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URBAN POINTS OF REST
An emerging digitally fabricated modular system

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Abstract
The paper presents a case study of a developed production system designed to produce customized social settings and spatial enclosures, responding to specific social needs of a particular group within an identified social unit. The paper describes the relation between digital fabrication and the rules for design and assembly; how varied interlinked parameters are generated towards the realization of the final design. The presented case study narrates and reflects upon the system deployment within a selected context; an academic regional setting with a monocultural learners' population. Going back and forth between practical and digital evaluation, the paper describes the sequential stages of applied design and several prototypes realization. The case study; Urban points of rest, argues for a design variation within formulated digital fabrication systems in par with user participation.

Keywords
lean-production, discrete architecture, digital fabrication, community involvement, prototype

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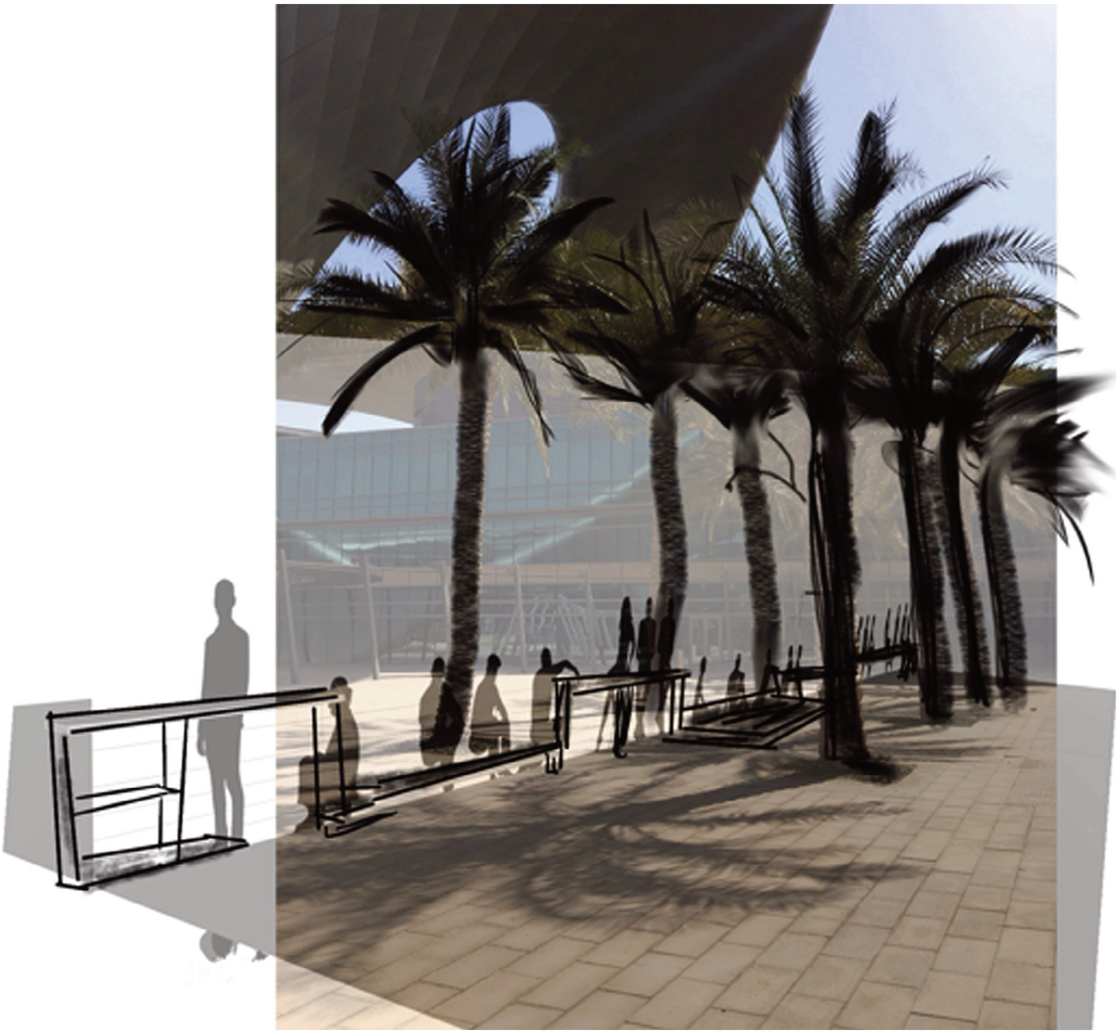
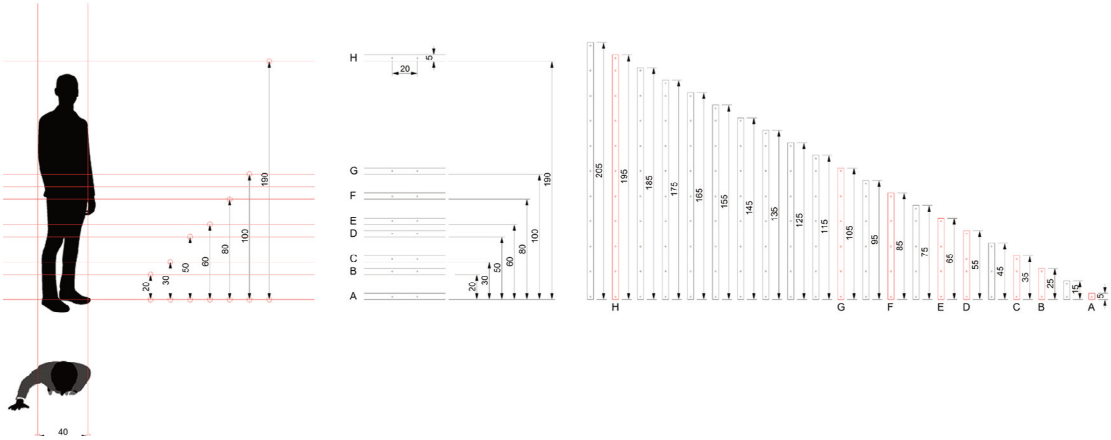
The paper presents a case study of a deployed modular system designed to produce and instigate a variety of urban spatial 'patterns' that promote customized social settings and spatial enclosures. The followed methodology emphasizes the value of doing, through an active explorative process of design and build, devising solutions to problems that would otherwise go unnoticed (Koskinen et alii, 2011) It describes a rigorous relationship between fabrication, making and community involvement through the application of coded prescribed process derived from specific rules of assembly. Drawing from the notion of 'discrete design' (Retsin, 2019a, 2019b, 2016) within perceptions from digital fabrication and making theorem, the case study narrates a system implementation within a selected context and locality. It argues for a design variation derived from the assembly of similar components in par with user participation.

In 1929, Fuller reflected on the concept of houses mass production and contemplated on the idea of how it could totally redefine the architects' role (Arieff and Burkhart, 2003). The twentieth century, however, witnessed a surge of mass-production backed by the industrial revolution and the introduction of new materiality which brought with it assembly-line practices; standardization where identical products were mass-produced (James-Chakraborty, 2014). Around the 1980s, a new paradigm that looked into devising strategies that provide customized products at production rates emerged. Its manifestation directly linked to product quality and produced quantity (Pine, 1992). Today's emerging computing power backed by the introduction of numerically-controlled machines and the spread use of computer-aided design – CAD and computer-aided manufacturing – CAM technologies have revived architects and designers' interest in mass-customization. (Willis and Woodward, 2010) This has allowed for design complexity and variation within the same parameters of the defined process and reintroduced the direct link between design and production.

'Making' has always been a central part in architectural design. It is the way architects and designers are taught to think, synthesize a problem and visualize a 3D space. Yet for centuries, design has been separated from production, with architects making 'building representations' rather than buildings (Carpo, 2011). Development in prototyping technologies and design methodologies (parametric and computational procedures) has altered the followed traditional design measures and created a direct link to manufacturing and fabrication processes. The rise of digital design changed the traditional designer role, shuffled the order of design processes and opened new frontiers through an interdisciplinary approach (Tedeschi, 2014).

On site-construction processes typically follows a comprehensive set of prepared shop drawings and specification documents done by specialized contracting companies. The presented case study explores the possibility of introducing on-site digital fabrication modular system and linking the design process directly to production. It also suggests the end-user direct involvement by altering or creating his own environment based on need and preference. Modulation and layering become the bonding element for a construction language that does not follow a predetermined pattern for a





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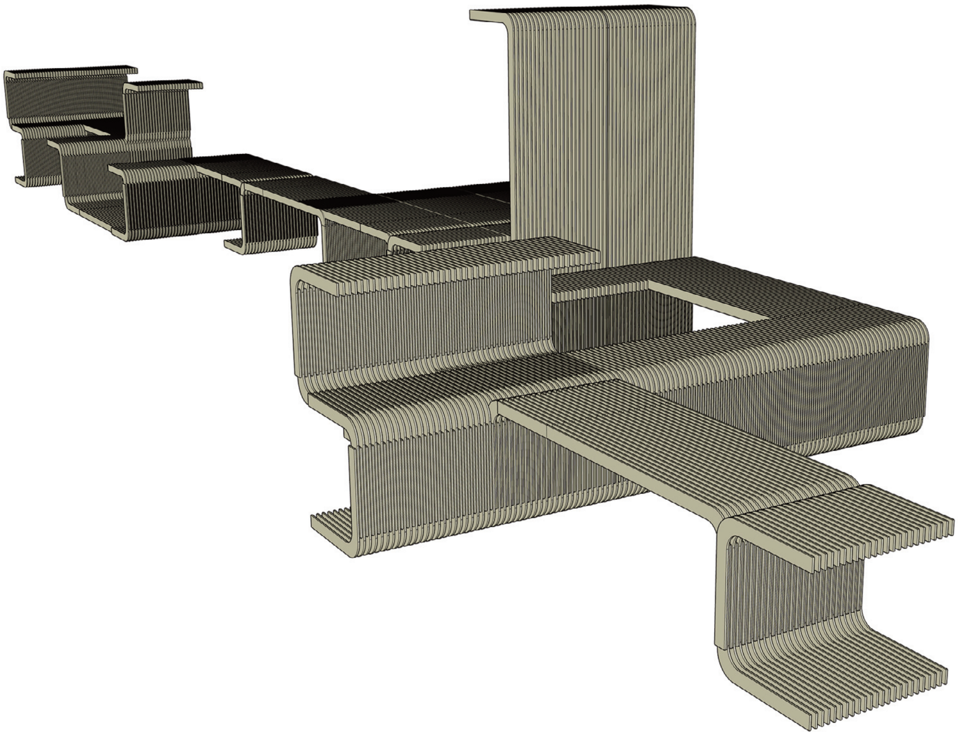

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Fig. 1 | Image of sketch of the prototype in site (credit: Authors, 2017).

Fig. 2 | Diagram for rules of Assembly (credit: Authors, 2017).

Fig. 3 | Image of digital model of the prototype simulating modulation possibilities (credit: Authors, 2017).

purpose but it is defined by the suggestive activity to occur. The modulation of the pieces is not guided by a predetermined aesthetic but have a certain freedom to flow, expand, encapsulate and generate.

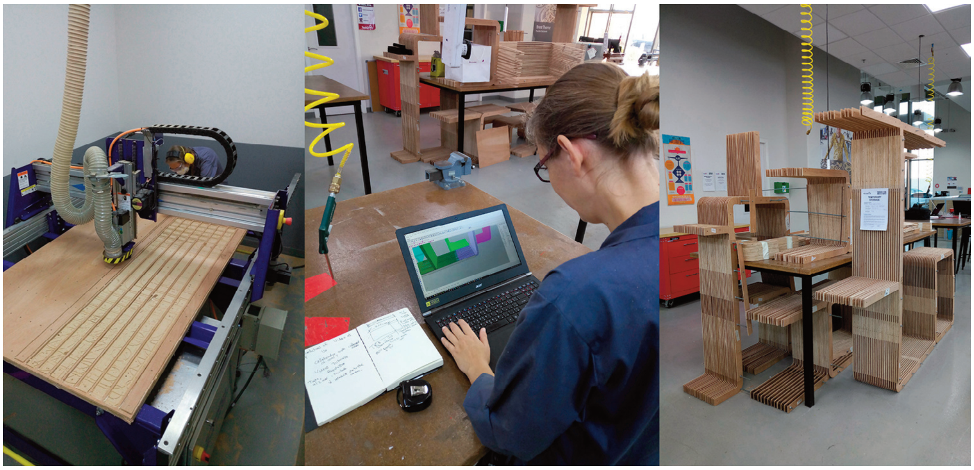
Today's CAD/CAM technologies provide the designers with tools to prototype their designs and manufacture building components; thus, altering and changing the design processes as well as reviving the past notion of designer's interdisciplinary knowledge and approach (Schodek et alii, 2005). The presented case study is in par with worldwide conducted explorations by students and professional architects into finding methods and techniques to bridge between representation and production; whereby digital fabrication is seen as a way to avoid the drawbacks of traditional manufacturing and allow the production of diverse alternate forms and components. The uniqueness of the conducted case study stems from the context, where fabrication knowledge is in its infancy, and from the end-user, with minimal or no previous design knowledge, active involvement.

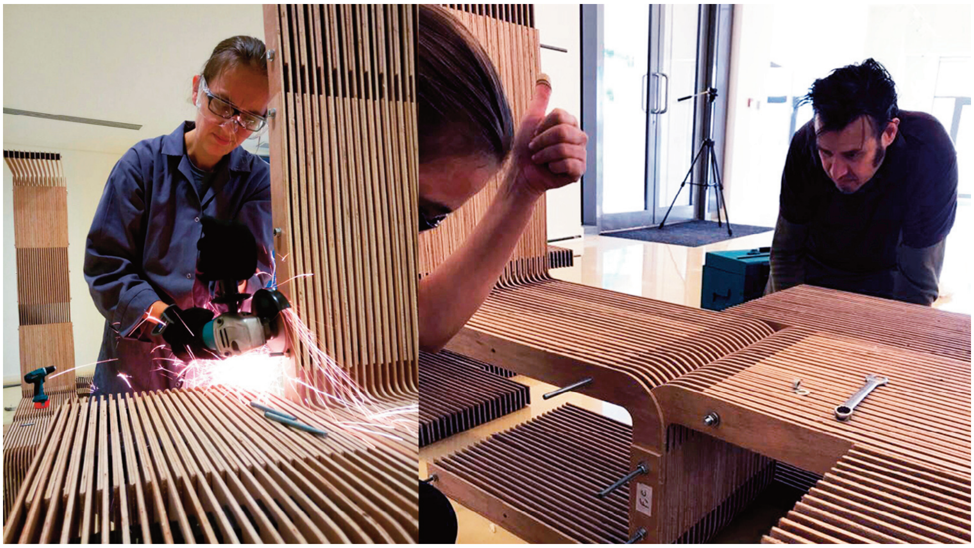
Prefabricated architecture, brief overview | The link between architectural design and fabrication can be traced back to 1906 to Aladdin Ready-Cut House; whereby pre-cut numbered pieces were delivered to site for direct assembly (Aladdin Company, 1995). Other companies, such as Gordon Van Tine, Montgomery Ward, the Hodgson Company, Roebuck and Co. and Sears whose products existed until 1940, continued with the notion of prefabricated homes presenting them to their client or future homeowners through catalogue pages (Harris, 2010). Prefabricated architecture differs in its build-up approach and assembling process, they all depart from the known concept of in-situ site construction, thus challenging its methodology and procedures. Backed by the economical drive and technological advancement specific to their time, they explored the concept of ready-made, off-the-shelf and kit-built houses. This notion shuffled the hierarchy of design and build-up process, brought it to the controlled environment of the manufacturing factory, and at times gave its occupant an element of choice in the selection of the assembled parts.

The relation between design, fabrication and technology has gone through several rapid iterations within the past decade. Gershenfeld's notion of digital mass-customization, programming the physical world (Gershenfeld, 2012) and the concept of Digital materials (Popescu, Mahale and Gershenfeld, 2006). Leach's dispute that acknowledges the use of digital tools in a design practice but negates digital description and title. (Leach, 2014) And the followed post-digital discourse that questions the use of digital tools and techniques in relation to their application and affiliation as well as the meaning of digital design and digital material organization. Capro's description of the Second Digital Turn (Carpo, 2017) as tools for thinking enforced by today computation power and advancements in areas of form-finding simulation and optimization, and experiments with new forms of machine learning and artificial intelligence. As well as the argument for bespoke design through the file-to-factory process.

Modular versus Discrete Assembly, brief overview | Modular design is linked to the notion of prefabrication, where identical pre-cut pieces are delivered to site for direct and relatively quick assembly. The serial production of identical unit-solutions correlates to the industrial era, the permutation of technology and standard operations of lean production (Smith, 2010). The recent emerging Discrete movement adopts a similar social and economic value but negates the same unit mass-customization. It is described as «[…] a new paradigm that attempts to reconsider serial repetition as an economy of scale» (Sanchez, 2014, p. 1). that conveys principles of fabrication, customization and adaptability through the combinations of purposely designed parts across scales (Sanchez, 2016). Autonomous parts through their cumulative relation to one another define a system that is formulated, and yet is independent of the whole; one that grows or retreats in relation to the surrounded contextual settings and as such results in a number of possible derived solutions and equilibrium states (Sanchez, 2019).

Pedagogical Perspective | Experiential education within the Bauhaus school setting is one of the earliest examples of design and build pedagogy connected to its time





Figg. 4, 5 | Images of fabrication and assembling of the prototype (credits: Authors, 2018).

emerging technology and social context (Hayes, 2012). Kolb (1984, p. 38) defined it to «[…] the process whereby knowledge is created through the transformation of experience». Knowledge results from the combination of grasping and transforming experience. More recently, Blikstein described through three main attributes: 1) Enhancing existing practices and expertise, 2) Accelerating invention and design cycles, and 3) Long term projects and deep collaboration. (Ockman, 2012) It is seen to offer «[…] a pedagogical alternative to the theoretical, desk-based and media-driven (drawings, digital models) design process» (Canizaro, 2012, p. 20). It has been known to 'sup-

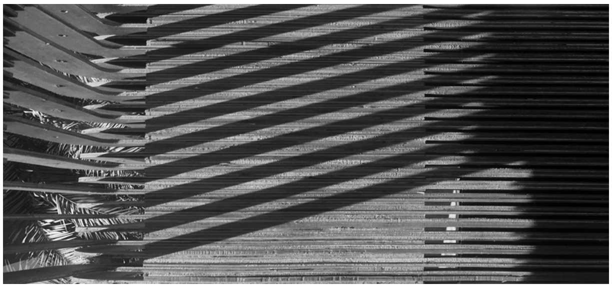


Fig. 6 | Image of the digital model of the prototype simulating modulation possibilities (credit: Authors, 2018).

Fig. 7 | Variation and adaptation to site conditions (credit: Authors, 2018).

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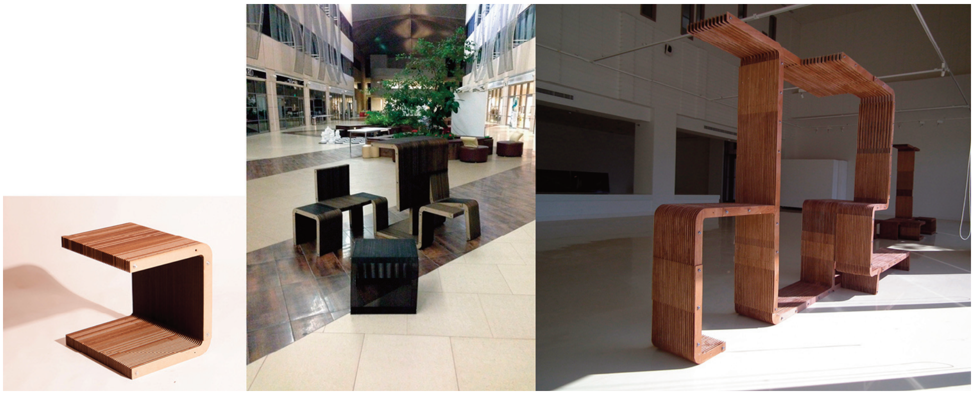
Fig. 8 | Interaction with and prototype usage (credit: Authors, 2019).



plants drawings, models, and all forms of representations' for the direct interaction with material and manufacturing processes (Brown et alii, 2013). The described methodology was further applied and extensively explored in many architectural schools across the globe (Erdman et alii, 2002).

Preamble | Design methodologies and trends correlate and adapt through time, responding to the latest technological advancement in tools, techniques and methodologies. The literature review presents a very brief overview of fabrication discourse. The presented case study situates itself within a government institution where the notion of fabrication is at its infancy, with a limited access to manual and digital fabrication tools and machinery. It also instigates the notion of making as a response to the current prevailing social consumerism trends. The study was conducted over two years, with all the data gathered prior to the international pandemic in 2020 enforced shift to online education. Phase I was the authors' initiative of instigating change in the local academic community, and Phase II is the transcended pedagogy implementation.

The contribution and originality stem from presented exploration of introducing digital fabrication and linking the design process directly to production. The process draws from the notion of discrete assembly using serial repetition. Parts and connections are repetitive. The uniqueness emerges from the design of larger formations that

correspond and are driven by parameters extracted from site, context and inhabitants/users' needs. The originality of this project is in its intake to democratise design through the use of technology. Next steps will look deeper into the possibility of deriving regional materials, thus adding the notion of sustainability to structural optimization. The approach combines design with rigorous research. It follows an empirical methodology that «[…] seeks to create knowledge that serves the design profession and others [an approach to] produce useful methods for practice or generalized methods that provide models for further development of domain-specific methods» (Poggenpohl and Sato, 2003, p. 5). Presented work fits within these two approaches; empirically through creating knowledge that is targeted to serve the local community identified within the selected academic setting, and methodologically through researching design systems, testing their implementations thus charting the next steps. The practice-research methodology leads to the creation of new discipline-related knowledge and suggests the inclusion of design as an assessment criterion (Pedgley and Wormald, 2007; van de Weijer, Van Cleempoel and Heynen, 2014).

The research shows a regional intake on the current debate of democratizing design, architecture and technology (Hyysalo, Hyysalo, and Hakkarainen, 2019; Ford, 2020). Through the devised process, the work assesses the devised system implementation and charts future possible scenarios. It draws from the usage of informal spaces in residential neighbourhoods and deciphers a typological language used by the participants and proposes an alternative system. To the authors' knowledge, there are not any similar studies in the other government-based institutions in the country.

Contextualisation, Targeted Audience and Participant Backgrounds | Both parts of the presented conducted case studies take place in the Gulf region where prototyping and fabrication approaches are at its infancy. The region itself has witnessed a rapid socio-economic change (WHO, 2006) driven by the oil and gas commercial utilization. Since the oil discovery early 1950s, the nation has transformed economically and demographically. Its major cities today are examples of modern metropolises with signature buildings and high-rise towers following the global and international style (Guéraiche, 2017). Because of the influx of the working force, the local population constitutes the minority of the demographics. Despite that, they have one of the world's highest per capita GPDs in addition to several social benefits (Fox, Mourtada-Sabbah Al-Mutawa, 2006).

The University where the study was initiated, is a federal gender-segregated institution for higher education that follows the American liberal arts college system. It has two main campuses in two of the major cities and is accredited by the Middle States Commission on Higher Education. The Interior Design program, along with the other four offered programs in the College holds a substantial equivalence accreditation from the National Association of Schools of Art and Design based in the US. As opposed to the multicultural demographic of the nation, the academic institution is characterized by a monocultural student body composed of mainly young national citizens. Furthermore, the Bachelor of Fine Arts in Interior Design is offered only to female students.

Methodology and Phases | Phase I (Figg. 1-9) followed a practice research method implemented by the authors. The project consists of three interdependent prototypes. Their succession was used as means to further develop the design, refine the structural and material system, evaluate the manufacturing procedures and assess audience receipt and response, points there were also used as criteria for evaluation and assessment. The used 'prototype' terminology refers to 1:1 scale, functional, build structures; a reference to the devised system of design and assembly. Further, all realised prototypes are ephemeral and transient in their nature; existing for a period of time. Following the same rules of design and growth, they successively increase in size within the same level of system complexity. The prototypes responded to identified site parameters, initiating users' and passers interactions and response to the spatial change of familiar environments.

Rules of Design and Assembly – Using 6 mm timber sheets, a language for the components was devised from serial vertical and horizontal elements. Limited to a 2400 x 1200 mm cutting bed, 21 different lengths are derived to 50mm wide by 6mm

Fig. 9 | Image of the final modular prototype on-site (credit: Authors, 2019).

linear elements with centred holes that are 200 mm spaced. From the 441 possible L-shaped configurations, 8 linear dimensions were selected based on distances extracted from the dimensions of the body at various resting points. The intersection corner is rounded off offsetting the hole by the half of the spacing distance in both x-axis and y-axis direction. This creates 64 possible L-shape configurations. For a more efficient material use and in order to minimize material wastage, any desired distance longer than 650 mm was divided into a linear element of the desired length and two 650 mm

Fig. 10 | Prototype example, Hexagon by Rawdha AlKetbi (credit: Authors, 2018).

Fig. 11 | Prototype example, Urban π by Zainab Alblooki (credit: Authors, 2018).

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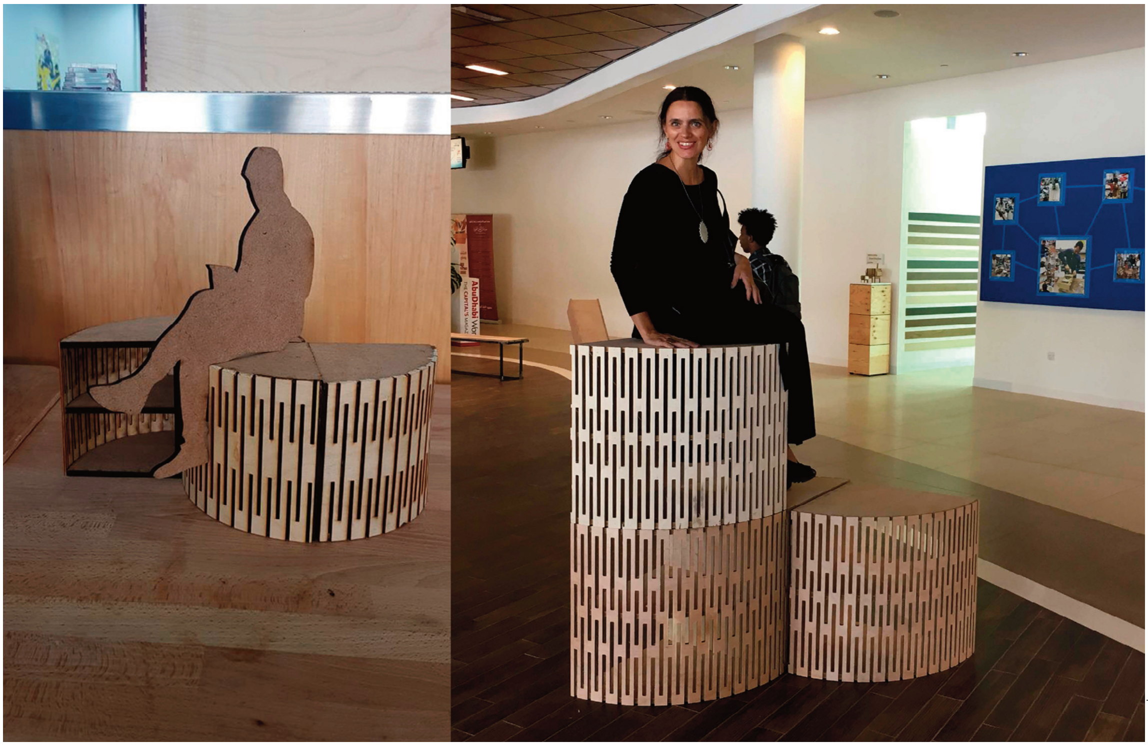
Fig. 12 | Prototype example, Quarters by Natnael Gezae (credit: Authors, 2018).



L-shape elements. An aggregation system is derived from a well-documented language of layered sectional elements (Iwamoto, 2009), aggregated along steel rods and secured with end nuts at each end without any adhesive to accommodate possible slight material deformation. The compositions are realized as dual, triad and quad organizations attaining the prototype's aesthetic quality and structural stability. The system allows the prototype to grow in width, length and height. The interplay between solid and void, thus the achieved surface density responds to the applied force and the foreseen weight load from the predicted use and occupation. This results in a varied aesthetic appearance for the different surfaces and in an interesting light and shadow interplay.

Prototype I was used to gauge the structural stability of the devised building systems. The outcome was three pieces with two varied resting planes. Each unit took 30 minutes to assemble. Prototype II was larger in scale and assembled by volunteered male students through a 7-hour workshop. The main objective was to evaluate a non-designer community response to the initiated assemblage and built-up process. Unlike the common industry practice whereby drawings are used to outline the construction process, a 1:4 model was used as a construction guide and assisted the participants to visualize the expected outcome. Throughout the assembly process, the model was used as a reference point upon which the steps were charted, and the achieved outcomes were evaluated. Prototype III is a linear micro-urban setting; it is realised as a more permanent piece as opposed to the ephemerality characterising the other two. Utilizing the devised system language and vocabulary, it demonstrates an example of an intervention at a micro-urban scale. The design of the prototype responds to two specific site parameters; linear spread and the successive change in light and shadow pattern. The tectonics forms an interesting interplay and an interactive language inviting passers to pause, inhabit and interact.

Phase II (Figg. 10-12) is practice-led pedagogy based on the experiential learning approach via making. The methodology is derived from the experimentation conducted in phase I and is used to diversify the learning process to embody four two main characteristics differentiating it from the standard classroom learning; interdisciplinary and based on need learning. In opposition to the stand classroom, the design via making process brought together students from all five majors from the junior, intermediate and senior level. Rather than following the learning standard of a defined curriculum, students learnt techniques and methods in response to an immediate presented need. They became experts in the tools and techniques they chose to utilize and had an overview of the ones used by their colleagues. Further, the followed methodology negated the drawing medium and resorted to scaled mock-ups made through manual and digital fabrication machinery as tools for design and construction. From the early project stages, it became evident how the practice method positively altered the students' learning approach. This was further strengthened through the personal and communal alliance and the systematic personal growth that accompanied the learning process manifesting itself through collegial involvement, participatory learning activities, critical dialogue, and innovative thinking.

The process was comprised of three main steps: 1) Problem or condition identification within the immediate local environment; respond with rapid sketches; communicate a design proposal through a scaled 1:10 model; understand the geometry, design the material joinery and figure the build-up process through a scaled 1:5 model; 2) Construct the 1:1 prototype working with the material tectonics, testing condition and mechanisms, curate the intended functionality and use, and examine the overall structure and prototype stability; 3) Position the prototype in the intended site and document its appropriation to the community, demonstrate the adaptation and use.

Reflection on deployed framework and conclusion | The presented case study is in par with worldwide conducted explorations by students and professional architects into finding methods and techniques to bridge between representation and production; whereby digital fabrication is seen as a way to avoid the drawbacks of traditional manufacturing and allow the production of diverse alternate forms and components. The uniqueness of the conducted case study stems from the context, where fabrication knowledge is in its infancy, and from the end-user, with minimal or no previous design knowledge, active involvement. Through the adaptable proposed system, it also responds to the unique social local context of present varied occupation form to in-between residential space.

Next research phase aims to continue the investigation of autonomous parts that come together to form the whole design; a hands-on practice-led research into modular and/or discrete systems and assembling methods. In addition to possible system adaptation to pre-identified conditions and parameters, and future injected functions and occupation scenarios. The intention is for the system to be able to grow and/or shrink in adaptation to the context, thus having a number of possible 'equilibrium' states. The aim is for the parts to embrace fabrication and structural logic and for the assembly patterns and languages to be driven by locality and functionality, including prototyping across scales. In addition to notions of sustainable measures to be taken into account at the deployment and deconstruction phases. The making of the part (the unit) and the testing of the assembly and the various possible scenarios either through physical or digital simulation, with the intention to demonstrate several inhabitation scenarios based on inputted parameters and identified inhabitation conditions; a system that will have the capability to reconfigure based on varying inputted data. The variation comes from changing the site or from altering the inputted parameters, including the observed – collated ones from the community and immediate surrounding environment and desired – designed conditions such as injected programs and functions.

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