DESIGN ANALYTICS AND DATA-DRIVEN COLLABORATION IN EVALUATING ALTERNATIVES

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Abstract. Evaluation of design ideas is an important task throughout the life cycle of design development in the AEC industry. It involves multiple stakeholders with diverse backgrounds and interests. However, there is limited computational support which through this collaboration is facilitated, in particular for projects that are complex. Current systems are either highly specialized for designers or configured for a particular purpose or design workflow overlooking other stakeholders' needs. We present our approach to motivating participatory and collaborative design decision-making on alternative solutions as early as possible in the design process. The main principle motivating our approach is giving the stakeholders the control over customizing the data presentation interfaces. We introduce our prototype system D-ART as a collection of customizable web interfaces supporting design data form and performance presentation, feedback input, design solutions comparisons, and feedback compiling and presentation. Finally, we started the evaluation of these interfaces through an expert evaluation process which generally reported positive results. Although the results are not conclusive, they hint towards the need for presenting and compiling feedback back to the designers which will be the main point of our future work.

Keywords. Design Analytics; Collaboration; Visualizations.

1. Introduction

In design, collaborating with the design stakeholders in evaluating design ideas has been an important challenge, especially when the design involves multiple stakeholders with diverse backgrounds and interests. Some of these stakeholders may directly participate in design while others provide valuable input as clients, local authorities, investors, public, etc. (Lu and Sexton, 2006; Serror et al., 2008; Daher et al., 2018). The complexity of design projects compounded with stakeholders' diversity can create serious bottlenecks in the design-evaluate-feedback cycle and design decision-making workflow (Klein et al., 2003; Sanders and Stappers, 2008; Bilal et al., 2016). These bottlenecks

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include the ambiguity of design information, lack of completeness of details or terms, unavailability or unfit of means for information sharing, sequential discourse, etc. This paper proposes a ’design analytics‘ approach relying on data-driven collaboration interfaces to enable effective design-information exchange and feedback sharing and gathering. We aim to alleviate some of these bottlenecks’ effects to improve collaboration between the design stakeholders and design-decision makers.

Our research has three main objectives: (a) to enable participatory and collaborative design decision-making on alternative solutions as early as possible in the design process, (b) to identify the basic features of a platform of discourse on design alternatives by collaborating with industry partners, and (c) to explore and develop interactive online interfaces for sharing alternative design form and data and completing the feedback cycle as an integral part of design workflows. There are various examples of systems or interfaces for supporting the design stakeholders’ involvement in design, in scenarios such as design review meetings (Fernando et al., 2013), online design modelling (Konieva et al., 2019), urban planning (Holzer and Downing, 2010), etc. Most of the existing systems are either highly specialized for designers or configured for a particular purpose or design workflow overlooking other stakeholders’ needs. The main gap stays unaddressed: how to facilitate sharing design information and receiving feedback into the design decision-making considering the stakeholders’ diversity and reducing the complexity of the design data.

We aim to improve collaboration between the designers, design stakeholders, and other parties by decreasing the overhead caused by discrete representations and labour intensive synchronous in-person meetings. We present our attempt to achieve this goal through an online platform we developed, called D-ART, as a simplified, data-driven, and flexible ’design idea and feedback’ sharing platform. A formative evaluation of D-ART with various experts in the architectural design industry has shown that our proposed approach is promising. However, the evaluations revealed a few key interaction design challenges. Notably, the stakeholders are required to reduce the complexity of the design information interactively at a level important for different purposes. This adds an extra task layer for the stakeholders. In addition, the stakeholders’ feedback on both form and performance data must invoke discussions around the ideas presented, yet fragmented interfaces or tools may hinder such discussions, including reporting the comments and suggestions back to the design teams.

2. Background

Participatory design aims for the empowerment of stakeholders and their continuous feedback to the design process (Klein et al., 2003; Robertson and Simonsen, 2012; Daher et al., 2018). In general, the stakeholders’ involvement is facilitated through project review meetings synchronously or reporting asynchronously (Gautier et al., 2008). The prior can be resource-intensive as they require the availability of most stakeholders at a certain time and place (Healey, 1998; Kingston, 2007). Besides, the evaluation of multiple design alternatives can be seriously hindered by the resource limitations (Nuojua and

Kuutti, 2008). For asynchronous participation, the stakeholders are presented with reports and their feedback is compiled and incorporated in decision-making. While each has its benefits, asynchronous and online collaboration groups can result in broader discussions and produce more comprehensive reports (Benbunan-Fich et al., 2003).

Both synchronous and asynchronous modes demand a system-support for exploration and collaboration (Shneiderman, 2007). Recent developments in interactive computing and visualizations such as interactive 3D views and online collaboration platforms create new opportunities for stakeholders' involvement in design, even starting from the early phases (Hanzl, 2007; Brown et al., 2016; Erhan et al., 2020). We suggest that bringing the advancements in data analytics (Thomas and Cook. 2006), collaboration technologies (Farshchian, 2019), and early decision-making to design stakeholders through interactive visualizations can enhance stakeholders involvement to develop a ”a stronger sense of commitment”, higher rate satisfaction, and realistic expectations as discussed by Al-Kodmany (1999).

A study conducted by Yeomans et al. (2006) on how AEC experts reflect on collaboration identifies a set of principles necessary for a successful collaboration. These principles include the involvement of all stakeholders as early as possible in the design decision-making, development of common processes and tools, and the use of performance measurements for informed decision-making. Based on these principles, the systems aiming to support collaboration in the AEC projects must consider a data-driven approach, applicability in various design workflows and involvement of the design stakeholders with different interests in every phase of design. In particular, the last expectation poses the most difficult challenge. That is, the interfaces should be able to adapt to the stakeholder interests without demanding to operate on system-level settings and promote visualization of design form and data information at different abstraction levels.

3. Methodology

In this research, we adapted the design study approach as a problem-driven research method. It involves “analysis of a specific real-world problem faced by domain experts, designing a visualization system that supports solving this problem, validating the design, and reflecting about lessons learned in order to refine visualization design guidelines.” (Sedlmair et al., 2012). In light of a comprehensive literature review, analysis of multiple collaboration systems, and directly collaborating with our industry partners, we identified five high-level system requirements for D-ART. These requirements are used as guiding principles in developing interface features and used in the formative evaluation of D-ART's first version.

- RQ1. Present each design alternative with customizable visualization of form and performance data along with the structured stakeholders' feedback.
- RQ2. Enable feedback as comments and questions on design form and performance data and responding to the other feedback.
- RQ3. Allow visual comparison of form, performance, and feedback on design

alternatives.
- RQ4. Accessible online, independent from the design environments, workflows, and systems.
- RQ5. Provide adaptable interfaces to accommodate a variety of stakeholders with different interests and backgrounds.

For building D-ART, we used an agile software development (Beck et al., 2001) process of continuous design-development-feedback cycles. D-ART is built as a Web application using the MEVN stack (MongoDB, Express, Vue, and Node.js) (Hautaviita, 2018). It is integrated with a design analysis setup (Figure 1) based on Rhino, Grasshopper (McNeel, 1998, 2020), and FlowUI (Erhan et al., 2020).

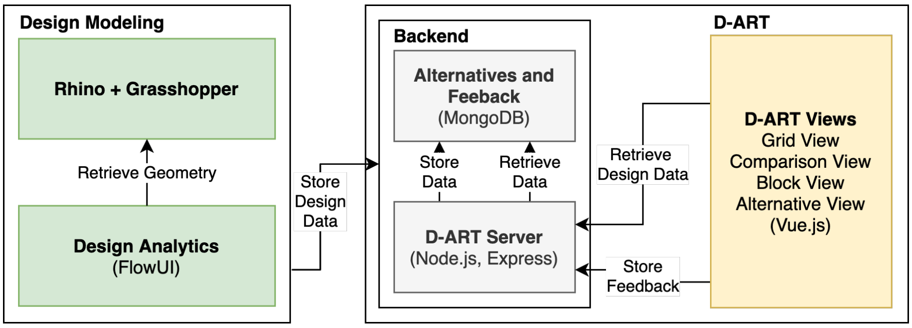

Figure 1. System Overview: System architecture for D-ART setup.

4. D-ART: System Design

D-ART's system has been developed using classical client-server web application architecture to accommodate communication between the design data repository and the D-ART's front-end interfaces presenting data on browsers and collecting feedback from the stakeholders.

4.1. HIGH-LEVEL TASKS AND WORKFLOW

D-ART supports three high-level tasks: design data visualization and discussion, maintaining persistent design data models, and receiving design data from CAD modelling tools (Figure 1). The D-ART interfaces facilitate the presentation of design form and performance information to design stakeholders and interactively reflect on the alternatives through commenting and discussions. D-ART's back-end component supports client-server communication and providing a dynamic and persistent repository of design data related to the curated design alternatives. The modelling environments connect with D-ART using a special plug-in responsible for enabling submission and update of design alternatives.

4.2. DESIGN DATA AND D-ART COMPONENTS

D-ART receives three different design data types: 1) design form, 2) performance metrics as categorical or numerical data, and 3) design targets. The form is the geometrical representation of design data and can take multiple formats such as images or 3D interactive models. Performance data relates to how an alternative performs on a metric interest to the stakeholders such as its cost, area, power consumption, etc. It can also be categorical such as program or function designation, e.g. residential, commercial, retail, etc. Targets are the anticipated values for the performance metrics to be achieved and set at the beginning of the design. The target values can change in the process as designers' and stakeholders' iterate on the solutions. Project targets and their units can be defined in the project creation interface. D-ART can receive an arbitrary number or type of performance metric data to accommodate the unique need of different projects (RQ4). This gives the flexibility of reusing the tool with multiple collaboration problems or scenarios. In the D-ART repository, the stakeholders' comments, questions and suggestions are associated with the design data and persistently stored for retrieval and report generation.

4.3. D-ART INTERFACE COMPOSITION

D-ART interface consists of four main views corresponding to the tasks associated with these views: Grid View, Alternative View, Building (Blocks) Components View, and Comparison View. A video demo of the interface can be found here: youtu.be/uuCCICYdP3E. The **Grid View** presents an overview of all curated alternatives in juxtaposed images augmented with controls to access the other views (RQ1) (Figure 2). Below each thumbnail image of an alternative, there is an expandable panel tabulating a summary of performance values. This view supports three tasks. First, the stakeholders can change the alternative thumbnail's size to show more or less of the form details. The second task focuses on a rapid comparison of alternatives through side-by-side tabulated performance data (RQ3). Finally, the Grid View is used as an entry point to access the Alternative Overview interface or Building Components Overview to examine each alternative in depth.

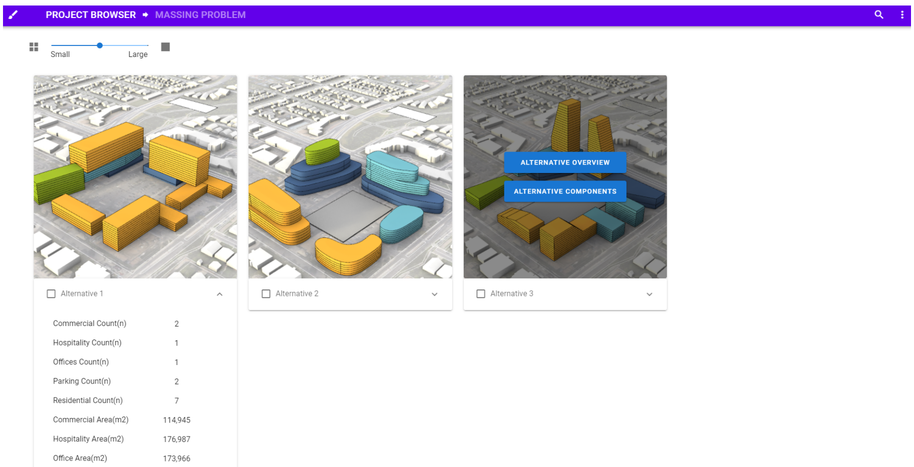

Figure 2. Grid View: An overview of curated design alternatives.

Alternative View supports inspection of a specific design alternative (RQ1) through four main interfaces focusing on design data, form, charts, and stakeholders' feedback (Figure 3). The data view is a tabular visualization of the select performance metrics, their target values, and their target satisfaction (percentage or real value) (RQ5). The form views include a 2x2 grid as a placeholder for displaying images of the design. The designers choose the images at the time of curating the alternatives. The stakeholders can zoom in on any of the images in a larger view. In the 3D model view, the stakeholders can interact with a 3D model of the design to inspect the 3D form in its context by zooming, panning, and rotating. In the charts view, the stakeholders create basic data visualizations like bar or line charts to understand better the relation between different performance metrics (RQ5). The interface for providing feedback is a dominant feature in D-ART to motivate discussion among the stakeholders (Willett et al., 2011). In the feedback interface, the design stakeholders can express their opinions, ask questions, or request changes to the present alternative (RQ2). This categorization aims to distinguish the stakeholders' concerns in the discourse and facilitate rich report generation. The stakeholders can review others' feedback and respond to them as in 'online discussion systems' in threads. A resolve feature is added to inform the stakeholders that the feedback is to be handled in the next iteration or an agreement is reached between the stakeholders.

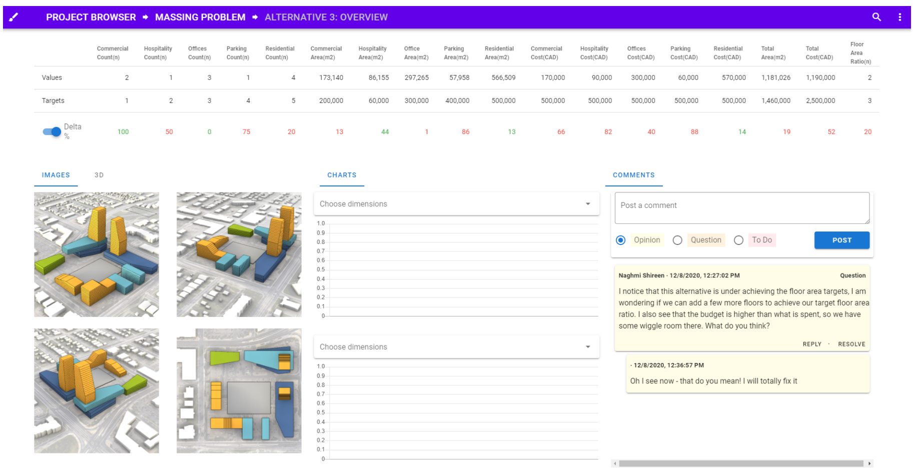

Figure 3. Alternative View: Inspection of alternative performance, form, and feedback.

Building Components View support inspecting the distinct components of an alternative in detail. A "component" in a design model can be any cluster of manifold geometry designated with a particular architectural function (e.g. residential, commercial, hotel rooms, etc.) as in a massing problem. This view is composed of a 3D Model View, Tabular data view, and Feedback interface (Figure 4). The tabular view lists each building component's performance. Selecting a row brushes and highlights the corresponding block on the model view or vice versa. The feedback interface works similarly in all D-ART interfaces. However, here it focuses on individual components (RQ2).

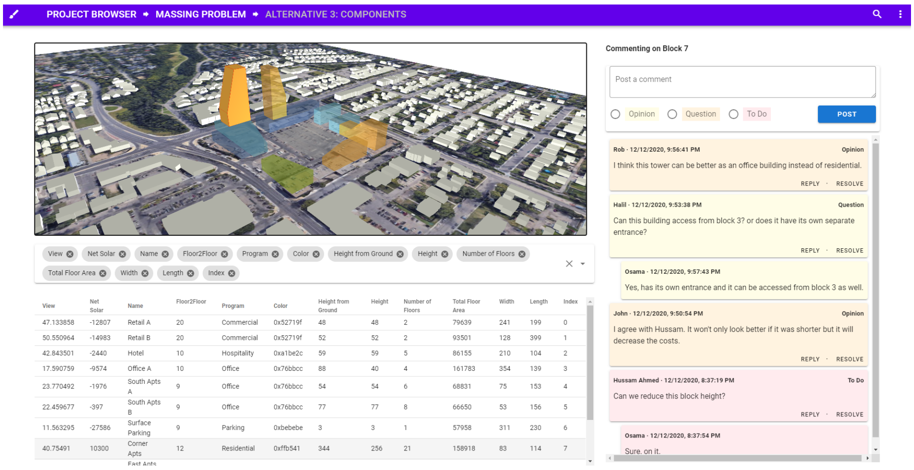

Figure 4. Building Components View: A block by block analysis of performance.

Compare View enables the stakeholders to compare multiple alternatives with each other (Figure 5). Presented in the Grid View, two or more alternatives can be selected, enabling a compare option in the menu. The stakeholders can visually compare form, performance data, and review feedback given to each alternative by other stakeholders (RQ3). The performance metrics can be compared using the tabular view on the upper section of the interface. The stakeholders can create custom charts by selecting the performance values they are interested in. Side-by-side visualization of 3D models enables rotating views using synchronized camera angles.

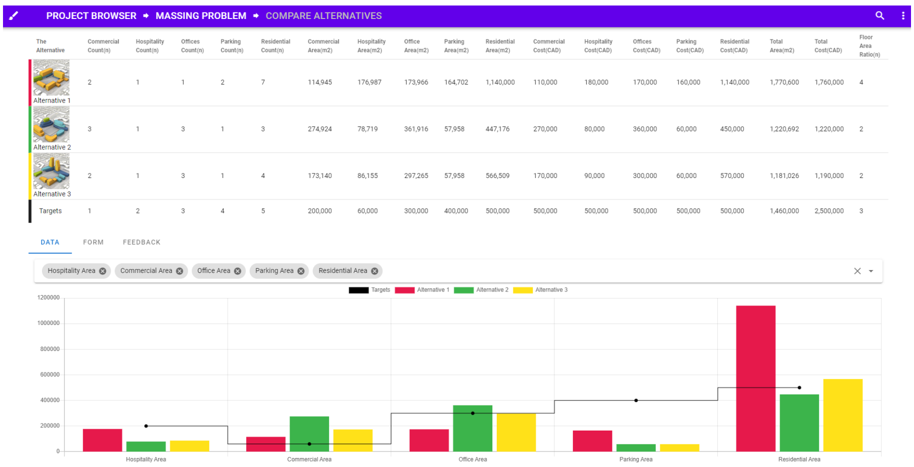

Figure 5. Compare View: Comparison of performance, form, and feedback on alternatives.

5. Evaluation

We developed an expert review analysis as a formative method to evaluate D-ART's current implementation to learn how it supports the proposed tasks. This method is generally used to discover the potentials and issues on the system in the early system development phases (Terry and Mynatt, 2002; Lam et al.,2012). The method involves inviting both domain and interface design experts to review D-ART under a predefined set of scenarios. The experts are asked to make comments on the system while performing the design review tasks from a design stakeholder's perspective, as described in the requirements section. A follow-up interview with the experts further probes the experts' opinion on the approaches we propose and the effectiveness of interfaces. We conducted a pilot study with one expert to assess our method design. In addition to the method's findings, the expert's comments hinted at what possible potentials or drawbacks D-ART may have when other experts complete the evaluation. Due to the time and COVID-19 restrictions, we could not complete the evaluation sessions at the time of writing this paper.

The pilot study showed that each expert would need about an hour to complete the given scenario. The feedback on tasks can be divided into four sections: design form and performance data presentation, exchanging comments and discourse on design alternatives, comparing a set of solutions, and feedback presentation. The initial findings on the interface were generally positive. The expert found the diversity of form-data visualizations helpful for accommodating multiple stakeholders' interests (RQ5). The consistent use of 'feedback features' was received positively for encouraging conversations on designs. However, the feedback functions should expand to include form and data visualizations, e.g. by marking or annotating design form or data in the context for a richer discussion. The comparison features could be enriched by adding a component-level comparison (within an alternative and across alternatives). However, this may increase the complexity of the interactions and traceability of the discussion. The expert suggested several system features for presenting feedback to the design team. For example, visualizing interaction logs can reveal how many times or by whom an alternative was explored, the most active stakeholder in giving feedback, sending notifications to indicate if any new activity occurred, etc. Finally, D-ART was found to be useful in other domains such as product design or engaging the public in projects involving both form and performance data.

6. Conclusion and Future Work

This paper questioned if and how design stakeholders' engagement with the design form and performance data can be supported through collaborative and data-centred design review tools. D-ART is a prototype web application developed in an incremental and iterative process with our AEC industry partners to seek answers to this question. In the pilot study of the formative evaluation of D-ART, we identified both limitations and strengths of our approach to online collaborative design review tasks and the interfaces supporting them. Although our findings are not conclusive, they are important to note here. D-ART needs to emphasize ’compiling and reporting results’ back to designers. In the next steps, we will complete the evaluation with four additional domain experts. We will also conduct a formal user study of D-ART with potential users using real-life scenarios after its refinement using the feedback to be received from the completed expert study.

In this phase, we believe that we made several contributions by raising questions about developing data-focused collaboration between designers and design stakeholders and seeking answers to them. For example, we contend that the primary obstacle in supporting collaborative decision-making on a given set of design alternatives is determining the level of details in design data to be shared with the stakeholders. This can be partially addressed by giving the stakeholders the option to add or remove details from the default visualizations. The second is more pragmatic: the design of systems that support information sharing from modelling, design presentation, feedback, and feedback compilation and presentation requires devising a highly complex computational platform while reducing the cognitive overload caused by the new tasks. Generic approaches are not effective for design information sharing. The nature of design particularly is a factor for this: each artifact is unique. Therefore, the associated data is expected to be unique. We have yet to see how the design stakeholders in real life will respond to the online interfaces in D-ART that somewhat removes the in-person contact with the designers.

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