Mapping the Architectural Genome

A Preliminary Study of Facade Syntax

Nicolai Steino
1
1 Aalborg University
1 steino@create.aau.dk

As its point of departure, this research contends that it must be theoretically possible to design a parametric urban design tool capable of simulating 90% of all conceivable site designs. The relevance of such a tool would be to quickly be able to simulate a large variety of site designs for any given context and location at a reasonable level of detail. The paper presents a preliminary study of facade syntax and its application to a prototype parametric design tool. The study finds that a combination of a compositional, geometrical and mathematical approach is promising to this end. From an empirical facade analysis, a taxonomy of three compositional levels is introduced and applied to the prototype. The paper concludes that the preliminary study is promising on a number of accounts. However, some issues must be investigated further, while other important issues have yet to even be examined. Yet while the task may seem insurmountable, there is potential to complete it, at least to a reasonable degree, and with a reasonable effort.

Keywords: Parametric urban design, Facade syntax, Composition, Geometry, Mathematics

INTRODUCTION

Urban design is often more concerned with building types than building artefacts. Operating on the typological level rather than the level of concrete design, principles for building design are of the essence, not the specificities of unique buildings. Therefore, parametric design lends itself perfectly well to urban design.

Being able to quickly and efficiently generate 3D models to illustrate design principles holds a great potential for many urban design tasks. From urban design competitions to urban design schemes within the framework of public planning, what is of relevance is to visualize ideas and principles for urban spaces to be.

While classical “white models” may be sufficient to convey an understanding of morphological and typological aspects of an urban design project, they lack sufficient detailing to be able to convey the architectural qualities of urban space. To compensate for this, urban design projects often feature perspective renderings which illustrate the architectural character without being based on actual architectural design of the buildings framing the perspective
view. But even so, such illustrations are both expensive and time consuming to produce.

A parametric design tool capable of generating urban design models with architectural detailing would solve this problem. While of limited use when it comes to the actual design of concrete buildings, it would facilitate the communication of architectural principles in urban design, in addition to the morphological and typological principles which are typical at this level of design.

Figure 1
A facade with a consistent glide reflection pattern of identical tiles, interrupted by a vertical and a horizontal variation (recessed tiles)

This paper presents some first steps in the process towards building such a tool.

Initial to this process is to consider the parametric logic which may be shared across different developments, buildings and facades. Traditional architectural analysis tends to operate by way of typologies and styles. Yet when performing a parametric analysis, buildings which may be typologically different or belong to different styles may share the same underlying parametric logic.

Such a parametric analysis may be applied to the levels of both site layout, building envelope and building facade. As an example, a row of terraced houses may be parametrically different from a housing block only in the sectioning of the block into individual units. And a strip of detached houses, in turn, may be parametrically different from a row of terraced houses only in the amount of open space between the units. The same is true for building facades, which is the focus of this paper.

In order for a parametric urban design tool to be useful in ideally any context, it should in principle be capable of generating any possible facade. However, mapping the parametric logic of any possible facade may seem an immense task. And truly, many facades are quite unique and may not share their parametric logic with very many other facades.

Yet a bold guess would be that 90% of all known facades have very similar parametric characteristics. Therefore, mapping what may figuratively be referred to as their “architectural genome” might not be such a vast undertaking after all. (see Figure 1)

ANALYTICAL FRAMEWORK
The results section of the paper is structured into three parts. In the first part, a basic framework for the parametric logic - or syntax - of building facades is established on the basis of an empirical analysis of a large number of existing facades, based on photographs. The analysis is limited to planar facades, i.e. facades without protruding or recessed elements such as balconies, bay windows, or niches. In the ontology of the study, such elements may be considered qualities of the building envelope, not the facade.

The analytical framework is unfolded on three levels. The first level is the overall composition of facades. This encompasses vertical parts such as the base, the middle and the top sections of facades, as well as the parts that structure the facade horizontally. The second level is the composition of each of
these parts in terms of patterns of repetition - or tiling - of walls and openings, and other facade elements. The third level is that of the individual tiles and their possible parametric variation.

The second part of the section discusses the semantic organization of the control handles of the parametric tool. As the tool is aimed at architectural design professionals who should not have to understand its underlying parametric logic, a sort of reverse engineering must be made, in order to translate the parametric variables into architectural variables which are meaningful to the professional architect user. This may seem to be an interface design problem. However, it ties directly back to the underlying parametric logic of the way the tool is built, as the variables which are operated upon in the interface ultimately are the underlying parametric variables deduced from the analytical framework. Postponing this part of the design might therefore render the tool useless and jeopardize the overall aim of the study.

The third part of the section presents a computational prototype for a select number of parametric variables for the generation of building facades. The computational prototype shows proof of concept on two levels. On the immediate level, it demonstrates the parametric versatility of the approach with regard to the selected variables. It does so, both with regard to the facade variations it is capable of generating. But it also does it with regard to the operability of the interface for the professional architect user.

As the prototype is work in progress, it is crucial that its architecture is expandable, in order to incorporate additional variables without cluttering up the code. Expanding the scope of the tool with additional variables is a potentially endless process. Therefore, this is an important issue. Otherwise, the expansion of the tool may too quickly become too cumbersome to be viable. Thus, on the meta level, the computational prototype also demonstrates the parametric expandability of the approach.

The presented work is part of a larger project which includes similar studies of site layouts and building envelopes. While these are different domains, the parametric logic applied to building facades, in principle, is similar to the one which may be applied to these other elements of the ontology of the study. However, there are variations. While site layouts and facades follow a planar logic, building envelopes are three-dimensional. Therefore, the parametric logic of building envelopes are partly different from that of site layouts and facades. (see Figure 2)

Figure 2
Facade with base and left wing parts. While the facade features only a limited number of different tiles, their distribution across the body part is too complex to be meaningfully described by means of variations. A stochastic distribution may be preferable though not exact in this case.

RELATED WORKS
On the general level of parametric urban modeling, different approaches have been applied to the solution of discrete problems such as designs for particular geographical sites (Godoi et al. 2008, Gürbüz et al. 2010, Hardy, Lundberg 2010) or for particular types of buildings (Matcha, Quasten 2009). Yet, these approaches only concentrate on a subset of parametric variables relevant to their respective domains. Yet other approaches target the level of urban planning (Beirão et al. 2011, Pellitteri et al. 2010), which typically deals with issues other than the layout and morphology of buildings. These studies also operate at a level of detail at which facade design is irrelevant.

On the specific level of facade modeling, several approaches exist to parametric facade generation, whether fully automated (Shen et al. 2011, Wan,
Sharf 2012, Weissenberg et al. 2013, Wu et al. 2014) or user assisted (Bao et al. 2013, Musialski et al. 2012). Some approaches focus on the parametric generation of existing facades from image (Weissenberg et al. 2013, Musialski et al. 2012, Teboul et al. 2010) or LIDAR (Shen et al. 2011, Wan, Sharf 2012) data. Other approaches focus on parametric variation of different facade schemas (Wu et al. 2014, Bao et al. 2013). And yet other approaches focus on computational efficiency through algorithm optimization (Weissenberg et al. 2013, Haegler et al. 2010). (see Figure 3)

Image or LIDAR data interpretation is highly relevant if the aim is to generate parametric models of existing urban environments. For large urban models, computational efficiency is relevant as CPU requirements for such models may strain even the best computers and require significant amounts of render time. And parametric variation of facade schemas can be relevant in the gaming industry, where the easy generation of plausible urban environments may precede over architectural quality and accuracy.

While Bao et al. (2013) have some concern for HCI in relation to user assisted parametric modeling, none of these approaches are entirely relevant to the aim of the research which is presented in this paper. Developing a parametric design tool for the easy generation and visualization of urban design schemes does not rely on image processing, as the focus is on new buildings rather than existing buildings. Computational efficiency is of lesser importance, as most such schemes are of overseable size. And finally, most attempts at parametric variation of existing facade schemas either display modest architectural quality, offer variations of specific types, or rely on historic and well-established architectural paradigms which may not be relevant to current-day architectural design, let alone in any geographical region.

**METHODOLOGY**

This study is being carried out in a heuristic manner, based on architectural, geometrical, mathematical and parametric knowledge and experience. The empirical facade analysis is abductive in nature, drawing from a vast catalogue of building facades, which have been examined repeatedly with regard to different parametric strategies. Test facades have been selected for their architectural and compositional qualities and variation in order to test and corroborate different parametric approaches.

The tool prototype has been developed in a trial and error fashion, testing different approaches with regard to their computational clarity and openness, as well as their compatibility with architectural thinking, while compromising as little as possible, the versatility and flexibility of the tool as well as the level of detailing it can offer. Hence, architectural logic and compositional progression have guided the script development in order to make the algorithm meaningful and structured to work with for the professional architect user.
As the results represent work in progress, they have not yet been tested with live users, nor have they been applied to large models. Reservations therefore have to be made at this point, as to the actual user experience in live usage, as well as to the usability of the prototype in real-life urban design. Similarly, the computational efficiency of the algorithm has not been tested on larger models with lots of geometry. However, it is assumed that such potential shortcomings may be mitigated in later stages of the research. (see Figure 4)

Figure 4
Facade (partial) with padding between tiles. This facade inspired (though is not identical to) the facade in the prototype example below. Here, the padding was integrated into each tile.

RESULTS
In this section, the preliminary results of the study are presented. The first three sub-sections present an empirical facade analysis and its derivate taxonomy of to facade composition, facade symmetries and variations, and facade tiles and elements. The following sub-sections present the issues of control handles for a parametric urban design tool and a preliminary prototype of the tool respectively.

Facade Composition
The empirical facade analysis suggested that a geometric descriptive logic to the composition of facades, in combination with a few compositional elements, both lends itself well to parameterization and offers a comprehensible syntax to the professional architect user.

Most planar facades of multi-storey office and residential houses - which constitutes the domain of this study - regardless of their age, style, type or provenance, share a number of features which can be described generically. In their most simple form, facade schemas develop uniformly across the facade from left to right and from bottom to top, regardless of size and number of floors. However, most often, small variations occur at the ground floor, if nothing else, then at least in the form of an entrance door.

Vertically, from the ground floor to the top floor, facades are often divided into different compositional parts. Apart from minor variations at the ground floor, such as the entrance door or window formats, the absences of balconies, etc., facades may have a base which follows a different geometrical logic than subsequent floors. The base may span across one or more floors, and is a feature of many architectural styles. Similarly, facades may have a top which is different from the previous floors, which may also span across one or more floors.

Hence, the facade may be described as constituted of up to three horizontal compositional parts, an optional base, a body (which is always present), and an optional top. These features may be found in different combinations. Many modernist buildings have a uniform facade from the first floor up, and a base in a different design. Some buildings may develop uniformly from the ground up and have a variation at the top. And yet others may even feature all three compositional parts.

A similar logic can often be applied horizontally. From left to right, facades may have a left, a body and a right part, each of which feature different, sometimes reflective, geometrical logics. In historical facades, a center part may be flanked by symmetrical wings, and modernist facades often have a side part which is different from the rest of the facade, typically with a blank or nearly blank wall.

In combination, these three horizontal and vertical parts constitute a 3x3 matrix with 9 rectangles. The four corner rectangles sometimes - though not often - have unique geometry. But mostly they are
extensions of either the respective row or column part (base, top, left wing, right wing) to which they belong. Described in this fashion, each of the nine rectangles may hold facade parts with different geometrical logics. While unique corner conditions are rare, however, only the five main parts, base, body, top, left wing, right wing, have been implemented at this stage. (see Figures 5 and 6)

**Symmetries and variations**
Across the facade, different symmetries may occur, in the form of translations, and horizontal reflections and glide reflections. Rotations and vertical reflections are rare in facades, as their design relates to gravity and use. Symmetries are important in architectural as well as in parametric design, as they constitute both order and variation, as well as computational efficiency as they represent simple variations of the underlying grammar.

In terms of symmetry, many facades are composed from simple translations. Alternating reflections, both vertically and horizontally, as well as glide reflections (which by nature are both vertical and horizontal) often occur across the entire facade or parts of it. Translations, reflections and glide reflections may occur in combination. As such, the facade pattern may constitute a regular tessellation. Other more complex patterns of repetition may also occur.

In addition to symmetries, facades may feature one or more variations. Variations are regions in the facade where the primary geometrical patterns do not apply. Such variations may be constituted by single balconies or bay windows, or single doors and windows with different size, position and/or design from other doors and windows. Such variations may be used as architectural accents or tensions, or exist for practical reasons. The latter is typically the case at the ground floor level, where entrance doors, shop windows or gateways constitute variations to the general geometrical pattern of the facade.

Variations may occur in combination with symmetries, either as slight variations of the substituted part of the symmetry or in complete contrast to it. The more variations there are on a facade, the more complex it may be to detect them as something distinct from an otherwise underlying pattern. If too many variations occur, it may be more meaningful to conceive of the facade as stochastic. From a computational point of view, variations are less efficient than symmetries. Also for this reason, a stochastic description may be more desirable, even if it cannot generate an exact description.

**Tiles and Elements**
Once the facade has been classified with respect to its compositional parts, symmetries and variations, the next level of analysis is the different tiles which oc-
cur in the pattern of each part. Tiles are separated vertically by the floors of the building, typically flush with the floor decks. Horizontally, their separation is guided by the symmetries of the facade. Thus their widths are likely to vary more than their heights. Simple facade schemas may contain only one type of tile. If the tile does not have self-symmetry, reflections and glide reflections may produce highly varied facades, even from a single tile. However, many facades are composed from two or more different tiles, with or without reflections. (see Figures 7 and 8)

Figure 7
A variation (petroleum) is added for every third floor at shifting heights

Figure 8
For remaining tiles, an additional variation is added for every third floor stating at the ground floor

In their simplest form, tiles consist of only a wall segment or an opening (door or window). More complex tiles may contain sub-symmetries and different combinations of walls and openings. Wall segments and openings are elements. Depending on the level of detail of the analysis as well as in the parametric model, they may have colors or textures. Walls may be made from different materials such as brick or concrete, and have minor recessions or protrusions such as lesenes and ledges. Apart from doors and windows, openings may be French balconies, have shutters, blinds and louvers, brise soleils, and more. While the catalogue of architectural elements is extensive, only elements with a reasonable effect on the morphology and character of the building should be considered.

Elements, in other words, constitute the smallest level of analysis. This is the level of texture and materiality. They also contain the final shapes of the parametric algorithm, also referred to as terminal shapes or leaf shapes in the terminology of computational grammars. Although every previous level of analysis (and computation) are important in terms of defining the overall and detailed composition of the facade, everything before the elements are just intermediary steps.

In total, overall composition and parts, symmetries and variations, and tiles and elements constitute the taxonomy which has been deduced from the empirical facade study. The different levels of the taxonomy have been applied, both to the considerations about HCI and user control in the parametric design process, and to the parametric algorithm design.

Control Handles
In order for a parametric urban design tool to be useful to the professional architect user, its user interface must be intelligible and meaningful. Many parameters go into the full definition of 90% of all site designs with building envelopes and facades. The design of the interface to control all the parameters could easily develop into a gigantic mixer panel with control handles for all the different parameters. And even if it would be possible to add meaningful labels to all the handles and possibly even tooltips and help sections, control handles which do not give any visual
hints about their effects are likely to not appeal even to the most devoted user.

Therefore, the approach to designing the HCI has been dual. On the one hand, a hierarchy has been attempted which ultimately breaks all the different parameters down into logical sections following the gradual refinement of a site design from the bare site to elements and textures. On the other hand, the idea is to have the algorithm guide the different design steps, through different render scapes, similar, in principle, to different levels of detail (LOD) in model representation.

Prototype
In order to be able to address each tile of the facade with respect to different aspects of its composition, each tile (cell) was parameterized with symbols indicating its x and y indexes in the matrix. In this way, any cell or series of cells may be evoked in the script at any time by calling its/their coordinates through mathematical functions.

The prototype facade design part of the parametric urban design tool is demonstrated in an example for a contemporary facade (Figure 11). At the level of overall composition, the facade has the following features (Figure 5):

- A base part spanning one floor at the entire width of the facade
- A left wing part spanning all the upper floors and 1 narrow panel (column of tiles)
- A body part spanning 5 floors and 4 wide tiles

In this example, the right wing part is used as a very narrow padding in order to add extra wall thickness to the right of the right edge (symmetry line) of the rightmost panel in the body part.

At the level of symmetries and variations, three overlays were applied:

- A symmetry overlay in the form of an overall glide reflection of tiles across the base and the body parts of the facade (Figure 6)
- A variation overlay spanning every third floor, counting from the ground floor (floor 0 and 4) (Figure 7)
- A variation overlay spanning the fourth vertical panel of the facade (row 3 of the 0-based matrix) (Figure 8)

While the symmetry overlay only mirrors the tile without changing its description, the variation overlay substitutes the description, i.e. points it to a different tile description.

At the level of tiles and elements, the following features were applied:

- A tile consisting of a wall element, three tall opening elements and one short opening el-

In the scope of this paper, this is demonstrated tentatively at the level of facade design. Figure 9 shows how the part of the facade design parameters controlling composition, floor heights and tile widths have been order hierarchically. In addition, the effects of applying different symmetries and variations can be rendered graphically by the algorithm (Figures 5-8 and 10-11).
element, padded with a narrow wall element on either side in the sequence aABBBCa.

- A tile consisting of two double opening elements separated by a wall element, also with wall paddings on either side in the sequence aBCABBa.

- A dark color wall element (A) with a ground floor variation which renders in a bright color apart from a top part which renders dark.

- A tall opening element (B) with a top dark color wall part.

- A short opening element (C) with dark color wall parts below and above the opening with a ground floor variation which renders is like the tall opening element (B).

In sum, this grammar results in five possible terminal elements, 3 main elements (wall, tall opening, short opening) and two ground floor variations (bright wall, tall opening), one of which, however, is identical to one of the main elements, adding to four visibly distinct elements. The resulting facade is shown in Figure 11.

DISCUSSION

While the presented work is still preliminary, it does lend itself to discussion on a number of points. The empirical approach to facade (de-)composition has allowed for the development of a parametric design approach which spans facades of different age, style, type and provenance. As the ultimate goal of the research is to develop a generic parametric urban design tool, this is important. However, as the facades have been abductively selected rather than based on a systematic, quantitative survey (which would have been unfeasible), there is a potential risk, that the sample is biased. Further testing should therefore take place.

The user interface design has proven to be a significant challenge. While careful thought has been put into the structure and semantics of the user interface, the number of foreseeable handles is substantial. The visual aid through intermediary renderings potentially provides important clues during the design process. There is still room for improvement, however, both as to the visualization and the implementation of different render stages in the user interface.

The three-level taxonomy of composition and parts, symmetries and variations, and tiles and elements is promising and meaningful, and seems to be able to embrace all necessary design steps in basic facade design. The number of overlays (symmetries and variations) which must be available in order to offer sufficient variation is yet to be determined and their implementation may represent a challenge.

The composition of tiles is still underdeveloped and should be subject to further development, both with regard to their number and their sub-symmetries. Similar to variations, tiles are not computationally efficient as every tile must be uniquely defined (although potentially by means of re-usable
sub-components which may represent an additional level in the taxonomy).

Finally, as the algorithm has not been subject to large-scale testing, it may potentially be slow due to the lack of focus on computational optimization.

CONCLUSION AND PERSPECTIVES
The presented work on a parametric facade design algorithm is only a small part of a larger plan of building a parametric urban design tool capable of modeling 90% of all site designs with building envelopes and facades at a reasonable level of detail. Yet while the task may seem insurmountable, it shows that there is potential to reach it in part with a reasonable effort.

Nonetheless, a lot of work still needs to be done. Notwithstanding the levels of site layouts and building envelopes, at the level of facade design, a number of aspects call for further exploration and development, apart from the ones listed in the discussion above. The issue of padding was briefly mentioned in this paper. However it may represent an important issue, both at the level of the overall composition of the facade, as well as at the tile level, Symmetry is a delicate matter and is easily broken due to missing padding (narrow elements in the facade schema) which may not be implemented within the matrix structure of the presented approach.

Another important issue is the question of when to use relative or absolute measures at the different levels of composition. By nature, parametric design must be flexible and adaptable to many different situations. The capacity to stretch various elements in the design is therefore indispensable. Yet, it is not always clear which elements in the design should be flexible and which should have fixed dimensions, and the grammar should be able to handle this.

Finally, the issue of randomization which has been only briefly addressed in this paper may hold some potential. Certain elements lend themselves perfectly well to randomization, such as curtains, shutters and other moving parts which in real life may be controlled by the users of buildings. However, given the fact that the ambition of this research is to generate a tool for urban design, capable of simulating distinct morphologies and characters rather than architectural accuracy and detail, randomization may represent an interesting shortcut to variation for some aspects of design.

REFERENCES