ANNOTATION ON INTERACTIVE DESIGN DATA IN DESIGN ANALYTICS TOOLS

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Abstract. Evaluating and deciding on design alternatives is a collaborative activity involving design teams and other design stakeholders in the Architecture Engineering and Construction (AEC) industry. Current tools for design offer limited support for data-informed collaborative decision-making and fall short of encouraging discussions. In a user study with eight domain experts, we investigated how a meaningful data-informed collaboration can be enabled in design through interactive visualizations of design alternatives. We argue that receiving feedback from the design stakeholders as annotations directly on data representations can improve design decision-making. The initial results from our study reveal extensive needs for multi-target coordinated annotations, sorting, and organizing annotations, and agility in creating and accessing annotations. We propose a set of high-level interactions and requirements for coordinated annotation for engaging in collaborative decision-making.

Keywords. Collaborative Decision-making, Visual analytics, Design Analytics, Annotation, Collaboration Systems

1. Introduction

Collaborative decision-making, as in many disciplines, is a core activity in the Architecture, Engineering and Construction (AEC) industry that involves multiple stakeholders with diverse backgrounds and interests (Jeng and Eastman, 1998; Klein et al., 2003). The stakeholders in a design project share their feedback with multidisciplinary design teams (e.g., architects, engineers, and construction managers) to reach a consensus regarding the design alternatives to be considered.

Computer-Aided Design (CAD) models are improvised for presenting design form and comparing and discussing the potential of different design alternatives. However, given their complexity they are not accessible to stakeholders, and lacking interactive features for presenting performance data makes them less effective for data-informed collaboration and feedback sharing. On the other hand, Visual Analytics tools (e.g., PowerBI and Tableau) are effective at representing and sharing design performance data, but they do not usually enable presenting design forms or coupling form and data. Therefore, we need a system that supports collaboration while allowing exploring

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design alternatives with their form and performance data. We investigated how we can encourage the feedback sharing in data-informed collaborative processes that support making sense of design form and performance data and incorporate annotations in this process (McMahon and Davies, 2006; Groth and Streefkerk, 2006). An annotation is a short text, graphical notation or symbols placed on any existing representation to briefly express an observation or an idea related to a content (Munzner, 2014). In design, annotations are created directly on design representations (e.g., sketches, technical drawings, CAD models, specifications, etc.) to capture ideas or recommendations briefly and in context. Some design presentation systems provide commenting features (e.g., OnShape, 2022), however, annotations extend beyond commenting, as often found in collaborative analysis systems in various data-focused practices (Isenberg et al., 2011).

As part of our Design Analytics research, we explored how annotations as feedback mechanisms can be an integral part of the next-generation design systems. Design Analytics refers to the analytical process of using both form and performance data of design alternatives for gaining insight and making design decisions (Erhan et al., 2020). In this paper, we propose that for meaningful collaboration, a Design Analytics interface should support sharing feedback through annotation-style interactions and facilitate compiling and presenting feedback shared in a collaborative setting. Therefore, as a first step, we seek to answer the following research questions: (a) How designers and design stakeholders in AEC projects collaborate on design data in real-world practice? (b) How annotations can be part of Design Analytics to encourage feedback-sharing for collaborative decision-making? and (c) what are the possible realizations of annotation-driven interaction methods on Design Analytics interfaces? We present a user study we conducted with eight experts that aims to reveal potential answers to these research questions with the hope that the answers can guide the development of novel collaborative Design Analytics systems.

2. Annotation in Visual and Design Analytics

Externalization refers to capturing, expressing, or processing a thought through an external media, e.g., diagrams, notes, or marks, instead of thinking internally alone. Externalization supports the process of exploratory data analysis (Keim et al., 2008). Analysts use externalization in the form of notetaking or annotation and later refer to them for collaboration, generating ideas or reviewing hypotheses (Chin et al., 2009; Kang et al., 2009). Groth and Streefkerk (2006) demonstrated that annotation could help the knowledge discovery process in data analysis and improve problem-solving in visualization environments by recalling and sharing provenance information. Literature in visual analytics shows three major roles for annotation in the design and visual analysis process: annotation for collaboration (Heer and Agrawala, 2007), annotation for sensemaking (Pirolli and Card, 2005; Ren et al., 2017), and annotation in storytelling (Kosara and Mackinlay, 2013; Ren et al.,2017). Relevant studies revealed the benefit of annotating visualizations in the context of information retrieval (Viegas et al., 2007). Heer and Agrawala (2007) define annotation as critical for conducting practical collaborative visual analysis and exploration. Annotation can initiate a discussion between collaborators (Keim et al., 2010). Users can add annotations to capture the recipient's attention and provide a description or question about an aspect of design or highlight a region in a view and guide the user towards it

(Wong et al., 2015). Many visual analytics tools provide annotation functionality at different levels (Viegas et al., 2007; Jo et al., 2017; Heer and Agrawala, 2007).

In collaborative design tools, annotations are used for asking questions, making suggestions, or leading the team to a specific region in the interface. Autodesk BIM Collaborate (2022) is a collaboration tool that provides visual or textual annotations as comments on images or 3D models. It supports recording the annotation along with its corresponding data. Modelo (2022) supports the presentation of interactive 3D views, VR walkthroughs, and 3D annotations, along with text comments. OnShape (2022) is a collaborative design platform that allows multiple designers to work on a 3D model and collaborate on it by visual and textual annotation. These tools do not present performance metrics through data visualizations; their features are geared toward design teams rather than non-expert stakeholders.

Within the design domains, there are multiple interfaces for exploring design options using both their forms and performance data (Goguelin et al., 2017; Matejka et al., 2018). They support annotations in the form of ratings, tags or comments. But those interfaces are designed for expert designers sifting through many alternatives instead of having an in-depth discussion about on design data with non-experts. D-ART (Alsalman and Erhan, 2022) is a collaboration tool for the data-driven evaluation of multiple alternatives aimed at non-experts and experts alike. It has various means for presenting and comparing alternative forms and performance, including 3D models, images, tables, and charts. D-ART allows users to share feedback through comments, but those comments are not tied to specific parts of design data (e.g., a portion of a chart or a 3D model) and they are not coordinated.

In summary, current design collaboration tools are: (1) limited in means for presenting design alternatives with both design forms and performance metrics, (2) do not support adequate feedback mechanisms for eliciting stakeholder's feedback on design alternatives, or (3) they are built for design teams' needs rather than non-experts.

3. Study Design

We conducted an expert-user study to derive high-level requirements for annotations-enabled and data-informed collaboration tools for evaluating design alternatives. The study explored how design stakeholders would share their feedback on the alternatives and interact with each other through annotations on data representations. We applied an exploratory research method involving in-depth interviews with experts from the AEC industry and user experience design. Our target design data included form (spatial) data as images and 3D models and performance data captured in tables and charts. In the study, we used D-ART (Alsalman and Erhan, 2022) for its capability to represent alternative designs' form and performance data in 3D models, images, tables, and charts. Also, its system evaluation revealed the need for localized data annotation features on individuals and across alternatives.

3.1. STUDY SETUP AND PROCEDURE

We recruited eight expert participants (five from AEC and three from user experience (UX) disciplines). All participants had two to five years of experience. The experts from the AEC disciplines have worked closely with multiple stakeholders on various projects. The UX designers worked on collaboration systems. All participants had experience with collaboration tools, such as Microsoft Teams and Zoom. Expert participants were chosen so they could offer the perspective of both experts and non-experts, which non-expert stakeholders alone could not provide.

The first author met the eight expert participants individually and conducted the study in person in a research lab. Experts were asked to imagine themselves in a scenario as stakeholders of a complex mix-use design project. As part of their role, they were to review three different design alternatives and share their feedback with the other stakeholders. The study took place in four steps. In the pre-task interview, we asked participants how they collaborate with other people in a project, how often they check their team's feedback, and whether they use annotations in collaboration. This was followed by Task 1, where the participants evaluated the first design alternative on the D-ART's mock-up interface printed on A3 size papers (297 x 420 mm), which is close to its on-screen size on a 24" monitor and included the same on-screen layout. Like D-ART's online version, the mock-up presented the alternative and comparison views. With the mock-up, we isolated the possible restrictions of input devices for free-form annotations so the users could provide feedback by using pencils and markers. Although we lost interactivity, it was an acceptable trade-off. We shared the data visualizations first separately, and then on one mock-up to ensure that participants viewed them on demand. We encouraged them to use annotation to express their comments on the mock-up. In Task 2, the participants reviewed the second design alternative using the D-ART online interactive prototype in the same scenario as in Task 1. Since D-ART does not have annotation features, we simulated by screen-sharing of D-ART in the Zoom App and accessing its annotation features as if they were part of D-ART. This setup enabled us to record the user's actions. In the final step, we conducted a post-task interview. The experts were asked about their experience with D-ART and its potential and limitations for feedback sharing.

3.1.1. Data Analysis

The experts spend an average of 1 hour 21 minutes (min 48 mins and max 1 hour and 44 min) on both tasks. The data we gathered includes: (a) scanned mock-ups with the expert's annotations (Task-1); (b) video recording of the expert's interaction with D-ART (Task-2); (c) the pre- and post-task questions (Text); and (d) notes from the researchers' observation (Text). We transcribed the recorded videos and coded the transcripts. Two researchers compiled the data and derived the themes and a list of potential codes. Through discussions, we divided the codes into three categories: annotation creation, annotation management, and annotation-based interaction.

4. Results and Reflection

Experts (E1-8) created an average of 29 and a total of 236 annotations (min 16, max 38) on the mock-up and an average of 17 and a total of 139 annotations on the online tool (min 7, max 26) (Table 1). About 65% of the annotations were made on the mock-up. The experts explained this difference by the restrictions in using commenting tools simulated on D-ART and the input devices. They mentioned they preferred analogue-like interaction with the pen and pencil instead of the mouse and keyboard. E8 noted: "...even if I had [touchpad], I would prefer to type…with pen and pencil, it's easier to draw and say, what is this or that?"

The input device limitation is obvious, and we expected such comments. However, we may observe different results if we had conducted the study using a tablet with a stylus closer to the analogue media.

We characterized the annotations on both the paper and online prototypes to find the possible common patterns in annotation format on different types of visualizations, the relation between the annotations and visualizations, the properties of the generated annotations, and the functions that experts suggest or anticipate for their annotations. We divided the annotation forms into four groups: text, sketch, mark and symbol, and tag (Figure 1). Hybrid annotations combine two or more of these forms.

	Paper Prototype					Online Tool					
	Text	Sketch	Mark	Tag	Hybrid	Text	Sketch	Mark	Tag	Hybrid	All
Form	50	5	32	2	13	21	17	17	2	8	167
Chart	33	0	49	2	15	13	0	19	0	5	136
Table	14	0	19	0	2	11	0	18	2	6	72
All	236					139					

Table 1 shows the number of annotations in different forms on each type of visualization.

(a) Marks on data visualization by E1 (b) Sketch annotation on the design form by E3

Figure 1: Annotation forms used by experts on different visualizations on the paper prototype.

4.1. CREATING ANNOTATIONS ON DESIGN DATA

The number of annotations varied depending on the type of visualization. About 44% of annotations were associated with the images and 3D model, whereas 36.2% were on the chart and 19.2% on the table. Experts selected specific forms of annotations more frequently on some types of visualization. For example, the annotations in sketch form (Figure 1b) only occurred on images and 3D visualizations. Five out of eight experts added sketch annotations on the images. Markings with symbols are 41.06% of all annotations (Figure 1a) and are often used in similar representation tools. For example, six experts used checkmarks to indicate their approval. One expert used an emoji sign to indicate her satisfaction with the data. Other frequently used marks included question (?) marks, exclamation (!) marks, and cross (X) marks.

4.1.1. Association Between Comments and Visualizations

All experts confirmed the need for connecting visual representations or data to their annotations. E6 mentioned that in her everyday work, she prefers screen-sharing to collaborate with her team “they can see the point or the visualization…instead of saying something like ‘top right corner of the page’ ” E4 noted that: “...I really want to mention which data part I'm thinking with. So, I prefer my annotations to be in context rather than in the comment box on the side.” Experts used various methods for associating annotations to the visualizations or data points. All experts used hybrid annotations, i.e., marks, arrows, and symbols, like numbers and stars or sketches, along with text annotations to create hybrid annotations. Four experts used tags in their text annotations to refer to a visualization or data parameter. Five experts added numbers or marks, such as a star, on the images and charts and used the same mark in their textual annotations. Another commonly used method for associating annotations to the visualizations was adding annotations in the proximity of the visualizations. All experts frequently added a text box to annotate in the proximity of the visualizations, even though there was a comment box in the interface. E4 mentioned: “...if there is enough space right next to the visualization, I write my notes in that area.”

4.1.2. Multiplicity between Annotations and Visualizations

D-ART supports quantitative and qualitative analysis at the same time. Experts used this quality for generating feedback and associating one annotation with multiple visualizations (Figure 2). Experts placed similar annotations on different views, e.g., suggesting a new approach or asking questions about the alternative or project. Annotations were also used independently from a view or data. e.g., E8 commented that “…the budget detail should be reconsidered”. Four participants referred to these comments as general comments. E3 described the general comments as more like a summary of their feedback.

(a) Annotation on multiple form visualization by E2

(b) Annotation on multiple parameters by E8

Figure 2: Experts use annotations to relate multiple data parameters or geometry

4.1.3. Properties of Annotations

As a property for annotations, privacy emerged as an important concern. Experts added target annotations for specific stakeholders and hid them from the others. E6 noted, “...I think the amount of information you share can be optimized for specific people.” Colour, as another property, was used for several purposes, e.g., green for satisfaction with the data and red for reporting a concern. Other mentioned properties were the importance levels and status, i.e., whether an annotation is in progress or resolved.

4.2. INTERACTION BY ANNOTATION ACROSS VIEWS

Experts used annotations to add an additional level of interaction, e.g., filtering, navigation between views and record-keeping. Annotations were used for filtering data. E3 mentioned, "...[this] lets you blur out the views and forms and only have those parts mentioned here." Experts suggested filtering out visualizations only to view the data related to a selected annotation. Two experts suggested moving between views by using annotation, e.g., as in hyperlinks. E3 said, "…I can see the annotations in the compare view, but what if I now want to move to the alternative view that this annotation talks about? Maybe I could use the annotation, like a shortcut...." They also underlined the potential role of annotations for backtracking.

4.3. MANAGING ANNOTATIONS ACROSS ALTERNATIVES

Experts confirmed the need to revisit annotations, e.g., to remember their last analysis, review or edit them, or explore others' feedback. All experts suggested enhancements to the comments box. E1 expressed that "…I prefer to have a moving comment box with me on all pages, so when I move to the first page, I can actually check my comments and decide what alternative to go to" These suggestions included filtering comments by annotator or the topic, editing or toggling visibility of comments. Following are experts' suggestions for combining and managing annotations.

4.3.1. Annotating with Pointers

Experts placed unique marks on visualizations, e.g., as a number or symbol and used the same mark in their textual annotations to refer to the mark's location. Heer and Agrawala (2007) noted that this method grounds user discussion. For example, users select a data point or visualization, and a dialogue box appears on the location for adding text, sketch, or mark. After removing the box, a mark remains on the annotated data or visualization as a link to the comment. E1-4, E6, and E8 suggested embedding annotations into the data visualizations with their original states.

4.3.2. Managing Annotations through Tags

Experts E1, E2, and E3 suggested using tags to link annotations to visualizations. They described a scenario where everything in the interface has a name tag. Selecting a tag on the visualization will appear in the comment 'floating' box, and users can add their annotations. In this scenario, users can later filter the comments to access annotations about a specific data point or a visualization. E2 suggested using tags for linking annotations to visualizations and added that using these links can help access specific annotations: "…over time, we will have so many annotations. [if] I care about residential cost, maybe I can click on a tag, and it shows me the annotations related to cost, and I don't search. I can find everything about cost."

4.3.3. Recording Annotations by Screenshot

Experts E1, E4, E6 and E7 preferred to select areas on the interface, take a screenshot, and combine it with a textual annotation. E4 mentioned adding the screenshot to an email: "…I prefer they send me a screenshot and say here are all the problems we have found. So that I can just zoom in on different parts and say, OK, there is a problem. Instead of them sending back 50 different screenshots to point out 50 different issues." This comments points at annotation management features found in tools such as Onshape and BIM Collaborate.

4.4. CHALLENGES WITH ANNOTATION ON VA INTERFACES

In the post-task interview, we asked experts about the challenges they foresee in annotation on design analytics tools. The experts within the AEC industry had two main concerns. The first is the stakeholders' reluctance to learn new tools for collaboration and preference for the familiar methods. E8 noted: "…it takes a lot of effort…[to learn] using it, you know, and, um…most of the time, [stakeholders] are not willing to just study your smart tool only so can give feedback...they are OK with printing them." The second concern is if annotations can be scalable to capture complex feedback. Three experts found annotations as short, brief, and somewhat ambiguous content limiting fully explaining rich ideas or questions. E6 mentioned that "…sometimes you may need other forms of communication with the stakeholder…because it makes it quicker…reduces the amount of confusion." These two comments are consistent with the 'low-threshold, high-ceiling, and wide walls' principle for creativity support tools (Shneiderman et al., 2006).

4.5. DESIGN IMPLICATIONS

Building on our observations and the responses from the experts, we discuss how we could improve annotation functionality and facilitate feedback sharing in data-driven collaborative design analytics interfaces.

Employing interactive techniques for increasing the expressiveness of design feedback: Our users highlighted the need for flexibility in creating annotations. They asked for freedom in choosing the format of annotations, associating annotation with design data, and support for multi-target annotations. Many collaborative design and visual analytics tools support editing annotations (Onshape, BIM Collaborate), assigning privacy levels (Onshape) and importance levels (BIM Collaborate) to them, our users confirmed the need for the same features.

Annotation-focused interaction across interfaces: Interactivity allows users to focus on multiple parts of a design. Therefore, navigating between interfaces and filtering design data can facilitate sensemaking. Users asked for multiple interactions that revolves around annotations. For example, to view only the data or visualizations related to the selected annotation, navigate on request to the view/interface or design state wherein the annotation was created. Annotation-focused interactions reduces the need to remember where annotations were created.

Clear compiled representation of feedback: For a meaningful collaboration, structured organizations of rich and diverse feedback on design data can enable annotation-focused exploration. Several techniques have been proposed to support this organization (Zhao et al., 2017; Badam et al., 2022). Any system for annotation management should allow finding relations and patterns between the feedback, support large numbers of annotations, and facilitate report generation of the complied feedback.

We propose a structural model for collaborative annotations on design alternatives in Figure 3. An annotation, in the form of text, mark, sketch, or tag, is associated with the design visualization instances made by users. Each annotation is associated with one or multiple design visualization instances. The annotation is recorded by a coordinate (e.g. (x, y) on the overview page), a parameter (e.g., residential area in alternative 01), or geometry (e.g., residential block no.01 in alternative 01).

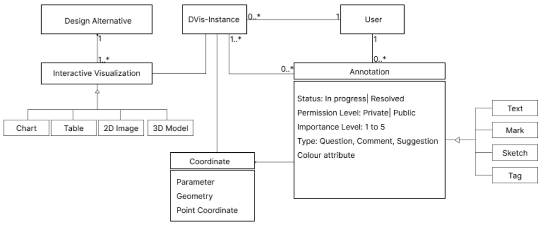

Figure 3: A conceptual model of one possible structure for creating coordinated annotations.

5. Limitation

The study was conducted in a lab environment with a limited number of relatively experienced participants; therefore, some caution should be used in generalizing the findings. As a limitation, the study focuses on design data presented on D-ART interfaces; therefore, our findings should consider possible design confounds. Future research can complement the insights from this study with large-scale surveys or other approaches that include a more diverse group of designers and a more variety of spatial and data visualizations on different tools.

6. Conclusion and Future Work

We investigated how a meaningful annotation-driven collaboration can be enabled by presenting design alternatives with their form and performance data and receiving feedback from the design stakeholders directly on data representations on Design Analytics tools. We presented our results in three groups: explanation of possible collaboration needs using design data, high-level requirements for interaction in interfaces supporting annotation-driven and data-informed collaboration, and management of annotations as collaboration artifacts across interfaces. We also proposed a structural model for designing an annotation-focused model on design visualizations. As guidelines, we suggest using interactive techniques to increase the expressiveness of design feedback, support annotation-based interaction and provide a compiled view of feedback across interfaces. In future work, we intend to implement interface features following these guidelines.

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