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HUMAN–COMPUTER INTERACTION FOR BUILDING DOCUMENTATION

Klara Santer, Manav Mahan Singh, and Ian F.C. Smith
Georg Nemetschek Institute Artificial Intelligence for the Built World
Technical University of Munich, Germany

Abstract

Good documentation of existing buildings assists decision making regarding interventions. For this task, we are developing a flexible user-centered method allowing for real-time capturing and documentation by various stakeholders through mobile laser imaging, detection, and ranging (LiDAR) technology. As a first step in developing this concept, this paper incorporates user requirements through the analyses of current needs and practices in building documentation. We conducted an exploratory study of stakeholder groups through seven semi-structured interviews to identify user requirements and group-wise documentation focuses. It is concluded that varying professionals needs and practices require unique sets of user interface features.

Introduction

Managing existing buildings is one of the key tasks that European building professionals are currently facing (European Environmental Agency, 2022). For this purpose, the current state of buildings needs to be documented. Workflow automation for the scan-to-building information model (BIM) is thoroughly researched (Patraucean et al., 2015; Wang and Kim, 2019). Nevertheless, personal responsibilities of planning professionals lead to on-site visits to update and enrich their documentation. Integration of information collected during site visits into automated workflows has potential to increase the productivity for documentation and for developing efficient intervention strategies. The current scan-to-BIM practice for existing buildings is compared with the envisioned interactive workflow in Figure 1. The current practice of capturing point clouds and post processing the captured data off-site are impediments to instant integration of additional information during site visits. An interactive approach does not have this limitation.

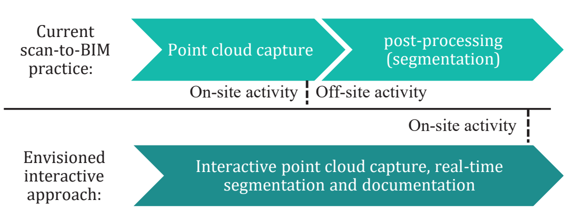

Figure 1: Current scan-to-BIM practice (top) and our envisioned interactive approach (bottom)

The idea of providing digital assistance to professionals during building surveying is not new, and prototypes for enabling the creation of a digital building model on-site with focus on capturing building geometries have been developed early (Petzold, 2001). However, possibilities of mobile real-time capture and segmentation allowed a new way of building documentation through real-time object detection (Franz, Irmler and Rüppel, 2018; Klauer and Plaß, 2021).

Human-centered design is a fundamental concept of human-computer interaction (HCI) and the interface is the key element for providing user-centered software support (Shneiderman, 2022). Both core ideas of HCI are mirrored in this work. Additionally, our interactive building documentation method supports the use of BIM and digital twins (DT) for existing building interventions. DT and digital building logbooks (DBL) are expected to play an increasing role in the built world (Dourlens-Quaranta et al., 2021; Mêda et al., 2021; Lu et al., 2022). This increases needs for structured on-site information collection. We assume that the documentation of existing buildings is currently carried out mainly through paper-based documentation. Image data are collected alongside using mobile devices.

To develop a human-centered approach for real-time building documentation, HCI aspects should be studied. We investigate which input possibilities and interface features are needed by relevant stakeholders for the task of compiling building documentation. For this purpose, we analyzed current practices by carrying out semi-structured interviews.

The need to capture three-dimensional (3D) data in real time has led to solutions for user-in-the-loop data tagging through augmented reality technology (Agrawal et al., 2022). This work involved creating annotations for real-time segmented objects and it was intended for non-professional users only. Intuitive interfaces for interactive building documentation are not available. Yet, attempts to providing them have been made (BIMeo, 2022). Regarding DBL, the need for appropriate interfaces was already noted (Dourlens-Quaranta et al., 2021). To create a positive user experience in the building management field, building documentation tasks require advanced software support. We argue that the needs of users vary amongst user groups for documentation tasks.

Based on the assumption of varying user needs, the goal of personalized interfaces is to empower professionals during the creation and revision of building documentation. Personalization can be achieved in two ways: adaptability and adaptivity. Adaptability allows the user to change the interface. Adaptivity describes interfaces, which change according to user models. Interface adaptation can be further distinguished as content, navigation, and visualization adaptation. The approach of adaptive augmented reality (A^2R) has been applied to other use cases (Damala et al., 2012; Hervás et al., 2013). However, no studies on A^2R are concerned with a range of professional groups. This paper contains a description of professional interviews that result in an identification of interface needs of various building-professional groups during building documentation. These interviews are conducted for the purpose of personalizing content and visualization with a view to create software prototypes. The next section provides a short summary of existing building documentation practices.

Building Management Context

Activities associated with management of existing buildings involve reconstruction, restoration, deconstruction, demolition, renovation, maintenance, repairs, refurbishment, conversion, gutting, modernization, decontamination, extension, fitting-out, and change of use (Giebeler et al., 2009). Several of the intervention types are usually carried out simultaneously. Therefore, no strict separation of the terms is used for the present paper. We intend “interventions on existing buildings” to include all possible scenarios. Alongside the terminology for interventions, a specific wording for procedures exists. Various concepts of process cycles are visualized in Figure 2. The circles should be looked at independently.

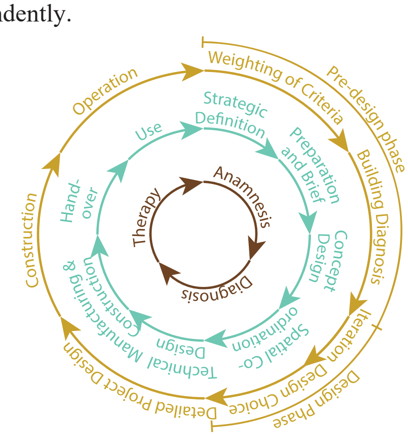

Figure 2: Project cycle concepts according to center: (Pieper, 1983), *intermediate:* (RIBA, 2020), and *circumference:* (Nielsen et al., 2016)

Site visits occur during all phases. In the present work, the term “building documentation” is used to refer to all occasions at which information is collected on-site. In the following, we refer to the plan of work published by the Royal Institute of British Architects for the time categorization of project stages (RIBA, 2020).

Interviews

Seven semi-structured interviews with stakeholders were carried out. The groups are shown in Figure 3 and consist of three structural engineers, one architect, two energy planners, and one building owner.

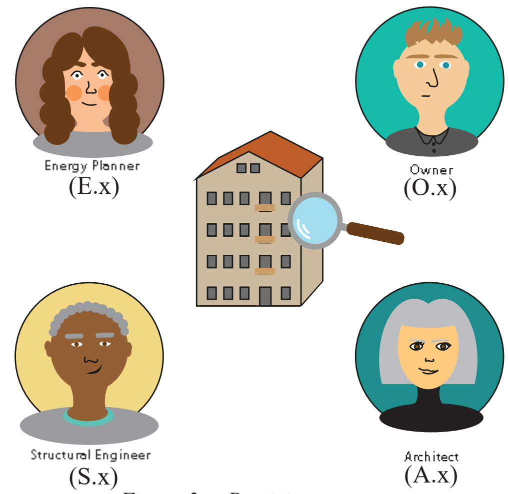

Figure 3: Participant groups

In the conceptual framework of semi-structured interviews, the topics of the interview are predefined, and questions can be adjusted spontaneously by the interviewer. Further explanations of the approach may be found in the literature (Robson and McCartan, 2016; Lazar, Feng and Hochheiser, 2017), amongst others.

The participants were asked to share their knowledge and experience in the following ways:

- Please explain the process of interventions on existing buildings and the involvement of stakeholders
- Please tell me about your preparations for building documentation
- Please share your experience of a usual building visit
- Please explain what happens after the building visit

These requests were followed by prompts and probes to encourage participants to share as much information as possible. The participants were in the age range of 25 to 34 years with working experience of two to seven years and one-half to five years specifically in interventions on existing buildings. Two participants were female, and five were male. Five participants were Italian and studied in countries such as Germany, Austria, and Italy. The remaining two participants were German and Austrian. The countries of work of the participants varied between Germany, Italy, Switzerland, and Austria. The diverse range of countries studied and working practices increase the robustness of conclusions. The interviews were conducted in German and Italian and both in-person and online. Two professionals work as autonomous freelancers. The other participants work in companies with 2 to 60 employees. The interview data was analyzed following informal techniques for qualitative emergent data coding and content analysis, following (Lazar, Feng and Hochheiser, 2017).

Interview Findings

The findings of the interviews are organized in the order in which the topics were addressed. First, an overview of the intervention procedure is given. Second, the preparations and site visits as well as the documentation carried out are described. Third, attention is given to information organization and post-processing of the documentation.

Existing Building Intervention Procedure

For many professionals (E.2, S.1, S.2, S.3, O.1), it was difficult to generalize how they proceed during on-site building documentation. As they stated, their approach would depend greatly on the objectives to be achieved. However, some (A.1, E.1) were able to draw a clear picture of repeating elements and patterns during the task of creating building documentation. The professionals who were able to do so were those who took leading roles, worked independently, and had the most experience in working on existing buildings. The site visits carried out by the professionals were described from project entry until the end of the planning phase. Table 1 shows a summary of the visits and their description.

The first visit carried out by all interviewed professionals is mostly described as a kickoff meeting, in which stakeholders participate. Afterwards, A.1 and S.2 visit the site again during planning works to carry out surveys and create the documentation.

The owner (O.1) stated that the number of site visits carried out by him strongly depends on the project size. When big works such as extensions are to be executed, frequent visits for discussions during planning and execution are carried out along with an architect. For small renovation work, O.1 expects that the professionals and contractors execute the works that he agreed on independently. The owner wants to be informed, although not every detail needs to be communicated.

Table 2 summarizes the stages at which the interviewees and other stakeholders join the projects. One of the participants (E.1) carries out projects where the energy planner leads the project, and no architect is involved. Therefore, E.1 joins at the stage of collecting data and preparing the brief. However, S.2 suggested that energy retrofits are often carried out by architects. One participant (A.1) is the leading architect who is also involved in collecting data and preparing the brief, and all others (E.2, S.2, S.2, S.3) join the project after being contacted by a collaborating architect during the stage of concept design. In other cases, structural engineers (S.1, S.2, S.3) carry out inspections to develop and evaluate intervention strategies.

Table 1: Visits carried out by stakeholders

Partici-pant	Number of Site Visits in the Planning Phase	Type of Visit	Description
A.1	2+	First visit, Survey	Clear working patterns
E.1	1	First visit	Clear working patterns
E.2	1	First visit	Depending on objectives
S.1	1	First visit	Depending on objectives
S.2	2+	First visit, documentation	Depending on objectives
S.3	1	First visit / damage documentation	Depending on objectives
O.1	1 for small works	First visit / Many visits	Depending on objectives

Table 2: Stakeholders and moment of joining a project, referring to (RIBA, 2020) *as visualized in Figure 1*

Partici-pant	Stage of Joining the Project	Other Stakeholders
A.1	From collecting data and preparing brief	Client, structural engineer, energy planner, contractor, building authorities
E.1	From collecting data and preparing brief	Client, planners (building envelope, technical building equipment), contractor, bank, building authorities
E.2	Concept design	Client, architect, structural engineer, contractors, site management
S.1	Concept design	Architect, client, technical building equipment professional
S.2	For developing and evaluating strategy or concept design	Client, preservation authorities, architect, structural engineer, contractor

Partici-pant	Stage of Joining the Project	Other Stakeholders
S.3	For developing and evaluating strategy or concept design	Architect, contractor, material testing institute
O.1	For developing and evaluating strategy	Architect, property manager, other building professionals communicating with the architect, contractors

Preparations, Site Visits, and Documentation

Many of the participants (E.1, S.1, S.2, S.3) study existing documentation before conducting the first site visit. However, (A.1) does not want to be influenced previous to the arrival on site and prefers to have a real-life picture before seeing drawings. The participants (A.1, E.1, S.1, S.2, S.3) use the existing documentation to check whether the current state of the buildings complies with existing drawings. Some participants (A.1, E.1) mentioned their personal professional responsibility in this regard. One professional (E.1) reported marking building parts as verified on the existing documentation when the parts comply with in-situ conditions. Next to viewing the existing drawings, professionals refer to other documentation sources such as satellite images (S.1), photographic documentation of construction (E.1), bills of previous interventions, and the information of formerly involved stakeholders (S.2). The importance of identifying possible safety issues on-site prior to the arrival and the preparation of the professional for such was pointed out (S.2). Some participants (S.2, S.3, E.2.) also distinguished between site visits due to planned works and periodic checks or visits due to damage.

The information as well as the tools and documents used by the participants is shown in Table 3. All participants (A.1, E.1, E.2, S.1, S.2, S.3) agreed that when building documentation exists, it is mostly limited to two-dimensional (2D) drawings. Some argue that even when there are computer-aided design (CAD) drawings, they are not available to the planner (S.2). Others (E.2, O.1) do not wish to use 3D CAD or BIM data and only use prints of 2D drawings of the relevant documents. The architect, when referring to geometries, considered mostly spaces, whereas the structural engineers referred to load-bearing building parts, and the energy planners were interested in geometries regarding cross-sections of the building envelope. In addition, structural engineers (S.1, S.2, S.3) identified the load-bearing building parts, and energy planners (E.1) focused especially on the insulation layers.

Table 3: Collected information, tools, and documents

Part ici-pant	Information and Details	Tools	Docu-ments
A.1	Client needs, 360° pictures, geometries (LiDAR data+ distance laser for checks) Details depending on the task	Pen & paper, drone, smartphone with LiDAR sensor, meter tape, distance laser, 360° camera	Drawings (print)
E.1	Client needs, building geometries, wall and ceiling cross-sections & geometries, panoramic pictures, pictures, window size & position, damages, heating system, materials, building age Details: window frame, window glazing, shadow elements type, shadow element control, heating niche, heating control, parapet height	Smartphone, tablet, meter tape, distance laser	Drawings (digital)
E.2	Pictures, interventions to be proposed, probes, sketches of experimental setups, locations of samples Details depend on the task	Smartphone, meter tape, pen & paper, moisture meter, thermal camera	Drawings (print)
S.1	Materials, geometries, pictures Details: deformations, cracks, spalling	Meter tape, pen & paper, smartphone	Drawings (print)
S.2	Client needs, pictures with measures, damages, damage causes, materials, geometries of building parts, surface quality and temperature, sketches, temperature, signatures for protocols Details: cracks, spalling	Personal protective equipment, meter tape, distance laser, ladder, pen & paper, smartphone, headlamp, laptop/tablet, hammer, crack card, chemicals, drill machine	Drawings (print)

Participant	Information and Details	Tools	Documents
S.3	Pictures and descriptions in mobile app Details: cracks, spalling	Meter tape, rebar scanner, hammer, tablet, crack card	Drawings (digital)
O.1	Visual inspection, possibilities for changing the room division, sound insulation Details: none	none	Drawings (print)

Only one professional (A.1) used mobile LiDAR technology for capturing existing buildings. However, a distance laser is used additionally to take a more accurate measure of some distances. After the visit the LiDAR measurements are checked using the noted distance laser measurements. Interviewees use meter tapes for physical length representation during the preliminary evaluations (A.1) as well as to add measurements to photographs (E.1, S.1, S.2, S.3). One structural engineer (S.1) mentioned that in case no meter tape is at hand, he uses the measuring app that comes with iOS. According to the initial use of mobile LiDAR technology for building measurement and documentation by a small number of interview participants, the technology is emerging.

Various participants (A.1, E.1, S.1) mentioned the risk of not being able to recall the in-situ conditions after visits. Some attempt to overcome this problem by creating 360° or panoramic images (A.1, E.1) or simply taking as many pictures as possible (S.1, S.2). Regarding images, one participant (A.1) mentioned the importance of the possibility of organizing pictures along a timeline for creating a chronological project overview. For structural engineers, (S.2, S.3) geo-tagging is more important, in order to note exactly where damage occurred. Furthermore, the interviewees make sketches of cross-sections (A.1, E.1), wall views (S.2), experimental setups (E.3), and testing locations (E.2, S.3).

For the owner participant, many site visits are carried out periodically. During these periodic visits, pictures are taken and consequently annotated and distributed via e-mail. The current approach could be much more efficient with the use of appropriate software, according to O.1. The interviewed owner prepares for building visits by carrying out a document check for financial viability and studying the current situation on-site including sound insulation and room division before meeting other stakeholders. He takes pictures only when either damage is found or there is a need to advertise the apartment.

Participants rely on manual inspection, such as knocking on surfaces for collecting information on the material used (S.1, S.2) or touching them for collecting moisture and temperature information (S.2).

Accuracy needs were described by the interviewed stakeholders. They vary according to tasks and building parts. One energy planner (E.1) reported that he notes certain information only regarding the accuracies needed by him at the time. He stated that instead of having exact information about the wall thickness, he is more interested in documenting the thermal behavior. E.1 referred to regulations demanding a maximum of 2% deviation. S.1 estimated a needed accuracy of 0.5%. S.2 explained that measures and their accuracies are relative in existing buildings, especially for historic buildings with tilted walls and uneven surfaces. Therefore, S.2 accepts deviations in the order of magnitude of centimeters.

Several interviewed professionals (E.1, O.1, S.2) mentioned that much communication effort is required for interventions on existing buildings. They explained the importance of appropriate communication with the client and referred to the problem of limiting the amount of information passed on as well as explaining complicated topics in an easy and appropriate way to clients who lack domain knowledge. Problems such as lack of information and wrong preliminary assumptions as well as the continuation of planning during execution were reported (S.1, S.2, E.1). They pointed out the need to communicate information or agreements instantly and to refer to a specific building part to minimize misunderstandings. One professional (S.2) underlined the importance of collecting signatures for protocols on agreements that have been made. Real-time documenting of information that is associated to specific building parts in a digital building model is seen as a big advantage to avoid misunderstandings and save time (S.2). However, it was stated that manually creating BIM models of existing buildings does not pay off in most cases (S.2).

Participants (A.1, E.1, S.1, S.2,) mentioned the evaluation paths they follow during building visits according to Table 4. Paths include the following:

1. Exterior overview
2. Building entry
3. Interior layout overview per floor
4. Interior overview in height
5. Detailed observations

as illustrated in Figure 4.

Interviewees reported that observations are made in increasing detail during the visit. The observed details where summarized in Table 3 (grey color).

One participant (E.1) mentioned that his visits are limited by time constraints.

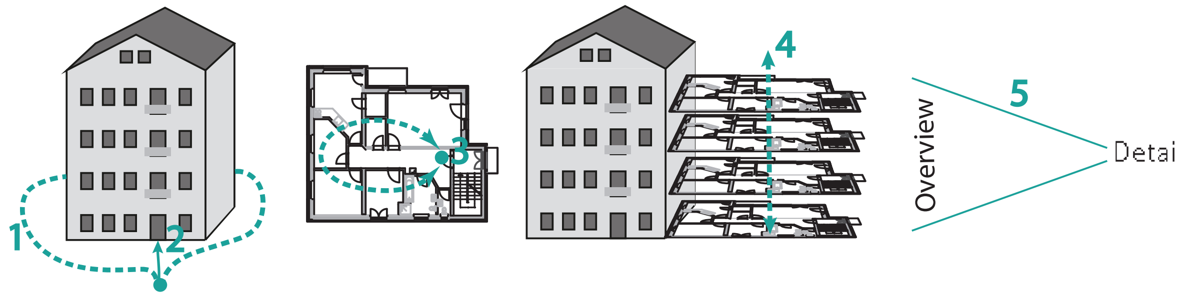

Figure 4: The path followed by professionals during the creation of building documentation

Table 4: Followed paths

Participant	A.1	E.1	E.2	S.1	S.2	S.3	O.1
Path followed	yes	yes	no	yes	yes	no	no

Two participants (S.1, S.2) described an interview-like setting, where they try to obtain information from those with knowledge of the building and its history. The owner, previous contractors, and planners are contacted to gather as much information as possible (S.1, S.2). One professional (E.1) mentioned that the understanding of building geometries on-site can be problematic. He explained that the understanding often evolves when organizing the collected information back in the office.

The energy planners (E.1, E.2) pointed out that there are specific national subsidies for energy retrofits. They have to carry out their work in compliance with those regulations. For example, pictures must be taken from all sides of the building and for all subsidized building parts. The states before, during, and after construction have to be documented photographically with visible geometries.

Information Organization, and Post-processing

After completing the necessary building documentation, the participants (E.1, E.2, S.1, S.2) take on planning tasks. For this purpose, they first digitalize and organize the collected information. Some (A.1, S.2) mentioned that they scribe each detail. One participant (E.1) referred to a potentially large time gap between the visit and the actual start of the planning works, leading to an elevated need for documentation. The strategies for ordering information in the group of participants vary between process, building-part, and room-based approaches (see Table 5).

According to E.1, A.1, and S.2, the visit is followed by multiple intervention proposals and discussions, which is an iterative process. In this process E.1 collects performance data such as heating energy consumption for model calibration. Two (A.1, S.2) interviewees stated that they try to involve the contractors of the work as early as possible in the discussion to gain their valuable input. Similarly, one interviewee (A.1) involves the building authorities to increase the client's planning safety.

Table 5: Information organization, and software

Participant	Organization Type	Software used
A.1	Process-based	None; organization through folders
E.1	Based on building parts	Excel
E.2	Process-based	None; organization through folders
S.1	Room-based	None; organization through folders
S.2	Based on building parts	Excel
S.3	Based on building parts	Software tool used during inspection
O.1	No information collected	None

The owner participant reported that the initial formalization, which is prepared by the professional, is usually not compliant with what was discussed on-site. Already exchanged information is often misplaced or missing. He stated that he must communicate details repeatedly. Usually, much communication effort is made until the expectations are met by the planner.

When asked about possible future improvements, some participants (E.1, O.1) referred to the lack of standards regarding project documentation. When handover of the building is completed, aside from the legally required documentation, no information is provided to the client by the planner or contractor.

Identification of User Requirements

The interview results indicate that the needs of the stakeholders vary according to their specialty and the specific tasks to be carried out for a given intervention. Although numerous project scenarios were described, the obtained observations were similar for professionals within the same group. With regard to the content, differences between the professional groups were identified with help of the interviews. While architects focus on documenting the client's expectations and the organization of spaces, structural engineers concentrate on geometries and materials of load-bearing building parts as well as any damage and deformations found. They carry out tests, which they document regarding location and outcome. Energy planners focus on the building envelope with its geometries and thermal properties. Details of windows and the heating system are important to them. They may carry out tests for registering moisture and temperature. Also, client needs are noted by energy planners. The owner focuses on room layouts and damage and collect little information in case they are present.

The differences in observational focus and the large variety of tasks are crucial conditions for having personalized interfaces. In most of the settings mentioned by the participants, architects have the leading role in the intervention. In the case of energy retrofits, an energy professional might lead the intervention planning, typically while coordinating with the architect or the owner. Hence, the stakeholder profiles included in the application should be flexible.

It should be possible to integrate 2D drawings in the interface to allow an immediate comparison between the documented and actual states of the building. Additionally, other information sources such as satellite images should be accessible at hand.

The same applies to capturing the current state through a LiDAR sensor, the possibility of inserting check measures should be incorporated because most interviewed professionals need to compare the in-situ conditions with the documented state. For example, a meter tape is kept at hand as a physical representation of length. This proposed concept complies with the practice of the only interviewed professional who uses LiDAR technology in his documentation practice. Furthermore, images should be captured within the application and be geo-tagged. At the same time, it should be possible to integrate panoramic 360° pictures of spaces and rooms to assist users.

A vast number of notes must be taken during the interviews. Due to the time pressure mentioned by the participants, we propose the possibility of integrating voice recordings to avoid a loss of focus due to typing. Sketching is carried out during visits by most participants. It should be explored whether related functionalities should be incorporated.

Information is collected from sources such as the knowledge from owners, professionals, and contractors. Information is categorized according to the way it was obtained as often the information cannot be validated until work is ongoing. In addition, the documentation needs to be organized in other dimensions: the project state, spatial structure and its dependencies, building parts, and the time at which a certain piece of information has been collected. Information should incorporate additional context describing its accuracy. While some professionals need very precise information overall, others annotate information with an accuracy that is compatible with their purpose. Required features and respective user groups are summarized in Table 6. The symbol "*" indicates need for advanced software support.

Table 6: Required interface features for each user group (the symbol "" indicates need for advanced software support)*

Feature	User group
Document	
• client expectations	A E
• organization of space	O A
• building envelope geometries and properties	E
• window details	E
• heating-system details	E
• testing locations and test results (humidity, temperature)	E
• load-bearing building parts (geometries and material)	S
• damage *	S O
• deformations *	S
• Testing locations and results (material)	S
Change management *	S A
Follow the users physical paths	A E S
Compare the current state of the building with existing 2D documentation *	A E S
Check-measurement documentation *	A E S
Organize information according to • project state • rooms • building-parts	A E S
Associate information attributes such as • the person who captured it • information source • verification status • accuracy • the time it refers to	A E S
Categorize information by • material • geometry • damages • testing results • agreements made	A E S
Integrate notes and sketches *	A E S
Associate images as well as 360° panoramic pictures *	A E S
Integrate all information for multiple data views *	A E S O

Conclusions

This paper contains a description of the needs of architects, structural engineers, energy planners, and building owners regarding interfaces for building documentation. The approach followed studies the practices and common use cases of seven professionals.

Each user group needs a unique set of user interface features. In addition, the interviews suggest that many project roles are relevant. Emerging possibilities of real-time and interactive building geometry capture, object segmentation, and documentation generate a growing need for studying HCI for building documentation.

Future Work

A prototype accommodating these results will be developed, tested, and enhanced using the knowledge gained during testing. In order to confirm conclusions, the pool of interviewees should be enlarged. In particular, it would be beneficial to include the group of contractors, because they are often included at early stages of planning. This approach has potential to be expanded to other engineering areas.

Acknowledgments

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