RESEARCH ARTICLE

The ‘Urban Elements’ method for teaching parametric urban design to professionals

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Abstract
The article proposes a method for teaching advanced urban design to working professionals in Singapore. The article aims to expand the discourse on parametric urban design education by introducing ‘Urban Elements’ as conceptual urban design instruments with an inherent rule-based logic, which can help to bridge gaps in teaching parametric urban design thinking. As case study we present a course developed for and delivered to the Urban Redevelopment Authority (URA) in Singapore in 2017 by the Future Cities Laboratory at the Singapore-ETH Centre. The article reports on the pedagogical method, course results and course feedback. The main difficulties of teaching professionals in parametric urban design are described and possible reasons and improvements are discussed. The results show that participants using the ‘Urban Elements’ method successfully linked theoretical input to urban design problems, applied evidence-based urban design strategies to these problems, and developed parametric definitions to explore the solution spaces of these urban design challenges. The teaching methodology presented opens up a new research field for urban design pedagogy at the intersection of explicating urban design intent, integrating multidisciplinary knowledge and exploring new software driven tools.

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1. Introduction

Building sustainable, resilient and liveable environments requires taking increasingly complex design decisions and integrating knowledge from various areas of expertise (Batty and Longley, 2016). To equip urban designers with the knowledge and tools to address these challenges, the Future Cities Laboratory (FCL) developed a course at postgraduate level in collaboration with the Urban Redevelopment Authority (URA) in Singapore. The course was called Advanced Studies in Urban Design (AS-UD) and aimed to challenge jaded notions of urban design and the primacy of form. The curriculum employed urban design knowledge, skills and understanding as a means of integrating the diverse disciplinary skills of participants, such as architectural design, landscape design, and social and environmental analysis. This called for more integrated methods of urban design pedagogy. Consequently, new conceptual and digital tools were needed for the teaching of urban design.

The course introduced a novel method to teach urban design concepts and to translate these into parametric urban design definitions: the ‘Urban Elements’ method. The course was evaluated at two stages, first around the middle of the course when the ‘Urban Elements’ method had been introduced and parametric definitions explored and a second time at the end of the course when the ‘Urban Elements’ method was used to produce a complete urban design proposal. The results show that the students’ abilities to analyse urban design problems, to abstract them, to translate them into parametric definitions and to use them for innovative urban design proposals significantly improved using the ‘Urban Elements’ method.

The main research questions can be summarised as follows: Can we develop a novel urban design pedagogy combining interdisciplinary research insights on the city in the form of a conceptual framework for urban analysis and parametric thinking? If so, what kind of insights can we gain from student learning while using such a method and can we validate the ‘Urban Elements’ method as pedagogical instrument for urban design? Is it possible to evaluate urban design results for specific design tasks in comparison to conventional, less explicit and non-parametric, urban design methods? How can we teach this to professionals, who have established knowledge system and methodology? Finally, how can we overcome gaps in parametric design education?

2. State of the art

Parametric design tools, which originated from CAD systems, were first proposed by Hillyard and Braid (1978). They allowed to specify geometric constraints and to vary these within a given range. Based on this, a more mature tool was later proposed by Light et al. (1981), which is generally regarded as the primary reference for the ancestry of parametric design tools. While the term implies the use of parameters to define forms, what is actually at play is the definition of relations between these parameters (Monedero, 2000). Clearly defined relations make it possible to tackle the challenge of modifying models built by designers to visualize their ideas interactively and also in 3D (Jabi, 2013).

Parametric design tools accept variable input data, establish mathematical relationships and produce further data, including geometric information (Steinø and Veirum, 2010). With advances in computing power and the growing availability of data, parametric systems can now be employed to deal with complex urban phenomena on a multi-scalar and multi-dimensional level. In comparison to conventional design methods, parametric urban design uses rule sets as the basis for the configuration of 3D urban models (Abdelalah, 2009). The advantage of this is that it enables the exploration of a wide range of alternative solutions by changing the parameters of the logical relationship (Karle and Kelly, 2011), whereas for traditional methods, designers usually only consider a relatively limited number of alternative solutions (Woodbury and Burrow, 2006). Another advantage is that designers can change and modify their own rule-based models at any stage of the design process so that the design process can be kept open and flexible, because all procedures, activities, and relations in parametric design are clearly defined (Oxman and Gu, 2015). In short, parametric urban design can be used to model alternative scenarios, visualisations and quantification all in one - a key advantage over conventional design methods. A parametric urban design is thus agile to changing input constraints and offers flexible solutions that can be re-computed depending on stakeholder perspective (Hernandez, 2006; Holland, 2012).

However, since many parametric definitions are ‘tailored’ to specific tasks, require input data in specific formats or are ‘locked’ into proprietary software, the agile integration of urban design concepts has to date been lacking. Despite advances in research and availability of tools, parametric urban design has not yet been widely adopted in practice. A useful contribution to improving the situation would be to conceptualise parametric ‘Urban Elements’. This is proposed in this article.

The translation of rule-based principles into geometric form originates in so-called ‘shape grammars’ (Stiny and Gips, 1971; Stiny, 2006). The implementation of generic urban design models with shape grammars has been explored by Beirão et al. (2010) and by Karakiewicz and Kvan (2010). Beirão, Duarte, and Stouffs (2011) also identified specific shape grammars necessary for urban design. Multiple technical challenges in identifying and solving particular urban design aspects have been addressed by Koltsova, Tunçer, and Schmitt (2013), as well as by Bielik et al. (2012). Architectural building information models (BIM) have been expanded to cater for urban design tasks (Kim et al., 2013) and some approaches offer systematic collection enabling urban designers to work with urban design tools (Beirão, 2011). These also accommodate the scalar dimensions of urban design by ‘nesting’ smaller scalar units (houses or neighbourhoods) into larger ones (districts or regions) (Zünd, 2016). Some software packages now also offer ‘shape grammars’, for example, the commercial software ‘CityEngine’ released in 2008 solves generic urban problems by means of the shape grammar logic.

The software used in our class is the parametric modelling system Grasshopper (Rutton, 2017) for Rhino 3D. Within the expanding field of parametric urban design, several attempts have been made to use these tools in education (George, 1997; Schnabel, 2008; Dennemark et al., 2017).
The advantage of parametric urban design is that it trains students to formulate relevant questions and translate these into logical design concepts instead of focussing on one primarily form oriented solution (Karle, Kelly, 2011). As such, training goes beyond gaining proficiency in using parametric urban design tools to focus on developing parametric urban design thinking, which is more about acquiring “an understanding of parametric structures of design knowledge that can be formulated and represented in a generic parametric schema” (Oxman, 2014). This generic parametric schema can be further interpreted as design patterns which have been observed in both traditional architectural design (Alexander et al., 1977) and parametric design (Woodbury et al., 2007). Parametric thinking requires prioritizing design parameters over solutions and developing interdependent rule-sets to facilitate the generative design process (Karle, et al., 2011). Although there is the widespread belief in architectural education that with enough practice and the right materials anyone can learn to code, teaching programming in practice has shown that this is not the case (Senske 2014). Program comprehension and composition are problems commonly encountered by the majority of programming students (Senske, 2014). Studies found that previous programming experience (Hagan, Markham, 2000) as well as a good knowledge in maths and science (Bergin and Reilly, 2005; Wilson, 2010) have a strong influence on the performance of students in programming courses and can serve as predictors for success. Furthermore, the comfort level of an individual student in class plays a major role, which includes the likelihood of asking questions and the perceived difficulty of the tasks as well as the perceived understanding of concepts taught in class (Bergin and Reilly, 2005; Wilson, 2010). As parametric design thinking is often not intuitive to urban design students, who have little training in programming and struggle with the additional level of abstraction and the dynamic understanding of design, we introduced the concept of ‘Urban Elements’ as a link between generic design patterns and parametric rule sets. In combination with parametric design tools, this translation facilitates rapid prototyping and design exploration.

An ‘Urban Element’ combines different aspects of related theoretical principles. Elements are typical features of good city form that can range in scale from the texture of a pavement, to a building entrance, shop front, pocket park, plaza and street, or neighbourhood and precinct, recalling pavement, to a building entrance, shop front, pocket park, city form that can range in scale from the texture of a pavement, to a building entrance, shop front, pocket park, Plaza and street, or neighbourhood and precinct, recalling Silverstein (1977). ‘Urban Elements’ as proposed in the scope of the AS-UD course are digital, parametric representations of urban units at various scales, which can be combined together in larger sequences and systems. Thus the ‘Urban Element’ translates the classical patterns into a digital, parametric urban design approach that makes it possible to model alternative scenarios, visualisations and quantification all at once.

3. Pedagogical methodology

A major challenge in urban design is to conceptualise a design problem while integrating theoretical and contextual information. Framing the open-ended solution space this way is a challenge for both conventional analogue urban design teaching as well as for digital and parametric approaches. In addition, addressing the challenges arising out of the complexity of urban design tasks and the need to create environments that are sustainable, resilient as well as livable require an increased awareness and better integration of expertise from various areas. The curriculum of the AS-UD aimed to reflect and address these changing needs over the course of three thematic terms - Urban Theory, Urban Tools, and Urban Design - through which participants could develop an advanced understanding of urban design.

The concept of ‘Urban Elements’ was introduced in term 2 ‘Urban Tools’ as a pedagogical tool to help rationalise the urban design process and to operationalise theoretical principles introduced in weekly topical lectures given by FCL researchers. An ‘Urban Element’ identifies, formalises and develops a specific urban concept as a short thesis statement. An ‘Urban Element’ acknowledges reference examples to declare its intellectual origin and invites the participants to draw a visual sketch or illustration diagram in a projective mode (Figure 1). Since the formulation of a thesis emerges from a specific urban analysis, a qualitative index grid indicates the intended application context. This index grid captures the main domains of conventional urban design as found in urban theory literature: Building, Street & Armature, Block & Plaza, Quarter & District, Fabric & Network. The ‘Urban Element’ is then formulated as prototypical script. This script should declare possible input

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Plot Porosity & Density

Figure 1 Example of an ‘Urban Element’.

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parameters, transformation rules and expected outcome values. The script serves as a guide to developing the parametric definition.

To translate this prototypical ‘Urban Element’ script, one needs to acquire technical skills in parametric design, which were part of the curriculum of term 2. Teaching employed the popular visual programming software Grasshopper (GH) in Rhino 3D and comprised three parts: a boot camp to teach the basics of Grasshopper, in-class tutorials on the development of basic ‘Urban Elements’ corresponding to the weekly theory input and tutoring of students to support them in the translation of their ‘Urban Elements’ into Grasshopper definitions.

4. Course process and layout

Each of the three terms consisted of 11 weeks with four hours of contact time and approximately four additional hours of individual studies, culminating in a final assignment. The total contact time over the 33 weeks of three terms equated to a traditional academic studio semester of 15 weeks. The course was taught by three urban design tutors and three parametric design tutors. Twenty professional participants attended the course from various authorities, including URA, the Housing Development Board (HDB) and the Jurong Town Council developer (JTC). All participants had a master’s degree in architecture. Apart from two participants, who rated their familiarity with parametric design before the course at 3 or 4 out of 5 on a scale from “not at all” (1) to “very” (5), participants had little to no prior exposure to parametric design before the course. Instead, participants were more familiar with CAD programs, such as AutoCAD, Google SketchUp and graphic design software, such as Adobe Photoshop, Illustrator and InDesign.

We held two days of GH boot camp to introduce and build up capacities in parametric urban design prior to the start of term 2. Since the participants had not yet begun to develop their own ‘Urban Element’ we needed to anticipate a set of generic urban design patterns. These included urban ‘infrastructure’ elements such as urban grids and networks, formation of blocks and building plots, creation of built volumes, distribution of massing and functions. This menu of generic urban design patterns provides the key components for solving basic urban design problems. The parametric logic of the GH definitions provided introduced corresponding basic concepts of parametric thinking (Figure 2).

Further parametric example definitions were introduced throughout the term addressing related concepts that corresponded to the topic of the weekly lecture. Concepts covered aspects of urban form, such as plot porosity (Figure 3a) and street profiles (Figure 3b), function distribution (Figure 3c), reworking topography (Figure 3d) and topography evaluation (Figure 3e), shortest path (Figure 3f), energy calculations with the plug-in Ladybug (Figure 3g) and designing for change using the Elefront plug-in (Figure 3h). The sample definitions and basic parametric and urban concepts covered by the tutorials were intended to provide a starting point for the participants to aid them in the development of their own parametric translations. In analogy to Christopher Alexander’s ‘Pattern Language’ these parametric urban concepts formed a basic vocabulary for the participants, which could be recombined and expanded.

A second GH boot camp was held in the third week of term 3 as a forum for addressing the challenges and problems reported by participants in the course feedback. The boot camp provided exercises to further support the development of parametric design thinking participants had been struggling with. In particular, we addressed the challenge students faced when breaking down a design idea and translating it into steps and rules as well as how to get started with a GH definition. An example exercise including its solution can be seen in Figure 4. Participants were asked to describe the different steps involved in creating plot setbacks first and then naming the components they would be using. In a last step, we assembled the definition together with the participants in GH. The participants used the ‘Urban Elements’ in their conceptual design phase. The format of the ‘Urban Element’ required a thesis statement of less than 100 words that positions the ‘Urban Element’ in a theoretical context. The theoretical statement responded to a topic of the input lectures delivered by the teaching team and could relate to ‘urban form’, ‘density and typology’, ‘function and use’, ecosystem services’, ‘engaging mobility’ or ‘sustainability and energy’. A site analysis revealed the necessity to engage on specific local conditions in Singapore such as ‘land-scarcity’, ‘tropical climate’ and ‘liveability’. The participants quickly realised that their ‘Urban Elements’ could not resolve all these challenges at the same time. Some ‘Urban Elements’ remained generic, while others became specific to the project. A further challenge was to translate the conceptual ‘Urban Elements’ into parametric design definitions. As participants started to learn Grasshopper, their capability was initially bounded to the tools and methods presented by the teaching team. A first approach was to find proportional relationships such as the ratio of street width to height in a section. Later participants developed volumetric relationships such as building envelope and floor ratios defined by the building form. Participants also included non-spatial dimensions into their elements as well such as function allocation. The development of the conceptual part and the translation into parametric definitions of the ‘Urban Elements’ became an extended design exploration. Collectively, they built up a common knowledge library, a catalogue of ‘Urban Elements’.

This catalogue formed the basis for the following urban design projects. These projects demanded complex urban design solutions that included the necessity to analyse and represent important site conditions, to negotiate contradicting site constraints and to combine different component layers of urban design such as ‘access and connectivity’, ‘volume and density’, ‘ecology and energy’, ‘character and typology’. The ‘Urban Elements’ were used to cast and prototype urban design both conceptually as well as by use of parametric design definitions geometrically and functionally. This allowed to identify further areas of design work quickly and helped to speed up the design process significantly. This was particularly important in the context of a professional education course where participants had significantly less time that for instance graduate students. The ‘Urban Elements’ also allowed an in depth and
knowledgeable discussion about the design steps and motivations. This process came closer to an evidence-based design process and revealed any biases that existed amongst participants. This helped to resolve design-related conflicts and ultimately raised the quality of the urban design projects.

5. Course results

The course resulted in a catalogue of ‘Urban Elements’ and their parametric definitions. The 20 participants of the course eventually produced 55 individual ‘Urban Elements’ that are compiled in the catalogue shown in Figure 5. The catalogue is organised by topical sections (rows) that follow the input theory topics: Urban Form, Typology and Density, Function and Use, Ecosystem Services, Mobility and Energy. Each topic is explored at three urban scales: Small, Medium and Large. Each combination thereof (e.g. Urban Form + Small) is explored in at least three variations. This catalogue grid was used as a framework throughout the course and gradually filled with content. It is not meant to form a complete set, but rather a taxonomy of possible solutions. Since the population of this matrix with content arose from the participant’s direct input, it also accurately reflects their subjective focus on questions of urban design.

The following examines two examples of ‘Urban Elements’ developed by participants in detail: ‘Balancing Privacy & Density’ (Figure 6) and ‘Green Replacement’ (Figure 7).

Element Title: Balancing Privacy & Density [student 1]

The index grid indicates that the element is applicable mostly to both building and block scales. The thesis statement reads:

“How close is dose? The relation between building height and distance between buildings influences the privacy in residential buildings when the building elevations

Figure 2 Examples of generic urban components taught prior to the beginning of the term in the boot camp (chart with grids, plots, massing, functions).
Figure 3  Examples of urban concepts taught during the term and translated into Grasshopper tutorials.
overlaps. This can be achieved by incrementally increasing the distance between buildings as the building height increases.

The prototypical script specifies:

**Input**: \( H = \text{Height of Building}; \ W = \text{Width of Building} \)

**Rule**: A wider distance (X) between buildings to be provided when:

- the buildings get higher, or
- the larger W value

**Output**: \( X = \text{Distance between Buildings} \)

**Element Title**: Green Replacement [student 2]

The index grid indicates that the element is applicable mostly to the building scale. The thesis statement reads:

“The green replacement is to further strengthen efforts in greening the city and to encourage more pervasive greenery within Singapore’s high-rise urban environment. The development will replace the greenery lost from the site due to development with greenery in other areas within the development. The development will have the greenery replacement areas on ground, rooftops, facades and sky gardens.”

The prototypical script specifies:

**Input**: \( A: \text{Area of a parcel}, \ P: \text{Percentage of green replacement over area of the site} \)

**Rule**: Greenery areas will be randomly assigned to ground floor, rooftop, facade and sky gardens so that the total greenery area of the development is equal to \( AxP \)

**Output**: Area of greenery on rooftop (R), facade (F) and sky garden (S)
As can be seen from these examples, students formulated a well-defined aspect of urban design: The proportional relationship of building distances and densities (student 1) and the distribution of green features on a building (student 2). The prototypical scripts express these relationships with relevant input parameters, rules and expected outcomes, and both examples also show a strong degree of abstraction. However, contextual information about the sites for the ‘Urban Elements’ is lacking. The range of application is also not declared. Finally, no information is given as to how to resolve conflicting problems, such as spatial-geometrical problems arising from contradicting input.

Figure 5 ‘Urban Elements’ catalogue with 55 elements developed by the participants.
The participants translated 15 out of the 55 collected ‘Urban Elements’ into parametric definitions. Figure 8 shows three examples of how the participants interpreted ‘Urban Elements’ as they matured in prototypical scripts and parametric translation. Figure 8(a), the development of ‘Urban Element’ Balancing Privacy & Density developed by student 1, shows a direct proportional relationship between the spacing of residential buildings in relation to building heights. This has been translated into a basic parametric definition and explored in three variations.

Figure 8(b) explores variable building typologies with constant Floor Area Ratio (FAR) towards ‘low-rise high-density’ typologies applicable in urban settings based on plot sizes. The parametric definition makes it possible to explore the solution space and visualises the results of the constraint ‘density’ on the site. Figure 8c) shows the green replacement ratio for buildings, Green Replacement developed by student 2, that has implications for Singapore’s ‘Green Replacement Policy’ LUSH. The examples shown here are chosen for their systematic translation from theory to script to parametric variation and immediate geometric output. Other examples that examined the organisation and distribution of programme, sectional relations of street edges, or the connection between ecosystem, transport or energy were also explored, but their parametric translation was less geometric in the ‘Urban Elements’ stage.

6. Course evaluation and feedback of participants

An online questionnaire was distributed at the end of term 2 in order to evaluate the didactic methodology of the course as described in Section 3, including the suitability of the course contents, as well as the usability and perceived usefulness of the parametric tools given to the participants. The questionnaire contained five sections with a total of 62 questions and comment items, which 13 out of 20 participants completed. A second questionnaire was distributed after term 3 to evaluate other individual parts of the course. This included a review of the input lectures of terms 1 and 2, the seminars of term 1, boot camps of term 2 and 3, the design studio of term 3, as well as the ‘Urban Elements’ of term 2. Out of the 16 remaining participants taking part in the design studio in term 3, 12 answered the second questionnaire. Feedback obtained from questions on ‘Urban Elements’ as part of the second questionnaire is included in the following subsections and indicated as such.


6.1.1. Parametric Design Tutorials

A total of 17 definitions were produced for the boot camp session and weekly tutorials. Participants were asked to rate these definitions with respect to their generative design
idea, transferability, easiness to learn, usefulness and applicability in the context of urban design in Singapore and relevance to the participants’ work by stating how much they agreed with the respective statements on a 5-point Likert scale from “strongly disagree” (1) to “strongly agree” (5).

According to the feedback given, participants found concepts that related to the generation of urban form, such as the parametric definition of street profiles (Figure 3(b)), objects on a grid (Figure 2(b)) and Singapore buildings (Figure 2(f)) developed for the boot camp and for week 2 of the course easier to learn than more abstract concepts such as, for example, those related to energy evaluation (Figure 3(g)), design for change (Figure 3(h)) or reworking topography (Figure 3(d)), which received a lower agreement rating. They also reported feeling slightly more confident in using, expanding and combining the first three concepts. However, definitions of concepts such as ‘evaluating topography’ (Figure 3(e)), which received relatively low ratings with respect to how easy they were to learn and confidence of use were rated high in terms of their usefulness for urban design in Singapore as well as their relevance to the respondents’ work. The definition of Singapore buildings, which addressed the particularities of local building typologies, as well as plot porosity (Figure 3(a)) were also perceived as being highly relevant and useful.

Qualitative feedback from respondents revealed a need to make the course contents easier for everybody to understand, to allocate more time to the teaching of the parametric part of the course, to proceed slowly, to manage expectations towards participants’ learning capacities and to provide more specific, relevant examples. Respondents named the generation of the existing site, the triangulation of point cloud data in urban layouts, addressing walkability, connectivity, and vibrancy, as well as social and demographic influences on urban design as additional concepts they would like to learn or develop. In addition, respondents expressed a wish to examine positive and negative case studies.

### 6.1.2. ‘Urban Elements’

In the course review questionnaire at the end of term 3, participants were asked to rate the usefulness of ‘Urban Elements’ in understanding the relationship between urban design theory, operational principles and possible design applications, in developing operational knowledge, in contributing to a catalogue of best practice, in enhancing urban analytical and representational skills, as well as in developing skills in parametric urban design. The rating scale ranged from “agree” (1) to “disagree” (5). Overall, the respondents rated the usefulness of ‘Urban Elements’ in respect to all mentioned aspects positively with means ranging from 3.91 to 4.25. However, the usefulness of ‘Urban Elements’ for developing skills in parametric urban design was rated slightly lower in comparison to other aspects. A standard deviation of 1.0 furthermore indicates that the concept of ‘Urban Elements’ as a means of learn parametric design was perceived more controversially by participants. The results can be seen in Figure 9.

### 6.2. Course attendance, interest, and learning parametric design

Ten out of thirteen participants reported attending the course at least 50% of the time or more frequently during term 2. Eleven out of twelve participants reported...
attending the course at least 50% of the time during term 3. As this course was held during regular working hours, work-related duties, such as meetings or looming deadlines, clashed with the course attendance of participants. Respondents also commented on the challenge they faced to keep up with the course, for example, working on and submitting assignments and following tutorials, amid their busy work schedule. They felt the expectations of the course were too high.

According to the ratings received from participants on their interest in (learning) parametric design before and after the course on a five-point-scale from “low” to “high”, their interest slightly declined (Figure 10). However, at the same time the self-assessed knowledge of Grasshopper slightly increased, from little familiarity with an average rating of 1.61 on a scale from “not at all” (1) to “very” (5) to a self-assessed level of proficiency rating of 2.0 on a scale from “poor” (1) to “excellent” (5) after the course. Furthermore, participants rated their familiarity with parametric design concepts at 2.77, their understanding of basic parametric design concepts at 3.54 and the perceived relevance of learning parametric design at 3.85 on a scale from “strongly disagree” (1) to “strongly agree” (5). However, the distribution of answers varied widely.

One of the aims of the course was to contribute to a better understanding of the potential and limitations of parametric support tools. To confirm that this teaching goal was met, the questionnaire asked participants to identify strategies for solving urban design problems that could either be solved conventionally, conventionally or parametrically, or only parametrically. In particular, participants were asked to describe how they would solve drawing a box, place rectangles on a grid with variable distance and size, as well as setbacks on a plot using Grasshopper. An analysis of the qualitative answers indicated that 3 out of 13 respondents were confident in applying parametric strategies. Four participants were not sure or did not know and the remaining participants gave answers, which were wrong or only partially correct.

6.3. Self-reported challenges and suggestions for improvement

In addition to rating the parametric course and its contents, we asked participants to describe the challenges they faced in learning parametric design with Grasshopper and in translating the ‘Urban Elements’ they developed during the course into a parametric definition. Participants cited a lack of basic understanding of the software and the basic principles of parametric modelling, a lack of familiarity with, understanding and knowledge of the existence of components but also a lack of basics in math and logic as challenges in learning parametric design and in working with Grasshopper. With respect to the translation of elements into parametric definitions, the problem of proceeding with the definition from a first step or one of the examples provided was described as a challenge.

Furthermore, one respondent indicated that the use-case of parametric modelling, i.e. its application in a real-life context, was not clear. In addition, one participant stated that “actual work in real life is more complicated than the class tutorial and assignment”, which resonated with previous in-class discussions about the feasibility of the tool with respect to real-life complexities. One respondent also felt that using Grasshopper in their daily work would not be feasible and that they would need a consultant or programmer to create the elements for them rather than doing it themselves.

Feedback also included the following suggestions to address the challenges encountered and improve the course and parametric learning process: to create periodic boot camps which would allow attendance with less interference, to upload closed-loop video tutorials, to limit the
workload and adjust expectations to fit a part-time course, and to ensure system compatibility.

7. Discussion

In the scope of the presented course, we introduced the concept of ‘Urban Elements’ as the basis of a novel urban design pedagogy, which couples urban design knowledge and urban analysis and facilitates parametric design thinking with its inherent rule-based logic. Although, the course results show the potential of the method, it also revealed some limitations.

The potential of the method is that ‘Urban Elements’ lead the way to explicit, logical and replicable urban design approaches. The explicit nature of parametric definitions render the urban design process transparent. This leads to a better understanding of the design process and provides insight into the student's approach to the design tasks as a method that makes both the design concepts and the parametric approach explicit. It further increases the accountability of designers or design-decision makers. It increases control by identify processes and parameters that influence the design process and it helps manage the expectations of all stakeholders concerning possible urban design outcomes. It increases the gain in knowledge on urban design and also assures its applicability to other settings. In addition, it makes it possible to incorporate and communicate urban design processes to other disciplines. It takes advantages of platforms that can integrate interdisciplinary models for urban analysis as a whole. The parametric implementation also tests the capacity of existing visual programming platforms like Grasshopper for urban design.

The ‘Urban Elements’ method was used by the participants as extension to their conceptual design phase. It became at the same time a record of design exploration and a common knowledge platform for design solutions amongst the group. The ‘Urban Elements’ helped to speed up the design process by means of conceptual and geometric-functional prototyping and to resolve conflicts and identify further design areas by means of supporting evidence-based discussion among the design team.

The proposed method of ‘Urban Elements’ also revealed limitations evident in the struggles we observed of participants during the course as well as the feedback given by students after the course. We introduced the concept of ‘Urban Elements’ as a link between urban design patterns and the development of parametric rule sets, which would allow to rapidly prototype and explore design alternatives. However, participants struggled to perceive and extract these patterns in urban form, let alone abstract the concept further by formulating design parameters and rule-sets for its translation into a parametric model.

The reduction of urban patterns into rule-sets and variables, which is at the same time the main strength of parametric design, implies a set of limitations, namely that it is not possible to include all aspects of a conventional design process and to reflect the complexity of urban design in one model. Participants consequently struggled to see the applicability of parametric design in general and of the method in particular in a real-life context and their everyday practice. Although the apparent aim and benefit of a singular ‘Urban Element’ is to study variations in an identified urban pattern, one of the underlying aims of the development of a catalogue of ‘Urban Elements’ was to eventually combine and apply these in larger sequences and systems to design. Modular approaches using shape grammars (Duarte and Beirão, 2011) as well as parametric tools (Dennemark et al., 2017; Konieva et al., 2018) have shown to be able to produce adaptive design systems, which allow to produce site-specific solutions up to the level of master plans. However, the application and development of such systems has so far been limited to design studios.

Another limitation lies in the fact that significant choices are still made outside the parametric design system by the
user, but also by other stakeholders completely foreign to the project. Also, underlying models of urban design are not really called into question by the parametric method itself since this method replicates and optimises the urban design model in the first place.

Furthermore, the course results showed that participants needed to develop both urban design skills and parametric skills in parallel. This will be a crucial aspect in future urban design education. Successful students managed to navigate the conceptual effort to create ‘Urban Elements’, the challenges associated with parametric urban design thinking and skill acquisition and finally the application to a specific urban design site. We found that participants with experience in numerical tools exhibited greater interest in learning parametric design than other students during the course and were more successful in translating their ‘Urban Elements’ into parametric definitions. However, the majority of participants struggled acquiring the necessary skills. Apart from having difficulties with parametric thinking, students struggled with understanding and scripting Grasshopper definitions. Only half of the students submitted a parametric definition for one or several of their ‘Urban Elements’ at the end of the term and only 3 out of 13 survey respondents showed confidence in applying parametric strategies.

In consequence, conducting a survey to retrieve previous math, science and programming knowledge and understanding at the beginning of a course could in future help to identify which students need more support and attention of tutors. It could also help to better tailor and adapt the curriculum, the teaching speed and the way of delivering the concepts to the existing skill set of participants, as mentioned in the feedback of participants. In turn, this could also improve the comfort levels of participants to ask questions, ask tutors for help, and feel more confident in approaching scripting tasks. Although we did not enquire explicitly about participants’ comfort levels in our surveys, suggestions of participants such as to better manage expectations towards participants’ learning capacities and to make course contents easier for everybody to understand indirectly point towards the fact that the tasks and concepts presented were perceived as too challenging by some.

Last but not least, teaching the topic of parametric urban design to professionals held their own challenges. The participants were professionals with a high workload and little to no time outside course hours to spend on practising parametric design and preparing for the course. This challenged the design of the course structure and expected outcomes. As visible in the chart in Figure 10, the self-declared level of interest dropped and level of proficiency rose after the course. While the first aspect could lead to the conclusion that participants became disillusioned about parametric urban design tools, this means that the course achieved a better understanding of what the potential of parametric urban design could be. The second aspect of proficiency underscores that participants are now able to better assess their capabilities and determine that they made progress.

The initial expectation was that participants would be able to efficiently learn and understand the essential concepts of parametric design within the limited time they had. Although we developed the ‘Urban Elements’ method as a pedagogical tool to help participants better rationalise the urban design process and bridge the gap towards parametric thinking, the application of the ‘Urban Elements’ could still have been more targeted and tailored to the participants needs in respect to the specific circumstances. The broad focus of the course was perceived as challenging, especially in respect to the time constraints. Instead of aiming to offer a more general approach and overview of urban design applications, the focus on more relevant examples for urban design and planning practice, such as the modelling of energy or transport related aspects, appears more feasible in the particular context. Although the teaching aims were met, namely to contribute to a better understanding of the potential and limits of parametric support tools, the question of how to better facilitate the learning process and improve the learning curve has been identified as one of the major areas for further research in the teaching of parametric design.

Despite the struggles and issues we identified during the course and were discussed above, the results clearly show that participants with a background in architecture and not necessarily mathematics, programming and descriptive geometry were able to abstract urban design principles and to develop parametric design thinking with the help of the ‘Urban Elements’ method. The method has the additional potential benefit of addressing the needs of those participants, who struggle to balance their work duties and course load at the same time in post-professional education. All these aspects contribute to the success of the method.

8. Conclusion

In this research, ‘Urban Elements’ have been developed and validated as a novel urban design pedagogy, incorporating the students’ domain knowledge and insights into the design tasks. As a conceptual urban design framework with an inherent rule-based logic, it is a novel approach because it can combine interdisciplinary insights on urban planning tasks while facilitating the learning of parametric urban design thinking. It also provides an avenue for the explicit evaluation of urban design results against the design tasks compared with conventional urban design methods. This is highlighted by the clearly shown potentials and limitations of the proposed teaching method. Based on the results of this study we recommend an integrated pedagogic approach that connects the development of urban design concepts with the education of advanced parametric modelling skills. A separation of urban design studios and classes for computational skills is clearly inhibiting the development of computational designers with a corresponding new perspective on parametric design thinking.

The method of ‘Urban Elements’ has been proved to be a useful pedagogical tool. It allowed the students to develop targeted tools for solutions they deemed important and relevant. They contributed to an open-ended collection of ‘Urban Elements’ that can be classified in various taxonomies: catalogue, tables, clusters, etc. A future iteration of the course will take these as points of departure for an expanded catalogue. The ‘Urban Elements’ also offer a basis for the semantic critique of isolated urban design aspects in turn fostering critical discussion and theoretical
investigation. The ‘Urban Elements’ method showed two clear advantages: It allowed for faster design exploration due to the aspect of rapid conceptual and geometric prototyping and for an explicit discussion amongst designers. Both aspects expedited the design process and raised the quality of the design projects. Given the tight time budgets many urban design professionals face, these are key advantages. The future elaboration of the ‘Urban Elements’ method could aim to develop these advantages even further.

A fundamental urban design challenge remains: The conceptual framework of the ‘Urban Elements’ method requires systematically identified urban design questions. Such an urban design thesis is usually open-ended and requires systematically identified urban design questions. The ‘Urban Elements’ are a method to explicate and expedite urban design teaching for advanced and professional students. The method opens up interfaces to interdisciplinary research input and can thus support evidence-based urban design. Gaps in research tools exist to test and evaluate parametric thinking capacity. Students in the course showed different degrees of parametric thinking capacity that cannot be explained by their age, professional expertise or previous training alone. Following such studies could refer to other studies available in psychology to test spatial understanding in order to shed light on the prerequisites for a future parametric urban design course. The ‘Urban Elements’ method presented in this study shall provide a sound reference for course aims, theoretical background, pedagogical structure, and empirical results for future studies in related areas.

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The ongoing research and educational activities are documented here: https://blogs.ethz.ch/UrbanElements/

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