ENRICHING CREATIVITY IN DIGITAL ARCHITECTURAL DESIGN

A hybrid digital design toolset as a catalyst for design emergence in early-stage explorations of complex forms

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Abstract. Although conceptual design is one of the most important stages of creation, impacting the quality and cost of the final product, current research indicates that designers still lack adequate tools supporting early-stage design. This research challenges that notion, by proposing a hybrid digital design platform for conceptual architectural design. The platform contains four miscellaneous techniques: animation, free-form modelling, associative parametric modelling and performance-driven modelling. In a digital design experiment we demonstrate that the collective application of these techniques to early-stage design explorations intensifies the architect’s visual and cognitive reasoning processes, and hence supports the emergence of promising design artefacts which bear the traces of all the techniques applied in the course of their conception. Additionally, the study also points at some other promising virtues of the hybrid toolset, including: provision of diversified form-finding opportunities on various levels of design abstraction; the potential to direct designers onto unplanned creation paths; the ability to increase the versatility and functionality of the solutions; and the capacity to sustain design activities of various character, ranging from highly intuitive ones to very rational ones.

Keywords. Conceptual design methods and tools; free-form modelling; animation; associative parametric modelling; performance-driven design.
1. Introduction

1.1. RESEARCH AIM

The aim of this paper is to demonstrate that the application of the hybrid digital design toolset in early-stage conceptual design has a promising potential to intensify the architect’s visual and cognitive reasoning processes, and hence to support the emergence of creative design artefacts. The originality of the proposal lies in the examination of the consequences arising from the collective use of several significantly different digital techniques in one design process. To our best knowledge, no such proposal has yet been investigated in digital design research.

1.2. RESEARCH METHOD

The study of the hybrid design toolset consists of an empirical and a theoretical part, combined together to reach the final research conclusion. The empirical study is based on a design experiment in which the hybrid toolset is tested in a hypothetical design assignment. The theoretical study embraces an analysis of the experiment’s course through the lens of the recent findings within the theory of visual reasoning in design.

1.3. RESEARCH PREMISES

The proposal to investigate the hybrid digital design toolset is justified by several premises. Firstly, current research in design creativity points at the need to focus on novel design means for the early conceptual phase, since this particular stage profoundly impacts the quality and cost of the final design solution. Secondly, it was indicated in previous studies that designers still lack adequate digital tools for conceptual design (Horváth, 2005). Finally, this research is essential to support the current advances within the theory of digital architectural design. Within this theory, the existing models of digital design focus on single digital techniques (Oxman, 2006). Although it has been suggested that compound models, embracing more techniques, could exist in the future, so far the details of their structure and functioning have not been introduced, apart from our most recent proposal in this respect (Zboinska, 2015a,b).

2. The hybrid digital design toolset for early-stage emergent design

The composition of the hybrid toolset takes advantage of the best properties of the four different digital design techniques explored in the experimental practice of digital architecture: free-form modelling, animation, associative
parametric modelling and performance-based design, i.e. modelling incorporating optimization algorithms which drive the development of 3D forms using computational building performance analyses/simulations. In our earlier research (Author, 2015a), this set of tools was developed into a hybrid CAD/E software platform. We supported the platform with a theoretical compound model of digital design, based on the principles of digital formation, generative design and performance-oriented design (Author, 2015b).

In this paper, we zoom in to investigate the design emergence-related aspects of the creative process executed using the hybrid toolset. The recent findings within the theory of design emergence suggest that the rise of innovative artefacts throughout the design process is not accidental, but resulting from a series of intentional actions, triggered by the intensive visual and cognitive activity of the designer (Oxman, 2002). Taking that notion as a plane of reference for our study, we examine more closely the relationship between the explorations of complex architectural forms using the hybrid toolset, and the visual and cognitive activities of the designer, occurring as the different techniques from the toolset are applied in the creation process.

3. The theory of visual reasoning and emergence in design as a context for empirical research

To indicate the relation between our toolset and design emergence, we conducted a design experiment. Its aim was to find out whether a conceptual design process supported with the hybrid toolset could be carried out according to the typical emergent design workflows. Consequently, if such a process would be possible with our tools, we would be able to infer that the process is creative and capable of yielding promising early design solutions. In this way, we could further claim that the hybrid toolset enhances the creative process in a manner which would have not occurred if a single design technique was employed.

The theoretical base for our experiment is the extended model of design emergence, based on visual re-cognition (Oxman, 2002). This model expands the well-known reflection-in-action model of Schön (1983). According to the extended model, both visual and cognitive acts are the necessary conditions for design creativity to occur. The model also proposes that during the emergent design process, a particular series of visual and cognitive occurrences takes place, namely: a perceptual event, image prompting, prompted interpretation and visual re-cognition. In the context of digitally-aided design, we interpret these occurrences as follows.

Firstly, when the perceptual event arises, the designer uses the digital tool to produce and then visually examine the first sketchy digital artefact. At this
preliminary stage, low-level seeing occurs. Namely, the designer determines what the object is, and not yet what it is about. By viewing the object in the digital space, the compositional elements, such as the boundaries and volumes are being noticed.

After this initial examination, the second step occurs, called image prompting. Triggered by the digital 3d image from the previous step, the recalling of mental images takes place. The designer moves on from “seeing with the eye” to “seeing with the mind’s eye”. The sensory process of seeing becomes intertwined with a mental process of cognition. What is now perceived is not the explicit object itself, but the implicit mental image of that object. The mental image is a visual image supplemented with additional elements, usually retrieved from the designer’s existing visual memory.

The third step advances the mental imagery process further, into a phase of prompted interpretation. The visual and cognitive processes become high-level processes. Now the designer restructures the mental image so that it is possible to determine what the object is about. Using general knowledge, including knowledge on shape syntax and shape semantics, the designer is looking for ambiguous attributes of shapes, hidden sub-shapes and hidden functions which the shapes are able to accommodate.

Directly after this, visual re-cognition takes place. The designer proceeds further with the visual thinking processes, but this time refers to more detailed personal design knowledge, to give a more specific meaning to the artefact. The artefact is positioned within that knowledge, classified using a domain-specific taxonomy, and related to an existing or newly-conceived design schema or prototype.

The above steps of visual examination and mental cognition demarcate and trigger the sequence of design emergence. Emergence occurs as the design taxonomies and prototypes are applied to what is seen, and then the design artefacts associated with them are creatively transformed by the designer, eventually turning into novel solutions (Gero, 1992). The transformations embrace purposeful design operations, such as restructuring of shapes and manipulation of their relationships.

4. The hybrid toolset in action in the organic building skin experiment

The assignment selected for the experiment was to develop a building façade concept. By choosing this subject of study, we wanted to demonstrate the hybrid toolset in action in a typical architectural design task. The façade was selected as a characteristic architectural element, impacting the building’s aesthetic appearance, material substance and functionality. To account for the maximum capabilities of the hybrid toolset, complex geometry and ener-
gy-harvesting potentials were chosen as the necessary spatial and functional features of the design. The experimental design process of the façade proceeded in four steps, presented below.

4.1. USING ANIMATION TO GENERATE THE COMPOSITIONAL FRAMEWORK FOR THE FAÇADE SILHOUETTE

This first design stage was executed using the animation software 3ds Max®. We generated a particle cloud containing 500 entities, emitted from a rectangular box. Within the particle system 3 vortex forces were placed to disrupt its arrangement. Animation was set to 11 frames, resulting in 11 different particle compositions. After a qualitative visual analysis of those compositions, frame no. 9 was chosen as the one in which the particle distribution promised to offer interesting further creative operations (Figure 1a).

4.2. USING FREE-FORM MODELING TO CREATE THE FAÇADE SILHOUETTE

At this stage, the particle framework from frame no. 9 was developed into a surface representation. For this task we employed the free-form NURBS modelling environment Rhinoceros®. Therein, we chose the profile curve-based lofting as a method of surface generation. The profile curves were manually constructed based on the locations of particle cloud points, imported from the animation environment. To keep the curve construction process ambiguous, we used only some of the points from our cloud to construct the curves. As a result, 8 profile curves were created (Figure 1a). We then lofted these to obtain a complex double-curved, characteristically-rippled NURBS surface. The surface was then sliced in the horizontal direction, which produced 5 elongated surface strips with varied widths (Figure 1b).

4.3. USING ASSOCIATIVE PARAMETRIC MODELING TO DESIGN THE FAÇADE DETAILING

The goal of this step was to augment the façade strips with decorative components. For this task, we used associative parametric modelling, enabled by Grasshopper™ in Rhinoceros®. We started by subdividing our surface strips into sub-segments, reflecting the compositional framework of laying out the decorative elements on the surface. The 3 narrower strips were subdivided vertically only, while the 2 wider ones in both directions (Figure 1c).

With those subdivisions in mind, we then created two types of decorative elements: a solid and flat one, with an edgy appearance and a fixed geometry definition; and an open one, protruded for energy-harvesting purposes, with an organic look and variable geometry.
Figure 1. Digital artefacts and their transformations in an emergent design process executed using the hybrid toolset.
The variability of the second component’s overall shape and taper was achieved by defining the top curves, employed to loft its surface, as movable in the x and y directions (Figure 1d).

4.4. USING PERFORMANCE-DRIVEN MODELLING FOR FINE-TUNING THE SHAPES OF THE FAÇADE COMPONENTS

Before applying the decorative elements onto our surfaces, we focused on finding the ultimate shape of our energy-harvesting, variable component. The goal was to find a taper which would allow the component surface to harvest as much solar energy as possible on an annual basis, assuming a southern orientation of the façade and its location in Gothenburg, Sweden. A good solution was difficult to predict intuitively, because the surfaces on which the components would be distributed had differentiated curvatures, oriented in various cardinal directions. Consequently, it was not obvious which component shape would perform in a good overall way when distributed over the surface strips.

To solve this non-trivial design problem, we decided to employ the computational tools in order to fine-tune our component’s form based on its energy performance results. We selected a relatively quickly-performing simulated annealing optimization algorithm in Grasshopper™, coupled with annual solar irradiation analyses using the DIVA software. Because of the conceptual character of our design, we simplified the optimization problem for faster optimization results. Namely, we analysed the outermost surfaces of 3 component clusters, each containing 4 elements, located in characteristic areas on our surfaces (convex, concave and close to flat), picked based on Gaussian curvature analysis (Figure 1e, characteristic areas encircled and numbered). The optimization algorithm altered the xy coordinates of the centroid of the top curves used to loft our basic element, hence influencing the components augmented onto the façade (Figure 1f). For each altered xy coordinate and shape, solar irradiation in kWh/m² was calculated as an average of the values summed up from the 3 component clusters. After finding the xy coordinates returning the highest average irradiation value $I$ (Figure 1f, the variant in a dashed frame, $x = -0.27, y = 0.15, I = 378$ kWh/m²), we used them as the final parameters defining the geometry of our variable energy-harvesting component. Lastly, we populated the entire surface with the two component types, reaching our final conceptual design outcome (Figure 1g).

5. Experiment analysis

Let us now analyse the design process using the hybrid toolset in light of the occurrences typical for the extended model of design emergence. In the first
design phase, involving the animation technique, the visual design activity began with a series of 11 perceptual events, caused by the particle images generated in the 11 animation frames. The following visual activity series embraced the assessments of how the relations between the particles were changing in time, how the shape of the particle cloud was altering and how the particles in force proximity were distributed.

After this 'seeing with the eye' sequence, the cognitive process of image prompting was activated. The digital images of 11 particle clouds were synthesized into one mental image. A moving bird flock was recalled from previous visual memory. This dynamic image made us perceive the particles as more than just a collection of discrete elements. What we now saw ‘with the mind’s eye’ was a volume formed by the particles, organically changing its shape as the time passes. This mental image pushed our thinking processes onto a higher level of cognition, embracing the interpretation of that synthesized particle image. By recalling our domain knowledge about free-form digital shape syntax and shape semantics, we discovered that each particle could be understood as a point in 3d space. Directly after this prompted interpretation, visual re-cognition took place. We now interpreted that the flock of points in 3d space could become a set of points demarcating the outline of a digital NURBS surface. In this way, we ultimately arrived at an image of a NURBS surface, representing our façade’s silhouette.

The above sequence of visual and cognitive acts, leading to the discovery of a surface hidden within the particle cloud, encouraged us to directly act upon the design artefact, and therefore also to switch from animation to a free-form modelling environment. Therein, using a network of NURBS curves, we created a surface, which became yet another design artefact, open for another round of visual and cognitive examinations. In that respect, the first act was again a low-level process of seeing. Looking at our new surface, we identified its basic features: borderlines, inner elements and overall shape characteristics. After this examination, we moved on from the visual image of our surface to its mental image. The cognition process, needed for this, was triggered by the system of isoparametric curves on the surface – a typical visual feature of NURBS objects in a digital 3d modelling environment. The surface fragments, visually demarcated by these curves, made us notice that within our global surface could be divided into an infinite number of sub-surfaces. Thus, in our imagination, we now saw the mental images of the potential surface strips and patches, embedded within our main surface outline.

The next step advanced these images further, into a phase of interpretation and visual re-cognition. To give architectural meaning to our mental images, we resorted to our domain knowledge. We related our artefact directly
to the facade typology, linking it to a design schema of horizontal façade divisions, in which the non-permeable strips of cladding intertwine with the light-transmitting strips of glazing. To apply that schema to our actual surface, we performed a series of surface-cutting operations, to produce the 5 horizontal façade patches of variable width.

At that point of the process, we proceeded to a detailed design level, embracing the augmentation of decorative cladding components onto our surfaces. Using associative parametric modelling, we began tampering with the number of subdivisions on our surface strips, generating various division compositions. The noticing of the potential to divide the 3 narrower strips of our surface in a single direction only triggered a process of cognitive thinking. We recalled from our domain knowledge the mental image of a similar composition: the alternating dark and light voussoirs of the arches typical for Moorish and Arabic architecture. This design prototype the emergence of our first element type appearance and distribution logic. We now decided to populate our narrow surface strips with edgy, voussoir-like components, placed one by one in single row.

At the same time, our parametric manipulations with the subdivisions on the wider surface strips led to their two-directional distributions. This generated a system of tiles on our digital surface, which triggered a biology-inspired mental image: a coral colony’s structure, consisting of self-similar polyps clustered together to build a complex form. This vision prompted us to give our second surface component a volumetric form and an organic look. An additional mental image of coral polyps flexing their shapes under the influence of underwater currents inspired us to make our component’s shape variable and adaptable based on its energy-harvesting performance.

As an ultimate result of this complex series of visual and cognitive acts, a complex design artefact emerged, concealing within its spatial features the hints of all the mental images and design schemas that inspired its creation.

6. Conclusions

The analysis of our experiment through the lens of the extended model of emergent design indicates that the hybrid toolset is able to trigger a number of unique visual and cognitive occurrences, followed by a series of transformative actions, leading towards the final design which reflects aesthetic complexity and utility. The use of the hybrid toolset causes the visual and cognitive cycles to be repeated every time the various design artefacts awaken visual and mental images which lead to new design ideas. The artefacts are placed in multiple contexts: of the designer’s imagination, general knowledge and domain knowledge. Design emergence occurs gradually, on
various levels of design abstraction, as the fuzzy design artefact is transformed into a more concrete solution. Each tool of the hybrid toolset requires a different workflow – a more intuitive or a more rationalized one – which triggers the visual and thinking processes each time in a different way, leading to multiple design scheme transformations causing design emergence. This suggests that our assumption about the robustness of the proposed toolset is true. Interestingly, the outcome design maintains in its geometrical features the traces of all the digital techniques that were used to create it.

The study also points at some other advantages of the hybrid toolset. Firstly, it shows how the toolset allows the design space to be expanded and contracted, depending on the needs of a particular design stage. The design process using the toolset can begin with an ill-defined design problem, which thanks to the visual and cognitive acts of emergence gradually becomes clearer and easier to solve. The toolset can also direct the designer on unplanned creation paths, triggered by the surprising mental images and unexpected design prototypes evoked from the designer’s memory and knowledge. Finally, the toolset exhibits the capacity to meet the basic creative need of designers, giving them the freedom to execute both very fuzzy and very precise design activities in one design process. This leads to the emergence of a promising and creative design outcome.

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References