is taking shape in the architecture and design practices, as technology and complex forms are inspiring novel investigations in materials, with new composites, intelligent, and active properties.

Consequently, this enforces the importance of not only the digital counterpart in the design process but also, and more significantly, the physical and material parts, enriching the process with a back and forth move from the digital to the physical. The methods of physical testing, trial and error, material understanding and know-how, become essential within the design process as parallel and symbiotic resources to the digital forming process.

Process & methodology

The above two approaches, from digital craft and its process of making, to learning from natural systems and models, have equally formed the framework within which the architecture seminar New Territories is given yearly at the Department of Architecture and Design, at the American University of Beirut. The course is offered as a technology research-based elective, where senior undergraduate architecture students are given the chance to advance their technical and digital skills, and to explore material systems through making. In New Territories, the approach has been to investigate this analog/digital process as relevant to the undergraduate level in architecture, with a parallel interest in producing building systems that have a productive environmental impact. Starting with natural systems as reference for environmental concerns, the students were asked to design prototypes and explore materials with the aim of creating building systems that would generate a positive environmental effect on the built environment. They had to involve hands-on tools, understand the materials they are working with in depth, and to utilize digital fabrication methods and digital models, to produce accurate design outcomes. As such, they focused on the continuous crossing between hands-on material explorations and digital iterations, using research and trial and error methods, to produce their inventive prototypes.

Each year, the course focused on a different project theme, however it constantly revolved around exploring the design of building products or active building systems, be it modular facades, intelligent cladding, or adaptable seating. And this was framed and approached every year by embedding current digital technologies with an understanding of natural systems and a physical know-how of material behavior. The aim however was never

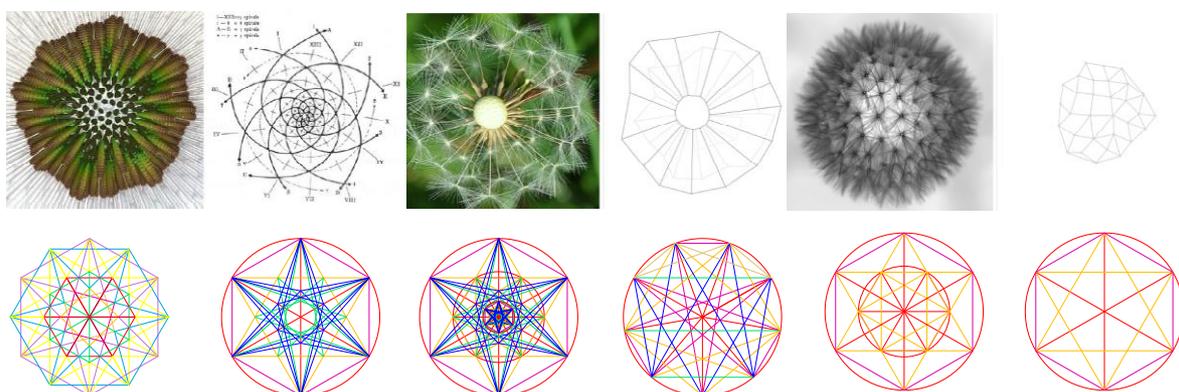
to reach a designated solution but rather to allow for open-ended explorations. The learning happens as such in the process itself rather than in the end product.

From these different aims, three main themes of inquiry emerged through the varied explorations across the three years, each one approaching materiality and digital technologies from a different lens. The first lens focused on intersections of nature, craft and digital techniques to form active façade systems that respond to environmental constraints. The second lens involved the plasticity of concrete material, fluid formwork and natural systems, to design urban seating. The third lens focused on concrete composites to produce various cladding and tiling prototypes with direct environmental impact.

New Territories – experiments 1

The first year and theme focused on the design of intelligent façade assemblies, through crossing the study of natural systems as precedents with traditional crafts methods. The students worked on designing performative facade systems, each group starting from the study of a relevant natural system and a specific craft, and then using parametric modeling to develop their modular facades. They looked at jellyfish, dandelions, and silk worms to design behavioral modules that responded to sun, visibility, and wind. They utilized hands-on experiments and digitally produced prototypes, to optimize their designs.

In studying the dandelion, one group of students were interested in the structural aspects of the dandelion's geometry and its connection to wind and ventilation. They looked at it as a reference for a modular façade system of assembly that allows cross ventilation and varying shading opportunities. The geometric analysis of the dandelion was then followed by parametric digital modeling, guided by ventilation and sun orientation constraints, to produce the façade's design. The students studied in parallel the craft of weaving to develop the interlocking parts, and accordingly designed an open three-dimensional grid system, with varying openings and axes for cross ventilation and sun protection. To produce their final prototype, their focus was on integrating new fabrication techniques in an optimized manner; Rather than produce the entire space-grid through digitally fabricated techniques, they opted to only produce the more complex connecting joints between the different units with high resolution 3D printing, while using market available rods to form the simpler connecting members. (Figure 1)



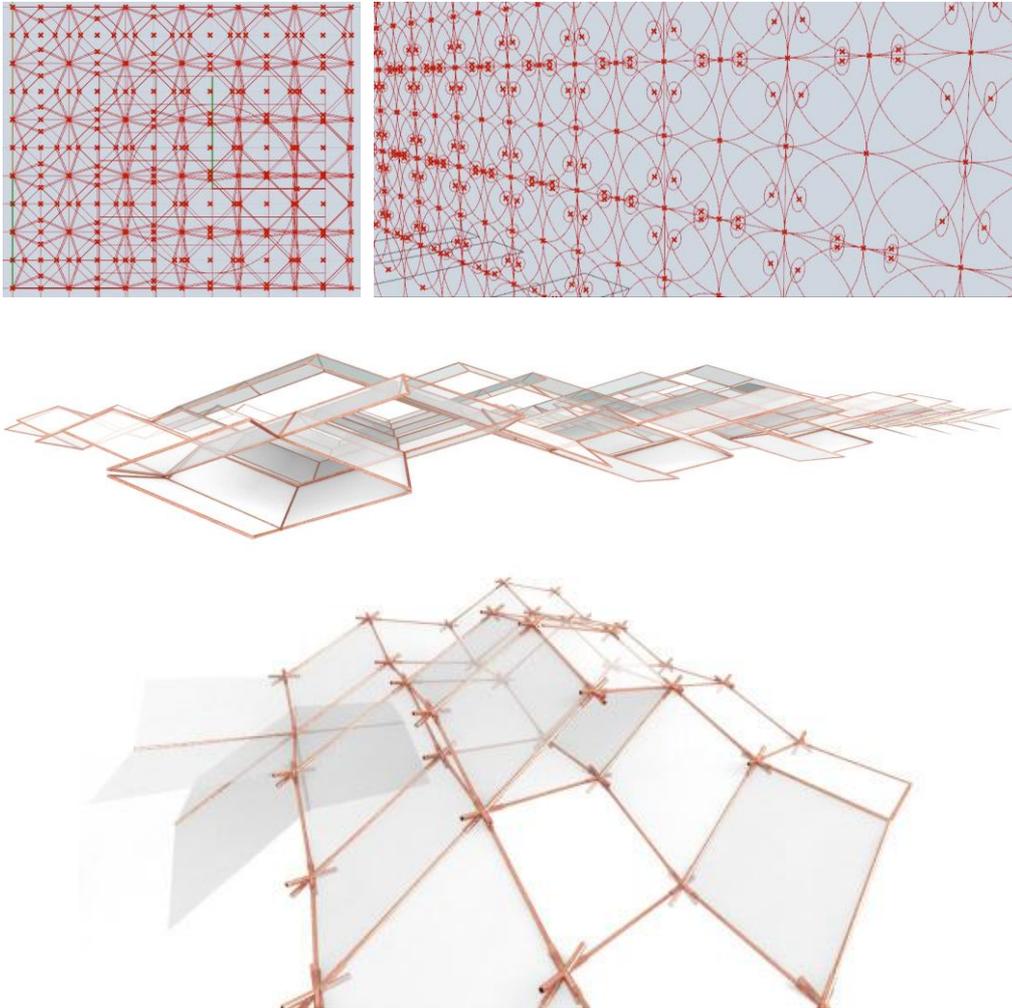


Figure 1. New Territories Fall 2014 - Alia Bader, Talia Fatte, Lori Kharpoutlian, Yara Rahme

New Territories – experiments 2

The second theme looked at the cross of craft and digital technologies through form-finding techniques and material properties, bringing in flexible formwork into the digital fabrication process. In groups, students explored concrete plasticity and behaviors with natural references, as they worked on the design of an exterior urban seating installation using lightweight concrete composites and casting methods. Themes of concrete casting, plasticity, and form-finding techniques, inspired by works of Antoni Gaudi and Frei Otto, highlighted the role of hands-on experiments, composites, and fabric formwork in producing plastic and elastic material qualities. The seating, designed for an outdoor area on the university campus, was required to accommodate several users and various modes of sitting. Two groups formulated two main approaches to the semester. The first one utilized form-finding techniques by applying tension on a stretched fabric to produce the design, and the second group utilized a natural system to create and cast a topographic seating prototype.

In the first approach, students experimented with fabric and casting at various scales, highlighting the role of tension, gravity, and materiality for form-finding and design intervention. They focused on creating centralized zones of depressions and mounts, moving between structural requirements and seating configurations. Their surface provided centralized meeting zones for seating. In parallel, they worked on concrete and plaster

composites, with acrylic and resin admixtures and reinforcing fibers, to produce various material tests ranging in strengths and plasticity. Their material studies allowed them to move up to a real-scale installation, using fabric-formed concrete method, to cast their topological seating design. (Figure 2)

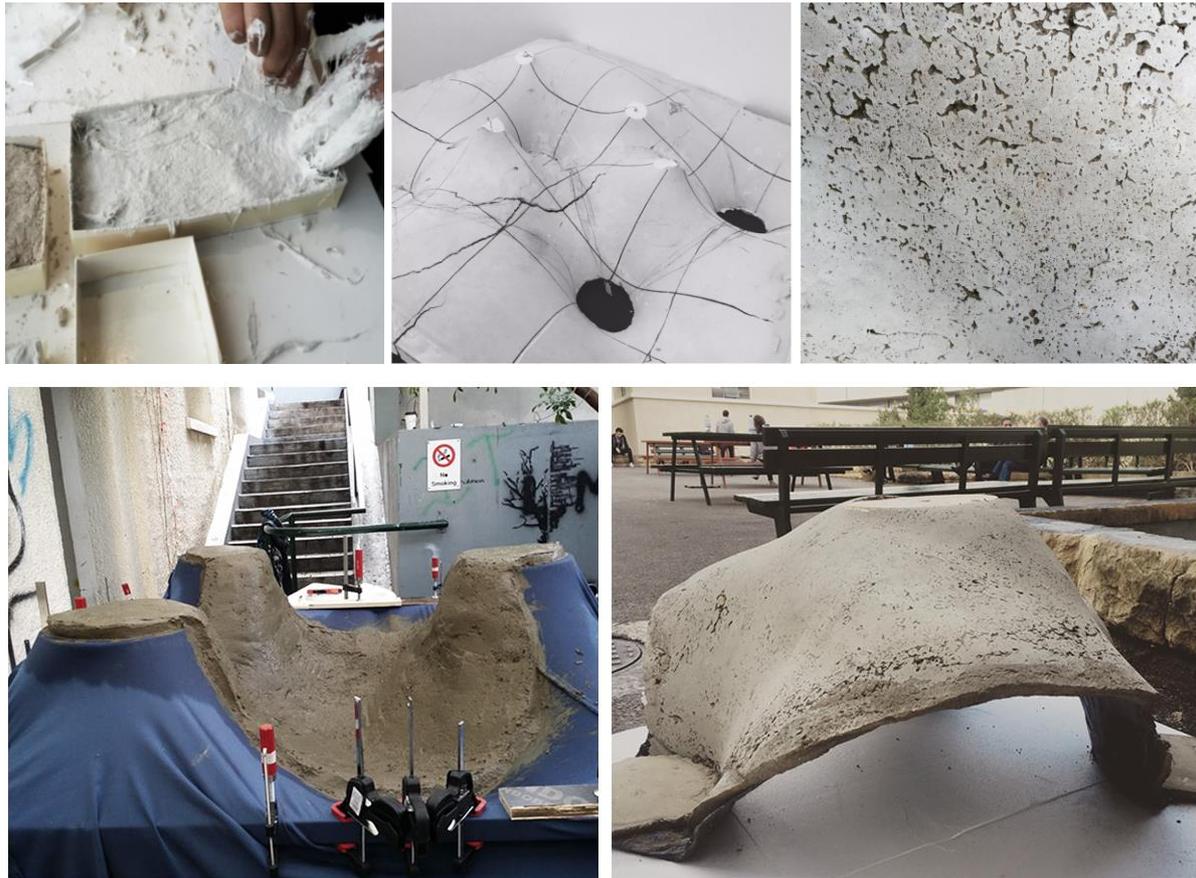


Figure2. New Territories Fall 2015 - Tina Najia, Fayssal Yatim, Henri Asmar

In the second approach, students were interested in the turtle shell as a modular hexagonal structure, where material, form, and structural integrity are interrelated. After geometric and formal analysis of the turtle shell system, they formed a modular hexagonal system of their own, where variations in the top surface of the hexagonal unit created a varied seating position. Their material experiments focused on variations of textures and elastic qualities of the concrete and plaster pours, using stronger mixes for lower pours, and more elastic mixes, enabled by the use of acrylic, for top layers. The formwork was CNC milled in wood and lined with acrylic sheets to form the hexagon's sides, with the seating surface milled in extruded polystyrene foam, to provide a textured finish. In their mixes and pours, the students worked with lightweight materials such as foam spheres and inflated balloons, to hollow the body of the concrete seating and decrease its weight. (Figure 3)



Figure 3b. New Territories Fall 2015 - Ismail Hutet, Ghida Chehab, Nour Hajj, Tracy Bou Zakhem

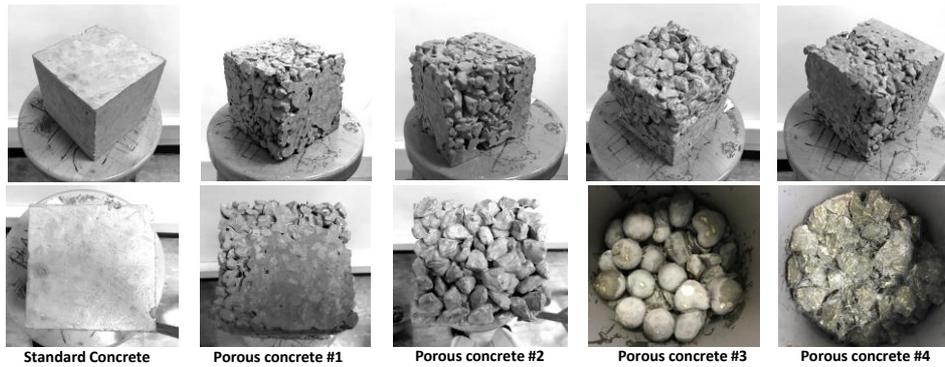
New Territories – experiments 3

The third theme focused on bio-composites and material experiments, working primarily with concrete mixes, and using digital fabrication techniques to create performative cladding or tiling systems that respond to environmental concerns. The interest was mainly in addressing critical urban and environmental issues through these architectural building materials, and to bring awareness to the imminent problems of waste, pollution, and other local crises. Several issues and contexts of interest emerged and became the center of the students' research.

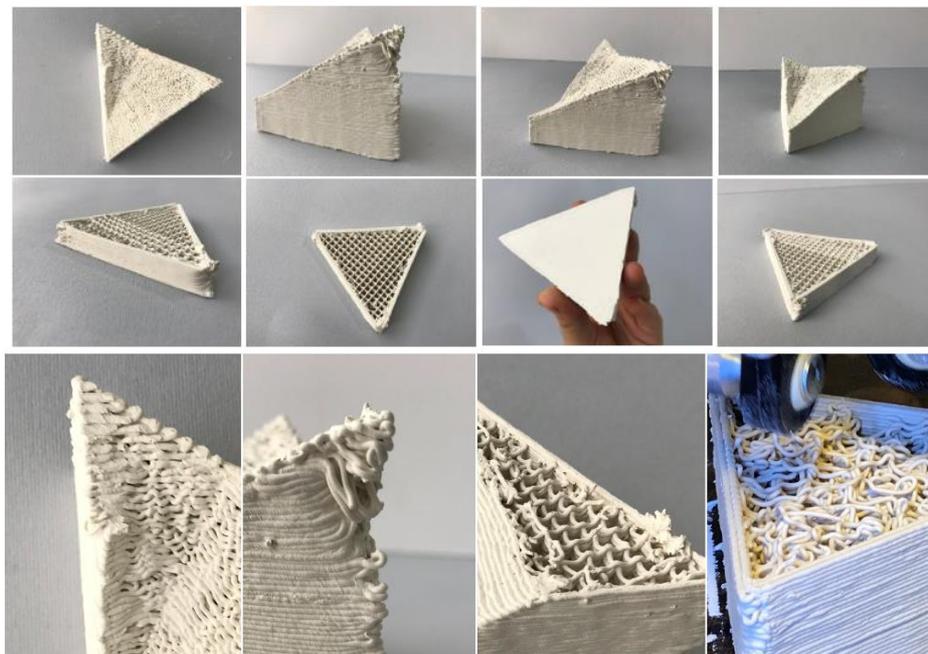
As a methodology, students began by investigating their issue, while looking at precedents and material composites that have addressed similar concerns. They were required to work with modular systems that can adapt to various situations and enhance actively their immediate environment. The different groups of students experimented with concrete composites, relying on material research, parallel case studies, and physical hands-on trials, to produce different cladding and tiling prototypes. Within the work process, clay 3D printing was integrated, as a fluid method of additive prototyping that involves the layered pouring of soft clay to form three-dimensional outcomes. The process of clay 3D printing played a major role on some students' projects as a formative agent for their design and its potential application.

The first group was interested in porous concrete pavers as a system that allows water infiltration into the natural ground, reduces water run-off in urban streets, and includes rainwater collection for irrigation needs of urban green surfaces. Their design was developed as a smart urban paving system that integrates seating and walkways along a widened pavement area in Beirut, and includes green zones and water collection system. It was envisaged as a smooth surface with varying dips and hills, formed by a modular triangular grid, with the modules prefabricated and assembled together on site, replacing existing urban pavers. The students experimented with various mixtures of concrete, using lightweight and foam-based aggregates of various sizes, and produced a series of potential compositions. They utilized clay 3D printing as a tactile "craft" method for real-scale fabrication, learning

from its textured results and the varying degrees of porosities and surface qualities that emerge as a result of the additive layering of fluid clay. The design of their modular prototypes therefore integrated this fabrication and material porosity to enhance the water infiltration performance of their urban paving system. (Figure 4)



	Sand	Medium Gravel	Small Gravel	Cement	Water	Styrofoam	Fiber Glass & white glue
Standard concrete	I	-	-	II	-	-	-
Porous concrete #1	-	-	I	I	I	-	-
Porous concrete #2	-	I	I	I	I	-	-
Porous concrete #3	-	II	-	I	I	-	-
Porous concrete #4	-	I	I	I	I	I	I



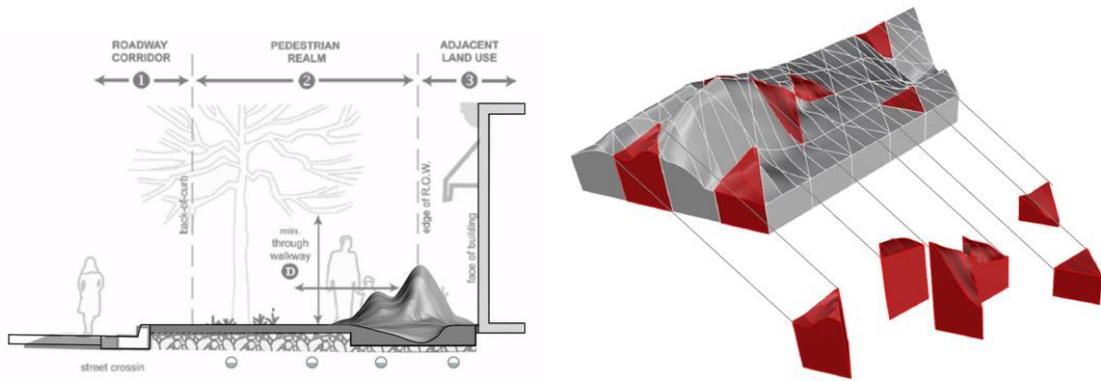


Figure 4. New Territories Fall 2017 – Yasmine Atoui, Sarah Abiad, Soraya Hachem, Reem Al-Awar

The second group also reflected on the urban streetscape, but focused their research on areas around main traffic arteries with large concentration of pedestrians and public activities. Their interest was to create a system of urban cladding that can reduce air toxins and car-generated pollution at the pedestrian street level, and accordingly focused on the area around Beirut’s corniche, to design composite cladding integrating concrete and natural moss. Their research expanded on work done by BiotA Lab at the Bartlett School of Architecture in London, and referenced the latter’s experiments in composites of concrete and moss; the moss actively helps by absorbing air pollutants in its vicinity, in addition to producing oxygen. The students further looked at aerated concrete techniques and experimented with additives to create lightweight pockets in the pour, while adding phosphate magnesium to lower the PH level of the concrete mixture, and thus allow for better moss growth. Their resulting design was informed by the naturally occurring geometry of the voronoi cell, creating an urban wall system with pockets and cavities of varying sizes, which allow higher water capture at the base and enhance the growth of urban moss. (Figure 5)

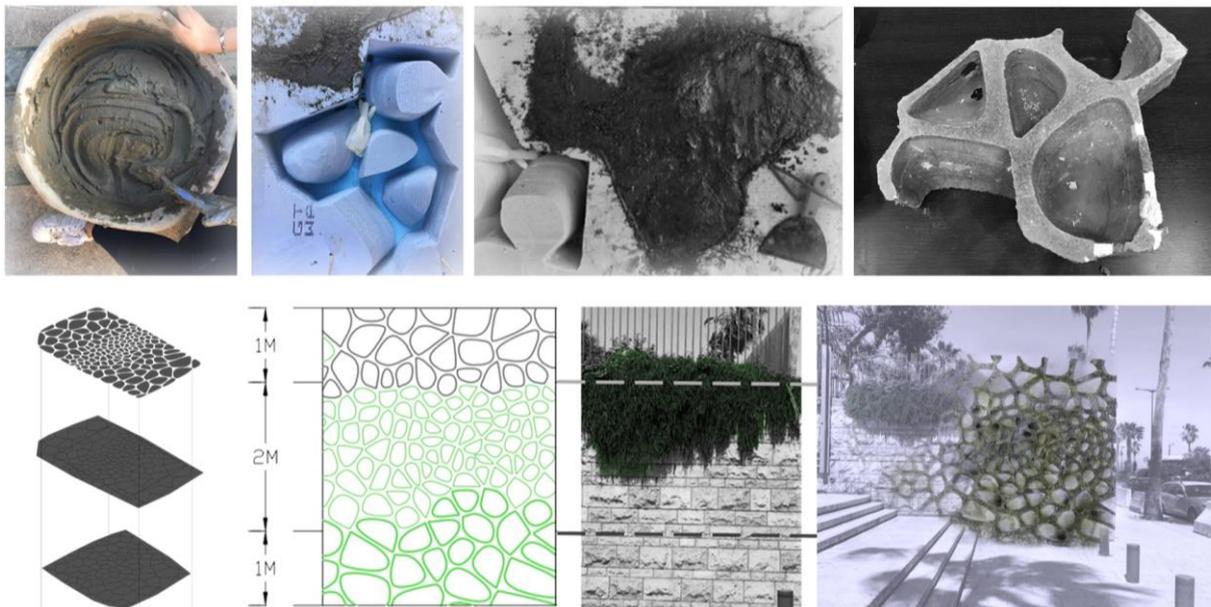


Figure 5. New Territories Fall 2017 – Faisal Annab, Manar Khatib, Taha Barazy, Hiba Hage

A third group was concerned with the refugees’ crisis in the Bekaa valley and the growing need for immediate protective shelters that can withstand the harsh weather

conditions in the Bekaa. Some of the main issues that students wanted to address in designing new forms of shelters were issues of durability, comfort, security and cost efficiency. Their investigations began by looking at modular lightweight concrete blocks, and their interest was to design a new block type that can generate the shelter's form and provide high efficiency in its construction.

Through research, the students became inspired by the traditional Musgum mud huts from Cameroon, which are conical shaped dwellings with an inherent structural capacity and an insulating thick wall. They researched further the formal and structural aspects of the huts, linking them to catenary arches and shell structures found in nature. Their design elaborated on this conical form, and resulted in a dome like shelter with a central top opening for ventilation. A tessellated pattern was projected on the dome, and formed the base grid for the modular block system. The new "hut" would be fabricated from the resulting diamond shaped blocks, stacked above one another with a locking compressive joint. To produce these blocks, the students experimented with various mixes and composites of concrete, trying to reduce the heavy aggregates in the mix and to replace them by lightweight alternatives. They were specifically concerned with different types of waste materials, such as wood saw, wood bark, and plastic fibers, as potential additives for reinforcing the concrete. Their interest was to integrate waste in an up-cycling strategy, reducing cost and increasing the efficiency of their modular blocks. Their different material experiments produced a variety of potential composites with different block weights and consistencies. (Figure 6)

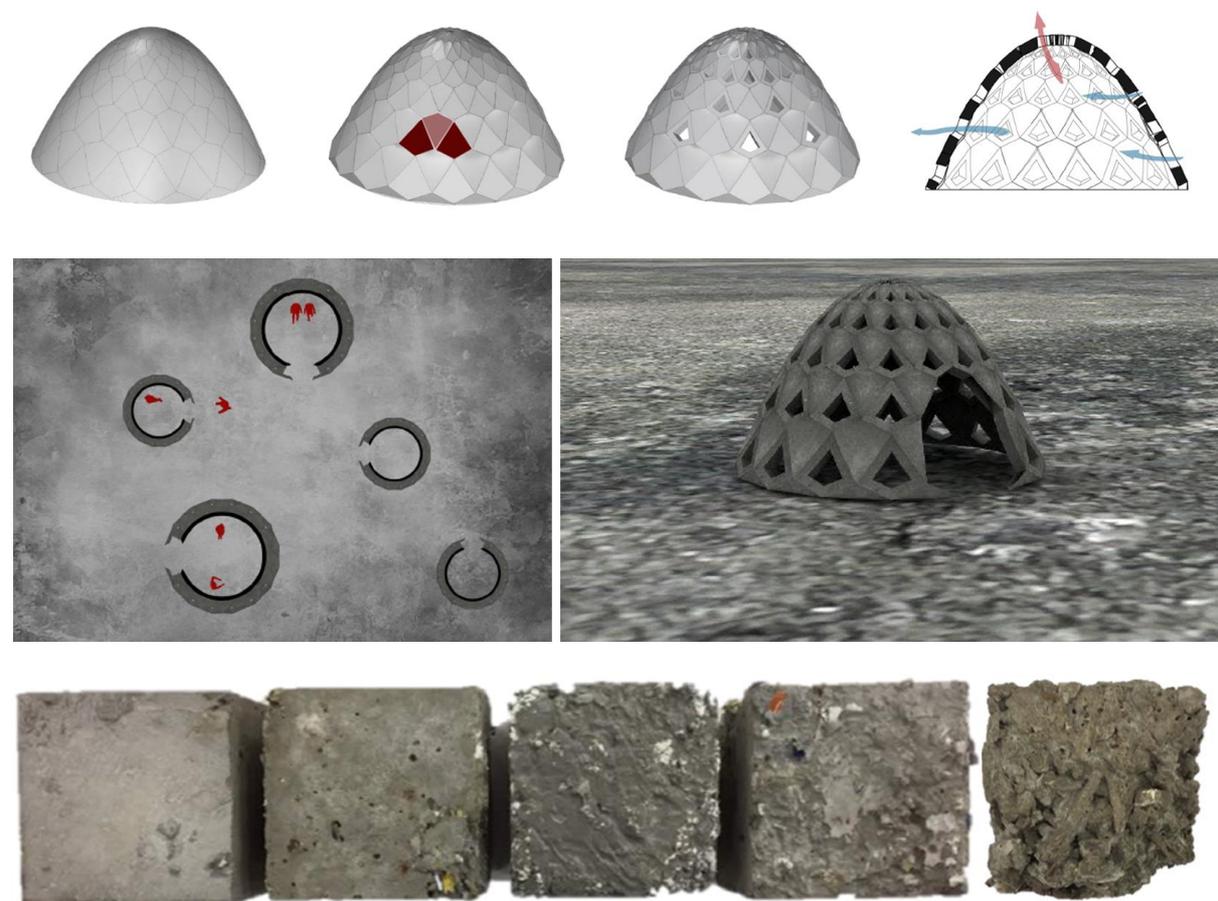




Figure 6. New Territories Fall 2017 – Karen Asmar, Souha Bou Matar, Lana Barakeh, Omar Darwiche

Learning & Outcomes

In the course, and over three sessions and three variations of digital/analog experiments, multiple learning outcomes came across. The back and forth process between digital iterations and physical prototyping allowed students a rich understanding of the different constraints at hand, and integrated a direct understanding of material within their design approach. Issues such as the behavior of concrete, its weight, the process of its hardening, the appropriateness of certain types of aggregates, and the constraints in forming the formwork for the pour, all enabled a rich and hands-on process that informed the design at different stages.

Furthermore, the integration of advanced fabrication techniques enabled the students to proceed into more complex formal applications, utilizing 3D printing and CNC milling at intermediary and final prototyping stages to test and optimize their shapes. In the course of three years, the different student groups approached the environmental issues and the concern with natural systems from varying points of entry. The earlier approaches were interested in nature as a parallel system of reference, one that can become an exemplary formal model to inspire their own designs. In later experiments, students were more interested in direct hybridity between natural systems and their material experiments, integrating material behaviors, bio-composites, and chemical reactions, to form their active products. Their concern with traditional and crafts methods of making was also varied, from looking directly at a craft technique to converting their own making process into a digital craft.

In a way, the course pushed the students to consider an environmental and design problematic in an open-ended fashion, to approach it as an opportunity for experimentation rather than as a problem-solving endeavor. The gained know-how in both digital and physical methods of making, with all the associated constraints and results, was more integrated within the process itself rather than in the final outcome. The hope was to give the students the opportunity to gain innovative and thorough understanding of the correlation between environment, materials, technology, and design.

Conclusion

This paper thus details the pedagogical and design methodology developed by the research seminar New Territories through its students' experiments over three years, elaborating on their material experimentation, digital and analog design methodologies, and final results. It aims to shed light on the persisting importance of material knowledge as it intersects with advanced digital fabrication, and the significance of learning from natural systems and biological properties to embed an active performance in today's design process. It projects forth an essential responsibility on the new generation of designers to address critical

environmental issues through design, and to benefit from advancements in technology and the design field at large to push the boundaries of making. With the abundance of digital fabrication techniques however, continuous awareness of the tactility of a material process is crucial for the designers of today, and is strongly needed to push forth critical and informed results in design.

References

- Gruber, P. (2011) *Biomimetics in Architecture*. in Gruber, P., Bruckner, D., Hellmich, C., Schmiedmayer, H.-B., Stachelberger, H., Gebeshuber, I.C. (eds.) (2011). *Biomimetics, Materials, Structures and Processes*. Berlin: Springer, pp. 127-147
- Brownwell, B., Swackhamer, M. (2015) *Hypernatural: Architecture's New Relationship with Nature*. New York: Princeton Architectural Press
- Kolarevic, B. (ed) (2003) *Introduction*. in Kolarevic, B. (ed) (2003) *Architecture in the Digital Age: Design and Manufacturing*. London: Taylor & Francis, pp. 1-16
- Papanikolaou, D. (2012) *Changing Forms, Changing Processes* in Kara, H., Georgoulas, A. (eds.) (2012) *Interdisciplinary Design: New Lessons from Architecture and Engineering*. Barcelona: Aactar Press, pp. 106-114
- Kolarevic, B. (2008) *The Risky Craft of Digital Making*. in Kolarevic, B., Klinger, K. (eds.) (2008) *Manufacturing Material Effects: Rethinking Design and Making in Architecture*. London: Routledge, pp. 119-128
- McCullough, M. (1996) *Abstracting Craft: The Practiced Digital Hand*. Cambridge: MIT Press
- Kolarevic, B. (2003) *Digital Production*. in Kolarevic, B. (ed) (2003) *Architecture in the Digital Age: Design and Manufacturing*. London: Taylor & Francis, pp. 46-87

ISBN: 978-1-9997971-9-5
Project website: www.newton-sdbe.uk
Twitter: @Newton_SDBE