D1.3 – Concept descriptions of user interfaces and human-robot interaction

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 958450. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

Project Title	Improving Building Information Modelling by Realtime Tracing of Construction Processes
Project Acronym	BIMprove
Grant Agreement No	958450
Instrument	Research & Innovation Action
Topic	Industrial Sustainability
Start Date of Project	1st September 2020
Duration of Project	36 Months

Name and Number of the deliverable	1.3 Concept descriptions of user interfaces and human-robot interaction
Related WP number and name	WP 1 - Systems design & specification
Deliverable dissemination level	Public
Deliverable due date	30 April 2021
Deliverable submission date	30 April 2021
Task leader/Main author	Kaj Helin (VTT)
Contributing partners	Timo Kuula (VTT), Marja Liinasuo (VTT), Vladimir Goriachev (VTT), Matthias Aust (FhG-IAO), Melissa Otto (USTUTT), Jörg Frohnmayer (USTUTT), Frank Sulzmann (FhG-IAO)
Reviewer(s)	Pål Ystgaard (SINTEF)

Abstract

This is the first version of Deliverable 1.3 "Concept descriptions of user interfaces and human-robot interaction", and it will be updated after each development sprint (at M13, M18; and M24). Deliverable introduces tangible ideas for user interfaces and human-technology interaction in BIMprove project. At a beginning, the main meanings of the concepts of 'human-robot interaction,' 'usability' and 'user experience' are introduced. Secondly, the general-level BIMprove user interface concept and BIM user interface categories are introduced. Thirdly, deliverable provides a more detailed description of two user interface categories (BIM@SiteOffice and BIM@Construction). Finally, conclusions are made about the work done from the perspective of this deliverable.

Keywords

Building Information Modelling, Digital Twin, User interface concepts, Usability, User Experience, Extended reality, Virtual reality, Augmented reality, Mixed reality, Human-Robot interaction

Revisions

Version	Submission date	Comments	Author
v0.1	22nd April 2021	The first integrated version	Kaj Helin (VTT)
v0.2	23rd April 2021	Ready for SINTEF quality check	Kaj Helin (VTT), Timo Kuula (VTT), Marja Liinasuo (VTT), Vladimir Goriachev (VTT), Matthias Aust (FhG-IAO)
v.1.0	29th April 2021	Approved, final version	Pål Ystgaard (SINTEF)

Disclaimer

Acronyms and definitions

Acronym	Meaning
AR	Augmented Reality
BIM	Building Information Modelling
FOV	Field of View
GUI	Graphical User Interface
HMD	Head Mounted Display
HRI	Human-Robot interaction
MR	Mixed Reality
MUVR	Multi-User-Virtual-Reality
UI	User Interface
UX	User Experience
VR	Virtual Reality
XR	extended Reality

BIMprove project

In the past 20 years, productivity in the European construction industry has increased by 1% annually only, which is at the lower end compared to other industrial sectors. Consequently, the sector has to step up its digitization efforts significantly, on the one hand to increase its competitiveness and on the other hand to get rid of its image as dirty, dangerous and physical demanding working environment. Construction industry clearly needs to progress beyond Building Information Modelling when it comes to digitizing their processes in such a way that all stakeholders involved in the construction process can be involved.

The true potential of comprehensive digitization in construction can only be exploited if the current status of the construction work is digitally integrated in a common workflow. A Digital Twin provides construction companies with real-time data on the development of their assets, devices and products during creation and also enables predictions on workforce, material and costs.

BIMprove facilitates such a comprehensive end-to-end digital thread using autonomous tracking systems to continuously identify deviations and update the Digital Twin accordingly. In addition, locations of construction site personnel are tracked anonymously, so that **BIMprove** system services are able to optimize the allocation of resources, the flow of people and the safety of the employees. Information will be easily accessible for all user groups by providing personalized interfaces, such as wearable devices for alerts or VR visualizations for site managers. **BIMprove** is a cloud-based service-oriented system that has a multi-layered structure and enables extensions to be added at any time.

The main goals of **BIMprove** are a significant reduction in costs, better use of resources and fewer accidents on construction sites. By providing a complete digital workflow, BIMprove will help to sustainably improve the productivity and image of the European construction industry.

Contents

Index of Figures

1. Introduction

The present, first version of Deliverable 1.3 is the first deliverable to present tangible ideas for user interfaces and human-technology interaction in BIMprove project. Firstly, the main meanings of the concepts of ‘human-robot interaction,’ ‘usability’ and ‘user experience’ are presented. Also, some practical notes are provided about the use of those concepts as part of technology development. Thereafter, the user interface concepts are provided; first, the general-level concept encompassing all user interfaces and second, a more detailed description of two specific user interface categories (BIM@SiteOffice and BIM@Construction). Also, a practical categorisation of all user interfaces is presented to guide the following user interface design. Finally, conclusions are made about the work done from the perspective of this deliverable. This first version of this deliverable will be updated after each development sprint (at M13, M18, and M24).

2. General concepts and guidelines

Usability and user experience (UX) both represent human-centred approach in the design of a system (such as the BIMprove application). Usability and user experience are important approaches when designing solutions for human use. Considering usability and UX in the design ensures that the users are motivated and capable of using the solutions as expected and in productive and fluent ways.

The general usability and UX guidelines can be utilised in all system design. Also, human-robot interaction is here presented. The concept is wide and will be clarified in the next section. Furthermore, more specific guidelines related to Extended Reality (XR) is described, to give deeper insights into the specific systems that are relevant in BIMprove.

Literature about usability, user experience, human-robot interaction, and XR can all be used as supporting design from the user perspective, resulting in fluent working and better results.

2.1. Human-robot interaction

Human-robot interaction (HRI) can be defined as the field of study about understanding, designing, and evaluating the robotic systems used by or collaborating with the human operator (Sharkawy, 2021); and/or understanding this interaction from both the human and robot perspectives; and/or extending the parties in interaction from the human operator to all individuals who are affected by the robot due to its’ vicinity. The difficulty in finding an appropriate definition for human-robot interaction reflects, at least, the novelty of it.

The application area of human-robot interaction is vast, including, for example, planning or coordination between the tasks for human and robot in collaboration or interaction, and programming. In this scope, human-robot task allocation and scheduling, metrics for HRI, social aspects, programming also including user interface related issues such as visual guidance and imitation, voice commands and haptic interaction as well as physical HRI and safety related issues are included (Tsarouchi, Makris, Chryssolouris, 2016). Studies have also been made in a smaller scope, such as the features of robot gaze behaviour and appearance that improve interaction (Admoni, Scassellati, 2017).

The difficulty in defining features in human-robot interaction is that the term ‘robot’ is not accurate. There are several types of robots, enabling different types of human-robot interaction. At least robot’s task and task-related functionalities and how they are realised, and in what way human is supposed to interact with the robot, are crucial factors to take into account. General-level rules are hard to provide.

Human-robot interaction experience is shaped by human and robot but not in a symmetrical way. From the human perspective, it depends on how a person perceives and experience the interaction. From the robot-centric view, the design of the robot (visual, behaviour, etc.) affects interaction experience. In both cases it is the human, of course, who perceives (Young, Sung, Voida, Sharlin, Igarashi, Christensen, Grinter, 2011). Young et al. (Young et al., 2011) have identified three main factors contributing to this interaction – visceral factors, social mechanics, and social structures (see Figure 1).

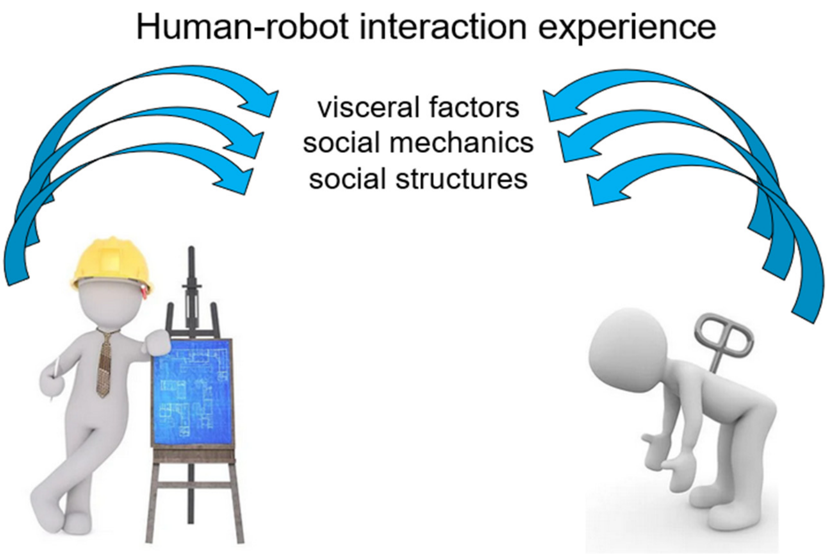


Figure 1: Factors affecting human-robot interaction experience.

Visceral factors of interaction focus on a person’s biological, visceral, and instinctual involvement in interaction. This includes such things as frustration, fear, joy, happiness, and so on, as an "instinctual" reaction to robot, in the level where they are difficult to control.

Social mechanics refer to the higher-level communication and social techniques in interaction. This includes both the social behaviour of a person when interacting with the robot and how the person interprets robot’s behaviour from the social perspective. Social mechanics function in many levels, starting from facial expressions and gestures to spoken language and cultural social behaviour related norms (such as the size of personal space and eye-contact rules).

Social structures cover the development and changes in the interaction between human and robot over a longer period of time.

These factors (visceral factors as well as social mechanics and structures) are probably the more relevant the more the robot resembles a human being by appearance and behaviour, especially depending on how autonomous the robot is or appears to be from the human's perspective. Regarding robots to be used at the building site, these factors do not probably play as relevant role as with robots, which are used, for example, in health care in nursing related activities.

Robots can be used in environments that are unreachable by or are unsafe for human beings. Then, effective human-robot partnership needs to be established. Trust is a prerequisite for this, affecting the successfulness of human-robot interaction. It was found in a review (Hancock, Billings, Schaefer, Chen, De Visser, Parasuraman, 2011) that when the effects of human, robot, and environmental characteristics were studied, the robot performance-based factors, such as robot behaviour and the reliability of the robot were the strongest contributors to the development of trust in HRI. Environment, defined as team collaboration characteristics and tasking-related factors in this study, played only a moderate role in this. Only a little evidence was found on human-related factors that were related to human abilities and characteristics in this study. This may not be the case in reality but the small number of studies found in this area can be the reason for this result.

From the studying perspective, human-robot interaction is such a vast concept that in practice, almost anything can be labelled as belonging to it, provided that the core parties – human and robot – are both included in it. In practice, from BIMprove perspective, the meaning of human-robot interaction depends on the qualities of the specific robot in question. If the robot is, for example, moving around the site, safety related issues need to be identified in human-robot interaction. If the robot is stationary, a usability or user-experience based evaluation may be all that is needed. In the following, usability and user experience approaches are clarified.

2.2. Usability

Usability is defined in the European standard EN ISO 9241-11:2018 "Ergonomics of human-system interaction. Part 11: Usability: Definitions and concepts". In the standard, usability is defined in the context of human-system interactions as "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use".

In practice, then, usability refers to a certain quality when using some entity. In the context of BIMprove, usability can be applied in situations where people use and interact with the building information model although usability also refers to other systems as well (such as built environments, industrial and consumer related products and technical and personal services).

Regarding the key concepts of the above quoted definition of usability, it is defined in ISO 9241-11:2018(en) that

- **effectiveness** refers to accuracy and completeness with which users achieve specified goals (point 3.1.12);
- **efficiency** refers to resources used in relation to the results achieved (point 3.1.13);
- **satisfaction** refers to the extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations (point 3.1.14).

Usability does not only depend on the quality of the system. The context of use affects usability as well (see Figure 2).

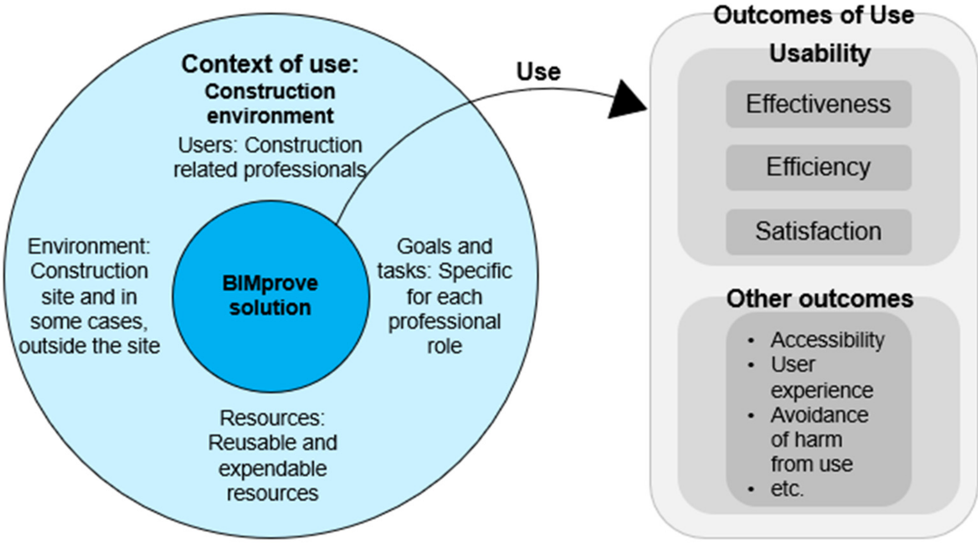


Figure 2: Usability that results from a use of a BIMprove solution in the construction context of use, modified from the figure in EN ISO 9241-11:2018 standard.

Usability is affected by users so that, for instance, a professional user appreciates logical, versatile functionalities and professional, business-like look while a casual user enjoys the few functionalities that are needed for casual use and enjoyable, possibly more colourful appearance. The fact BIMprove system is for professionals eases a bit the development of the system. When the system is used by professionals needing the system for work, it usually means that the system does not need to be entertaining or attract the user. Instead, it is enough that the system is logical and easy-enough to use. Even a complex system can be appropriate from the usage perspective; if it is used frequently, the complexities will be learned by heart. If the system is appropriate for its intended usage, user forgives more easily the difficulties in learning to use of the system. The situation is quite the opposite when a system for casual users are in case as then, immediate pleasure is sought for.

Usability is also affected by the goal, the intended outcome of the user when using the system, and the tasks with which the system is to be used. If the user's goal and tasks are well known, it is easier to develop a usable system than in the situation when the goal and tasks are not known or when there are diverse types of users with different goals and tasks. In BIMprove, the main features of work of BIMprove users are identified, described in section 6.3, which supports the development of a meaningful system.

The environment in which the system is to be used - technical, physical, social, cultural and organisational - affect usability. For instance, if the system is to be used while moving outside, the usability related requirements are different from the ones for a system, which is to be used indoors and in when not moving. In BIMprove, the physical environment is especially considered.

Finally, resources that need to be used to achieve the specified goals have an effect, too. Resources can be reusable, such as equipment and information. Expendable resources include available time, human effort, financial resources and materials. Regarding a system, which is used in a mobile phone or tablet that is carried along, like in BIMprove solutions, connectivity belongs to the important expendable resources.

Usability can be studied when the designed system has some functionalities so that it can be tested from the usability perspective; so, the object can be a mock-up with simulated functionalities or a more or less finalised system with real functionalities.

2.3. User experience

User Experience (UX) is a concept used nowadays probably more than the one of usability. In the 21st century, it has become a buzzword in the field of human-computer interaction and interaction design (Hassenzahl & Tractinsky, 2011). According to EN ISO 9241-11:2018, UX is "a person's perceptions and responses that result from the use and/or anticipated use of a system, product or service". Thus, contrasting to usability, UX is even more subjective as UX is something that can be relevant even before the use of the system. Despite being highly subjective, or perhaps because of that, UX explains more of users' preferences and usage of the system than usability. Furthermore, UX moves towards a more emotionally appealing relationship between the user and the product. Usability theories focus on pragmatic aspects of product use that are at least partly objectively definable; for example, task completion, efficiency, effectiveness, and ease-of-use. UX is more associated with vague, dynamic, and hard-to-quantify concepts, such as "experience," "perception," "pleasure," and "emotions." The main challenges related to UX can be divided to (1) designing a user experience that is pleasurable, engaging and stimulating, and appropriate in the user's context, and (2) evaluating the UX and overall acceptability of the applications. (Olsson, 2013.)

UX is a dynamic concept; its quality is not, roughly stated, a matter of a moment but captured by how it changes over time (Harbich & Hassenzahl, 2016). Thus, one should not trust on the evaluated UX at some point but reflect its possible change during the time of its usage and, in accordance with time, the possible changing needs and preferences. It is, however, found that more playful users lose their interest than the less playful ones (Harbich & Hassenzahl, 2016). Regarding BIMprove, this fact facilitates the development of interesting applications as the BIMprove users are professionals who need it in their work.

User experiences can be asked already in the concept phase to receive feedback of the concept from the usage point of view. UX can also be studied when the device or system in question has been used for a long time to, for example, find out, why that device or system is used, if its use is not obligatory (like tools for professional use). When UX is studied to guide design, user experiences can be collected to form UX goals and, based on them, UX vision. For example, in the study by Kaasinen et al (2021), it was identified that building ecosystem members, here, tenants, had the goals for a smart building such as 'Enjoyable' (I enjoy working and living in this environment) and 'Responsive' (the environment knows my needs and reacts to them smoothly). The UX goals were combined to form the ultimate goal for design, the UX goal of *'Feeling cared for and empowered as part of the community'* (Kaasinen et al., 2021).

To conclude, user experience is something that can be studied at any phase of a system development, starting from an idea, a concept or a mock-up and to a ready-made product. Studying user experience is not restricted to any specific aspect of the usage of the system, as long as there is the idea of the usage of that system included.

2.4. Usability and UX in mobile and XR applications

The general usability and UX design principles can be utilised broadly for all kinds of devices and human-technology interactions. However, in the context of BIMprove, the mobile devices and solution usage *on the move* play an important role. For example, map and navigation tools, warning/information messages and augmented reality solutions are primarily aimed at mobile and portable devices, such as smart phones, tablets, and even smart watches, to be used in specific and changing locations at the specific time. There are some specific usability and UX matters to be considered when designing such solutions.

Generally, in mobile applications, the design requires special attention due to **limitations of mobile devices** (e.g., screen size) and the **context-awareness afforded** by the embedded sensors (Dirin & Laine, 2018). The solutions are expected to provide **context-relevant information at the right moment,** and to support **situational awareness**. The availability of **internet connection** is usually crucial in the use of the mobile solutions and may not be self-evident. **Physical ergonomics** and comfortable use need to be considered as well, especially related to the larger portable devices (tablets) and wearable devices (AR glasses etc.). [1]

According to Dirin & Laine (2018), especially in AR solutions, users are engaged both mentally and physically in the application. The mental engagement in this context means that users fully concentrate on the application, and short- and long-term memory are engaged in the application. Physical engagement means that users often need both hands, eyes, ears and even the rest of their bodies to be involved with the application.

Olsson (2013) describes six categories for design and evaluation of mobile augmented reality (MAR) solutions. These categories would emphasise the UX aspect, but also include some of the more pragmatic (usability) viewpoints in the user's experience:

(1) instrumental experiences (e.g., efficiency, meaningfulness): The feeling of being able to perform tasks and activities with less effort, time and other resources; the solution appearing personally meaningful, appropriate and relevant in the user's current context and activity.

(2) cognitive and epistemic experiences (awareness, intuitiveness): Awareness can be manifested as becoming aware of, realizing something about or gaining a new viewpoint to one's immediate surroundings (e.g., locations and objects). Intuitiveness relates to the feeling of naturalness and human-likeness in interacting with the AR information.

(3) emotional experiences (e.g., surprise, playfulness): Being able to receive contextually relevant, extraordinary, and useful information (e.g., being positively astonished of the content); supporting feelings of joy, amusement and playfulness (this is more relevant in leisure time activities than in work context but can be applied in certain ways.)

---

[1] Some detailed practical guidance for mobile solution design is available online from many sources, such as: https://www.smashingmagazine.com/2018/02/comprehensive-guide-to-mobile-app-design/

(4) sensory experiences (e.g., captivation, tangibility): The feeling of being immersed and engaged in the interaction with the environment enriched with AR content; the augmented content seems a tangible and integral part of the environment.

(5) motivational experiences (e.g., inspiration, creativity): Feelings of being cognitively stimulated, curious and eager to try new things.

(6) social experiences (collectivity, privacy): Feelings of participating in a user community, having novel ways for social interaction and communication; privacy issues.

Dubois et al (2013) have similar elements in their list of usability aspects, but it includes some additional relevant aspects for BIMprove solutions:

- Interaction forms: Evaluation focus on interaction devices, display format (e.g., perspective view) or interaction languages (e.g., gesture)
- Environment: Evaluation focus on work environment, such as luminosity, noise, dirtiness etc.
- Influence of technology on social interaction: Technology can facilitate communication, but it can also disrupt interaction because of cumbersome equipment.

These experience descriptions and elements can serve for solution developers as inspiration and targets for design, as well as a theoretical baseline against which to compare and assess design solutions and developed prototypes.

Usability and user experience have specific qualities when applied to specific contexts, such as VR. As stated above (citing Dirin & Laine (2018)), users are especially mentally and physically engaged in AR solutions. This is probably even more true for VR. Similarly, Olsson's six categories (Olsson 2013) are just as relevant to VR. Especially the feeling of being immersed (point 4 in the section above), and, in the case of multi-user-VR, social experiences (point 6 in the section above) are to be highlighted.

Tcha-Tokey et al. 2018 have proposed a model (see Figure 3) for UX in Immersive Virtual Environments in which it is decomposed into the sense of presence, flow, and experience consequence, which all influence each other. Tcha-Tokey et al. 2016 propose a questionnaire to measure UX in an Immersive Virtual Environment using this model.

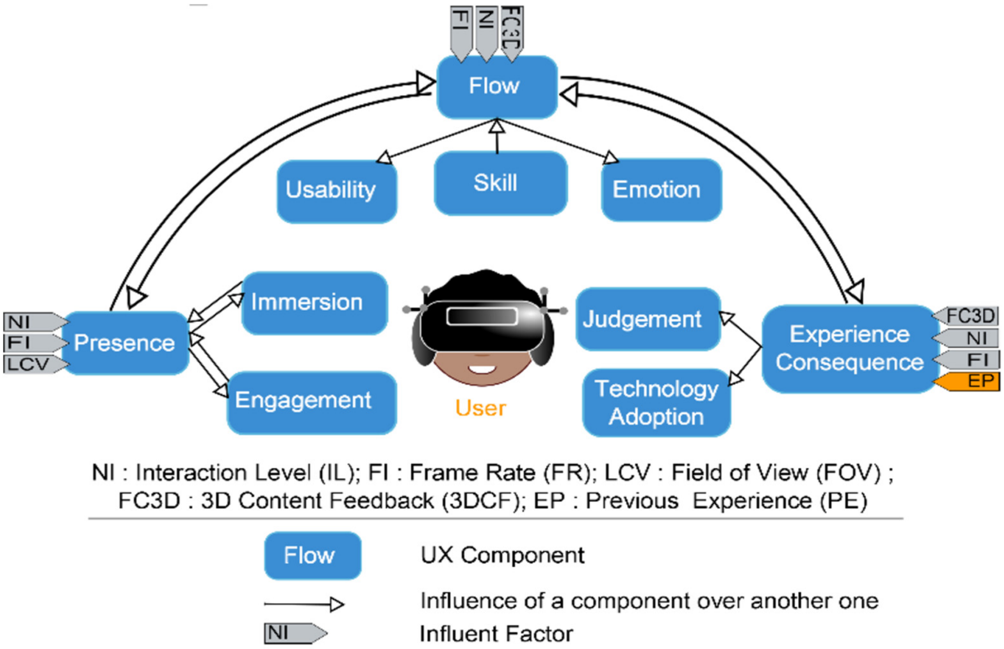


Figure 3: Model for user experience in immersive virtual environments, based on Tcha-Tokey et al. (2018).

Wienrich et al. (2018) have compared different measurements for UX in VR. The two major factors that are special about VR when measuring UX seem to be a) the concept of a sense of presence – the feeling of "being there" and b) the overall well-being of users during their use of VR, as discomfort and simulator sickness play a role.

Considerations of usability and UX in mobile, AR and VR applications are relevant, because user interfaces to be designed in BIMprove will also include a VR option. This will be further described in the following sections.

3. General UI concept

3.1. Overview

The construction Digital Twin Model has various layers and users with different needs and requests for information. There is no ‘one-fit-for-all’ graphical user interface (GUI) for all user roles and needs. BIMprove’s general UI concept has been created based on user stories from deliverable 1.1 "Overall system design", requirements from deliverable 1.2. “Requirements list of BIMprove”, and expert evaluation to fulfil the most of user needs. The general UI concept could be seen in Figure 4. The UI concept has four modes:

1. Digital Twin
2. Immersive Digital Twin
3. Mobile
4. Notification and Warnings

User is able to change modes based on device features and user profile based access rights. User can have the 1st person or 3rd person view in Immersive Digital Twin and Mobile modes. Digital Twin mode allows user to exploit just 3rd person view. In the 1st person view, user will see information from digital twin in real scale, e.g., can feel as if being located in a real room in Virtual Reality. In the 3rd person view, user can see information from digital twin in free distance, e.g., zoom in and out in a 2D map. There are mini maps on the 1st person or 3rd person views, which supports user’s orientation on the BIMprove Digital Twin model and gives better situation awareness. The most urgent and relevant information will be given to user via Notification and Warning mode.

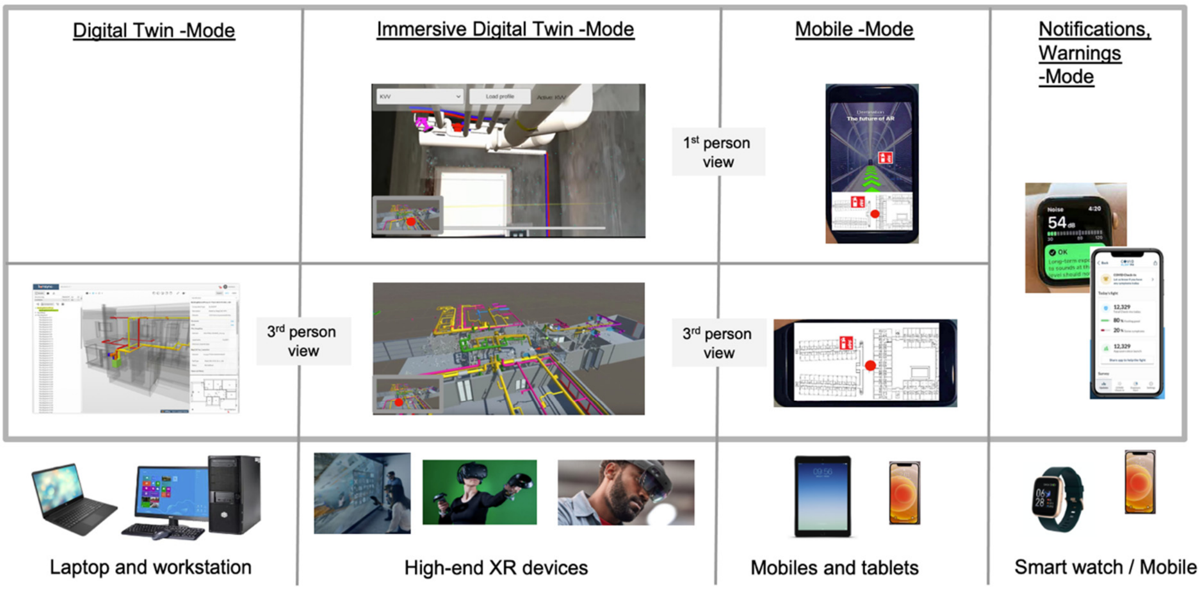


Figure 4: BIMprove's general-level UI concept, to be used in various devices.

3.2. Modes

3.2.1. Digital Twin Mode

The main purpose of Digital Twin Mode is to modify and insert data to BIMprove Digital Twin. This mode is mainly based on existing BIM software, e.g., BIMsync. The Digital Twin Mode allows the user to explore the model from the 3rd person view and access meta-data based on access rights defined in the user profile.

Main device to have Digital Twin Mode is personal computer, e.g., laptop or workstation.

Below can be found an example of BIM model coordination based on user story from D1.1. "Overall system design", which is using Digital Twin Mode:

As a BIM Manager (or BIM coordinator)	I want to be able to overview and track changes to BIM models (plans)
	so that I can coordinate them
	I need the following device: PC

3.2.2. Immersive Digital Twin Mode

The main purpose of Digital Twin Mode is to show user BIMprove Digital Twin model in as realistic and detailed format as possible. With this mode, user is able to jump in to BIMprove Digital Twin and experience the environment in one-to-one scale by using high-end XR devices. This viewpoint is called the 1st person view. In the 3rd person view, user is able to experience BIMprove Digital Twin model from free distance by zooming in and out. The mini map is supporting user to orient him/herself in the 1st and 3rd person views, which supports better situation awareness.

Main device will be high-end eXtended Reality (XR) devices e.g., Big screen, Powerwall or VR/MR/AR headsets.

Below can be found an example of Contractor Briefing user story from D1.1. "Overall system design", which is using Immersive Digital Twin Mode:

As a Contractor	I want to view the BIModel of the next milestone in construction
	So that I can show the workforce/forepersons what needs to be done
	I need the following device: Big screen, Powerwall or Multi-User-HMD-VR-System

3.2.3. Mobile Mode

The main purpose of Mobile Mode is to show user BIMprove Digital Twin model as as suitable format as possible with handheld devices. This mode is a simplified version of Immersive Digital Twin mode. User still has possibilities to switch between the 1st and 3rd person views, but the level of information is more limited. Main focus of Mobile mode is to provide user the most relevant

BIMprove Digital Twin information based on his/her user profile and locations. This gives easy access to information and gives better situation awareness when being, e.g., on-site.

Main device will be mobile devices, that is, tablet and smart phone.

Below can be found example of Locating people for safety purposes user story from D1.1. “Overall system design", which is using Mobile Mode:

As an emergency professional (role outside the construction organisation)	I want to know the location of the people at the site, especially of those who are at risk in the affected area.
	So that I can help them, especially those who are injured.
	I need the following device: Smartphone or tablet

3.2.4. Notification and Warnings Mode

The main purpose of Notification and Warnings Mode is to inform user about the most urgent and relevant information without any delays. System will be based on most common notification functions which are natively supported in smartwatches and mobile phones. These functions are vibration, sound and notification texts. Notifications and warning will be triggered based on BIMproves digital twin data and/or user location in construction site.

Main device will be handheld and wearable devices, e.g., smartwatch and mobile phone.

Below can be found an example of Entering hazard zones user story from D1.1. “Overall system design", which is using Notification and Warnings mode:

As a Worker	I want to be notified when I enter a hazard zone at the construction site
	So that I can be extra aware and careful
	I need the following device: Smartwatch

3.3. User roles

In Deliverable 1.1 Overall system design of BIMprove, a first list of stakeholders who might use the BIMprove system in some way was introduced. This list, including the descriptions of the different roles, has been updated and will be iteratively refined throughout the project. A part of this refinement process is the discussion on who will be the most important and most profiting users of BIMprove. User Stories have been collected for these roles.

- A great part of the tasks of **BIM Manager (or BIM Coordinator)** includes the support of less experienced personnel in BIM technology as well as model and data management on the

project. Also responsible for contacting designers and guaranteeing right quality digital design documentation. Such a person is also a link between the design office and the construction site. Her/his task is to maintain a good level of communication, which is mostly carried out by using IFC models. She/he also prepares well-written contracts with the designers, including the execution of the project with the use of BIM technology.
A BIM Manager is mainly active in the planning phase of the building.

- **Client**: An entity, individual or organisation commissioning and funding the project, directly or indirectly.
  A Client is mainly active in the planning phase of the building.
  (Depending on the construction project the owner and the client can be the same entity.)
- **Construction Site Manager (or Site Manager, Construction Manager)** is the overall responsible person for the project construction management at the construction site. The Construction Site Manager is required to keep within the timescale and budget of a project, and manage any delays or problems encountered on site during a construction project.
- **Construction worker**: A worker employed in manual labour of the physical construction.
- **Crane Operator**: Operates a crane (i.e., rotating tower crane) on the construction site.
- **Emergency Professionals**, i.e., fire fighters, paramedics, first aid workers, etc, are called to a construction site in case of an emergency.
- **Facility Manager** ensures functionality, comfort, safety and efficiency of the built environment by integrating people, place, process and technology.
  Facility Manager is mainly active in the operation phase of the building.
- **Foreperson (formerly Foreman)** is a construction worker or skilled trades-person who is in charge of a construction crew. This role is generally assumed by a senior construction worker.
- **Health and Safety Specialist** plans, makes audits, reviews and through overseeing the site can notice possible risks and dangers and then pass them on in an accessible and understandable form to the employees.
- **Owner** has the legal right or title to a piece of property.
  (Depending on the construction project the owner and the client can be the same entity.)
- **Planner Engineer** (e.g., architect, structural engineer, building services engineer, etc.) works with the construction technology and time schedule. She/he models and understands all the subsequent phases of the construction, creating 4D models.
  Planner Engineer is mainly active in the planning phase of the building
- **Project Controller**: A person working in this position must know, among other things, how the data and documentation management system works or where to find the current status of the project.
- **Project Manager** plans and oversees construction projects from beginning to end, hires subcontractors and works with engineers and architects as needed, and keeps track of an inventory of equipment and materials.
- **Quality Engineer** is responsible for archiving in the system or directly in the BIM model, assigning documents to the specific elements.
- **Surveyor** works within construction on the measurement and monitoring of projects, as well as producing maps, plans and charts of different features. When construction workers are unsure about the data in the model, or whether taken dimensions are correct, they often ask surveyors to mark and check, for instance, construction points or from work. 'Surveyor' is a very broad term that covers a wide range of disciplines and activities.
- **Tender Engineer** handles data needed to prepare a tender of the project.

- **Truck Driver**: Drives a truck to and from the construction site, e.g., to bring materials, carry off waste, etc.
- **User Representative**: A representative of the later users of the building/facility. This entity might or might not be different from owner and client.
- **Visitor**: Visitor to the construction site who wants information about the planned construction, or the construction process, out of private, professional or public interest, e.g., as part of civic participation or journalistic coverage.

4. BIM user interface categories

The construction of a building is a complex task. It involves many stakeholders from different companies, with different backgrounds and expertise, performing a huge variety of sub-tasks. The BIMprove systems aims to support a wide range of these tasks. So, it needs to facilitate being used not only by many different people, but also in very diverse contexts with suitable technical devices. This dictates that the conceptualisation of the BIMprove User Interfaces have to go way beyond a one-for-all graphical user interface (GUI). Instead, a variety of UIs will be designed that need categorisation in order to facilitate streamlining their design, development and testing. As implied above, this categorisation can be done based on the following features:

- User role(s)
- Task(s)
- Technical device(s)

As already described in Deliverable 1.1 "Overall system design", we think that the BIMprove UIs are best categorised by their context of use, as each of these contexts usually involves only certain subsets of user roles, tasks and technical devices. (The importance of the context of use has already been emphasised in section 2.2 Usability.) There are six such categories. The following four subsections show the idea of four of them, whereas the next section describes the remaining two in more detail, as these are the two we deem most important and also possibly the most complex ones.

4.1. BIM@Vehicle


[2]

This category covers the use of BIMprove from a vehicle or by the operator of a vehicle. The most prominent example is the one of a truck driver, e.g., connecting to the BIMprove System by using a smartphone or tablet (attached to the dashboard of the vehicle) to navigate in the construction site or

[2] BIM@Vehicle logo

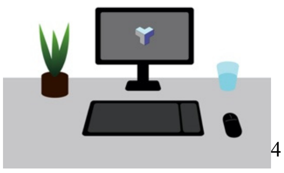
exchange information about the delivery of materials. This category also includes the use of BIMprove by crane operators.

4.2. BIM@Emergency

 [3]

One of the BIMprove-project's major goals is to improve both the avoidance of and the reaction to emergency situations. The BIM@Emergency category encompasses UIs to support both these goals. Possible user roles in this category are personnel of the construction company (e.g. Construction Workers as well as Health and Safety Specialists) on the one hand, and emergency professionals, such as fire fighters and paramedics, on the other hand. Likely scenarios include connecting to BIMprove via a mobile device to locate areas of (risk of) accidents on the construction site, after a Construction Worker has identified those areas to the BIMprove-System via their mobile device.

4.3. BIM@OffSiteOffice

 [4]

One goal of using Building Information Modeling is to facilitate coordinated planning by providing a single source of truth. The BIMprove project aims to maintain this single source of truth throughout the construction process. This requires the possibility for planner engineers (such as architects e.g.) to make changes to their plans, when requested, even during the construction phase. This is the most prominent example of the BIM@OffSiteOffice UI-category: Someone accessing the system remotely from their own office, away from the construction site, usually via a desktop computer or laptop to make changes to the as-designed-BIModel.

[3] BIM@Emergency logo
[4] BIM@OffSiteOffice logo

4.4. BIM@Anywhere

[5]

BIMprove will be a cloud-based system. This UI category facilitates accessing it from anywhere via a mobile device. The difference to other categories of UIs, where the expected main devices will also be smartphones and tablets, are the user roles and the tasks. User roles of BIM@Anywhere will be very diverse.

5. Detailed UI examples

Based on user stories from deliverable 1.1 "Overall system design", end-user interviews and expert evaluation following BIMprove UI concepts has been selected for detailed desig*n and implementation the first BIMprove system tests:*

- BIM@SiteOffice
- BIM@Construction

Following sub-chapters will explain these UI-concepts in more detail.

5.1. BIM@SiteOffice

[6]

The idea of having a "BIMprove hub", like a control centre, for a construction project, in a container-office, right at the construction site, has already been described in Deliverable 1.1 *Overall system design* and, especially regarding the idea of a multi-user-virtual-reality (MUVR) system, on a poster at the EuroVR 2020 conference (Aust, Otto, Helin, 2020). The concept will be reified, evaluated and refined during the course of the project.

It is envisioned that the site office will act as a connection hub between the different BIM@*-categories, equipped with a Head-Mounted-Display-(HMD)-based Virtual Reality (VR) system for multiple users (MUVR), a large interactive screen and a "normal" graphics workstation to view and discuss BIModels and support decision making and planning.

[5] BIM@Anywhere logo
[6] BIM@SiteOffice logo

The **HMD-MUVR**-system will be for co-located and remote use, so that users at the site office can discuss a model, e.g., comparing the as-designed-model to the current as-built-model (see Figure 5). But they can also be joined in their session from a remote location, e.g., for a planner engineer to give their opinion from their remote office. The motivation for a MUVR-system is the conviction that VR can a) ease communication about complex geometrical issues between users of different disciplines and b) induce a sense of presence in its users which in turn facilitates a state of flow. This will hopefully increase satisfactory task completion and overall usability and UX.

The following is an example use case, connecting BIM@Construction with BIM@SiteOffice (From Aust, Otto, Helin, 2020): A Foreperson on site is unsure about a construction issue, notices something unknown, or reports an error. They call the Construction Site Manager at the site office and raises their concern. BIM@Construction equips the Foreperson with AR, so they are able to see the current plans and compare them with reality. The Site Manager uses his/her high-fidelity VR equipment in the office to help overcome drawbacks of that AR-equipment, e.g., in field of view. Both can view and compare the current construction situation to the original plans and discuss about deviations to find a solution.

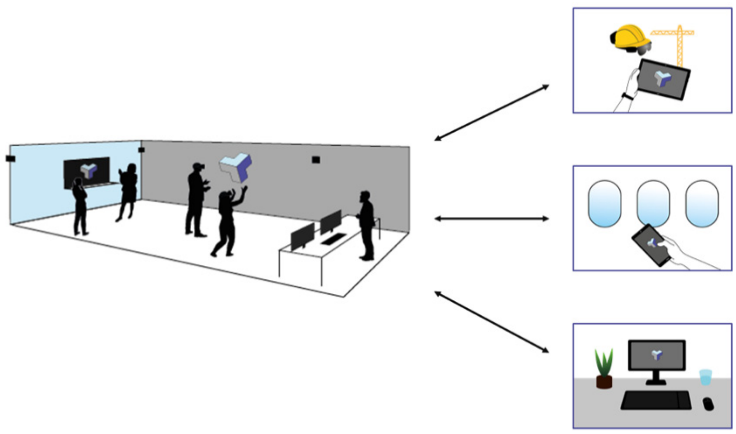


Figure 5: The SiteOffice-MUVR-System as a hub, where the VR-session can be joined remotely from different contexts with different devices

One important purpose of the **large screen** will be for other people to follow what the MUVR-users are seeing and discussing. As of now, discussions within the consortium about other purposes, features, and consequently on which hard- and software to use, are still ongoing. The screen could be used as a power-wall - a VR display of its own, for example. But also a lot of functions not involving the 3D-model of the building are being discussed, such as features supporting organisation like GANTT-charts- or other task-visualisation like KanBan-boards with virtual sticky notes.

In addition to the two kinds of VR-displays, we envision a desk with a graphics workstation PC, which could be the main workplace for the Construction Site Manager.

Regarding BIMprove's general UI concept (see the table in Figure 4), the three kinds of UI displays at the SiteOffice will implement the left side of that table: The Digital Twin Modes, both immersive and non-immersive, both 1st- and 3rd-person view, and both with workstation and high-fidelity VR-devices.

The following screenshots show first drafts of the graphical user interface (GUI).

5.1.1. Digital Twin Mode

Figure 6 and Figure 7 shows a draft of the GUI as it could be shown on a large screen in the SiteOffice (or, of course, on a PC-screen), while the same BIModel/digital twin is being examined in MUVR simultaneously. The three screenshots show three different selections of toggling the different discipline-layers and transparency.

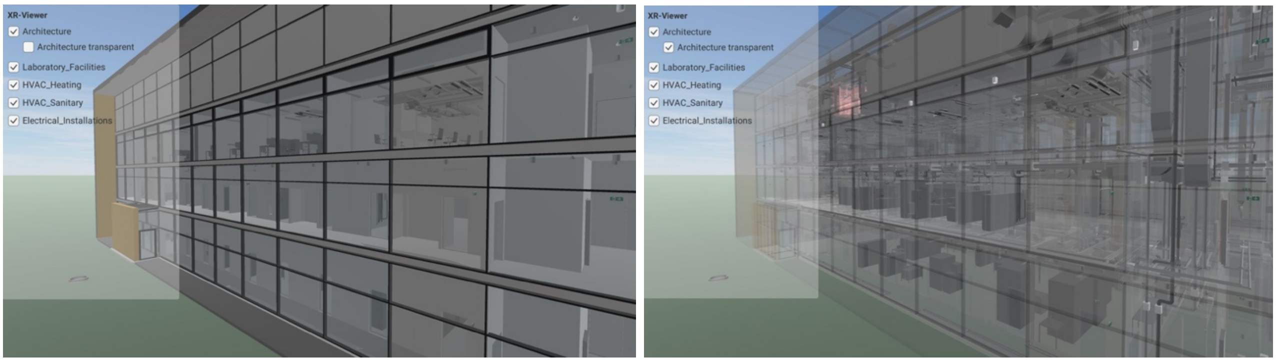


Figure 6: Draft of the GUI of BIM@SiteOffice. With and without "Architecture transparent"

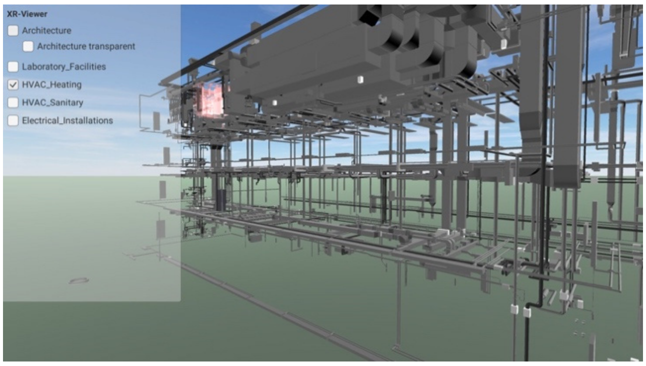


Figure 7: Draft of the GUI of BIM@SiteOffice of filtering visualised data.

5.1.2. Immersive Digital Twin Mode

In HMD-VR the same or similar GUI is not shown in the top left corner, but attached to the user's hand controller, as shown in Figure 8.

Figure 8: Draft HMD-VR GUI of BIM@SiteOffice. With and without "Architecture transparent"

The visibility of the hand-GUI in VR can be toggled, objects can be selected with a selection ray which is also attached to the hand controller (see Figure 9).

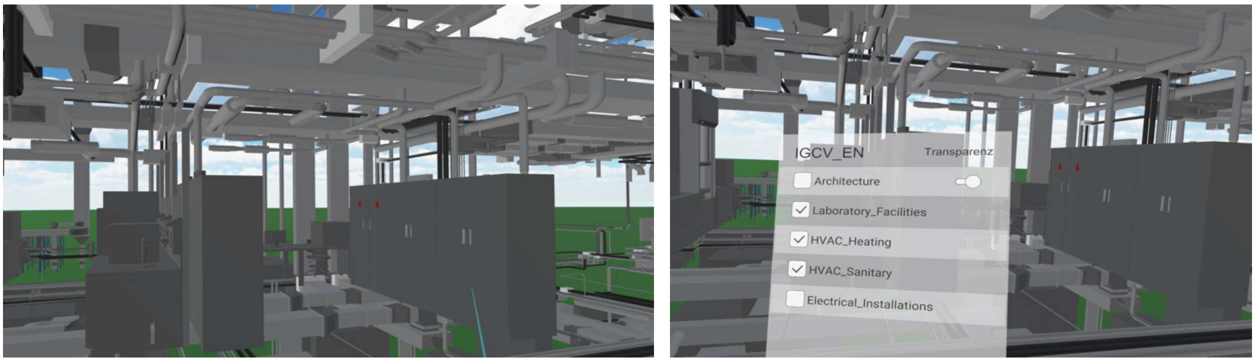


Figure 9: Toggle visibility of GUI, selection ray

5.2. BIM@Construction

[7]

5.2.1. Immersive Digital Twin Mode

Main idea behind BIM@Construction concept application is use of BIM as digital twin data in immersive XR devices at the construction site. While AR devices like Microsoft HoloLens 2 are

[7] BIM@ Construction logo

already built for interaction with 3D models (or “holograms”, as shown in Figure 10), scale of those models is usually dictated by the FOV of the headset.

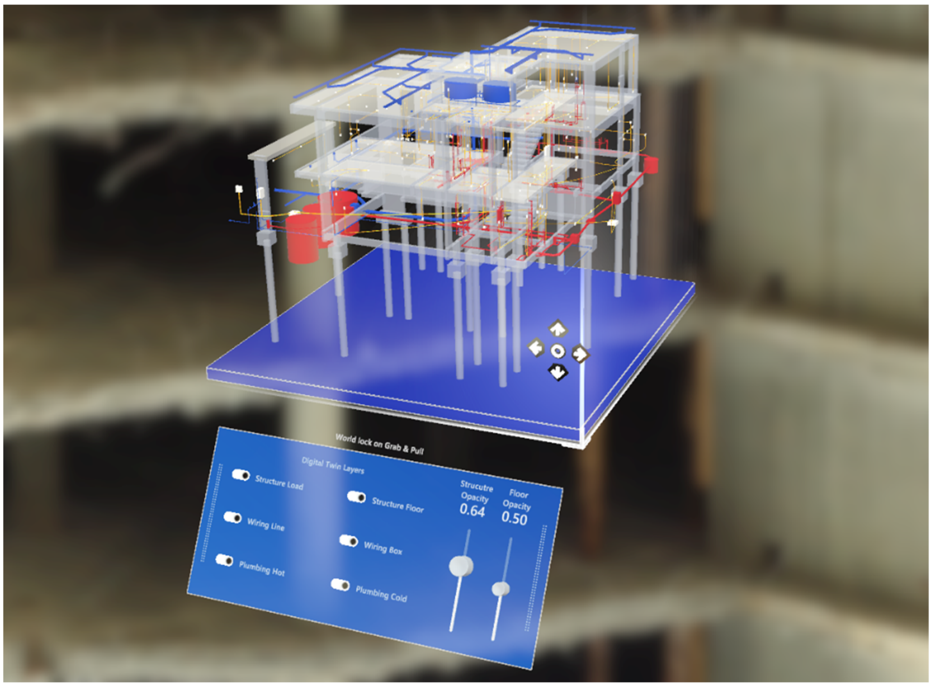


Figure 10: Immersive Digital Twin in 3rd person view[8]

Combining those small-scale models with the real scale immersive view can provide additional benefits for construction workers. Precisely matching real-scale hologram with actual building is a challenging task which requires additional tracking system to be installed on site. For example, multiple fiducial markers can be placed on the load-bearing structure of the building. When viewed in AR headset, those markers can be used to create anchors between real building and its digital twin (Figure 11).

[8] Building 3D model used in this concept application: "PROJETO HIDROSSANITÁRIO - BARRA VELHA / SC" (https://skfb.ly/6SBw9) by Diago Fagundes, licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).

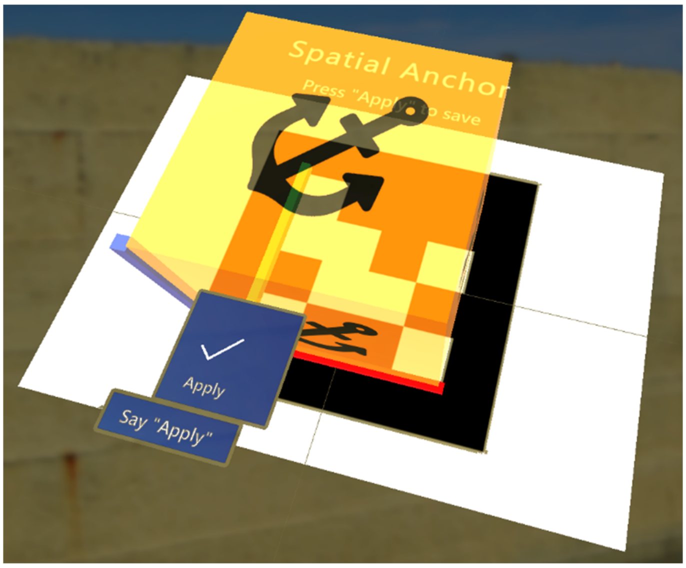


Figure 11: Fiducial marker and AR anchor hologram

Hologram displayed on the marker can not only be used for anchor creation, but also serve as authentication device - it can ask worker to provide a pin code in order to display suitable information. Alternatively, role of the immersive device user can be determined by the device itself since most devices are going to require unique accounts or profiles, and the fiducial marker can incorporate additional information for an automatic login (Figure 12).

Figure 12: Left: Interaction with AR anchor. Right: Example of interaction in real world

In order to overlay digital twin information on top of the real building, additional pivot objects should be crated. Naturally, pivot object placement should match the placement of the fiducial makers in the real world. That way the digital twin and its real-world counterpart will be located in the same coordinate system (Figure 13). Multiple markers and anchors are required because tracking precision and hologram stability will degrade with the distance.

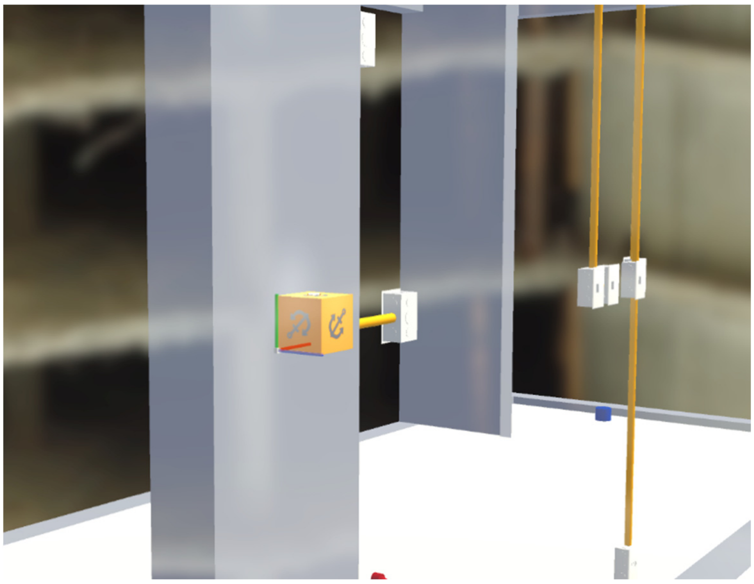


Figure 13: Pivot object and AR anchor in digital twin hologram

Since digital twin object is split into layers, there is a way to control which layers will be displayed at the current moment. User is able to toggle layers on and off and control the transparency of the structural layers. Hand menu of HoloLens 2 is used as a control panel - it can be displayed on demand on user's right hand, and also be locked to the world position (Figure 14).

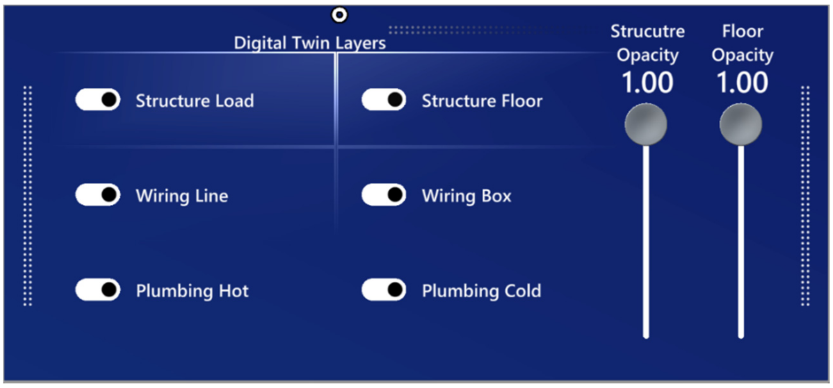


Figure 14: Digital twin control panel

Additionally, floor plans are used as a mini map while in immersive or third person mode. Floor plan is displayed on a left hand panel, which can be zoomed in or scaled after locked to the world position (Figure 15).

Figure 15: Immersive Digital Twin modes map (floor plan) panel

In the images below (Figure 16 and Figure 17) is shown how controlling the layers can reveal information about the building - changing transparency of the floor can open the view to the wiring or water pipes, and removing the load-bearing structure can show the entire electrical or plumbing system.

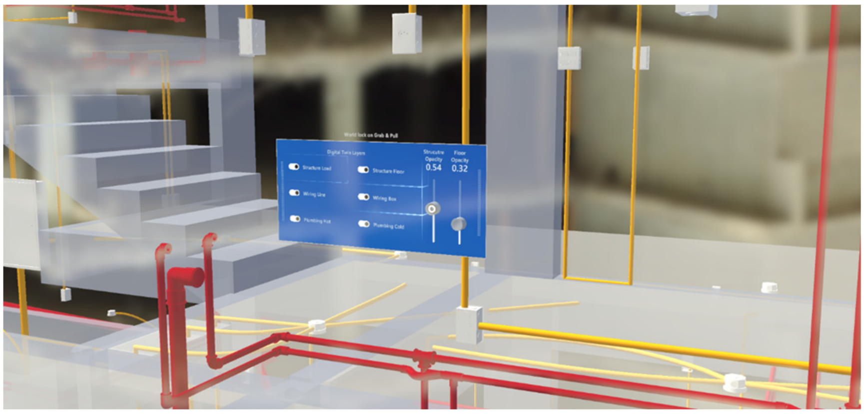


Figure 16: Different levels of transparency for the structural layers

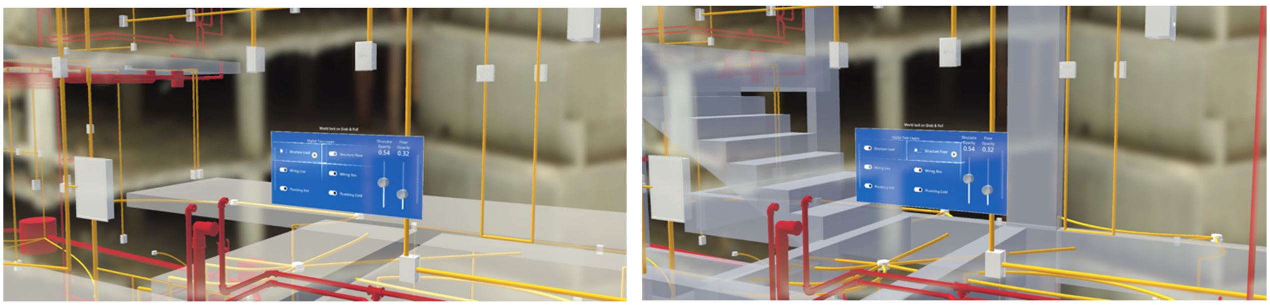


Figure 17: Left: Floor layer is switched off. Right: Load-bearing structure layer is switched off

5.2.2. Mobile Mode

Mobile mode version of BIM@Construction concept application (Figure 18 and Figure 19) is using computer vision for feature and plane detection in order to place AR object in the scene. It doesn't necessarily need the fiducial marker but works well with them since they can be used for on-site tracking and contain additional image features (texture and contrast variation). In the same way as a HoloLens application, tablet version of the mobile mode provides both 1st and 3rd person views.

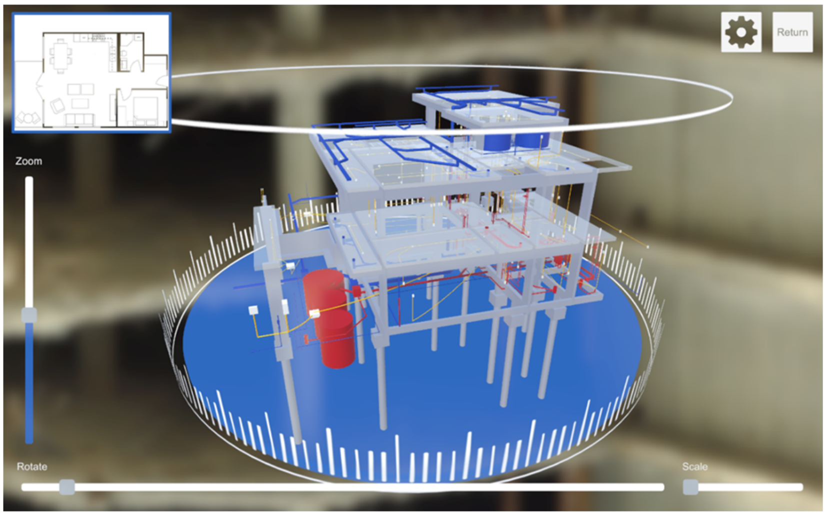


Figure 18: Mobile mode version, 3rd person view

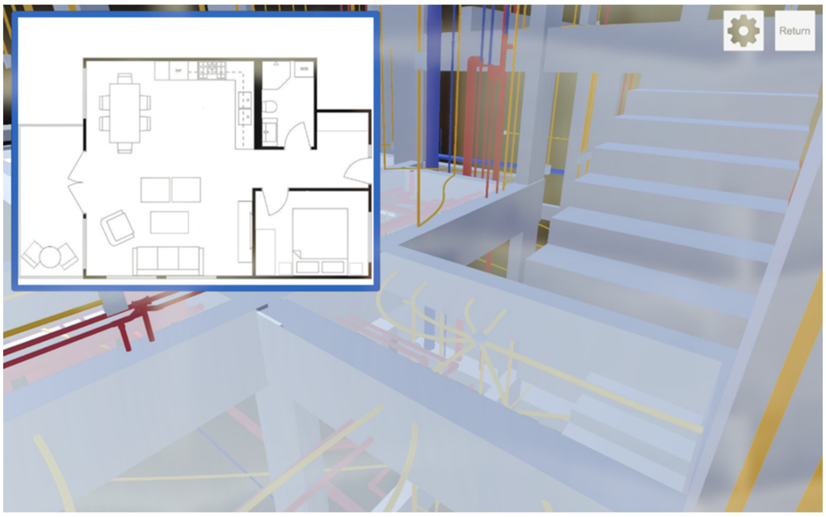


Figure 19: Mobile-mode version, 1st person view

6. Conclusions

This deliverable has presented the conceptualisation of the BIMprove User Interfaces. The different modes of interaction have been classified and the UIs categorized.

As noted above, this is the first version of Deliverable 1.3 – the UI concepts presented here are preliminary and their development and concretisation will be done together with the industry partners throughout the course of the project. Functionality, usability and UX will be evaluated in detail and tested with real end-users, e.g., using the methods presented by Tcha-Tokey et al. (2016) or Wienrich et al. (2018). Based on the results of those evaluations and the end-users' feedback, UI concepts and implementations will be updated during each of the three development cycles and reported in the three respective updates of this deliverable.

The usefulness of these ideas will very much depend on their integration in daily practices and processes at the construction companies. Differences between companies and between individual users, especially regarding previous experiences with the use of technologies such as VR will have to be taken into account.

Next steps are the development of a first simple version of those UIs for first user demonstrations and tests in the first BIMprove system tests. Also, a common look and feel for the UIs will be developed.

References

Admoni, H., & Scassellati, B. (2017). Social eye gaze in human-robot interaction: a review. *Journal of Human-Robot Interaction*, *6*(1), 25-63.

Aust, M., Otto, M., Helin, K. (2020). BIMprove User Interfaces: Multi-User-XR for construction (Poster). In: Helin, K., de Antonio, A., Reyes-Lecuona, A. (Editors): *EuroVR 2020 Application, Exhibition & Demo Track: Proceedings of the Virtual EuroVR Conference*, ISBN 978-951-38-8741-4, 71-75.

Dirin, A. & Laine, T. (2018). User Experience in Mobile Augmented Reality: Emotions, Challenges, Opportunities and Best Practices. Computers. 7. 10.3390/computers7020033.

Dubois, E., Scapin, D.L., Charfi, S. & Bortolaso, C. (2013). Usability recommendations for mixed interactive systems: Extraction and integration in a design process. In *Human Factors in Augmented Reality Environments*, eds W. Huang, L. Alem, and M. A. Livingston (New York, NY: Springer), 181-199.

EN ISO 9241-11:2018. Ergonomics of human-system interaction. Part 11: Usability: Definitions and concepts.

Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y., De Visser, E. J., & Parasuraman, R. (2011). A meta-analysis of factors affecting trust in human-robot interaction. *Human factors*, *53*(5), 517-527.

Harbich, S., & Hassenzahl, M. (2017). User experience in the work domain: A longitudinal field study. *Interacting with Computers*, *29*(3), 306-324.

Hassenzahl, M., & Tractinsky, N. (2006). User experience-a research agenda. *Behaviour & information technology*, *25*(2), 91-97.

Kaasinen, E., Aromaa, S., Halttunen, M., Jacobson, S., Lappalainen, I., Liinasuo, M., Nuutinen, M., & Turtiainen, R. (2021, February). User Experience Goals for Cognitive Systems in Smart Business Buildings. In *International Conference on Intelligent Human Systems Integration* (pp. 440-446). Springer, Cham.

Olsson, T. (2013). "Concepts and subjective measures for evaluating user experience of mobile augmented reality services." In *Human Factors in Augmented Reality Environments*, eds W. Huang, L. Alem, and M. A. Livingston (New York, NY: Springer), 203–232.

Sharkawy, A. N. (2021). Human-Robot Interaction: Applications. *arXiv preprint arXiv:2102.00928*.

Tcha-Tokey, K., Christmann, O., Loup-Escande, E., Loup, G., Richir, S. (2016). A questionnaire to measure the user experience in immersive virtual environments. In *Proceedings of the 2016 Virtual Reality International Conference* (*VRIC '16*). Association for Computing Machinery, New York, NY, USA, Article 19, 1–5. DOI:https://doi.org/10.1145/2927929.2927955

Tcha-Tokey, K., Christmann, O., Loup-Escande, E., Loup, G., Richir, S. (2018). "Towards a Model of User Experience in Immersive Virtual Environments", *Advances in Human-Computer Interaction*, vol. 2018, Article ID 7827286, 10 pages, 2018. https://doi.org/10.1155/2018/7827286

Tsarouchi, P., Makris, S., & Chryssolouris, G. (2016). Human–robot interaction review and challenges on task planning and programming. *International Journal of Computer Integrated Manufacturing*, *29*(8), 916-931.

Wienrich C., Döllinger N., Kock S., Schindler K., Traupe O. (2018) Assessing User Experience in Virtual Reality – A Comparison of Different Measurements. In: Marcus A., Wang W. (eds) Design, User Experience, and Usability: Theory and Practice. DUXU 2018. Lecture Notes in Computer Science, vol 10918. Springer, Cham. https://doi.org/10.1007/978-3-319-91797-9_41

Young, J. E., Sung, J., Voida, A., Sharlin, E., Igarashi, T., Christensen, H. I., & Grinter, R. E. (2011). Evaluating human-robot interaction. *International Journal of Social Robotics*, *3*(1), 53-67.