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Interpreting User Narratives in CAD: A Graph-Based Approach

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ABSTRACT

Users' narratives offer architects insights into real everyday experiences that can guide design processes to address diverse preferences and needs. They are, nevertheless, seldom applied within the computer-aided design (CAD) environments commonly used in architectural practice and research. This absence of user narratives within CAD may be explained by the applications being designed for formal geometric information. However, we argue that this absence indicates a potential for introducing user narratives within CAD to align computational design decisions with the preferences and needs of actual users. The pilot study presented here explores this potential by developing a plugin for the CAD application Rhinoceros that enables linking user narratives with CAD geometry. Based on protocol analysis involving 14 architects employed at the Royal Danish Academy, the study critically examines both the plugin and the underlying approach. The architects were asked to interpret a user's preferences and needs from six user narratives linked with a Rhinoceros model of the user's house, and to report whether and how the linked narrative-geometry might be used in other design contexts. Results show that participating architects interpreted preferences and needs relatively consistently, while their reported imagined use of the linked narrative-geometry in other design contexts varied considerably. These findings indicate practical feasibility for linking and interpreting user narratives within CAD, pointing towards directions for future studies - both to determine whether the plugin can meaningfully support design processes aiming to accommodate actual and diverse users, and to examine more specifically how CAD frameworks may constrain the use of narrative to inform computational design decisions.

Keywords: Human-centred design, User narrative, CAD, Design information, Knowledge graph

INTRODUCTION

User narratives are applied by human-centred architects and designers to gain insights into users' everyday life to better accommodate them through design (Celikoglu et al., 2020; Shaw & Nickpour, 2024b). Key differences from other types of design information, such as codes, guidelines, and best-practice examples, are that user narratives are often personal and situated: they can convey experiences that are tied to particular contexts, moments, and bodies and are structured by the perception and interpretation of a particular "knowledgeable agent" (Krippendorff, 2006, pp. 69–70). Such properties are

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reported to be relevant when addressing users who are already marginalised within society and whose preferences and needs may extend beyond regulatory compliance (Van der Linden et al., 2019; Hendren, 2020; Kajita, 2020; Shaw & Nickpour, 2024b). User narratives are, nevertheless, seldom applied to inform design decisions within the digital design environments of computer-aided design (CAD) applications commonly used in architectural practice and research. CAD applications typically render design as algebraic geometry with key-value properties and attributes (Carranza, 2017; Eastman et al., 2009) but address also phenomena, such as usability and exclusion, that exceed the geometric and formal descriptions. This suggests that such phenomena are represented and negotiated elsewhere in design processes: in the minds of architects, in other software, in printed documents, etc. While such dispersal of information is by no means necessarily a problem, we argue that making user narratives operable within CAD could hold two complementary potentials: first, to better sensitise architects' CAD-based design decisions to users' experiences; and second, to document the reasoning involved so that users and other stakeholders can better understand the decisions.

This paper presents a pilot study that explores the former potential. First, by developing a CAD plugin that enables reading user narratives within CAD environments and establishing links to relevant CAD geometry. Second, by examining the plugin based on architects' interpretations of the linked user narratives – both to evaluate its practical feasibility and to surface challenges potentially complicating the integration of user narratives and CAD. The paper is structured as follows: next, the use of user narratives in architecture and design is unfolded. Then, CAD applications are introduced, with an emphasis on differences between its standard information and open-ended narratives. In the Methodology section, the plugin RhinoGraphViewer is first introduced followed by the pilot study's combination of case study, CAD and graph modelling, and protocol analysis. Results are presented and discussed, pointing towards future investigations, before conclusive remarks are given.

BACKGROUND

User Narratives

Narrative is a concept used across many disciplines, with varying definitions, perspectives and applications in academic literature. According to Shaw & Nickpour (2024a), "narratives are a dynamic way to organize, express, share and comprehend personal or collective experiences, thoughts, and knowledge." As such, they argue, narratives "offer designers insights to better understand lived experiences, histories, or beliefs and can help inform and frame a design" (Shaw & Nickpour, 2024a, p. 39). Grimaldi et al. (2013, p. 204) identified several uses of narratives in design, for example, to describe stories facilitated or evoked by design and the use of narratives to support design processes. In cases of the latter, Krippendorff (2006, pp. 246–250) notes that interpretations and rearticulations are involved in the mapping of narrative structures to material structures when using narratives to guide the design of material artifacts. Such mapping is not straightforward, however; among other things, because narratives omit details that need to

be articulated and solved to make design work (Krippendorff, 2006, p. 249). To navigate such ambiguities, designers rearticulate narratives in different ways, for instance, as design scenarios (Jones, 2016; Krippendorff, 2006), or through coding schemes that categorise narrative content (Celikoglu et al., 2017; Shaw & Nickpour, 2024b).

User narratives refer here to narratives in which users' experiences, routines, thoughts, feelings and other personal aspects – which may or may not relate directly to objects and spaces – are conveyed. The narratives are often tied to particular contexts, moments, and bodies, and they are structured by the perception and framing of particular person(s) (Boys, 2014, p. 119; Jones, 2016; Shaw & Nickpour, 2024b). Hence, user narratives hold capacity to combine descriptions of design with descriptions of how it should work on several registers (functionally, emotionally, socially, etc.) in specific contexts (Hendren, 2020). This capacity is considered relevant as the information can support designers in conceptualising how design, once realised, may afford certain, interrelated uses and constrain others (Krippendorff, 2006, p. 224). Such insights are particularly relevant when users are already marginalised (Boys, 2014, p. 22; Shaw & Nickpour, 2024b, p. 2); whose bodies are different to those of the architects themselves (Van der Linden et al., 2019, pp. 87–88); have preferences and needs that extend beyond regulatory compliance (Hendren, 2020, p. 146); and may feel stigmatised by design (Bonfils et al., 2024, p. 57; Hendren, 2020, pp. 122–123). As for narratives in general, the application of user narratives in design processes requires rearticulating them into forms operable within design processes (Krippendorff, 2006, pp. 246–247), for example, by coding themes and categories (Shaw & Nickpour, 2024b; van der Bijl-Brouwer & Dorst, 2017).

Celikoglu et al. (2017) analysed how designers interpreted user narratives from cultural probes and identified three categories in the narrative content that designers focused on: lifestyle and environment; experience and practice; and visualization and imagery. These categories, the authors reported, reflect how designers selectively transformed user narratives into human-centred design ideas (Celikoglu et al., 2017, pp. 94–96). In a later empirical study, Celikoglu et al. (2020, p. 135) identified five essential content categories: difficulties; obstacles; manifestations; goals; and purposive actions, that designers derived from user narratives. They further identified four categories of design implication: opening new perspectives; setting design criteria; improving existing designs; and proposing new design ideas, that was stimulated by narrative content. Similarly, van der Bijl-Brouwer & Dorst (2017) proposed the NADI (Needs and Aspirations for application in a Design and Innovation process) model. The model distinguishes four levels of user needs and aspirations: solutions; scenarios; goals; and themes, ranging from context-specific to context-independent. The authors demonstrate the NADI model using interviews with parents about the design of a carrier bike. Context-independent themes identified in the interviews informed new context-specific solutions, purportedly bridging human-centred design and design innovation (van der Bijl-Brouwer & Dorst, 2017, p. 18).

Rearticulations of users' narratives in order to address specific preferences and needs among users through design, however, raises the question: to

which extent can users' intended meaning be preserved when narratives are rearticulated in design-operable forms? Shaw & Nickpour (2024b) addressed this question methodologically by clustering transcripts from user interviews "to identify emerging narrative themes while ensuring the qualitative data was kept intact and not diluted" (Shaw & Nickpour, 2024b, p. 6). Krippendorff's (2006, p. 246) narrative design method, however, emphasises variability in rearticulations of narratives as an inevitable process through which design proposals become usable and meaningful to those involved. This study aims not to resolve such questions of accurate communication and understanding, but rather to examine preliminarily how, and how consistent, architects may read and apply user narratives within CAD environments.

CAD Applications and Design Information

CAD refers here to a large number of applications that are used across design disciplines to create, manipulate, analyse, and visualise representations of design as digital geometry. CAD has been central in the digitalisation of architecture (Bernstein, 2018) with AutoCAD, Revit, Sketchup, and Rhinoceros 3D (Rhino) as some of the most commonly used applications. The interface of Rhino, which is the application used in this study, consists of a viewport showing virtual design environments, commands access, modelling aids, and panels (see Figure 1). Together, these elements structure how design can be engaged with and represented within the software – primarily as algebraic geometry visually rendered in viewports, with key-value pairs describing non-geometrical properties and attributes in the panel.

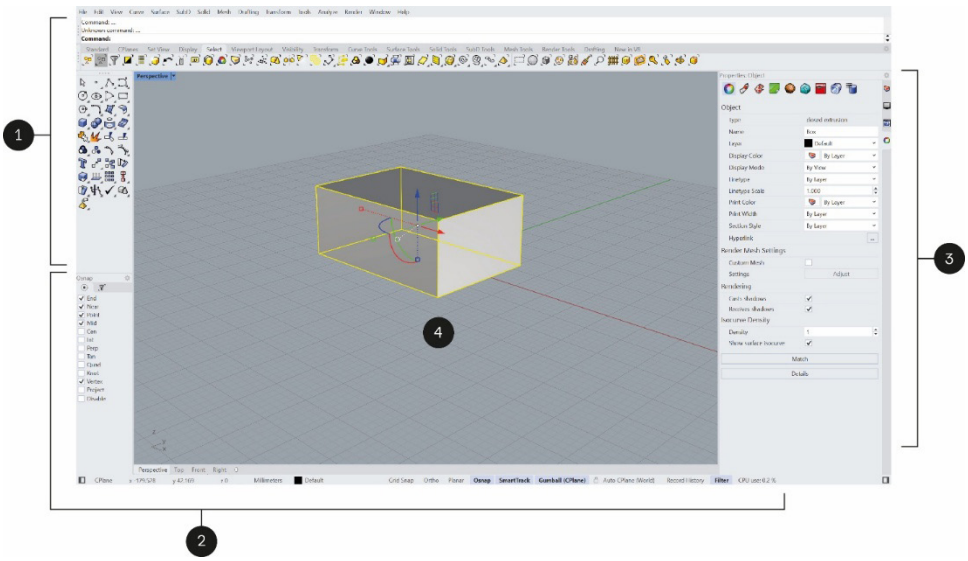


Figure 1: Elements of Rhinoceros' user interface: 1) commands access, 2) modelling aids, 3) panels, and 4) viewport.

While the precision, efficiency, and communication benefits of CAD are generally recognised (Krippendorff, 2006, pp. 17–18; Robertson & Radcliffe, 2009), they have also been suggested to constrain designers' creativity (Bernal

et al., 2015; Lawson, 2002). In part, researchers note, such challenges relate to the indifferent CAD representations of design throughout design stages (Bernal et al., 2015, p. 164). CAD geometry describes "final objects" (Lawson, 2002, p. 328), even when depicting loosely defined ideas at conceptual design stages. Representations of vague and ambiguous forms in CAD are therefore challenged, entailing a risk of premature fixation of design (Robertson & Radcliffe, 2009, p. 137). Consequently, researchers note that architects and designers switch to other design media, such as analogue sketching, to capture and develop their conceptual design ideas (Shih et al., 2017).

When working in the CAD environments, architects also conceive of their design's performance, for example, in relation to future use (Bernstein, 2018, pp. 40–41), and similar challenges can be identified in representing users' personal and situated use within CAD. The formal geometric representations of design in CAD can support architects in developing design and assessing its performance against formal codes and guidelines (Eastman et al., 2009). Via such approaches, isolated and context-independent requirements of accessibility, visibility, safety, and other use-related aspects can be checked in architectural design processes (Shih et al., 2017, p. 50). However, personal, interrelated, and context-dependent factors, as those conveyed in user narratives, exceed formal geometric representations as those used in CAD. Consequently, narrative descriptions of use as experienced by particular users – how design may include them, evoke stigma, or support their everyday routines – are largely absent within CAD environments. While this is not necessarily a problem, it hinders the direct coupling of computational architectural design decisions and users' experiences guiding those decisions.

This indicates a largely unmet potential for informing digital design decisions with user narratives within CAD-based design processes – for example, to stimulate various design activities as described by Celikoglu et al. (2020), or to bridge the context-independent themes and context-specific solutions as proposed by van der Bijl-Brouwer & Dorst (2017).

As described below, we explored this potential by developing a plugin for Rhino that enables text, stored as graphs, to be linked with CAD geometry. Based on architects' interpretations of the linked user narratives, we critically examined both the plugin and the broader approach of engaging with user narratives with CAD environments.

METHODOLOGY

RhinoGraphViewer

We developed a plugin for Rhino named RhinoGraphViewer to enable the storing of user narratives and link them with Rhino geometry. The plugin seeks to support architects working in Rhino, in applying user narratives to inform their design decisions within the Rhino environment. RhinoGraphViewer allows for importing, creating, and manipulating knowledge graphs in an additional Rhino window. Information can be stored in graph nodes or in labelled relations between the nodes, providing structure to information, such as user narrative, that is often lengthy and interrelated. Graph nodes

can be paired with Rhino geometry. In the study described here, this feature was used to link geometry-nodes with corresponding Rhino geometry (see Figure 2). Additionally, narrative-nodes containing user narratives were created and they were related to the geometries mentioned in the narrative. To make the text readable while providing overview in the RhinoGraphViewer-window, the full narrative text can be shown and hidden by clicking a small speech bubble icon in the narrative-nodes' lower corner. In the following study, we sought to examine whether and how the plugin supports architects in interpreting user narratives linked with Rhino geometry within a digital design environment.

User Interview and Text Sampling

Ethnographic interviews (Spradley, 1979) were conducted with "Jane" on-site, in her detached house located north of Copenhagen. Jane is a retired medical doctor in her late 80s, living alone and independently. She does not consider herself disabled or marginalised but has made several changes in her interior in response to increasing fatigue and growing concerns about external dangers, such as burglaries. Specifically, three reflexive interviews (Hammersley & Atkinson, 2010, p. 117), each lasting about an hour and based on a list of topics to cover, were conducted and recorded with the informed consent of Jane. From the interviews we transcribed 31 standard pages of text containing multiple narratives about her experiences and thoughts. Six narratives from the transcribed text, containing between 48 and 94 words, were sampled for this study. The first narrative for instance read: "I think there is an excellent light in this entrance hall. It gets top marks – the light is good and evenly distributed, and I don't think one could wish for anything better than this. Also, the fact that he [the architect] has placed them [the sidelight windows] on both sides of the door instead of one wide pane. That would never have produced that beautiful light."

The narratives were selected as they all mention or refer to the sidelight windows on both sides of Jane's front door, providing a stable point of reference. Moreover, we interpreted that each of the texts, more or less explicitly, express some of Jane's preferences and needs tied to the sidelight windows.

Rhino and Graph Modelling

Jane's house was modelled in Rhino. The modelling emphasised showing the building's interior organisation and foregrounded the building elements mentioned by Jane. Legibility was prioritised in the modelling process, for example, by removing the building's roof and large parts of the building to provide overview (see Figure 2a). In the RhinoGraphViewer window, each of Jane's narrative texts were stored in a narrative-node. Five geometry-nodes representing each of the building elements mentioned by Jane in the six narratives were created and paired with the corresponding CAD geometry, as shown in Figure 2b.

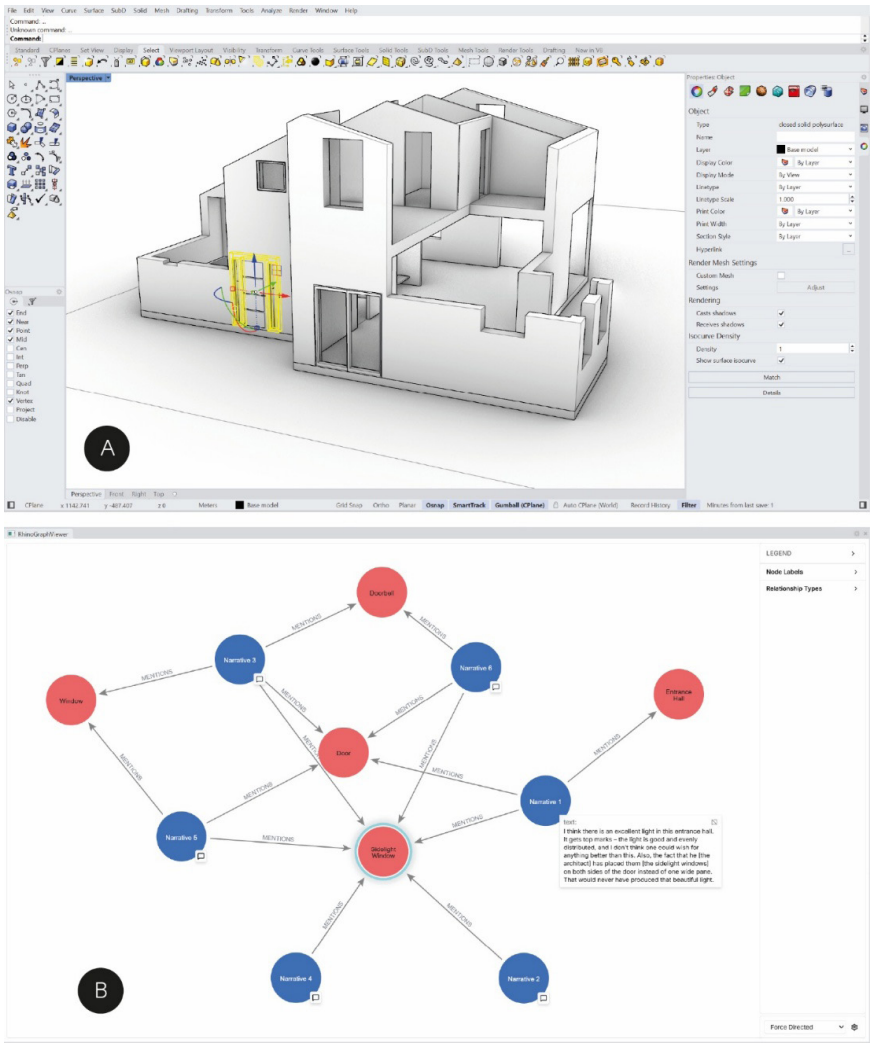


Figure 2: A) The Rhino model of Jane's house shown in the Rhino viewport, and B) the graph consisting of (blue) narrative-nodes and the (red) geometry-nodes, the latter paired with Rhino geometry, shown in the RhinoGraphViewer window.

Protocol Analysis

A retrospective protocol analysis (Gero & Tang, 2001; Shih et al., 2017) was developed to study, first, how architects interpret Jane's preferences and needs from the narrative-nodes linked with the Rhino geometry, and second, what design activities the texts may prompt them toward in other design contexts. Due to the early stage of research and the general character of the research question, no idealised or homogenous group of architects was sought. Recruitment among architects employed as staff at the Royal Danish Academy provided practical access to participating architects with varying experience in architectural research and practice and design focus. They were recruited by email, resulting in 14 staff members, from associate professors to research assistants across three institutes, participating. The participants were invited

to an office with a computer setup with screens showing the Rhino model and the integrated user narratives in the RhinoGraphViewer, and a computer mouse to navigate the Rhino model (see Figure 3). Written introduction and instruction to the study was given before the participants inspected the Rhino model of Jane's house and read the linked narratives. Afterwards they filled out a survey with two questions tied to each of the 6 texts. The first question asked participants to write down the preferences and needs they interpreted from the narrative. The second question asked participants to report their imagined use of the particular narrative-geometry in other design contexts, using predefined answers adopted from Celikoglu et al.'s (2020, p. 135) categories. These were: to open up new perspectives; set design criteria; improve existing designs; propose new design ideas. Moreover, the options "do not know" and "other" – the latter encouraging free-text answers – were also provided.



Figure 3: A participating architect inspecting the linked Rhino model and graph as part of the protocol analysis.

The protocol responses were then analysed by the authors. Analysis of participants' interpretations of preferences and needs combined inductive and deductive coding, focusing on recurring themes, relationships between different preferences and needs, and whether they read as particular to Jane and her house. The responses conveying the imagined use of the narrative-geometry in other design contexts were counted and free-text answers were interpreted and discussed collaboratively. Variations in the answers were analysed against the particular narrative and/or the Rhino model.

RESULTS

Themes in Preferences and Needs

The participating architects expressed the preferences and needs interpreted from Jane's accounts differently: some mentioned one or few preferences and needs per text while others identified several, some used full sentences while

others used keywords, some echoed Jane's wording while others used alternative phrasing, and some proposed solutions to meet the interpreted preferences and needs while others did not. Despite these differences, the interpretations of several narratives largely align thematically (regardless of architects' position, design field, or level of experience), as illustrated in Table 1.

Table 1: Themes identified in the participants' interpretations of preferences and needs from the narrative-geometry with the number of mentions in parenthesis.

Narrative	Themes in Participants' Interpretations
Narrative 1	Even distribution of light (7/14) Daylight (3/14) Visibility (1/14)
Narrative 2	Contact with outside (11/14) Overview (3/14) Privacy (2/14) Safety (1/14) Community/belonging (1/14)
Narrative 3	Safety (12/14) Overview (7/14) Control (4/14) Communication (3/14) Privacy (2/14)
Narrative 4	Contact with nature/outside (10/14) Overview (3/14)
Narrative 5	Safety (8/14) Overview (6/14) Communication (2/14) Control (2/14)
Narrative 6	Safety (11/14) Autonomy (8/14) Control (5/14) Overview (2/14) Communication (1/14)

Preferences and Needs – Relationships and Specificity

Moreover, several participant interpretations of each text described relationships between various preferences and needs. This was particularly the case for interpretations of Narrative 6, for example:

"The user values being able to identify visitors, which provides a sense of safety and control but *at the same time* maintains a feeling of openness" (Participant 2, emphasis added).

"The need to feel safe *but also* wanting to trust and explore" (Participant 14, emphasis added).

"Safety. A design that allows you to interact with the outside *without having to* expose yourself to unknown people or events" (Participant 8, emphasis added).

Finally, we found that the participants' interpretations of preferences and needs varied in their specificity to Jane and her house, as the below interpretations of Narrative 4 illustrate:

"Connection with nature" (Participant 8).

"Need and pleasure to have contact with the outside - contact with nature" (Participant 4).

"Jane likes to get in touch with nature from the windows without actually going outside. A chair in the entrance hall might be needed since she will be there for a long time" (Participant 3).

Imagined Use of Narrative-Geometry

Results of the protocol study show that the architects' imagined use of the linked narrative-geometry in other design contexts diverge considerably. All four predefined options were chosen by at least 2 participants for each text, and no single option (or any combination of options) was chosen by a majority of participants. The distribution of answers is illustrated in Figure 4. Responses were fairly evenly distributed across the four options for Narratives 2, 4, 6, while Narratives 1, 3, 5 showed more variance with "Setting design criteria" selected more often than other options. Moreover, some participants added other options, for instance, the use of the linked information to confirm design assumptions.

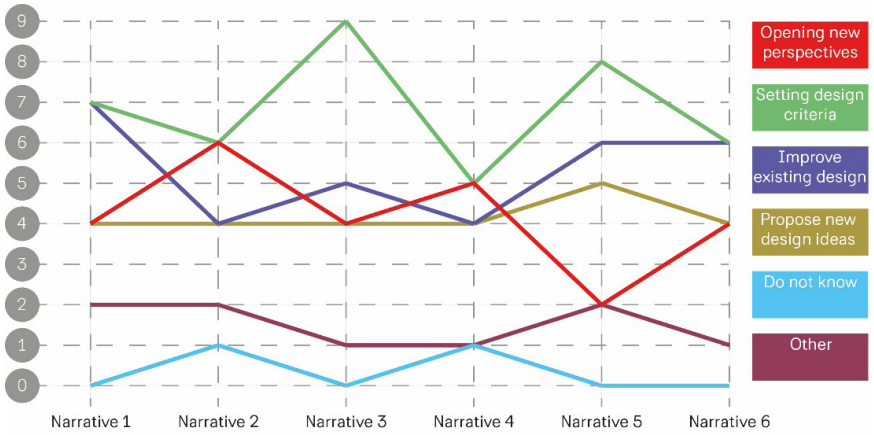


Figure 4: Graph showing the distribution of participants' imagined use of narrative-geometry.

DISCUSSION

Findings show that the RhinoGraphViewer plugin can practically link Rhino geometry with user narratives stored as graph nodes that can be read by architects. In doing so, the plugin facilitated their interpretation of Jane's narratives linked to a Rhino model of her house. Architects' rearticulations of the narratives often overlap thematically, conveyed interrelated preferences and needs, and some did convey preferences and needs specific to Jane and her house. These findings indicate potential for using the plugin in efforts

to align design decisions in CAD with actual users' preferences and needs expressed in user narratives. In what follows, we consider these findings in relation to the background literature, before turning to the limitations of the study and the challenges in working with narratives in CAD they suggest.

Themes in Preferences and Needs

van der Bijl-Brouwer & Dorst (2017) argued that context-independent themes of user needs and aspirations can be used to reframe context-specific design problems, supporting human-centred design efforts. On a related note, Shaw & Nickpour (2024a, p. 41) argue that stakeholders reaching shared understanding of narratives is essential for carrying user narratives forward into design processes. The overlapping themes of preferences and needs in the participant responses suggest similar understandings of Jane's experiences. Considered alongside the above arguments, we find this result promising for using the presented plugin and approach in coherent design problem framing, potentially leading to solutions that address preferences and needs similar to those of Jane. Important to note, however, the overlapping themes neither guarantee faithfulness to Jane's actual experiences, nor that resulting designs may accurately reflect them.

Preferences and Needs – Relationships and Specificity

The descriptions of interrelated preferences and needs in the protocol responses indicate potential for securing such relations in computational architectural design processes. That would, for instance, be relevant in describing disabled users' expectation of design that serves practical as well as aesthetic functions at the same time (cf. Hendren, 2020, pp. 7–8). Moreover, the reported preferences and needs tied specifically to Jane and her house indicate that the plugin can be used to preserve personal and situated accounts within the Rhino environment. These properties could secure essential information for architects seeking to accommodate users with different conditions than themselves and whose preferences and needs may extend beyond regulatory definitions (cf. Boys, 2014, pp. 23–24; Shaw & Nickpour, 2024b, p. 2). Responses such as: "There are two glass doors in the room next to the entrance, so that she likes to look out of those smaller side windows is intriguing!" (Participant 6), show that the Rhino geometry influences the interpretation of preferences and needs from Jane's narratives (as the other doors are not mentioned in the narrative). Such influences are, however, seldom made clear and the role of CAD geometry in the interpretations remains uncertain.

Imagined Use of Linked Narrative-Geometry in Other Design Contexts

We assume that the divergence in the participants' responses about the potential use of the linked narrative-geometry can be explained either by genuinely divergent viewpoints, different understandings of the question, or, most likely, a combination of both. This assumption was supported by participants reporting confusion and asking follow-up questions after returning the protocols about

the meaning of both "other design contexts" and the predefined answers adopted from Celikoglu et al. (2020). This points to a specific limitation of the present study's design that is discussed further below.

Limitations and Perspectives

The pilot study reported here is subject to several limitations. Below we discuss three limitations drawn from the above discussions of findings.

All interpretations reported here were produced with the plugin, with Jane's narratives linked to specific geometry of a Rhino model representing her house. Without a baseline to compare against – such as architects' interpretations of the narratives or the geometry alone – it is difficult to assess the plugin's specific contribution to the reported interpretations. Future studies could productively advance this study by introducing such comparison conditions.

The second survey question about participants' imagined use of the linked narrative-geometry in other design contexts, and the predefined answer options were confusing for several participants. In hindsight, the question and options were not sufficiently clear to elicit responses that could qualify the plugin's potential to inform computational design processes, nor allow us to discuss possible connections between variability in the interpretations and potential design activities as addressed by Grimaldi et al. (2013) and Krippendorff (2006). This acknowledgement, however, strengthens the case for future investigations that study directly how the plugin is used in a real design process as alternative to imagining ambiguous "other design contexts."

Participants' responses varied considerably in length and elaboration from single word answers to multiple sentences of interpretations. Because the analysis of responses focused on themes, regardless of how elaborated the response was, the reported thematic consistency does not reflect aspects of such divergence in interpretations. Future investigations could account for differences in response depth or specify expected minimum in participants' responses.

Taken together, these limitations show that the findings of this pilot study primarily establish the plugin's practical feasibility in enabling the integration and interpretation of user narratives within CAD. As a pilot study, the limitations point toward directions for future work. Most centrally, these include whether the plugin can meaningfully support actual human-centred design processes in practice, and, more broadly, how the computational framework of CAD may constrain the narrative content in informing design decisions.

CONCLUSION

Narratives can convey the personal and situated experiences of users. Therefore, user narratives are an important type of information in efforts of accommodating particular and diverse users' preferences and needs, since they are tied to such experiences. Nevertheless, user narratives are seldom applied to inform design decisions within the design environments of CAD applications such as Rhinoceros. This absence, we argued, indicates a currently unmet potential for informing digital architectural design decisions with user narratives. The pilot study presented in this paper addressed this potential. First, by developing a plugin that enables

the storing of lengthy and interrelated user narratives, and linking them to CAD geometry, and second, by evaluating the plugin. 14 architects employed at the Royal Danish Academy were invited to take part in a protocol analysis. Using the plugin, they interpreted preferences and needs from six user narratives linked to a Rhino model of the house where the narratives unfold and reported how they imagined the linked narrative-geometry could be used in other design contexts. Results indicate the plugin's practical feasibility, showing that it enabled user narratives to be stored, linked to CAD geometry, and interpreted with notable consistency. The results also surfaced limitations to be addressed in future studies – most centrally, the need for comparable conditions to isolate the plugin's specific contribution, and protocols also examining its use in actual design processes. Such future work could lead to justified conclusions about the plugin's potential in digital architectural design for particular and diverse users. More broadly, it could clarify the challenges that may constrain the engagement with narratives in computational architectural design.

ETHICAL STATEMENT

The research was reviewed by the researcher's institution and found to be ethically sound and in line with the principles stated in the Danish code of conduct for research integrity. The participating user and architects were sufficiently informed on the purpose of the research, and all signed an informed consent agreement which includes a detailed description of the use of data and possibilities for withdrawal and/or deletion of information. Anonymised interviews and protocol responses are available on request.

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