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Teaching principles of network and agent-based models to architecture students

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Abstract

Architectural design is necessarily a situated learning process that continues to be a subject of interest in architectural education. Whether designers should give preference to a functional design product or whether the focus should be centered on creative output are issues that need to be questioned. Given the typically vague descriptions of creativity it is even harder to determine whether design functionality and design creativity should be treated as separate entities. The implications of any preferences made on the methods of assessment are crucial. While teaching is necessarily aligned to design as an experiential learning process, it also requires careful understanding of how knowledge can inform rather than constrain creativity. In evaluating the creativity or even the functionality of a design there are challenges present in accounting for a comprehensive and yet practical framework for assessment. In teaching practices the challenge is to ensure that the assessment process is sufficiently specified without limiting creative explorations. It is argued that through exposing design propositions to internal and external criticism, assessing progress becomes less of a challenge. In this course of development 'creativity' is revealed not as value-neutral but as a product of a social process that is practiced through experiential learning.

Keywords
Space syntax, teaching, architectural design, urban design, teaching and learning, architectural education, agent based modeling.

1. Introduction

The problem of thinking systems in the understanding and the making of architectural phenomena presents itself in the course of the pedagogical practice of teaching architecture in higher education. This problem becomes more visible where the epistemologies of science and art meet, and where there is divergence between analytical and synthetic methodologies. This is exemplified by the varied demands of the curriculum in MSc *Spatial Design: Architecture and Cities* (SDAC), a post-graduate course at the

Bartlett School of Architecture, University College London.[1] Over the last three decades, the MSc SDAC was directed towards outlining and testing an analytical theory; namely that of space syntax (Hillier and Hanson, 1984). Students who successfully apply to this course enter a specific type of "community of practice"[2] (Lave and Wenger, 1991); that is the space syntax community[3]. Students who enter this course broadly share a conviction as to the existence of a relationship between the physical space of the built environment and the social logic of human behaviour; a theoretical proposition common to all aspects of the MSc curriculum. The belief in some form of social logic embedded in spatial relationships framed by space syntax theory, defines the identity of the SDAC programme. Students on this course come from a variety of educational backgrounds; architects, planners, designers, anthropologist and others. Depending on their background, they are likely to take different perspectives on space syntax; whilst maintaining a shared identity as a community of practice in their future career. For them not to fall under the constraints of what Kuhn (1962) called 'normal science' – that is to take for granted the epistemological framework within which one is working – there is a need to subject the shared identity that coalesces around space syntax to critical negotiation of meanings.

Research within the framework of space syntax outlines a knowledge-based model that interprets the architecture of buildings and cities sociologically, as agents of social reproduction. The course has a history of evolving pedagogies and has succeeded in establishing a unique culture of architectural research into the science of architectural and urban space (Conroy Dalton and Vaughan, 2008). During the course of their study on the MSc SDAC students undertake a range of theoretical and analytical modules focused on the relationship of space and society. Some of these question the premises of space syntax theory and debate these with reference to other scientific and social theories. In 2010, the course changed its agenda to incorporate strategic architectural design and urban design (Al_Sayed, 2012; Karimi, 2012; Griffiths, 2014). This change necessitated new strategies for teaching graph theoretic as instrumental techniques to aid design thinking. For this purpose, hands-on architectural design workshops are being delivered at the beginning of each academic year to help architects learn basic mathematical principles of graph theory by applying them in design thinking. The workshops are also delivered separately in independent teaching activities overseas to help architects grasp space syntax principles more easily. In the following sections, we will explain these workshops, the philosophy behind them, and will aim at introducing a method for assessing the maturity of design outcomes in the context of a loosely-supervised studio environment.

2. Understanding learning in design

Over a period of one academic year, the SDAC course presents a unique pedagogical environment where architecture is researched and explored on all scales. The theories and methods introduced on the course are intended to question the architecture of the built form by positioning this in a broader social context. In many architectural pedagogical practices the scientific understanding of architecture is seen to be separate from the art of making architecture. For the course to succeed in bridging the gap between research and design and actively engage the theory into practice, its design teaching needs to incorporate a process of knowledge materialization that is open for self-criticism and for external assessment. This approach aims to render the 'non-discursive' qualities of architecture, discursive, in particular pedagogical contexts (Hillier, 1996). Accordingly, it could be argued that design can progress from the universal towards the particular following a prioritized structure model where a functional spatial structure is given preference over other criteria (Al_Sayed, 2014). By universal, we refer to the property of 'generic function' of movement and occupation (Hillier, 1996). The property can be modeled through a graph that represents spatial relationships in a layout. In two pilot workshops, we report here

[1] Prior to its renaming in 2013 this course was known as *MSc Advanced Architectural Studies*
[2] a group of people who interact around common knowledge and practices
[3] Information about this community is available in the Space Syntax Network website http://www.spacesyntax.net/ [accessed 1 April 2015]

an attempt to reverse this process of representation. Instead of representing a layout by a graph, students start defining their design brief and design problem through a graph representation, and move on to structure a set of tasks that build on the graph description to formulate spatial arrangements. Through examining progress, we question design as a learning process and investigate the possibility of applying learning models in assessing design performance.

For a carefully studied prioritized structure of design thinking (Al_Sayed, 2014), the structure needs to critically engage with the theory of space syntax in a manner that is both non-didactic and open-ended. The presence of an explanatory theory of architecture where designers become more self-conscious of the implications of their actions is key to any sensible design approach. For space syntax theory to actively engage in architectural practice, teaching approaches need to adapt the application of the theory to serve in synthesizing design solutions. Equally, with the incorporation of a design-based approach into analytical practices there is a concern not to undermine the scientific rigour that the course stresses through its academic practice.[4] This is balanced by an equal concern that by arriving at design solutions on the basis of an existent reading of spatially-driven relationships, the novelty of such designs might be restricted. Yet concerns raised on the side of space syntax as 'science' claiming that tackling the ambiguous logic of design might threaten its methodological credibility should not stand against the design practice that empowers a theory by applying it on different contexts. A systematic approach to design knowledge would serve to externalize students' design ideas and would consequently ease the assessment of design as a process. With a systematic approach in action, we assume that architects will be more specific when defining the relationships between the spatial components of their solutions and will allow for creative variations on the features of design solutions. This hypothesis was tested on the performance of students during hands-on workshops that were planned at the introduction of the SDAC course, and during the course of a separate space syntax module taught on the MSc *ATC*[5] at UACEG[6], Sofia.

4. Assessing design tasks

In assessing design, the challenges of assessing creativity and, to a lesser extent, of assessing design functionality are a priority. Assessing design functionality can also become a complex matter, given that designs can easily encounter conflicting and overlapping variables where there is no optimum solution particularly given the ill-defined nature of architectural design problems (Simon, 1984). To respond to the challenges of assessment, a learning model is to be implemented in one case considering design itself as an experiential learning process (Kolb, 1984). Kolb's experiential learning theory is based on considering knowledge as a product of multiple modes of learning. In these modes, experience transforms conceptions about the problem-solution definitions in design in a virtuous learning cycle comprising four phases; concrete experience, reflective observation, abstract conceptualization and active experimentation. Knowledge assimilated by students in a learning cycle can be deepened through emphasizing multimodal learning. For that, teaching should aim at engaging mental and physical capacities by exposing students to experiences that stimulate different sensory-motor channels. Within that planned framework, knowledge accumulated from observations can be directly implemented and externalized through visual representations. This externalization would enable a reflective practice on design teaching (Schon, 1983, 1987) to report progress in design and ease evaluating the process. Schon (1987) defines the design process as 'reflection-inaction' that engages active learning through doing. Based on that understanding, we question the applicability of a learning model for assessing design, and enquire whether design needs to incorporate further elements that go beyond generalized learning models.

[4] In 2015 15 credit studio-based elective module *E-merging Design Research* was introduced into the MSc SDAC curriculum

[5] Architecture Theory and Criticism Master Program, Sofia, http://archimasters.uacg.bg/?page_id=689

[6] University of Architecture, Civil Engineering and Geodesy, Sofia

In modelling learning, Biggs and Collis (1991) recognize four types of knowledge retrieved in learning; tacit knowledge, intuitive knowledge, declarative knowledge and theoretical knowledge. By devising discursive knowledge, that is knowledge that can be readily articulated in language, into the procedural form of declarative knowledge, we convert tacit information into explicit descriptions. Intuition would be supported in this case by discursive reasoning. The process of learning in this course of design development can be projected against a SOLO taxonomy model (Biggs and Collis, 1982). A SOLO model elucidates different learning cycles; prestructural, unistructural, multistructural, relational and extended abstract. The second, third and fourth cycles comprise the target mode of learning. Learning accumulates through this process of structural genesis marking situated cognitive development for a specific task (Piaget, 1963). The extent to which a relational structure is capable of describing -or in this case synthesizing- a phenomenon marks intelligent behavior. In design learning, the 'facilitation of top-down lower order learning' that is needed to understand a problem feeds directly into the 'facilitation of bottom-up higher order learning'. Both types of learning are multimodal; they involve multiple cycles from the target mode. To engage a higher level of representation that is needed for mathematical modeling, a process that precedes design in the hands-on workshop needs to be adapted taking Bruner's model (1964). Bruner identifies three channels of development in learning subjects such as maths; enactive (learning by doing), iconic (spatial representations) and symbolic (linguistic interpretation). In the planned workshop, a graph that derives from a linguistic symbolism has an inherent spatial dimensionality. The graph is to be enacted by means of design to transform it from a scale-free topological iconic structure to a tangible structure of space that can have a symbolic meaning.

Inspired by Kolb's and Bruner's models and Schon's reflective practice, two workshops were designed to engage students with intricate subjects in maths, specifically graph theory, and architecture through devising a learning strategy that would stimulate mental imagery and cognitive capacities. In what follows, a description of the workshops will be made. We will reflect on the prioritized structure model in designing the workshops tasks, keeping in mind that the purpose is to direct the design course without imposing its conduct. After discussing the workshops experience and assessing student performance through subjecting that to the SOLO taxonomy model (Biggs and Collis, 1982), we will briefly review the main challenges that emerged from these teaching exercises.

The workshops were designed to prompt constructive learning through doing. Students were guided through a process of experiential learning (Kolb, 1984); where experience, perception, cognition and behaviour are all brought together to leverage a maximised gain of the intended learning outcomes. Following this initiative, students construct knowledge starting from simple principles to form representational models of the physical space. Students were left thereafter to construct different interpretations of the representational models, using empirical knowledge and analytical techniques as to inform design decisions and trigger new forms of creativity.

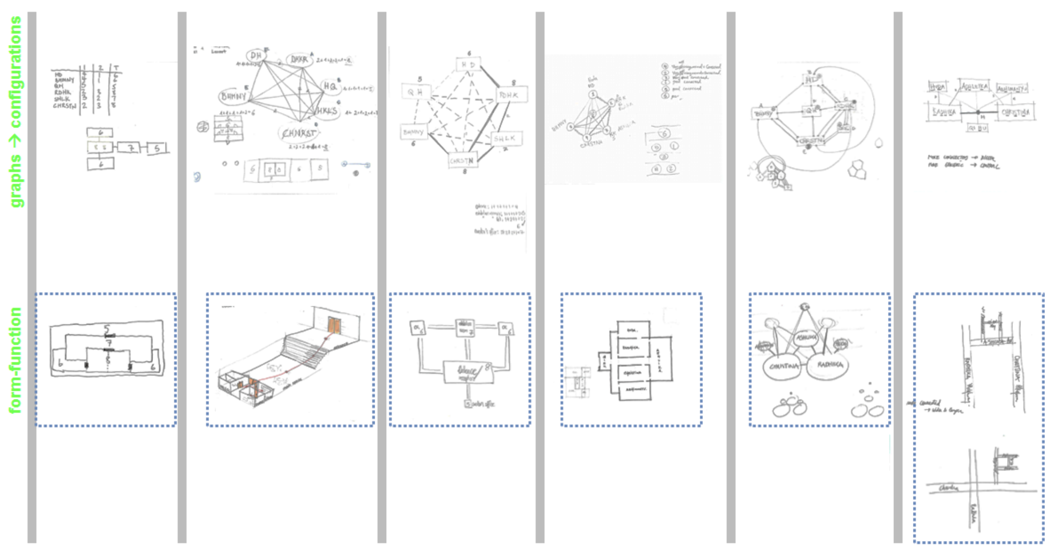
5. Design as an experiential learning process

Following a theoretical introduction to space syntax, the hands-on workshops were intended to answer questions that might arise about the significance of a socio-spatial theory in the course of design practice. Indirectly, the workshops also served to introduce an experimental alternative to the analytical emphasis of space syntax research.

The hands-on workshops were designed for students to exercise their design experience while acquiring the basic principles of graph theory and its social and spatial applications. The aim was to encourage them to derive mathematical models from their social settings and to devise these models to generate spaces that embody a social meaning. In doing so, the workshop helped students structure their design thinking by establishing principles and priorities for design reasoning. Graphs were used to inform the relational socio-spatial structures in design outcomes. The evolutionary learning was directed as an experiential process (Kolb, 1984). The experience is driven by a collaborative approach through which students interface with different modes of representation. The phases where representations reflect the direct experiences into abstract manifestation reveal a real-time and context-driven materialization of thoughts into actions. By limiting interaction to the direct environment of the class, we were able to ensure a neutral assessment of students' learning capacities at an early stage in the course. The capacity of learning would be described as the depth to which students can reach in their progressive learning from recognizing pre-structures onwards to the making of relational structures (Biggs and Collis, 1982). Building on that, the assessment of student's performance was defined as the extent to which design outcomes can be fitted in a SOLO taxonomy model. This is accounting for the methods of representation and theorization that are particular to the design process. The assessment of design outcomes was formative (Duhs, 2010), in that the performance of students did not count in the final module grades.

1. Using graph configurations as design principles

In this section, we will describe workshop 1, which was directed to teach students how to represent social networks by graphs and perform some preliminary graph theoretic analysis to aid design decisions. In this workshop, 14 students were to follow a set of tasks. The first task required them to act as nodes in a graph; each student had a card on which his/her name was written, and his/her expertise was listed. Students were asked to extract rules through matching their expertise to build connections amongst them; if one shared urban design expertise with others a connection is then established between the two names. Students were then asked to assign their nodes numbers that reflect on their configurational setting within the graph. For example, a certain weight would be given to a graph node depending on the number of expertise domains it shared with neighboring nodes (connectivity/degree value). Following a preliminary representation of the graph rules on the class board, students were asked to work in groups of two or three and redraw the graph. Each group would annotate students' names on their representative nodes together with their associated connectivity value. After finalizing the graphs, the next task was to consider nodes as spaces in a layout and the weighted links as spatial relationships that would emphasize functional connections. After finalizing their proposals, students were asked to present their visualized designs (see figure 1).



Group 1 2 3 4 5 6

Figure 1. Graph representations and Design outcomes that were presented by the students towards the end of workshop 1.

Following this learning scheme, we directed students to represent linguistic relationships that link their names with a graph. The graph was then used to inform them about potential spatial relationships that can be constructed to fit with a design brief for an architectural office. The task required multiple skills in a process of transforming a linguistic problem into a mathematical problem, eventually arriving at a spatial manifestation in response to the problems defined. The learning process in the workshop can be assessed through evaluating student performance as they move from representation, to attributing a semantic meaning and context to their mathematical descriptions.

Overall, students' design outcomes varied while the mathematical representation remained relatively similar. In their graphs, students have differentiated the links either by assigning more lines to certain links (group 5) or by thickening lines with higher value of connectivity (groups 3, 4). Group 6 has gone further to assign certain sizes for nodes with different connectivity values. Group 1 has translated numbers directly onto topological spatial relationships, while group 2 has projected the graph representation onto visual configurations. When rendering design outcomes, group 2 has interestingly distinguished a higher dimensional relationship based on the preliminary graph. In a 3D representation of space, group 2 has translated the topological graph onto a vision-based relational structure. With this performance, the students in this group went beyond the task requirements to explore higher dimensions of structural relationships. Compared to them, group 5 has hardly gone beyond the initial graph representation. Group 5 made one step further beyond graphs to assign sizes to nodes depending on their connections. Group 3 went a minor step forward to replace links by corridors. Group 4 converted the graph into an architectural layout by translating links into adjacency relationships. Group 1 found an internal architectural layout less helpful to explain the symmetry in the graph. Instead the group members explained that as an exterior-interior relationship. Group 6 presented a different context considering nodes as streets and tested their graph representations against different street patterns. Group 2 presented an innovative framework considering links as visual connections in a 3D environment.

Learning in this exercise marked a transition from quantitative representations towards qualitative judgment that has implications on the social organization that might be attributed to certain spatial arrangements. While projecting the abstract graph onto a material form, students were free to rearrange the graph representation so long as the nodes and connections are fixed. The graphs would form the skeleton for which space is an envelope. The SOLO taxonomy model[7] can be read in this process seeing graph representation as a step that follows comprehending prestructures. Evidence on thinking about a parallel social structure would move the progress of learning to a multistructural level. Externalizing a relational structure that links spatial relationships to a social organization presents a higher level of contribution to the initial prestructural understanding. Theorizing about the functioning of a relational structure would move this further to the abstract level. Following this model in assessing the designs made by the groups, group 3 and less so group 5 stop at a unistructural level of learning given the basic translation in representation from nodes to shapes. Group 3, however, presented some level of multistructural understanding by presenting links as corridors. Group 1 and group 4 presented some form of a relational structure where spatial relationships inherit social meaning. Group 6 shows a less intuitive relational structure by considering nodes as streets and presenting variations based on this representation. Group 2 revealed a higher order level of thinking by presenting nodes as spaces in a volume and links as visibility relationships pushing their representation towards questioning former theorizations about socio-spatial relationships. In this case, it is not very intuitive for an external observer to judge how functional a design outcome is. While the relational structure proposed by group 2 presents a new vision for a materialized representation, it is hard to state whether it functionally performs better than the design proposed by group 4. This presents a dilemma for the assessment of design outcomes.

[7] A SOLO model elucidates different learning cycles; prestructural, unistructural, multistructural, relational and extended abstract.

2. Experiential learning: Agent-based design hands-on workshop

The workshop described in this section (workshop 2) was taught as part of a one week space syntax module on the MSc *ATC* at UACEG, Sofia. MSc ATC students were asked to arrange their tables in a random way in the teaching room leaving spaces in-between the tables for people to move through, and leaving spaces at the edges of the room for students to stand. This arrangement was drawn on a large sheet. A linear network representation of the spaces in-between the tables was then drawn as to expose the spatial structure of the void left by the tables. Students were asked to stand at the edges of this arrangement. Each student was asked to choose a random path to move through the tables; starting from the point where he/she is standing to a destination of his/her choice. Each time a student chose to walk through one space represented by one linear segment the segment will be assigned a score of one, this number will add-up if another student chose that space again (see Figure 2). After finishing the experiment, the scores that each linear segment has hit are summed up. The resulting numbers represented the aggregate movement potentials for that particular spatial segment. Students were then asked to work in groups of four and redraw the spatial structure defined by the table pattern. The spatial structure was to be used to design an urban area as an envelope for that structure; the spatial structure might be equivalent to the street structure. Students were advised to use the scores they have accumulated for observed movement as parametric rules to assign certain land uses and three dimensional features to the outer envelope of this spatial structure. For example; it was suggested that where there are higher records for movement flows, there is more likelihood for retail activity, wider streets and high-rise buildings. The design propositions were then presented publically (see figure 3). During the presentation, a traditional “crits” assessment model was followed, where the tutor provided feedback to students on their design work. It was recognized that there is a need to improve on that format of feedback for a maximised learning outcome, and to reflect on the process of constructive learning.

6. Learning outcomes

During the course of this workshop (1hour in total), students were able to learn principles of;

- Agent-based modelling (Turner and Penn, 2002; Turner, 2003).
- The application of Network theory on urban space; namely that of space syntax (Hillier and Hanson, 1984)
- The theoretical and technical framework of “cities as movement economies” (Hillier, 1996b)
- Systemic movement traces observation techniques.
- Basic arithmetic and graph theoretic.
- A novel application of the abovementioned theories and models in the realm of urban design.

Beyond the tangible learning outcomes, there are tacit learning qualities that were achieved through this experiment; some are to do with learning in a situated social context and through group work (Lave and Wenger, 1991), learning through doing (design), and object-based learning (Lyon, 2012). By aligning to this mode of teaching and learning, it is possible to achieve a “Higher Order Learning”, one that involves creating knowledge rather than transmitting knowledge (Duhs, 2010).

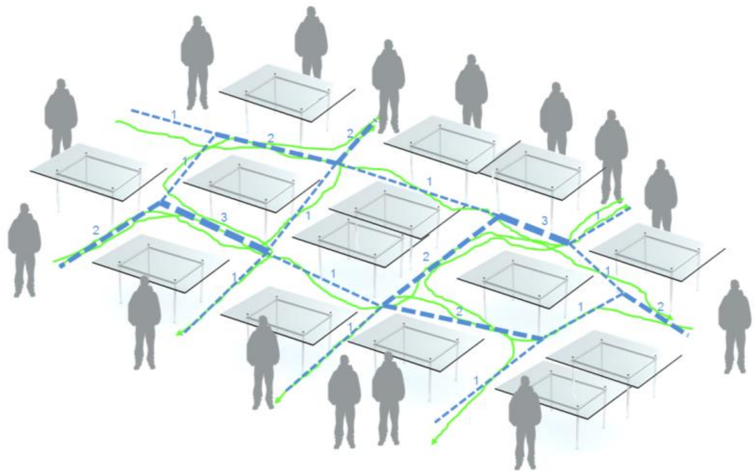


Figure 2. A model representing the workshop settings and the structural representation of the spaces between the tables in workshop 2.

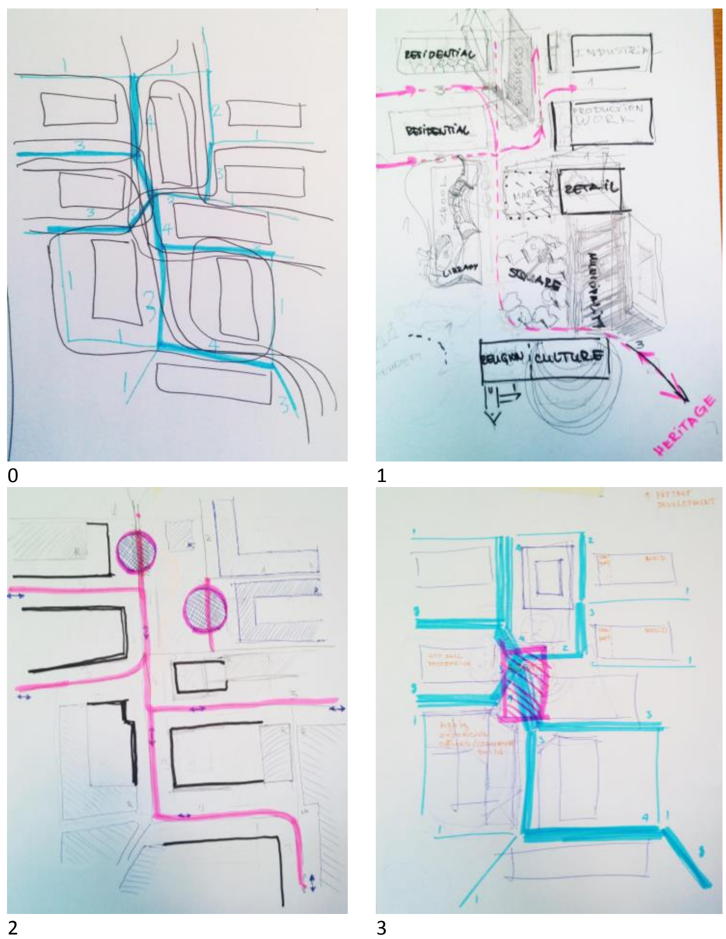


Figure 3. (0) Schematic representation of the spaces between the tables illustrated in figure 2. (1, 2, 3) Examples for three urban design propositions based on workshop 2. The designs were produced by students[8] on the MSc ATC course, Sofia.

[8] Petar Petrov, Ivelina Mincheva, Polina Kyosseva, Konstantina Hristova, Stefka Terzieva, Daiana Nikolova, Daniil Ninov, Magdalina Rajeva, Milla Zlatanova, Rositca Bratkova, Elina Hadzhieva

7. Assessing urban design proposals using the SOLO taxonomy model

As explained in previous sections, the SOLO taxonomy model identifies several stages in learning/design development. This can be explained here considering graph representation as a step that follows comprehending prestructures, or the traces left by people moving in-between the tables and acting as agents in space. Evidence on thinking about a functional land use structure that corresponds to walk-through movement likelihoods would be recognized as the multistructural level in the learning/design development. Externalizing a relational structure that links spatial relationships to land use distributions is yet another milestone in the process of learning/design. Theorizing about how –in a loop of transactions- urban processes materialize into certain forms would be recognized as an abstract level in the learning/design development.

Judging on the design outcomes in figure 3, design outcome (1) stands as the highest level of development in a SOLO taxonomy model. It demonstrates evidence for clear-cut relational connections between movement as afforded by the network structure of streets, land use, and the height of buildings. This goes beyond the multistructural level of thinking to frame –verbally during the presentations- how urban processes build up into this physical manifestation. In design outcome (2), this learning/design development stops perhaps at the multistructural level, if we consider that students have identified a relationship between movement, spatial structure of streets, and building setbacks leading to the creation of public spaces to correspond to potential movement flows. Design outcome (3) shows evidence for a higher maturity than design outcome (2), where designers have assigned land uses to building blocks in relation to movement flows, and allocated a public square to accommodate dense traffic. Design outcome (3) is yet less developed compared to design outcome (1). The judgment criteria is not very clear in this case, since both attended to abstract descriptions, but the maturity of relational structures in design propositions differs. The abstract level of thinking might be sensed in the ability of designers to cast own interpretation of the analysis, to synthesize solutions, to show evidence for creativity, strategic thinking, and to communicate that verbally and visually through their sketches and annotations.

The innovative dimension in using graph theoretic and agent-based principles was manifested in how students went beyond conventional space syntax descriptions in design, to adapt new models in response to design problems. The issue of selectiveness is recurrently emphasized, whilst at the same time evidence on creative problem solving is a requirement.

8. Conclusion

The workshops discussed in this paper presented two of the first attempts to build a synthetic approach towards space syntax teaching practices. They did so by exposing students to mathematical representations that would inform their design decisions. In this learning process, the level of engagement was evident in the general explorative design trend demystified in the learning outcomes. Design originality arose through a systematic building of the workshop where a new task is only declared after the completion of the former one. Following this logic, the instrumentalization of knowledge in design thinking proved to be effective in supporting design decisions.

A formative type of assessment was used to improve the quality and depth of the learning experience. In both workshops, it was possible to apply Biggs and Collis' SOLO taxonomy model (1982) to evaluate the shift from graph representations to design outcomes. There is a limitation however when designers reach a more detailed description of their designs. In such cases, most architects are likely to produce relational structures that are embedded in design solutions. This yields the need for a finer-grained model that defines sub-categories within the relational structure to distinguish the extent to which a design 'satisfices' agreeable expectations. Given their cognitive limitations and constrained by their 'bounded rationality', designers choose solutions that satisfy their expectations rather than seek out optimum ones (Simon, 1957). With that in mind, the description of a relational structure as a learning cycle needs to be reconsidered to account for the limitations and challenges in design contexts.

In assessing design performance, we considered a relational structure to describe the setup of spatial relationships in such a way as to convey social meaning. Finalized designs might go beyond this fundamental property to produce structures of a higher level of complexity. Yet, the arrival at a complex relational structure does not ensure a better functional performance of designs. This counts as another challenge for assessment. Further to that limitation, there is the prominent issue of assessing or even defining creativity in externalized design solutions. Externalization itself is a challenge given that creative ideas normally lie in hidden descriptions. Even when ensuring that both creativity and functionality are externalized, it is difficult to determine which one to prioritize when it comes to assessment. This relies on the definition of creativity and functionality and how they relate to each other; is a novel yet dysfunctional design creative? Can we consider design functionality to be an element or even a condition of creativity? The question remains whether it is possible to assess how creative a work is. The uncertain nature of design itself while continuing to challenge all methods of assessment might allow for the thought that absolute objectivity is unrealistic. Given this perspective, it might be legitimate to align the concept of a 'bounded rationality' assessment to design learning. Following this concept, the performance of a design process can be measured against a set of well-defined elements leaving a margin for a subjective assessment of quality. This type of assessments is practiced intuitively in design studios. In conclusion, we suggest that educators need to take account of the concept of "bounded rationality" in designing learning activities to be able to introduce fairer and more reflective assessment measures for design process in architectural education.

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