FLOWUI: COMBINING DIRECTLY-INTERACTIVE DESIGN MODELING WITH DESIGN ANALYTICS

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Abstract. In a systems building experiment, we explored how directly manipulating non-parametric geometries can be used together with a real-time parametric performance analytics for informed design decision-making in the early phases of design. This combination gives rise to a design process where considerations that would traditionally take place in the late phases of design can become part of the early phases. The paper presents FlowUI, a prototype tool for performance-driven design that is developed in a collaboration with our industry partner as part of our design analytics research program. The tool works with and responds to changes in the design modeling environment, processes the design data and presents the results in design (data) analytics interfaces. We discuss the system's design intent and its overall architecture, followed by a set of suggestions on the comparative analysis of design solutions and design reports generation as integral parts of design exploration tasks.

Keywords. Non-Parametric Modeling; Performance-Driven Design; Design Analytics; Information Visualization.

1. Introduction

Designers use multiple computational tools throughout the life cycle of a design project. The tool selection and use are consistent with the task at hand and the level of design resolution at any given phase. An obvious challenge for designers is the limitation of tools for binding different design representations across them with varying levels of details. This challenge is emphasized when designers take advantage of divergent exploration of form by directly manipulating design geometries as if they are 'sculpting' in the early phases of design. They miss the advantage of using the capabilities of parametric modeling for computing performance data for informed exploration (Touloupaki and Theodosiou, 2017). On the other hand, designing using parametric modeling tools lacks the flexibility of using the sculpting features of directly interactive CAD tools. Analysis systems are used after the design is substantially developed and to validate the design

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performance and to maximize the efficiency of an already established geometry (Anton and T˘anase, 2016). In this paper, we present a system addressing this challenge as part of a larger research program focusing on how to bring design exploration with data analytics using interactive visualizations, in short, which we call this program *design analytics*.

In a system's building experiment with our industry partner, we developed a flexible prototype tool to simplify and develop a seamless workflow in moving between form-finding and performance analysis in design. The prototype system adapting this architecture, called FlowUI, receives pure geometric definitions of the design models that are under development; pulls desired performance data; computes select performance metrics; and presents the data through interactive visualizations for analysis and decision-making. This experiment also suggests system features for making a comparative analysis of design alternatives and their relative performances in this workflow. The FlowUI's interactive visualizations facilitate a comparison of alternatives considering calculated and target-performance metrics. Our initial observations and the feedback we received from our industry partner present encouraging evidence that applying the FlowUI's features in practice can improve design exploration.

Below, we first discuss the motivations of the study and development of FlowUI, its high-level requirements and the architecture. This is followed by the introduction of FlowUI's interfaces as an add-on for a directly-interactive geometric modeling tool, Rhinoceros 3D (McNeel, 1998) and interactive visualizations using Grasshopper's parametric capabilities for computing performance data from non-parametric models. We also present FlowUI's platform independent interfaces for data visualization, comparative analytics, and reporting. We conclude with our reflection on the potentials and limitations of the solutions we propose and future work.

2. Engaging Design Form-Sculpting with Data Analysis

2.1. PARAMETRIC VS DIRECT MODELING OF DESIGN CONCEPTS

The current parametric CAD tools have features to support the analysis of parametric designs‘ performance for informed decision making in the design development process (Danhaive and Mueller, 2015; Touloupaki and Theodosiou, 2017). However, taking advantage of these features requires a systematic parametric setup of a design model (Fu, 2018) that restricts the exploration of diverse alternatives from different designs. The designers working on concept development may not prefer parametric modeling to directly-modeling of geometric forms or lack the skills of using parametric tools (Zarei, 2012). In such cases, they use directly-interactive modeling tools like SketchUp or Rhino for sculpting forms, e.g. for mass-modeling or form exploration without committing to one parametric model. Directly-modified design models as geometric forms are preferred for their agility and low-effort for initial design setup (Hanna, 2012; Megahed, 2015). However, the analysis of non-parametric design models developed using directly-interactive modeling tools is highly limited (Weytjens et al., 2012; Soebarto et al., 2015): designers are required to take additional data-processing steps that may hinder design exploration flow by reducing the chance of getting immediate performance feedback (Soebarto et al., 2015). Another disadvantage is that the models are built using purely geometric elements and the design performance details are only left to the designers' interpretation without further computational processing (Zapata-Lancaster and Tweed, 2016).

The literature covers form exploration using computational methods extensively. The notable different methods include Harding and Shepherd's (2016) Meta-Parametric Design that combines parametric modeling with genetic programming to widen design exploration with graph representation. In an earlier work, Bentley and Kumar (1999) explored the use of growth processes within evolutionary systems. For using non-manifold geometries for form and performance exploration, Jabi et al. (2018) propose hierarchical and topological representations of architectural spaces as part of parametric data flow models.

2.2. PERFORMANCE-DRIVEN DESIGN

Performance-driven design is gaining momentum mostly in the context of sustainability because it provides a shift from focusing only on form to emphasizing the balance between the traditional concerns of architectural design and building performances (Shi, 2010). This requires an agile analysis of performance metrics. However, the frequently used simulation programs such as EnergyPlus (Crawley et al., 2001) and Ecotect (Roberts and Marsh, 2001) require design models to be restructured for their computational format. Once a model is set up, the simulation program is called upon to analyze one or several select performance metrics. The simulation results are then analyzed. The designers modify the design based on the result of the analysis to improve their design. The process, in essence, is discrete and several modifications needed to achieve the desired outcome. However, the iteration is often not conducted fully in practice for many reasons among which it requires a sudden stop in design and computing design performances followed by form revision (Shi, 2010). Furthermore, these iterations are more appropriate in the late phases of design when most design decisions are already committed, which limits the divergent search.

2.3. TOOLS FOR PERFORMANCE-DRIVEN DESIGN

There are two categories of computational tools proposed to address the challenges above. In the first category, the tools work as an add-on on an existing design platform. These tools in general link a parametric definition to one or multiple performance computing modules, e.g. Ladybug for Grasshopper (Sadeghipour Roudsari and Pak, 2013) for environmental analysis. The design data may not be directly accessible through these tools and may require using external tools or set up to reveal the data. The second category provides interfaces that bring one or multiple add-ons together to allow designers to access the computed performance data from parametric models. *Reach* is an example of this category of tools (Wang and Steenblik, 2019). Both categories have a set of common restrictions: (a) they mainly require a well-defined model, which may not be preferred due to the cost of initial setup; (b) the add-ons used assume a complete set of inputs to be decided for computing design performances, which may not be available in the earlier exploration phases. Hence, the iterative cycle of formation, performance computing, and analysis is rather prematurely executed. A change in the design, then, may require substantial revisions in the setup, which can limit the search to a few well-structured parametric models rather than an abundance of solutions. In addition, these tools fall short for directly working with design data available through other sources, e.g. program requirements in a spreadsheet. In addition, we believe that the most important bottleneck of these tools is that they continue to support single-state models that at any given time, only one design becomes the locus of attention of the designers. This hinders the comparative analysis of design alternatives explored along with their performance data hinting each alternative's potentials or drawbacks. Focusing on multiple alternatives together with their associated data helps designers to evaluate options as they are created.

3. FlowUI: Engaging Design with Data

The discussed challenges and bottlenecks of geometric or parametric modeling tools can be among the most salient ones faced by designers. We propose that we can overcome these challenges by tools that seamlessly support design decision-making in the early phases of design exploration and without creating an additional task layer. Our goal is to create a system solution to simplify the creation and evaluation of alternative design forms by learning from only relevant data to the task at hand. Below, we present the higher-level requirements, the conceptual architecture, and interfaces for this system, which we call FlowUI. The system attempts to provide a flexible and simple interaction combining directly-editable geometric models, visualization of design performances, association with external data, and dashboards for comparative analysis and reporting.

3.1. DESIGN CRITERIA

The design criteria of FlowUI were developed over time with our partner from the AEC industry during a research collaboration. The criteria emerged through an iterative process where the requirements, system architecture, and interfaces evolved based on the feedback received from professional designers. Below are some of the high-level criteria highlighting the basic system features of FlowUI.

Allow form-first exploration: In practice, not all design cases prefer parametric modeling, but definitely almost all need to reveal at least some aspects of design information that are not obvious on the geometry. Sculpting design forms by moving between sketches and geometric modelers directly is a powerful combination for design ideation. This should be supported by continuously maintaining performance analysis. The goal is to enable accessing design data as early as possible without building a well-structured model. This is design-first interaction rather than emphasizing data and parameter.

Incorporate program as input: Designers should be able to associate their emerging design criteria with the design being explored and use the performance data computed for evaluating the form and the program. The program may include definition of the function types, the assignment of functions to building blocks, the definition of custom properties such as labels, floor heights, unit cost, etc.

The system should be able to visualize target values e.g. for budget constraints or usable areas. These values are externally defined and expressed as tentative targets that can change over the course of the design: if one source changes, the tool should propagate the change to maintain consistency between computed and target values without disturbing the design flow.

Enable context definitions: The context details can include site data, existing structures, desired view targets, location, environmental data, etc. The tool should allow designers to use this, possibly as non-parametric, information only when relevant and incorporate in computing performance values.

Manage multiple design ideas: This can be in the shape of: an effortless switching between design alternatives, recording and recreating different iterations on a design option, supporting a multi-state comparison and manipulation of design alternatives. The tool should coexist or refine the ability to explore alternatives in relation to their performance data. Any tool working with alternatives should also support the creation of a report on individual or compared alternatives for sharing with other stakeholders.

Accommodate diverse design-analysis scenarios: This can take the form of a flexible interface layout, the ability to constrain the performance calculations, and providing means for analyzing multiple aspects of an alternative at the same time. The tool should be configurable to enable different aspects of design as desired.

3.2. SYSTEM ARCHITECTURE AND DESIGN WORKFLOW

The system architecture of FlowUI is built on three functional modules: Design Modeling, Data Extraction, and Design Performance Analytics (Figure 1). The architecture specifies a structure for organizing the interfaces and their use considering the high-level requirements discussed above. The design exploration task workflow starts with creating design models as non-parametric geometries using the directly-interactive CAD tool. The Design Modeling module is a custom setup that enables defining the context, establishes custom attributes, and creates a layer structure where alternative solutions are stored and retrieved. Designers can associate a geometry by a program criterion, e.g. type of building function, in the Design Modeling module. Independent from the parametric modeling, designers can explore forms using manifold geometries in any technique, e.g. for changing geometry by pushing-pulling or using solid modeling operations.

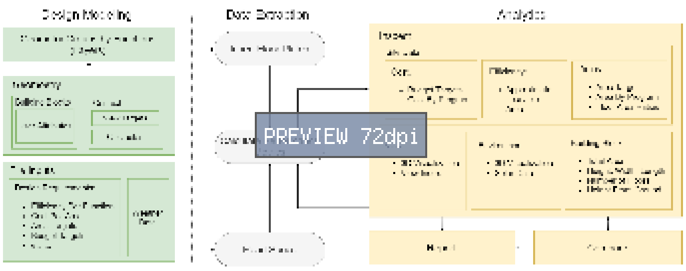

Figure 1. The architecture of FlowUI: non-parametric design modelling coupled with parametric data computing and supported by interactive data visualization dashboard.

The modeling setup directly links geometries to the Data Extraction module which recognizes the functions and program requirements associated with the geometries. This module has a parametric definition that can be extended to compute additional aspects of design when needed. The DE module is also linked to external data sources to retrieve design program data.

On the interfaces in the Design Analytics module, designers can select the relevant data for the task at hand to be computed and visually displayed. They include construction cost estimates, efficiency in area use, view quality, environmental metrics, etc. These visualizations are presented in a configurable dashboard layout (Figure 2) and assist designers to investigate each alternative as they are changed in the Design Modeling setup in Rhino. As part of the FlowUI ecosystem, we also developed two additional interfaces as design analytics of alternatives and reporting. These interfaces are used for further comparison and reporting of design alternatives in a Web browser outside of the FlowUI setup but are directly linked with the FlowUI Data Analytics module. These interfaces are further discussed below.

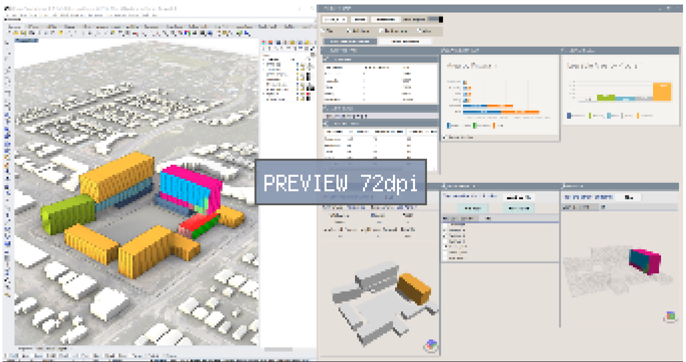

Figure 2. FlowUI interface: Directly sculpted massing model in Rhino analyzed and corresponding data is selectively presented in FlowUI's dashboard in real-time or on-demand.

3.3. FLOWUI TOOL FEATURES, INTERFACES, AND INTERACTION

FlowUI is a tool of performance-driven design aimed at mixed-use massing problems that have interrelated objectives and constraints channeled through form-finding. FlowUI provides immediate feedback about the performance of alternatives and enables comparison to design goals. The main components of the FlowUI interface are composed in the Data Analytics (DA) dashboard. They visualize the results of the performance calculation through textual and visual formats. The FlowUI DA dashboard can be arranged to be a vertical slice that occupies a small portion of the screen, or a horizontal mode that expands as needed in a multi-screen setting. The horizontal mode makes it possible to track all the performance visualizations simultaneously. The visualizations are organized in layers and change in response to changes in the modeling environment. Switching between design alternatives is performed on the dashboard that activates the selected alternative in the Design Modeling.

The visualizations in the DA dashboard are three types: simple bar charts dedicated for showing the floor area and cost of each building function; 3D views visualizing different aspects of the design forms such as the view quality; the solar energy across the year, etc. The 3D views are built upon the user interaction with the geometry to enable a granular level of details. The tables show the design targets such as the sought floor areas and the budget limits, building dimensions, and floor areas. The DA dashboard responds automatically to changes in the modeled geometry, but it requires an on-demand update for the changes in the modeling module layer structure. This limits the frequency of updates in response to events that are less relevant for the task.

3.4. COMPARATIVE ANALYTICS AND REPORTING

However, a comparison can be the basis for the cross-pollination of design ideas. Comparisons can reveal the impact of the design form choices on the performance metrics. To enable comparative analysis, we retain the act of design exploration and use the FlowUI as a mediator through which satisfactory alternatives can be sent to an external environment to compare them against other alternatives or shared with other stakeholders. We studied a number of existing design explorer solutions proposed in the literature. These include interactive visualization dashboards for comparative analysis of design alternatives (Woodbury et al., 2017; Matejka et al., 2018; Tomasetti, 2019). While FlowUI output can be exported to be used with these systems, in FlowUI models are directly linked with data visualizations (Figure 2).

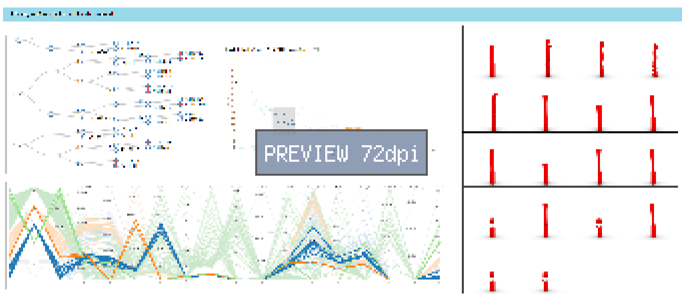

Figure 3. The interface design for the design analytics dashboard enabling comparison of alternatives based on the design and performance data.

Our ongoing development of a design analytics explorer interface (Figure 3) we combine visualizations showing design similarity along with their geometric forms and performance data. Although the main goal of the interface is to enable simplifying and exploring design spaces, selected solutions can be pushed back to FlowUI (Abuzuraiq and Erhan, 2020). On the FlowUI DA, the local version of the chosen alternative can be reactivated on-demand, and all the views on the DA are updated. Hence, the designer can study the chosen alternative in more details. This idea of ‘restoring’ an alternative from an external design analytics context is borrowed from Woodbury et al. (2017). We extended their approach to non-parametric modeling of design alternatives.

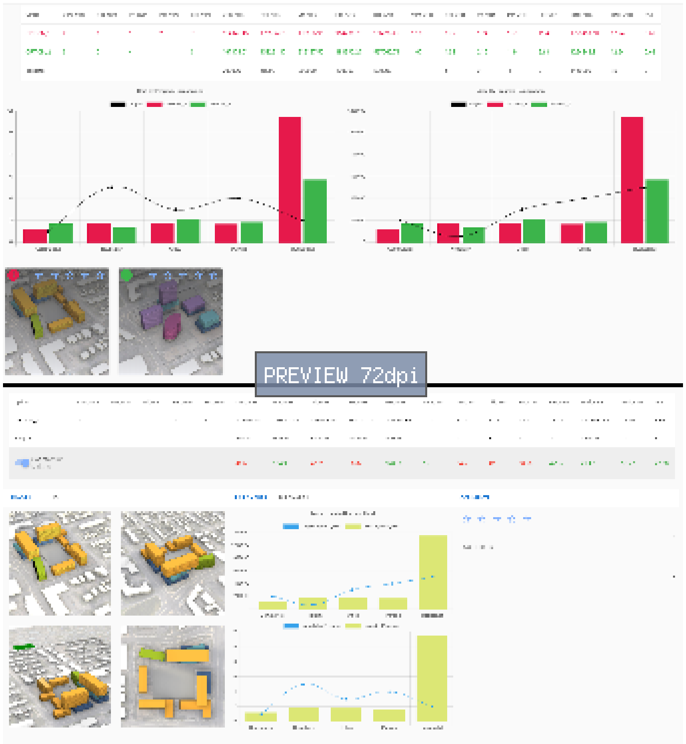

Figure 4. FlowUI Alternatives Reporting Tool. (Up) Two alternatives are compared side-by-side with their corresponding performance data visualized on a data table and bar graphs (Down) One alternative with views and corresponding data shown.

The FlowUI Alternatives Reporting Tool (ART) supports generating interactive reports that can be used to present and further study the selected alternatives. It relies on the data-sharing model of the FlowUI for retrieving select design alternatives for reporting that are updated on-demand. An important role of the ART is to help designers reflect in and share about their search process with other stakeholders. While the DA dashboard focuses on analytics, the ART focuses on reflection and presentation. It consists of three main visualizations. The first is an overview that displays alternatives in a juxtaposed layout for an overall evaluation. Its grid size and density can be adjusted by the designer to show alternatives in different multiples. The ART provides ranking and commenting functions for each alternative. The comparison visualization, the second view, shows multiple snapshot views or a 3D model of the design along with data graphs for a detailed evaluation of a set of selected alternatives (Figure 4 (Up)). The third view displays one alternative in detail with its form and performance data. The views are dynamically linked and support *highlighting* and *brushing* interactions across the views. In this view, the stakeholders can comment and rank the solutions (Figure 4 (Down)). The stakeholders can decide what aspects of performance metrics are to be compared in this view and can generate printable reports.

4. Reflection and Conclusion

The use of parametric modeling tools in the early phases of design is different than the later phases: the prior may use parametric definitions for form exploration and the latter for detailing structural elements for fabrication. Parametric models are labor-intensive to build and are rarely fully reusable, more so for complex and large projects. However, they also present computational capabilities that can reveal salient design aspects quickly. The directly-interactive CAD modelers provide agility for sculpting design geometries in the early phases of design and make a divergent, almost sketch-like, exploration possible. To take advantage of the benefits of both approaches, we proposed a systems approach supporting direct-modeling of geometries, performance computation by feeding design geometries to a parametric definition, and interactive visualization of design alternatives with their form and data. This aims to let designers work in a way that is familiar to them while leveraging real-time data analysis and reporting. The first functional iteration of the FlowUI shows the potentials for design exploration. However, it falls short for being practical to be used in a professional setting. Aside from its reliability, the system's fragmented modules should be better integrated in the workflow. We also think that there are opportunities for improving the overall workflow before we conduct a proper user testing. We plan to demonstrate the use of the prototype in a realistic design scenario borrowed from the industry. We think that our work on design analytics interfaces may make a positive change in the computational design task environments as the research matures and the prototypes become usable in time. For future work, we will conduct a series of case studies to test the FlowUI and ART's integration into the design workflow.

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