www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

SOCIAL EXTENDED REALITY—USE CASE ENTITIES ON PROPERTY LIFE CYCLE

SUBMITTED: June 2021
REVISED: January 2022
PUBLISHED: April 2022
EDITOR: Robert Amor
DOI: 10.36680/j.itcon.2022.025

Mauno Lounakoski, VDC Manager, M.Sc. (Tech.)
Suomen Aluerakennuttaja Oy
mauno.lounakoski@sara.fi

Jukka Puhto, Postdoctoral Researcher, D.Sc. (Tech.)
Tampere University
jukka.puhto@tuni.fi

Henri Jalo, Doctoral Researcher, M.Sc. (Tech.)
Tampere University
henri.jalo@tuni.fi

Osku Torro, Doctoral Researcher, M.Sc. (Econ.)
Tampere University
osku.torro@tuni.fi

Henri Pirkkalainen, Associate Professor, PhD
Tampere University
henri.pirkkalainen@tuni.fi

SUMMARY: *Virtual reality (VR), augmented reality (AR) and mixed reality (MR) are collectively referred to as extended reality (XR). In recent years, the hardware and software of said technologies have developed to the point where multiuser experiences have been enabled; thus, the conversation surrounding social extended reality (SXR) has begun.*
SXR—or collaborative extended reality—has many possible use cases in a property's life cycle, and the architecture, engineering, and construction (AEC) industry can be its forefront user. The AEC industry's work assignments include visuality and multiple stakeholders; thus, the SXR's level of applicability is high throughout the industry. Despite these possibilities, we need a more structured understanding of SXR use cases to aid in its deployment.
The current research article examines and identifies the five key entities from those use cases: involving stakeholders in decision making, effective teamwork, remote assistance, training and simulation and sales and marketing; it also recognises the greatest potential entities for utilisation from a value-creation standpoint and considers the transferability of these entities to other business sectors.
Qualitative empirical data were collected in twenty-one semi-structured interviews and three focus groups with professionals from the AEC industry. The focus groups and semi-structured interviews surveyed SXR's use cases in the property life cycle, examined the situation of companies' invocation of the technology and contemplated the benefits and obstacles of using SXR.

KEYWORDS: *Property life cycle, Social extended reality, Use case entities*

REFERENCE: *Mauno Lounakoski, Jukka Puhto, Henri Jalo, Osku Torro, Henri Pirkkalainen (2022). Social extended reality—use case entities on property life cycle. Journal of Information Technology in Construction (ITcon), Vol. 27, pg. 512-528, DOI: 10.36680/j.itcon.2022.025*

1. INTRODUCTION

From observation to immersion, virtual reality (VR), augmented reality (AR) and mixed reality (MR)—or, collectively, XR—are changing the way people perceive and interact with physical and virtual environments (Chuah 2018). For years, forecasts have predicted significant XR revenue growth; for example, IDC (2020) is anticipating revenue to grow from $12 billion in 2020 to over $72.8 billion by 2024. However, despite its great potential, the possibilities of XR technology are unclear, making its deployment slower than mainstream technologies such as smartphones (Cranmer et al. 2016; Kalantari 2017).

Over time, social XR (SXR) research has evolved, and currently, the discussion has turned to the technological developments and changes around main use cases, focusing on XR's expected capacity, growth, and challenges for the future (Cipresso et al. 2018). Larson and Larson (2004) have defined use case to be a description of all the ways an end-user wants to "use" a system. In this study we adapt this by defining use case as an area that has potential to implement SXR. In this end-user being an area (e.g., phase like design), "use" potential to implement and the system SXR.

Interdisciplinary use cases of XR technology, however, have led to decentralised research work and the transfer of only partial insights to practical uses (Chuah 2018). There are many factors driving the use of XR at the private and corporate levels, and their precedents have been suggested to end users, but company-level factors have not been empirically studied hands-on (Chuah 2018).

XR research has often focused on single users rather than on multiuser contexts. There are some SXR publications (Jalo et al. 2020; McVeigh-Schultz et al. 2018, 2019; Maloney et al. 2020), but they are mainly focused on social virtual reality (SVR), not on social AR (SAR) or social MR (SMR), because these technologies are not as mature (Miesnieks 2018). Despite the lack of research, social extended reality is already in use and there are countless possible use case scenarios that, however, are lacking in structural cohesiveness.

Rapidly digitalising the AEC industry is an opportune target for SXR use case research because many of its work assignments are focused on examining and interacting with digital visual content. Moreover, the industry is fragmented (Dubois and Gadde 2002), providing ample opportunities for applying SXR to more quickly help organisations come to a mutual understanding in projects. Organisations are constantly looking for ways to stay ahead of the competition and eliminate communication issues and unnecessary movement, which have been identified as the biggest losses in construction processes (Manninen 2012).

The goal of the current research is not just to offer choices for AEC organisations but to unify the scattered SXR use case research and use cases. By doing this, we hope to achieve a better understanding of the possibilities of the technology, enable the expected growth and create a baseline for future research. Hence, the research question for the present article is as follows: *What are the key use case entities for SXR on the property life cycle?*

The current article is structured as follows: Section 2 covers the relevant theoretical background concerning SXR and the property life cycle, examining them via the lens of virtual collaboration theories and discussing the communication aspects but bypassing the social sciences. Theory is followed by methodology, and the fourth section presents the findings. The fifth and final section brings together the discussion regarding the findings, contributions, evaluation of the study and suggestions for future research.

2. PROPERTY LIFE CYCLE AND SOCIAL EXTENDED REALITY

2.1 Property Life Cycle Model

The life cycle of a property can be modelled with different phases in many ways, depending on the perspective and role used (Kiiras and Tammilehto 2014). Miles et al.'s (2000) model is based on the invention of ideas and their development and does not consider marketing separately. In the Cadman-Topping process, generating ideas is not emphasised, and the process focuses on the more general project phase through initiation, acquisition, and implementation (Cadman and Topping 1995). The stages of the process of division of Kykyri and Kiiras' (2014) model includes a greater focus on the property manager's point of view and on finding development sites.

All these models can be formed into an eight-step process, although Kykyri and Kiiras' (2014) model is usually presented as a six-step model without the design and construction phases. Decision making takes place at the end of the various stages of the processes, making it possible to interrupt the process, and in Miles et al.'s (2000)

model, after step four, it is possible to go back to the beginning if the process does not prove to be profitable (Kiiras and Tammilehto 2014).

For the current study, we analysed these process models from different perspectives in detail and used a life cycle that combined them into a single model. The model does not specifically focus on real estate development because it lacks project orientation and an analysis related to projects, nor is it in line with life cycle thinking because it does not take a position on materials, recycling, or energy because the use of SXR is not relevant in this area. The process is not tied to a timeline but acts as a five-phase circle that eventually returns to the starting point (FIG. 1).

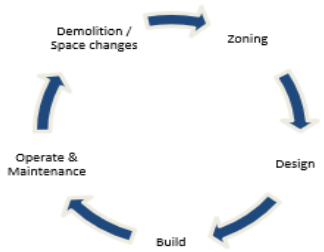

FIG. 1: Property life cycle model

The model does not editorialise on new and renovation construction. All design phases are placed under one area, and involvement of demolition reinforces circular thinking. We can move back from design to zoning, design and build can take place at the same time, and demolition can be interrupted if the property is redeveloped, and the process restarts from zoning.

2.2 **Extended Reality**

Extended reality refers to all real and virtual environments that have been combined through computers or wearables, and it consists of virtual reality (VR), augmented reality (AR) and mixed reality (MR) but identifying and bringing up interfaces between said realities is tricky because technology is evolving and shaping people's perceptions.

According to Girvan (2018) the world is formed of three ideas:

1. Shared space, that is inhabited and modified by people.
2. Experiences and their interpretations transmit through reactions as well as actions of our bodies and are not predefined.
3. We move in a shared space with our physical bodies and by collaborating with objects and other people we build a shared understanding of the world of that time.

The virtual world is a simulated environment that corresponds to this three ideas world framework. Virtual world is distinguished from the material and physical worlds by the experiences offered to the user by various technical qualities, especially avatars (Girvan 2018).

Jason Jerald (2015) has defined VR as 'a computer-generated digital environment that can be experienced and interacted with a real like environment'. The goal of the virtual environment is to fully engage the user and make him or her forget the real world (Jerald 2015). In the enterprise context, properly utilised VR provides experiences that are impossible to implement in the real world, improves work efficiency, training and teaching and reduces production costs (Jerald 2015). The three defining characteristics of VR are immersion, presence, and interaction (Mütterlein 2018). Together, these factors affect human VR observations and cannot occur individually (Bailenson et al. 2008; Mütterlein 2018).

Azuma (1997) defined AR as something that combines the real and virtual, is collaborative, is in real time and is registered in three dimensions. However, we find this definition too narrow because it excludes two-dimensional virtual objects such as text, audio, and video; thus, we adopt Azuma et al.'s (2001) updated definition that identifies the three essential properties of AR:

1. The combination of real and virtual objects in a real environment
2. A system that aligns/registers virtual and real objects with each other

3. Runs interactively in real time.

The definition of MR in the current study is based on the virtuality continuum and definition by Milgram and Kishino (1994). Milgram and Kishino (1994) defined MR as an environment where between the ends of the continuum, virtual and real objects are simultaneously shown on screen. According to this, MR contains AR, augmented virtuality (AV) and a partially virtual environment.

The weakness of the definition is the low emphasis on interacting with real-world objects. If positioning is not enabled, AR cannot be connected to the real world, but we can still, for example, project holograms while everything else is completely real. VR is not AR when one is immersed in the virtual world. After removing positional tracking from VR, one can still use head-mounted displays (HMD) and be immersed in a completely digital world. A clearer way of approaching this can be obtained by modernising the virtual continuum of Milgram and Kishino by adding VR (FIG. 2). In this classification, VR, AR, and MR are their own entities.

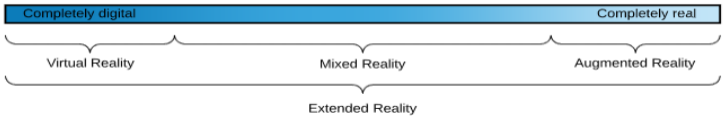

FIG. 2: Modernised virtual continuum based on Milgram et al. (1994)

At its simplest, MR is the combination of the real and virtual worlds, resulting in new environments in which physical and digital objects are located and interact with each other simultaneously.

2.3 Collaboration in XR

2.3.1 Virtual work

Mittleman and Briggs (1999) defined four different levels for virtual work: 1) Virtual work occurs at the same time in the same place, 2) at the same time, in a different place, 3) at different times in a different place and 4) at different times in the same place. These levels are affected by their related dimensions (Table 1).

Table 1: Dimensions affecting virtual work levels (Vartiainen et al. 2004)

Location	**Time**	**Diversity**	**Communication method**
Same location or on different sides of the globe	Same or different time zone	Backgrounds of workers	Face-to-face or through communication technologies
Working location might change			

According to the dimensions, at its simplest, virtual work is the sharing of notes collected from a face-to-face meeting, for example, by email. However, the office of the future may not have a physical location. XR enables a new kind of employee collaboration, eliminates distance problems, and brings people together in a new kind of decentralised work environment (Codrea-Rado 2018).

Communication using extended reality devices is computer-assisted communication (CMC), which was defined by Herring (1996) as human-to-human communication through computer hardware. Today, the definition also covers mobile devices, which, because of the technology they contain, can be classified as computers.

Interaction in virtual worlds is instrumental for communication; thus, synchronous, as well as asynchronous, interactions are found withing (Sun et al. 2014). Both types are location independent (Shore 2016). In XR, synchronous interactions are real-time conversations between individuals and the data processing and asynchronous reading and responding to comments stored in 3D models. Synchronicity is directly related to the time dimension of virtual work (Sun et al. 2014).

2.3.2 Virtual human interaction

The collaborative virtual environment (CVE) is a digital system that enables the interaction of geographically dispersed individuals through computer networks (Yee et al. 2009). Based on the CVE, Bailenson et al. (2004)

formed the transformed social interaction (TSI) research paradigm. According to the TSI, VR enables the enrichment, filtering and modification of social interactions. The three important categories of the paradigm are as follows (Bailenson et al. 2004):

1. Self-image
2. Sense capacity
3. Context

In a CVE, self-images are usually formed with an avatar, whose appearance and gaze can be influenced by influencing the interaction event (Bailenson et al. 2004). In virtual environments, it is possible for people to radically change their self-images (Yee et al. 2009). Here, the Proteus effect refers to a situation in which a person decides on his or her abilities based on the appearance of an avatar and adjusts his or her attitudes and behaviour accordingly (Yee and Bailenson 2007). The effect can influence one's behaviour, even after the user has exited the virtual environment (Yee et al. 2009).

In the context of the interaction, it is possible to modify, for example, the location and time of the person and to automate the reactions that take place during this absence in the virtual environment. Individuals are happy to be in a certain location in relation to others, and in a virtual environment of collaboration, it is possible for everyone—up to a certain point—to grant their desired location. When a timeline is changed or a person is absent, that person is no longer just geographically separated, and interactions inside a CVE momentarily become completely separated. At its most efficient, the system utilising a TSI is utilising a combination of all categories (Bailenson et al. 2004).

2.4 Framework and Use Cases

The framework of the current study is formed by combining the concepts of the property life cycle and SXR, which indicates the interaction and communication between humans through different realities. Between these two, there are countless but fragmented use cases that need structural cohesiveness (*FIG. 3*).

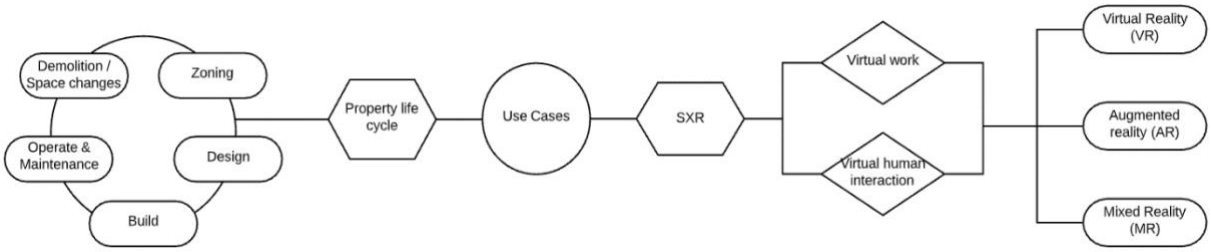

FIG. 3: Property life cycle and SXR framework

SXR use case research can be technological and can examine how something can be done and how, for example, technology creates immersive enough experience and what goes into implementing it (Alsafouri and Ayer 2017). How certain use case works, in what ways do people benefit from their utilisation and what challenges are related to it form another type of research. These different studies add up to the long list of SXR use cases (Table 2).

In the AEC industry, there is the need for additional tools, because, for example, BIM itself does not necessarily lead to uniform and high-quality design (Strandman 2018). There are a wide variety of means of presenting the information contained in BIM. Virtual reality visualises information, and in the construction industry, VR can support the development of cooperation and collaboration if it is used to create facilitated and purposeful opportunities. For example, it is possible to create workshops that improve collaboration and communication. In addition, by collecting comments and feedback, goals can be set for the future development of the activity (Strandman, 2018).

VR is already somewhat utilised in the design phase because technology saves money and time and reduces risks. VR is a tool for expressing, presenting, marketing and selling plans. Technology helps make decisions, find mistakes and understand the relationships of spaces on their natural scale. The use of VR improves the design process and cooperation between customers, designers and the project team (Nuutinen, 2017).

Table 2: Sampling of SXR use cases and related studies.

SXR use case	Source
SVR in design team collaboration	Strandman (2018), Nuutinen (2017)
Involving end users to design phase with VR	Song et al. (2018), Nuutinen (2017)
Premarketing	Nuutinen (2017), Debika (2018)
AR in construction task training	Chalhoub et al. (2021)
Safety instruction with AR/MR	Guo et al. (2017)
AR as a Building Information Model (BIM) visualisation tool in construction site	Wang and Love (2012), Thomas and Sandor (2009), Mutis and Ambekar (2019)
Construction site monitoring and documentation with AR	Zollmann (2014)
SAR as a support tool in operative work	Jalo et al. (2018), Webel (2012)
AR/MR in space changes	Thomas et al. (2000)

User experience has a significant impact on effective product design and development, especially when the product is intended to meet customer needs (Song et al. 2018). Customers want to see what they are buying and increasing the media visibility of properties through virtual tours, for example, has led to higher selling prices (Benefield et al. 2011). Demonstrating the facilities with AR/MR/VR can be carried out before the building or space changes have been completed, offering a better customer experience than traditional marketing methods (Debika 2018).

Based on the residential real estate market analysis conducted by Debika (2018), AR, MR and VR has been shown to enhance consumer information retrieval and reduce the time spent evaluating purchase options. As the design features of technologies increase, they can also increase the number of items that go from evaluating alternatives to purchasing, but only if they seem realistic and provide a quality enough experience (Debika 2018)

The use of AR/MR in the AEC industry has also been explored in visualising BIM objects hidden behind walls (Thomas and Sandor 2009), space changes (Thomas et al. 2000), safety instructions (Guo et al. 2017) and training speciality construction tasks (Chalhoub et al. 2021). However, the design phase is a good example of how VR is ahead of AR/MR in terms of XR technology implementation, partly because of SAR and SMR's technological limitations (Miesnieks 2018).

Most of the SXR use cases can, however, be utilised with every type of XR technology, with support situations (AR/MR), at least for now, being exceptions. Meetings can be held inside a virtual world around BIM, but site workers can also walk around the job site and transmit a video feed where BIM is projected on top of the actual building. Construction site workers can be trained through simulations in VR or in the actual site with AR/MR glasses that project directions. Technologies can be combined, and it is on the users to decide which method best suits them.

3. METHODOLOGY

In the current study, the researchers drew conclusions based on their own observations and were part of the study. The approach to the study was abductive and timewise; it was carried out as a cross-sectional study. The present study aimed to understand SXR technology and find the greatest potential applications for it, here with little presupposition. The research material was collected in a real context and situation. The collected material was summarised, grouped and rebuilt to create a narrative. Thus, the research strategy is qualitative (Saunders et al. 2009).

The qualitative data were collected by five researchers from twenty-one semistructured interviews and three focus groups with the AEC industry's professionals. Semistructured interviews were used because SXR is a new research topic in terms of use cases, so the interviewees had to be able to answer as freely and widely as possible. The interviewees also worked in organisations that operated in different phases of the property life cycle, and with semistructured interviews, we were able to modify the interview structure to best suit them.

The focus groups and semistructured interviews surveyed SXR's use cases in the property's life cycle, examined the situation of companies' implementation of the technology and contemplated the benefits and obstacles of using SXR. The participants were mainly chosen from organisations that had shown interest towards SXR or were already using it in some form and the organisational palette of all the participants aimed to represent the property life cycle as comprehensively as possible. An XR-related background of those participating helped us get a thorough overview of the possibilities and challenges of said technology.

The attendees represented both public and private organisations, and in total, empirical data were collected from 19 case organisations and 54 attendees. All the organisations were from Finland, with 10 small- and medium-sized (under 250 employees) and 9 large ones (over 250 employees). Here, 33% of the attendees were in senior management positions, 24% were in middle management, and 43% were experts.

The interviews and focus groups were held between the fall of 2017 and spring of 2020. Both the interviews and focus groups were conducted in Finnish, lasted from 30 to 120 minutes, and were audio-recorded with the consent of the participants. Ten interviews had more than one interviewee attending, and apart from two interviews, there were always more than one researcher present.

In addition to conversations, the focus groups comprised VR trials that enabled the collection of user experience notes. The software used was multiuser and either commercial (e.g., Iris VR) and/or custom developed. Devices included standalone (Oculus Go) and tethered (e.g., HTC Vive) VR headsets. User behaviour was observed during trial situations, which lasted until all the essential features of the software and devices had been tested.

Transcriptions were made of the pertinent parts of the recordings, and the analysis was carried out primarily by one researcher. Sorting of the gathered data began by placing all the previously known and suggested SXR use cases on the property life cycle. This helped create a bigger picture before any further actions were needed. The second phase included going through the transcriptions, highlighting all the mentioned benefits and potential of SXR and categorising these according to the number of mentions.

After initial sorting came reflecting connection between seen potential and benefits to known biggest losses in construction processes: eliminating communication issues as well as unnecessary movement. The discovered connections were cross-referenced to the framework of the present study (Figure 3), which led to forming the first version of the SXR use case entities. This preliminary version then underwent investigator triangulation, where we compared the findings and interpretations between the researchers and notes from the VR trials to confirm and disconfirm observations. Entities were refined after each iteration until we reached conformity with the five entities.

4. FINDINGS: FIVE KEY SXR USE CASE ENTITIES

4.1 Involving Stakeholders in Decision Making

In construction projects, developers often fail in communicating with the end user. The property is made for its end user, and the whole project can be defined as a failure if the user is not satisfied with the outcome. With XR, the goal is to make it easier to outline plans and make participation in urban planning more interesting. The conversation can take place around BIM or move within it. Many interviewees felt that presenting design solutions in a virtual world is more concrete and understandable for end users.

> *In the planning events, the message usually is that we interact too late.* – Urban Planner, Town Planning

> *[…] Developing such involvement tools that would increase understanding of the matter by also transferring feedback giving of the plan to a proper stage would decrease friction involved in planning.* – Urban Planner, Town Planning

> *It has come up that we want to get feedback from the end user in as early design stage as possible and that cannot be done in any other way than by producing virtual models.* – Chief of Development, Engineering Office

The solutions related to participation included plan development and the planning of the facilities and designing of spaces. The virtualisation of plan development is aimed at reducing the number of complaints and increasing the number and diversity of opinions. When people cannot interpret the drawings, their first reaction is to resist. With the help of MR, the effects of buildings on landscapes can be assessed in the terrain, and with VR, a resident can be taken several floors up in height. In this case, people know exactly what is being built and the number of misunderstandings, and consequently, complaints will decrease. For example, in the plan development of neighbourhoods and other larger entities, SXR allows for the visualisation of alternatives. When asking for opinions, people do not have to perceive ideas in their head but can directly comment on guiding options in the virtual world.

> *From a technological standpoint, plan service in a virtual world is an awesome idea. […] but then again, it should include the possibility to say this is the planned area, then place different options and then somehow the group of people that is in there could with some systems start sketching their own option. Then we would clearly be on a different level.*
> Urban Planner, Town Planning

Utilising new technology makes it easier to involve young people. As virtual glasses become more common, the younger generation will be the first to adopt them, so it is important to create a platform for plan development that interests them. The solution must emphasise decades of living with the built environment solutions now being made. Increasing transparency and leveraging gamification can further increase interest. Getting rewards for answering surveys and keeping leaderboards are simple ways to influence interest.

The development of spaces and planning of facilities using SXR will have a significant impact on improving communication for the end user. Creating alternatives and virtual tours with guided movement between larger areas and within areas independently are just two examples of the many solutions that can be created around inclusion. The opinions of users and residents can become more precise, and usually, quieter people get a better chance to participate when comments can be tacitly attached to the virtual model. Going through the plans is systematised when the facilitator of the VR experience creates a clear script for navigating the 3D model.

4.2 **Effective Teamwork**

Most of the interviewees mentioned that many of the problems in the AEC industry are related to communication. Communication chains are long, ambiguities emerge, and concrete links to real-time plans are lacking. Travelling from one place to another consumes time and incurs costs. Eliminating location dependency is one of the most important things that SXR offers. With SXR, it is not necessary for the parties of the project to physically gather in the same place: they can be in the same virtual space discussing the project around the 3D model. Different layers of the plan can be shown to various user groups (e.g., piping shown to Heating, ventilation, and air conditioning (HVAC) engineers) to give them access to information that is relevant to them. Comments can be pasted to the desired locations, and reports can be printed from the comments.

> *[…] It is also a normal procedure that designers gather at the construction site between certain timespan and at the site office go through issues as well as come up for solutions on the spot and if that somehow could be done smarter, without the need to go to the site, that would be awesome.* – Chief of Development, Engineering Office

At least for the foreseeable future, an obstacle to bringing design tools into the virtual world is problems with the dimensional accuracy of processing 3D objects. Some interviewees pointed out that there is no direct need to bring all design work to the VR world because current modelling applications are adequate, and VR serves mainly as an additional tool. However, moving objects and creating scenarios are qualities that need to be brought to the virtual world at some level.

Virtual construction site meetings eliminate site specificity and allow those absent from the meeting to observe the issues discussed in the form of a recording. Different interaction scenarios can be created for meetings, in which the roles are already preallocated. 3D objects can be located on tables, and it is possible to move among them on a 1:1 scale. The 2D material opens on the walls and in the optimal situation; for example, details and

sectional images are linked to the 3D model. If necessary, the contractor's representative can move to the problem areas on the site with an MR display device, and others can see his or her view of the walls in the virtual space.

A more efficient authorisation phase for the building permit process brings about benefits, but the type of activity needs to be carefully considered. As a solution, the interaction would take place around a 3D model of the city formula, and the advantages can be considered in the clarity of communication when the public authority gets a clearer image of what is being planned. Another potential solution that involves cooperation is the plan framework design phase. A few interviewees mentioned that earlier, cooperation can be started with the right methods and that when changes are made to the plan design, the more savings will be made. The problem for planning phase cooperation, at least for now, is the conversion of plans into a building information model format.

> *[…] with this (SXR) we could get past the developing together part quicker. We could have boundaries, certain things to certain areas and then even the processes could be changed in a way that citizens can participate in.*

> *One example case, it has been developed jointly, but it has advanced quite poorly. City was not okay with what investors were planning to do and that is why the project was stuck for five years. If we had moved those blocks together and gotten to an understanding, a decision that takes five to ten years could come about in a year.* – Real Estate Development Director, Real Estate Investor Company

4.3 **Remote Assistance**

In terms of working on the construction site, SXR allows people to perform other work. The display devices can be used to take measurements, direct the employee to a room or device that requires maintenance, access drawings and compare the plans with completed work by reflecting on the BIM through MR glasses. Unnecessary movement to the drawings or to look for them is eliminated when the plans can be checked virtually in the area one is working at. In assistance situations, the devices reflect the instructor's comments and drawings, and it is not necessary for the instructor to have a display device at his or her disposal.

> *[…] Remote supervision has been thought about, like, could you with the help of HMDs solve a problem coming, for example, from a shopping centre's HVAC system before an actual serviceman gets sent to the scene.* – Chief of Development, Engineering Office

Other remote assistance solutions like construction site supervision and additional and modification work, were not seen as potential areas for development. As with the site meetings, a discussion would be possible in a virtual space around the building's information model, and if necessary, the contractor's representative will reflect his or her view on the wall. Some interviewees, however, felt that illustrating the transformation work would be difficult because ready-made alternatives have not been visualised and because virtualisation does not bring significant additional benefits. The differences between videocalls and XR was also questioned by the interviewees. It was not clear why one would want to use XR when one could just simply call someone.

4.4 **Training and Simulation**

The creation of startling experiences in occupational safety training with XR applications was seen as a step forward compared with traditional videos and slideshows viewed on a 2D screen. In VR, dangers appear in different ways when accidents can be visualised.

Another use scenario—the simulation of work steps—was also seen as a potential solution. One interviewee mentioned the possibility of installing a VR system on construction site offices, where the plans and simulated steps can be viewed and recalled if something was forgotten. In this situation, one can have a discussion and leave comments. The probability of errors occurring decreases, especially in more difficult projects.

[…] new kind of techniques have emerged, for example composite pipes and workers have not been able to do installations correctly, this would have a huge value in it. – Real Estate Development Director, Real Estate Investor Company

[…] we went to into an actual construction site office to present VR equipment with that site's actual model […] after a bit of figuring out, construction personnel moved towards his assignment location and started looking how things had been planned. Immediate response was that this kind of equipment should be in the field, for example, in the site office so that you could occasionally go and look at how things had been planned to be executed. – Chief of Development, Engineering Office

Maintenance training was not similarly valued. Many of the things to maintain were already familiar to companies, but as building services solutions develop, new things to learn are constantly being developed. One possible modified use case could be easing the learning curve if the maintenance company changes, and the company does not have that specific real estate's information. There was no development potential to be seen for SVR in familiarising residents, either.

4.5 **Sales and Marketing**

Empty spaces are not very tempting if you have an office decorated in the eighties and you take customer there with the idea that it is their future workspace; they will not be overly excited. You should somehow be able to show the future and balance between not showing something too fancy (with XR). – BIM Specialist, Commercial Enterprise

Investing in an apartment causes a mixture of worries, hopes and doubt. It is key for real estate agents, construction companies and interior designers to present their products in a way that reduces any feelings of worry and doubt. The imagination and perception of a few people is enough to imagine an apartment as their own home based on a floor plan or seeing a concrete space. In these situations, there might be no desire to move, and deals may not be created.

Interesting case could be that if you have an empty floor in some office building and then we try to get one of our clients there with the idea that take this as a baseline for your new business premises. […] chance to move around inner spaces with a handheld device and location tags with what the device creates a virtual environment. […] Typical problem with this kind of solution, however, is that the space in question does not have any designs with what we could sell it because it only gets designed once the client gives it green light. […] In theory, it could be possible that we have typical office solutions (in virtual form) even though they are not exactly the ones that the customer will want... – BIM Specialist, Commercial Enterprise

It would be nice to get to know potential moving destinations e.g., apartment in peace and consider different options. When illustrative marketing begins with AR, MR or VR, a construction site does not even have to be set up.

In project marketing, we recently did a demo where people walked with HoloLens to the lot. There was no house, just an open field and they looked where real estate would be placed from different angles. This is something that I think many people have asked: the ability to see a projection of a real-sized house in its correct location. – BIM/VDC Manager, Construction industry concern

VR solutions are already utilised in real estate marketing, so their development potential was not seen as similar to other solutions among the interviewees. The discussions touched on the marketing of regional and real estate development projects to international investors, so the benefits of removing location-based properties were

identified. SVR is intended for situations where construction has not started, the customer cannot get to the site, or when there is a desire to create a very visual image of the object for the customer.

4.6 **Perceived Potential of Use Cases and XR**

More than half of the interviewed companies saw all the key SXR use case entities as somewhat important to their company and involvement; in addition, collaboration rose as being the highest potential use case entity. Virtual Big Room, town planning and construction site meetings were voted as the greatest potential of development use cases. The biggest possibilities of the technology are removing location-based working and clarifying interactions (FIG. 4).

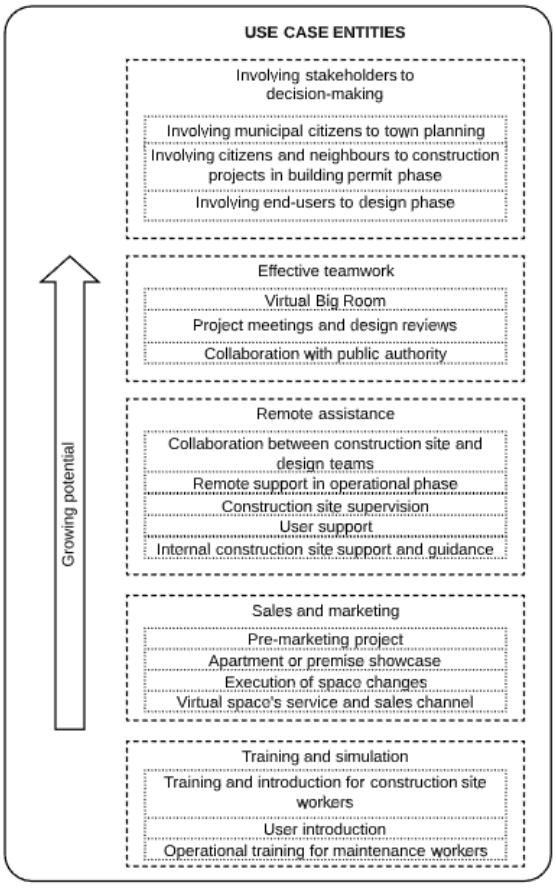

FIG. 4: SXR use case entities according to their perceived potential.

Most of the interviewed companies are in the same situation when it comes to SXR utilisation. VR HMDs have been purchased and different software tried out, but solutions have not proceeded into productization because they have not beaten traditional methods. Only a few interviewees mentioned that their company had found ways to utilise VR.

> *[…] we have kind of, in our opinion, found the way, how we can utilise VR. To clarify, we have certain tools, with what our designers can easily execute VR solutions.*

Potential growth was seen in AR and MR, but the solutions were still unclear. The companies were somewhat familiar with the technology, but in their opinion, the technology and its solutions still needed to be developed before they started to utilise it in their business activities. The problem arises when you cannot convince the customer about how they could benefit from the solution.

> *Next point of interest is then that AR is still sort of new. There are not ready solutions or sensibly operating equipment for it […] In a way the use case is missing, who do we offer this kind of service. Well, serviceman, property maintenance is one where you could think about it.*

5. DISCUSSION

5.1 SXR Use Cases and Their Entities

By combining SXR use cases found in the literature and in the current study, we cover the whole property life cycle model, with majority of the use cases spreading between the design, build, as well as operate and maintenance phases (FIG. 5).

SXR use cases on the property life cycle and the entity categorization (FIG. 4) support one another. Use case can be selected from either of the two and then examined how it is placed on the other. It is also possible to select an entity or life cycle phase and see how it's use cases get distributed.

In the present study, we chose an unambiguous approach angle and divided these use cases into just one specific entity because of clarity, but some of them fall under multiple entities. For example, remote assistance use cases can enhance project-wide teamwork, and a proper introduction to construction sites can lead to effective teamwork. However, these relations and refinement are left for future research.

In our opinion, these entities comprehensively represent the AEC industry's use cases and categorise them in a way that enables companies to approach SXR as a tool solving their development problems. SXR can eliminate or reduce communication issues and unnecessary movement that has been identified as the biggest losses in construction process. It is no wonder that involving stakeholders and effective teamwork were seen as holding the most potential. These two also greatly highlight the social aspects of XR.

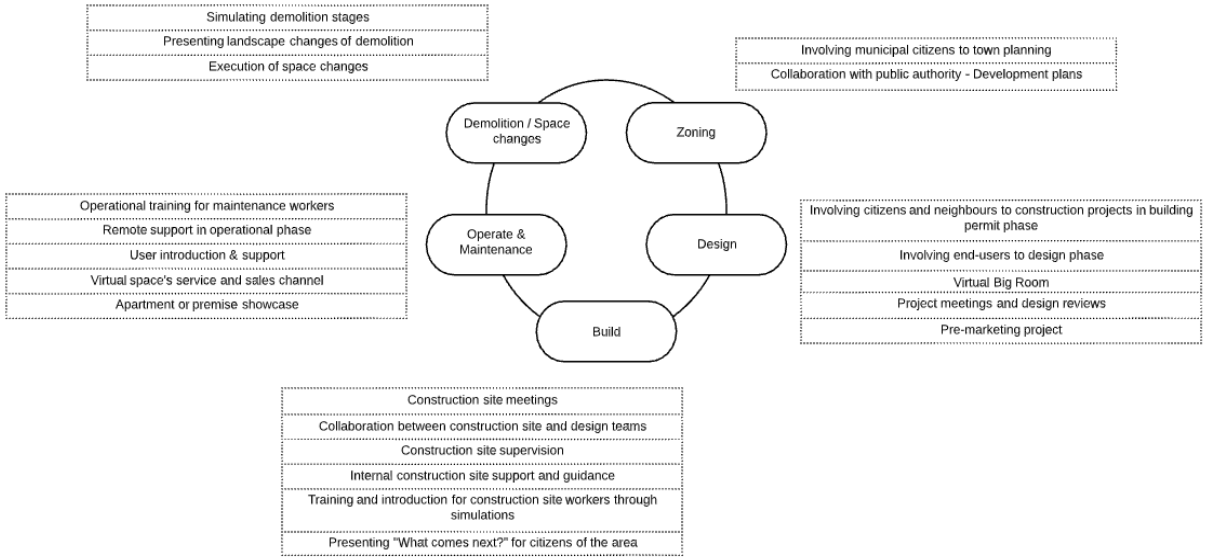

FIG. 5: SXR use cases on the property life cycle.

Training saw the least amount of interest, even though it is one of the most well-known use cases for XR and can be seen as a major reason why VR is a game-changing technology for organisations (Torro et al. 2021). In the AEC industry, the majority of work tasks are not complex, but XR can be used to teach untrained individuals. This could be an important use case in the future if the lack of workforce continues to grow and robots do not cover every scenario (Chalhoub 2021). The reason for low interest might also be because the interviewees saw training simulations as individually executed, not as social experiences. This would mean that the potential benefits of entities differ greatly between single- and multiuser solutions.

XR helping free up human resources in remote assistance situations is a benefit, but the entity's use cases were still seen as cautiously optimistic. The worrying element is the comparison to traditional methods. Calls and videocalls were seen as working great. Hence, it may not be beneficial to use something else. People do not perceive how AR/MR could add to these situations, partly because the technology is new, and its capabilities are unclear.

Premarketing has been one of the first and most obvious single-user VR solutions. When one wants to immerse the end user or buyer in the design and move from seeing the design to experiencing it, VR is the solution. Marketing is not, however, a one-dimensional entity. Showcasing projects to international investors emphasises SXR's social aspect in addition, XR can work as a service and sales channel, which is something everyone might not even have thought about because it requires mainstream attention that XR has yet to receive.

SVR was seen as suiting situations where nothing physical has been built yet and where everything is still completely digital, for example, design reviews and premarketing. Completely real and AR/MR, which are the other side of the modernised virtual continuum (FIG. 2), were seen as suiting situations where something physical is already in place, for example, space changes and site supervision, where digital can be projected in relation to what is already built. The connection between different technology usage and virtual continuum is not univocal; AR/MR can be utilised in the earlier and VR latter stages of the property life cycle as well, but this highlights their main beneficial uses: 'nothing physical → VR / completely digital' and 'physical → AR/MR / completely real'.

People's knowledge or experiences about SXR technology affect how they perceive its possibilities. One might have had a bad first experience with the technology, and that obstructs seeing where the benefits are. Putting the generational leap and youth adopting technology faster aside, evolving technology can help us get people working in the AEC industry to better understand the technology and relate their businesses to these entities, as well as see them as problem solvers. Smoother experiences, new applications and hardware are just a few things rapidly evolving technologies have at their disposal. Evolving technology is not likely to directly affect and modify entities, but it might bring up use cases that we have not even thought about yet and indirectly create relations.

5.2 **Contributions**

A greater part of earlier SXR research has focused on specific use cases (Jalo et al. 2018; Chalhoub et al. 2021; Song et al. 2018) in different industries, adoption (Jalo et al. 2020; Chuah 2018; Kalantari 2017; Cranmer et al. 2016) and technology itself from hardware (Miesnieks 2018; Mütterlein 2018), as well as the social interaction standpoint (Bailenson et al. 2008; Bailenson et al. 2004). Dispersion has been imminent, with a connection to practicality missing and an essence of certain industry's possibilities unclear.

From the practical point of view, we ease organisations' SXR valuation and implementation by creating a structure around SXR. This structure allows one to approach SXR from three angles (FIG. 6).

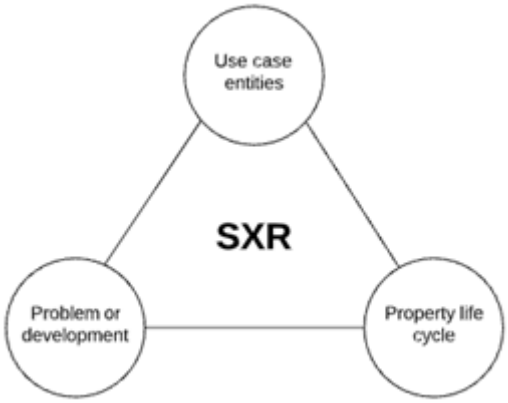

FIG. 7: SXR approach angles for the AEC industry

The first option is access through a problem or development case. Does the dilemma, for example, fragmentation, slot into a certain entity? What is its perceived potential and challenges? What use cases does it contain, and how are they positioned on the property life cycle? Second, the organisation operates in specific parts of the property life cycle. What SXR use cases are there for them? To what entities do they belong? What use cases can be focused on? Third, does the business sector, for example, involve marketing, or does it involve multiple stakeholders? What SXR use cases there are for this? Where do they position themselves on the life cycle, and how one can benefit from them? By doing cross-referencing between these three angles, organisations can obtain a better understanding of SXR and devise their development towards one use case entity, property life cycle phase or development case and not just SXR, which, as a new technology entity, can sound confusing and intimidating.

5.3 **Limitations and Future Research Topics**

The current study has a few limitations. First, the current qualitative study was limited to Finnish organisations; thus, the results might not be fully transferable to other countries. These Finnish organisations were also mainly those that had shown interest in SXR technology. Among the interviewed organisations, a few had not yet considered integrating any XR technologies into their processes, but the business sector of these organisations did not represent the entire property life cycle. Therefore, we did not cover the whole life cycle with insights from those that were not familiar with the technology in question. This data deficiency and approach, however, was deemed acceptable because the interviewees who had knowledge of SXR's capabilities were able to give better insights into the possibilities and, thus, better serve the goal of this study.

Iterative qualitative analysis of the collected data was mainly carried out by a single researcher, but because of the co-authors' review of the findings, the effect on the interpretive validity of the study was not prominent. The reliability of the study was impacted by two things. First, in 10 interviews, there were multiple people present, which may have led to answer adaptation and leaning on socially acceptable answers (Hirsjärvi et al. 2007). Second, understanding of the questions and concepts can differ not just between interviewees, but based on the way the interviewers present them.

The current study identified five use case entities for the AEC industry and can be used as a starting point for future research. For entity-level research, we propose several perspectives. The entities were perceived as giving organisations insight into the possibilities of SXR technology, but that alone does not lead to diffusion. The empirical data on conceived of benefits, as well as utilisation and connection of growing possibilities to technology adoption research, such as with Rogers' diffusion of innovations (DOI) theory, are just a few ways we can streamline the deployment of SXR. Interrelationship research and the formed entities being valid in other business sectors could create even more structural cohesiveness and lead to larger scale diffusion.

For use case–level research, we propose focusing on stress testing and the evolution of technology as well as solutions. Can we refine them using different naming methods? What are the connections between different entities and do these entities match in other areas of business such as manufacturing? Similar research methodology could be used which would allow cross-referencing the results to this study.

One example for use case research is further examining design reviews like 3D-model clash-detection in the virtual world. People attending the review would first do it from their computer screens and then proceed inside the 3D-model with VR. Both would be done without pointing out the clashes beforehand and afterwards questioning focuses on the perceived differences between the two methods.

Other methodology is having two separate focus groups do the exact same review, one from their computer and the other in VR. This would make comparing the results possible. Do people notice clashes or design deficiencies more effortlessly in VR? Does VR conduct distinct concentration points?

Developing XR hardware enables or makes some of the use cases easier to utilise. Methods like gamification can change how we, for example, facilitate a meeting inside the virtual world. There are use cases that we do not know of yet, but with further studies, they can be formed or found.

6. CONCLUSION

We studied a framework that includes the property life cycle, XR and virtual collaboration theories and created cohesiveness for SXR research by structuring use cases that stand in the middle of this framework. As a result, five key SXR use case entities in the AEC industry were found. By doing this, we answered our research question: '*What are the key use case entities for SXR on the property life cycle?'*

We also placed use cases on the property life cycle, combined the impact of VR (Torro et al. 2021) and different use cases as well as gave the AEC industry different approach angles for SXR. However, this study is only the beginning, and we need to research if the SXR key entities work in other industries as well.

REFERENCES

Alsafouri, S. and Ayer, S.K. (2017) A step-by-step procedure for implementing mixed reality visualization interfaces in design and constructability review sessions. *Lean and Computing in Construction Congress: Proceedings of the Joint Conference on Computing in Construction*, 1, 913–921.

Azuma, R. (1997) A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4), 355–385.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., and MacIntyre, B. (2001) Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, 21(6), 34–47.

Bailenson, J., Beall, A., Loomis, J., Blascovich, J. and Turk, M. (2004) Transformed social interaction: Decoupling representation from behavior and form in collaborative virtual environments. *Presence: Teleoperators & Virtual Environments*, 13, 428–441.

Bailenson, J., Patel, K., Nielsen, A., Bajcsy, R., Jung, S., and Kurillo, G. (2008) The effect of interactivity on learning physical actions in virtual reality. *Media Psychology*, 11, 354376

Benefield, J. C., Rutherford, R., and Allen, M. (2011) The effects of estate sales of residential real estate on price and marketing time. *Journal of Real Estate Finance and Economics*, 45(4), 965–981.

Cadman, D., and Topping, R., (1995) *Property Development.* 4th ed. Taylor & Francis Group.

Chalhoub J., Ayer S. K., and Ariaratnam S. T. (2021) Augmented reality for enabling un- and undertrained individuals to complete specialty construction tasks. *Journal of Information Technology in Construction*, 26, 128–143.

Chuah, S. (2018) Why and who will adopt extended reality technology? Literature review, synthesis, and future research agenda. Available: *https://ssrn.com/abstract=3300469*

Cipresso, P., Giglioli, I.A.C., Raya, M.A., and Riva, G. (2018) The past, present and future of virtual and augmented reality research: A network and cluster analysis of the literature. *Frontiers in Psychology*, 9, 2086.

Codrea-Rado, A. (2018) XR will transform the workplace, starting with collaboration. Available: *https://www.raconteur.net/technology/xr-workplace-collaboration*

Cranmer, E., Jung, T., Dieck, T., and Miller, A. (2016) Understanding the acceptance of augmented reality at an organisational level: The case of Geevor Tin Mine Museum, *Information and communication technologies in tourism 2016.* 637–650, Springer, Cham.

Debika, S. (2018) Home sweet virtual home: The use of virtual and augmented reality technologies in high involvement purchase decisions. *Journal of Research in Interactive Marketing*, 12(4), 398–417.

Dubois, A., and Gadde, L.-E. (2002) The construction industry as a loosely coupled system - Implications for productivity and innovativity. *Construction Management and Economics*, 20(7), 621–631.

Girvan, C. (2018) What is a virtual world? Definition and classification. *Educational Technology Research and Development*, 66(5), 1087–1100.

Guo, H., Yu, Y., and Skitmore, M. (2017) Visualization technology-based construction safety management: A review. *Automation in Construction*, 73, 135–144.

Herring, S.C., ed, (1996) Computer-mediated communication: Linguistic, social, and cross-cultural perspectives. *John Benjamins Publishing Company*.

Hirsjärvi, S., Remes, P., and Sajavaara, P. (2007) *Tutki ja kirjoita.* 13th ed. Tammi

IDC. (2020). Worldwide spending on augmented and virtual reality forecast to deliver strong growth through 2024, according to a New IDC Spending Guide. Available: https://www.idc.com/getdoc.jsp?containerId=prUS47012020

Jalo, H., Pirkkalainen, H., Torro, O., Kärkkäinen, H., Puhto, J., and Kankaanpää, T. (2018) How can collaborative augmented reality support operative work in the facility management industry? *Knowledge Discovery, Knowledge Engineering and Knowledge Management*, (IC3K 2018), 41–51.

Jalo, H., Pirkkalainen, H., Torro, O., Lounakoski, M., and Puhto, J., (2020) Enabling factors of social virtual reality diffusion in organizations. *Proceedings of the 28th European Conference on Information Systems (ECIS): An Online AIS Conference.*

Jerald, J. (2015) *The VR book: Human-centered design for virtual reality*. Morgan & Claypool.

Kalantari, M. (2017) Consumer's adoption of wearable technologies: Literature review, synthesis, and future research agenda. *International Journal of Technology Marketing*, 12(1), 1.

Kiiras, J., and Tammilehto, S. (2014) *Kiinteistökehitys*. Helsinki, Finland: Kiinteistöalan Kustannus Oy

Larson, E. and Larson, R. (2004) Use cases: what every project manager should know. *Paper presented at PMI® Global Congress 2004—North America, Anaheim, CA. Newtown Square, PA: Project Management Institute.* Available: https://www.pmi.org/learning/library/use-cases-project-manager-know-8262

Maloney, D., Freeman, G., and Wohn, D.Y. (2020) 'Talking without a voice': Understanding non-verbal communication in social virtual reality. *Proceedings of the ACM on Human-Computer Interaction*, 4(CSCW2), 1–25.

Manninen, S. (2012) *Rakennusalan hukkien priorisointi ja eliminointi*. University of Oulu. Available: https://www.finna.fi/Record/oy.9911919023906252

McVeigh-Schultz, J., Segura, E.M., Merrill, N., and Isbister, K. (2018) What's it means to 'be social' in VR? Mapping the social VR design ecology. *DIS '18 Companion: Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems*, 289–294.

McVeigh-Schultz, J., Kolesnichenko, A., and Isbister, K. (2019) Shaping pro-social interaction in VR: An emerging design framework. *CHI '19: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 594, 1–12.

Miesnieks, M. (2018) Multiplayer AR—Why it's quite hard. Available: https://medium.com/6d-ai/multiplayer-ar-why-its-quite-hard-43efdb378418

Miles, M.E., Berens, G., and Weiss, M.A. (2000) Real estate development: Principles and process. *3rd ed. Urban Land Institute.*

Milgram, P., and Kishino, F. (1994) A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, E77-D (12), 1321–1329.

Mittleman, D., and Briggs, R.O. (1999) Communication technologies for traditional and virtual teams. *Supporting Work Team Effectiveness*, 39, 246–270.

Mütterlein, J. (2018) The three pillars of virtual reality? Investigating the roles of immersion, presence, and interactivity. In *51st Hawaii International Conference on System Sciences (HICSS)*, 1407–1415.

Nuutinen, A., (2017) *Virtual creation - Architectural design with virtual reality*. Aalto-yliopisto. Available: http://urn.fi/URN:NBN:fi:aalto-201712208304

Saunders, M., Lewis, P., and Thornhill, A. (2009) *Research methods for business students*. 5th ed. Prentice Hall.

Shore, J. (2016) Synchronous vs. asynchronous communication: The differences. Available: https://searchmicroservices.techtarget.com/tip/Synchronous-vs-asynchronous-communication-The-differences

Song, H., Chen, F., Peng, Q., Zhang, J., and Gu, P. (2018) Improvement of user experience using virtual reality in open-architecture product design. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 232(13), 2264–2275.

Strandman, J. (2018). *Virtuaalimallityöpajat rakennushankkeissa - Virtuaalitodellisuus yhteistoiminnan välineenä*. Aalto-yliopisto. Available: http://urn.fi/URN:NBN:fi:aalto-201901171296

Sun, L., Fukuda, T. and Resch, B. (2014) A synchronous distributed cloud-based virtual reality meeting system for architectural and urban design. *Frontiers of Architectural Research*, 3(4), 348–357.

Thomas, B., Close, B., Donoghue, J., and Squires, J. (2000) ARQuake: An outdoor/indoor augmented reality first person application. *Personal and Ubiquitous Computing*, 6(1), 75–86.

Thomas, B.H. and Sandor, C. (2009) What wearable augmented reality can do for you. *IEEE Pervasive Computing*, 8(2), 8–11.

Torro, O., Jalo, H., and Pirkkalainen, H. (2021) Six reasons why virtual reality is a game-changing computing and communication platform for organizations. *Communications of the ACM.*

Vartiainen, M., Kokko, N., and Hakonen, M. (2004) *Hallitse hajautettu organisaatio: Paikan, ajan, moninaisuuden ja viestinnän johtaminen.* Helsinki: Talentum.

Wang, X., and Love, P.E.D. (2012) BIM + AR: Onsite information sharing and communication via advanced visualization. In *Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design*, CSCWD 2012, IEEE, 850–855.

Webel, S., Bockholt, U., Engelke, T., Gavish, N., Olbrich, M., and Preusche, C. (2013) An augmented reality training platform for assembly and maintenance skills. *Robotics and Autonomous Systems*, 61(4), 398–403.

Yee, N., Bailenson, J., and Ducheneaut, N. (2009) The Proteus effect: Implications of transformed digital self-representation on online and offline behavior. *Communication Research*, 36(2), 285–312.

Yee, N., and Bailenson, J. (2007) The Proteus effect: The effect of transformed self-representation on behavior. *Human Communication Research*, 33(3), 271–290.

Zollmann, S., Hoppe, C., Kluckner, S., and Poglitsch, C. (2014) Augmented reality for construction site monitoring and documentation. *Proceedings of the IEEE*, 102(2), 137–154.