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PATTERNS, HEURISTICS FOR ARCHITECTURAL DESIGN SUPPORT

Making use of evolutionary modelling in design

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Abstract. Software used by architectural and industrial designers has shifted from becoming a tool for drafting, towards use in verification, simulation, project management and remote project sharing. In more advanced models, design parameters for the designed object can be adjusted so that a family of variations can be produced rapidly. With the advances in computer aided design (CAD) technology, design options can now be generated and analyzed in real time. However the use of digital tools to support design as an activity is still at an early stage and has largely been limited in functionality with regard to the design process. To date, major CAD vendors have not developed an integrated tool that is able to leverage specialised design knowledge from various discipline domains (known as expert knowledge systems) as well as to support the creation of design alternatives that satisfy different forms of constraints. We propose that evolutionary computing and machine learning be linked with parametric design techniques in order to monitor a designer's cognition and intent based on their design history. This will lead to results that impact future work on design support systems which are capable of supporting implicit constraint and problem definition for wicked problems that are difficult to quantify.

Keywords. Design support; heuristics; generative modelling; parametric modelling; evolutionary computation.

1. The use of computers in architectural design

This paper outlines a conceptual framework and ideas centred on an evolutionary design support system that interfaces between human inputs through the traditional CAD process in order to monitor and respond to the designer's process. This system may include the following capabilities: performing composition, specifying relations, constraints, styles, and suggesting improvements by providing the more optimised solutions.

The conventional design approach in a building construction project involves iterative processes of design, modelling, analysis, development and optimisation steps, which are executed separately. Given the complexity and diversity of the disciplines involved in a building design, this conventional approach requires numerous successive iterations in order to generate even the most trivial design changes and hence is considered as inefficient and time-consuming. This also leads to sub-optimal design in areas such as energy performance. If we consider the benefits associated with intelligent passive design an increase in efficient in the order of 50–75% can be expected through better design alone (Clarke, 2001). More streamlined processes in generating and visualising design options are required which not only meet design constraints and point towards optimised solutions, but also allow designers to work collaboratively, with the benefits of expert knowledge and with the opportunity for reflection and continued learning.

This paper does not cover the feasibility of utilising evolutionary systems with regard to energy, lighting or structural analysis. Writings verifying the feasibility of such systems are available given by Caldas (2006), Keene (1996), Frazer (2002), and Janssen (2006). The key topic discussed is the integration of such a system into the design process, especially the very early design stage. This is when the building forms are still malleable and the cost incurred by generating design changes is less significant. By aligning the computational process with the human design process, the aim is to work towards systems that are more articulated and intelligent. This is distinct from models that contain sophisticated but 'heavy' virtual constructions representing the building in high degrees of detail. The examples given in this paper are simple massing models, opening discussion on representation and the stratification and hierarchy of data as is needed for a designer. Finally, this paper does not deal with 'auto-generated' design options or how such a strategy can be made feasible. This is not due to the ethical problems associated with the auto-generative approach for example as critiqued by *whom* but due to the simplifications and abstractions that arise in the consideration of this topic. Leaving aside the lack of engagement with cultural and contextual conditions, there are many purely formal and spatial limitations that seem 'hard-wired' to many approaches that are given. While no introduction is given to the methods of evolutionary, parametric, generative or associative modeling – there are full definitions given by the authors mentioned so far.

2. The design process

As an activity, architectural design relies heavily on intuition, preconceptions, heuristics and 'guiding principles' (Lawson, 1990) which cannot always be reduced to first principles, fundamental laws or epistemology in the way that the sciences can. Each designer's own principles can be unique and suited to their own personal preferences and history. The traditional ways in which computer-aided design (CAD) processes are utilised are centred on drafting, documentation and verification.

Robert Aish (2000) criticises the current fragmentation of design documentation from the holism of design as the result of the paradigm given by the personal computer where each file is a 'discrete' document stored as a file. While this is not so different from the earlier, manual design processes – each architectural drawing on a separate sheet of paper – there is an internal need to view the project holistically – to consider many things at the same time and to draw on knowledge from prior experience. Hence the danger being considered, is that with CAD, we may go 'too fast', to a developed design. We are at this point making little mention of the obvious hybrid process of beginning with manual sketches and then digitising these into computer data. This has been critical in the world of many renowned architects such as Frank Gehry or Santiago Calatrava due to the complexity of their designs. Such practices however display a strong 'visionary' point of leadership and reference where the design intent follows through from conception through to design. Furthermore such projects which only utilise the computer for the purpose of documentation are unrelated to the topic discussed. They do however, along with the initial observation highlight the inherent need for 'design direction' and the concept of 'intent' which has had little consideration in the primary literature of digital architectural design and design support.

2.1. DESIGN INTENT

Treating design as a 'search space' problem – which dominates artificial intelligence literature – is of little interest to fostering good design. Even a very simple case has so many possible states that there is very small statistical possibility that the solution will meet enough of the criteria that *were not explicitly stated.* A summary of headings from Lawson's (1990) writing on *problems and solutions* provide an overview of this:

Design problems cannot be comprehensively stated.
There are an inexhaustible number of different solutions.
There are no optimal solutions to design problems
The process is endless.
There is no infallibly correct process
The process involves finding as well as solving problems
Design inevitably involves subjective value judgments.
Designers work in the context of a need for action

With regard to the work of architect / engineer Santiago Calatrava, Lawson (1988) points out that a single design idea must be explored to the exclusion of all others. While we cannot give a complete systematic and complete account of *intent* – we can elaborate on how it be related to the digital process and to do so we need to consider some of the internal issues of design:

- Being able to move between part and whole.
- Being able to consider a range of entities in isolation, such a view shall be described as a *Perspective* in this paper.
- Being able to utilize a set of abstract procedures for a specific task – such a function shall be described as a *Pattern* in this paper. A perspective may be a specific instant of a Pattern.
- Being able continually re-define and re-use new perspectives and new patterns.
- Being able to relate two dimensional and 3-dimensional data coherently, i.e., to be able to articulate *composition.*
- Being able to articulate rules without a formal description – referred to in this paper as a *heuristic.*

2.2. PERSPECTIVES AND PATTERNS

The choice of terms 'perspective' was adapted from the work of Haymaker et al. (2008). It is used to describe a certain 'point of view' during the design process and can range from an orthographic drawing, a perspective projection or a symbolic list. While it may seem a trivial point to give a name to something so basic to design, it should be noted that certain constraints related *directly to the perspective* where it is created. An example of this would be facade composition. The term 'pattern' stems from the seminal work of Christopher Alexander (1977) as well as Gamma et al. (1994) and Woodbury (2007). A pattern is described as a general solution to a recurring problem. Figure 1 gives an example of a perspective. In this case the task is set to modelling a timber framed wall and can thus be named as a 'wall-building' perspective. Several patterns are utilised to allow the necessary geometrical data to store an instantiation of such an object. The dominant one would be a 'grid defined by spacing' (as opposed to defined by parameter) as well as its projection onto a surface. The second would be the shape Boolean operation subtracting the space where the windows are to be. The third step in logic is for the special treatment of the entities around the opening – the lintel, headers, and trimmer studs. Finally the replacement of the model lines with sized elements or wall studs in this case. Note that if the grid was not *projected* then it would not allow for the elevation of the wall to appear as anything other than a rectangle. The data that is needed as an *input* to this perspective is either a line which represents the path of the wall in plan or an outline shape that represents it in elevation. Both have their limitations with regard to three-dimensional geometry, but together they form a very robust system. This can be further generalised for the outline to be a 3D curve. But it is a necessary that the wall view can operate in 2 dimensions and 'wrap' itself to a three-dimensional situation. During the final pattern of replacing the abstract with the material, meta-data can be set to reference material properties, i.e., conductivity values for thermal analysis, colour for lighting and strength for structural analysis. The perspective which in turn runs a visualisation-pattern can automatically present the wall at different levels of detail, showing only the outer-skin when constructing a model for viewing in 3D or rendering, but allowing for a detailed model when needed, i.e., for collision detection with ductwork.

Figure 1. Perspective for building a timber wall.

Once such a perspective has been instantiated, the evolutionary process is free to manipulate the length of the wall; its profile based on manipulated the outer corner points or the sizes and placements of windows.

2.3. CONSTRAINTS

The placement of constraints that do not exist mislead the design process, for example a non-existent boundary. Equally, the exclusion of constraints that should be there – such as minimum room size – not simply by area, but also accessibility, i.e., an acute triangular space is hard to access at the corners. There are also degrees of constraints – for example, having grids largely orthogonal, but not completely rigid. In the wall-builder perspective given previously there might be an explicit requirement that windows are all of the same size, are of a certain proportion or are defined as a *percentage* of the total wall area. In a traditional CAD system, it would be very unusual for a child object to be able to access data from the parent object containing it or to have *dynamic* data used to specify it. Section 2.4 gives mention of the query language used to remedy this. Section 3.1 will describe a case where a constraint is not explicitly stated but instead is inferred from test data.

2.4. COLLABORATIVE DESIGN

Until now, we have been describing the 'designer' as a single being. It is naïve to assume that any design collaboration could keep all members of the team happy unless there is some communication between the designers and overall intent is reached through some team effort. As yet, it is very difficult to know when something has been over-constrained or certain constraints clash with each other without seeing some outputs. The reason for this difficultly is that the evolutionary cycle begins with a solution that approximates the solution and starts to move towards an optimum. As in most cases we do not know what would constitute an ideal situation – or what satisfies the majority of criteria. We cannot be sure that a lack of progress is due to a problem with the constraints or that the best solution has in actuality already been reached.

2.5. AN OPEN FRAMEWORK

The evolutionary models of the past had a tendency to be constructed with a system 'hard-wired' to a set of operations. Attempts have been made to keep all parts of the system as open and upgradeable as possible. The idea of a single integrated tool has repeatedly failed in the past and therefore there is a need for more focus on interoperability. The software used for analysis is freely available and both the recombination and shape description schemes are referenced through external files in an XML schema which allows for easy verification and upgradability, as are the wrappers that allow access to the simulation software. An entity might be described as follows:

```
<SUBDIV> <COMMENT text= ‘Villa Thiene at Cicogna’></
COMMENT> <Grid size = ‘500,300,4’ newname = ‘A’></Grid> <S
selection = ‘A’></S>
    <DivideHorizontally divisions = ‘.25,.75,1’newnames=’A,B,A’></
DivideHorizontally>
```

This representation shows the relationship between natural language and computation operations. The description allows for the intuitive manipulation of geometry parametrically as given in parametric grammars, i.e., Stiny (2006) while still being able to codify this relatively quickly. Note that this differs from the traditional genetic algorithm where the population member is described by a bit-string sequence.

3. Case studies

It is necessary to work at different levels of abstraction and detail in the design process. It is also noted that the practicalities of ‘designing’, working from the ground up, is very different from the top-down (management) view of design that may reduce it to a smooth, controlled process! Therefore it is necessary to speak of actual case studies to articulate further some of the issues.

3.1. THE NINE-SQUARE GRID PROBLEM

The example of the nine-square grid was chosen because it has an established place in architectural theory, being described by Rudolf Wittkower (1949), John Hejduk (1979) and Greg Lynn (1992.) Lynn raises the point that the grid gives the discourse on Palladio by Wittkower an *origin* which in turn could be used to read the work as well as give it to a *body*.

The sequence of steps described uses the specification of a grid as its primary means of description. Operations of merging or removing cells to make the spaces deviate from the original grid. Note that in this case concepts of being ‘orthogonal’ or symmetric are not specified but instead are inherent to the formation of the entity. This may or may not be desirable. Should a property such as ‘symmetry’ be explicitly stated as being a fitness criteria (an operation involving symbolic logic targeting specific design goals) or should it (in this case it is desirable) be inferred by using test data that all contain a large amount of symmetry? We opt for the latter as a more generalised solution as other criteria are not as easy to notice or to define as that of symmetry. This then forms a ‘heuristic’ function in the systems’ evaluation function. In regard to this process of data-mining patterns and descriptions, the next problem lies in regards to the relatively few examples that were left by Palladio (figure 2). In relation to the high amount of data required by most data mining algorithms, this can be solved by modelling a few examples in the schema and allowing it to generate variations with no topological changes.

The schema was later adapted for use in the specification of Mosque descriptions with the aim that they be optimised with regard to environmental

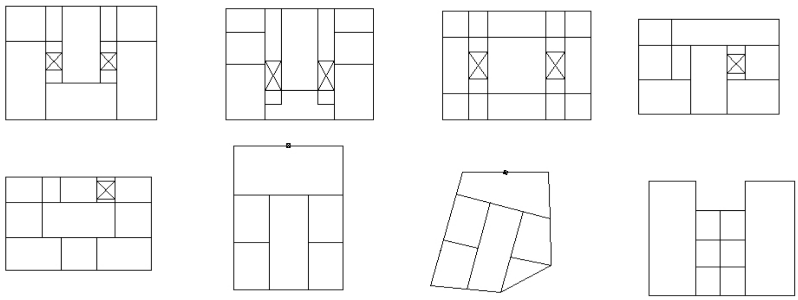

Figure 2. The top four images show digitisation of Palladio's villas, the lower four are computer generated variations using the schema.

performance which followed through with the problems in constraint definition that have been mentioned before. The rule stated that the Quibla wall was to face towards Mecca as depicted in the lower four images of figure 2. If the evolution specified by the description is limited to orthogonal forms then the orientation (as a rectangle) is very static with the long axis being elongated along the axis closest to north–south finally stopping at the minimal area of a space (in this case we are considering a very basic analysis limited only to heat gain.) However if we take away that constraint altogether, our solution may ignore cultural references such as the aesthetics of symmetry and produce undesirable results. With more sophisticated evaluation such as buoyancy flows come more levels of differentiations and possible solutions.

3.2. PAVILLION DESIGN

In the second case, support was provided for the conceptual design of a pavillion made of precast concrete modules. The aim for evolutionary modelling was to have as much repetition as possible, i.e., minimise the number of panel types while at the same time having as much variation as possible in the assembled units. It was also desirable to have as much variation in the assembled units as possible and to have an organic composition. Figure 3 shows an image of the precast concrete units. In this case, two descriptions were difficult to formally state – the overall composition and whether the shapes were tiling. The scene description began with hexagons – ensuring that they were able to tile and then applied distortion to make the shapes more regular. This could only be done when there weren't any fully enclosed polygons and that at least

2 shapes change with every distortion.

As fitness criteria could not be easily defined, the work flow involved having the generated designs sent to modelling software and sending the ren-

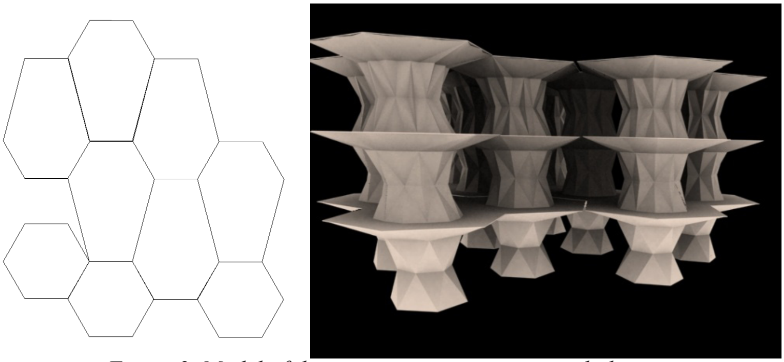

Figure 3. Model of the pre-cast concrete units and plan.

dering to the architects for their subjective opinion. The quick visualisation of complex form did however prove to be very useful. In such a case, we have no way of being certain whether our solution was optimal. It did however provide a solution that was 'good enough' which was helped by being able to isolate the problem from all the other considerations. The second task was to look for variations where the top part of the column meets with the floor plate. In this case a regular hexagon was explored in isolation and later projected onto the irregular shapes. In this case the symmetry shown in figure 4 was inherent to the description. No criteria were used to differentiate the design other than the designer's opinion.

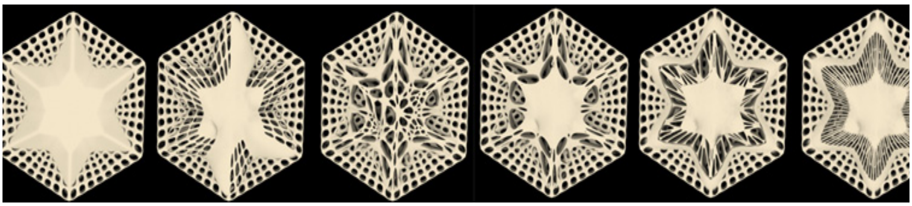

Figure 4. Variation of column capitals for the pavilion structure.

4. Conclusion

As an activity, design relies on being able to work with an intuitive understanding of problems and their possible solutions. It is important to be able to break a problem into parts, but also to be able to work holistically. Attempts have been made to follow through the architectural process in an integrated and multi-disciplinary way. New methods of generative, associative, parametric and evolutionary modeling may speed up the time spent modeling as well as make it easier to create variations at an early stage and fine tuning at a later stage. By utilising the data that is provided by previous cases or in the designer's own prior work, CAD systems can work more intelligently such as to provide auto-generation of parts.

By analysing the heuristics used in the designer's prior work in response to structural, lighting, energy, environmental and building services modeling, a diverse range of perspectives are quantified. The proposed approach in this paper offers design reuse through providing performative reflection on design. In this way, stakeholders involved in a building design are able to weigh on the cost, performance, and aesthetics of the design options presented.

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