Drivers and barrios in using augmented reality in renovation projects - literature review

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Abstract

Reducing the emissions of greenhouse gases is of utter importance for the mitigation of climate change mitigation. In Sweden, the building and service sector is responsible for 21% of total greenhouse gas. Renovating existing buildings, more specifically those which were constructed before 1980, can significantly contribute to the reduction in energy consumption and emissions of greenhouse gases. Because the majority of these buildings are in need for renovation. But the energy renovation and energy efficiency-related maintenance rate in Sweden is very low due to lack of technical drawings and documentation of information about material specifications and structure systems. Adoption of augmented reality technologies can be beneficial as these technologies present digital information in the context of the physical environment. However, the level of adoption of these technologies in renovation and maintenance projects is still very low. This paper expands the technology acceptance model to evaluate determinants of users' acceptance of augmented reality technologies in renovation and maintenance projects.

Introduction

The global climate system is being affected by the rising energy consumption as well as the emission of greenhouse gases, of which the most significant is carbon dioxide (International Energy Agency., 2019). The Paris climate agreement was therefore hailed by 195 countries, to limit the global temperature increase well below 2 degrees Celsius above pre-industrial levels and later, to pursue efforts to keep the temperature rise even further to 1.5 degrees Celsius (United nations, 2019). Furthermore, the European Commission issued its renovation wave strategy to reduce the energy consumption in the building sector and thereby tackling climate changes (European Commission, 2022). The main objective of the renovation wave is to at least double energy renovation rate by 2035 (European Commission,2022). Therefore, the government of Sweden set a goal to have net zero emissions of greenhouse gases into the atmosphere to subsequently achieve negative emissions by 2045 (Government Offices of Sweden, 2019). The target means that emissions of greenhouse gases from Swedish territory must be at least 85% lower in 2045 than emissions in 1990 (Government Offices of Sweden, 2019). In addition, the energy consumption in Sweden should be reduced by 50% until 2030 compared to 2005 (Government Offices of Sweden, 2019).

In 2019, the building and service sector was responsible for about 144 TWh energy consumption (Swedish energy agency, 2021) and 11.7 million tonnes emissions of carbon dioxide equivalents (Swedish National Board of Housing, Building and Planning, 2022). However, the energy renovation and energy efficiency-related maintenance rate in Sweden is very low (Government Offices of Sweden, 2020). Approximately 80%[1] of the multifamily houses and commercial buildings, built before 1980, are in need of extensive energy renovations to meet the current national codes in Sweden (Government Offices of Sweden, 2020). Similarly, the majority of the detached houses built before 1980 (almost 70% of them) have poor energy performance due to deteriorations in building envelopes as well as heating, ventilation and air conditioning systems (Government Offices of Sweden, 2020).

The low energy renovation rate is mainly related to challenges such as owners' lack of awareness regarding the existence of new technologies (The Swedish National Board of Housing, Building and Planning, 2022), difficulties in quantifying the actual energy savings (López et al., 2018), high investment cost (The Swedish National Board of Housing, Building and Planning, 2022) and long payback period (Swedish Energy Agency,

[1] About 88% of the multifamily houses and commercial buildings, built between 1971 to 1980, need extensive renovations and maintenances. While this value is about 82% for those built between 1961 and 1970. Similarly, 87% of single-family house buildings, which were constructed before 1960, have poor conditions and should be renovated to meet the current energy codes in Sweden (Government offices of Sweden, 2020).

2021). During the past years, the government of Sweden offered an array of solutions to manage the abovementioned challenges such as financial aids, tax-deduction, free energy consultancy, and training programs for experts. Another challenge in performing energy renovations and maintenances is related to the lack of:

- Technical drawings: there are variety of hidden objects such as pipelines and electricity wires, which are not readily visible for maintenance workers (López et al., 2018),
- Information about material specifications (López et al., 2018),
- Location of structural components (López et al., 2018).

The latest challenge is more illustrated when renovating cultural and historic building stock in Sweden as these buildings should be renovated with caution, so their cultural and historic values are not negatively affected (Eriksson & Johansson, 2021).

Augmented reality (AR) is a beneficial technology, which can be used to manage the above-mentioned difficulties (Shakil Ahmed., 2018). The unique capability of AR, known as X-ray vision, allows users (maintenance workers, designers, engineers, and other practitioners) to see through solid elements such as walls and visualises the hidden objects in situ (Fei & Seipel, 2018; Okimoto et al., 2015). AR presents relevant digital information in the context of the physical environment and embeds the digital information into the real physical environment so that both can simultaneously be experienced by users, resulting in better quality at lower cost (Fei & Seipel, 2018; Okimoto et al., 2015).

Despite sizable amount of AR-related research in the fields of medical operations, gaming, and manufacturing (Agarwal, 2016), the level of AR adoption in renovation projects is still very low (Delgado et al., 2020) and their full potential is not thoroughly achieved (Delgado et al., 2020). The reason for failure in the deployment of AR technologies (and more generally any digital tool), is not that these technologies are unsuccessful to fulfil as expected, but rather that the users decline to use them (Park et al., 2012).

The technology acceptance model (TAM) has been commonly adopted to evaluate determinants of users' acceptance of a given technology. TAM enables tracing the effects of external variables on users' cognitive beliefs and thereby their influence on actual technology use (Venkatesh et al., 2003). One of the main advantages of TAM is its simplicity, as it can be easily expanded to evaluate determinants of users' acceptance of different technologies within various domains (To et al., 2018).

This paper conducts a systematic literature review to specify external variables with effects on AR adoption in renovation and maintenance projects, thereby expanding TAM. The expanded TAM will later be exploited to evaluate determinants of users' acceptance of AR in renovation and maintenance projects in Sweden.

Methodology

Scopus database was used to search for relevant studies, thereby specifying external variables on AR adoption in renovation projects. Table 1 presents search-terms, keywords, and the total number of literatures found. The subject area was limited to "social science", "economics, econometrics and finance", "engineering", "decision science", "computer science", "energy", "material science" and "environmental science". Additional limitations were considered to search for English language studies, published from 2010 until 2022. From 98 found studies 65 were found eligible to review. Furthermore, relevant studies cited by eligible ones were also reviewed to obtain better understanding about AR technologies, TAM, and effects of external variables on users' acceptance of technologies.

Table 1. Search-terms used in Scopus

Search-terms	Keyword	Found studies
technology acceptance model + augmented reality + renovation		30
technology acceptance model + augmented reality + energy efficiency	Augmented reality	33
technology acceptance model + augmented reality + maintenance + construction	Augmented reality	87
TAM + AR + renovation		20
TAM + AR + maintenance		19
TAM + AR + energy renovation		14
Total found studies		203

Technology acceptance model (TAM)

TAM was initially derived from the theory of planned behaviour and theory of reasoned action (Lee et al., 2015; Venkatesh et al., 2003). It aims to evaluate determinants of users' acceptance of a given technology by specifying external variables and their influence on cognitive beliefs (Figure 1) (Venkatesh & Davis, 1996). Cognitive beliefs are characterised by the perceived ease of use and perceived usefulness (Venkatesh & Davis, 1996). The perceived use of each refers to the degree to which users believe that adopting a technology is free of effort (Venkatesh & Davis, 1996). While the perceived usefulness is linked to users' belief whether a given technology improves their performance in doing a task (Venkatesh & Davis, 1996). Enhanced perceived ease of use and perceived usefulness can improve users' intention to use a technology that can lead to actual technology use (Liao et al., 2018; Venkatesh & Davis, 1996). The first step in using and expanding TAM is to specify external variables influencing the adoption of a specific technology. Later, one should develop hypotheses to explore the degree to which the external variables affect the cognitive beliefs (perceived use of use and perceived usefulness). Further hypotheses should be posited to show the relationships between cognitive beliefs and users' intention in using the technology and finally its effect on actual technology use.

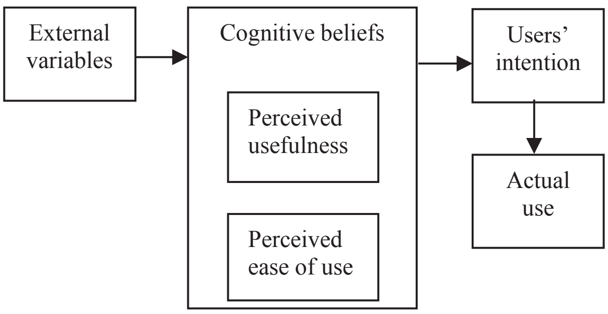

Figure 1: Technology acceptance model (TAM) generated using (Venkatesh & Davis, 1996).

Results

The most influential externa variables, which were discussed in former studies, are presented in Figure 2. Technological features with a share of 46% were the most analysed external variables, followed by organizational features with a share of 35%, trust features with share of 11%, and economic features with share of 7% (Table 2).

Table 2 2: Former studies which analysed technological, economic, organisational and trust features

External variables	References
Technological features	Alves et al. (2019) Aromaa et al. (2016) Belletier et al. (2021) Bosch et al. (2020) Chu et al. (2018) Elshafey et al. (2020) Gavish et al. (2015) Gu & London. (2010) Henderson et al. (2010) Ho et al. (2022) Hou et al. (2013) Hou et al. (2015) Jo et al. (2014) Kim & Hyun. (2016) Li et al. (2018) Masood et al. (2020) Fan et al. (2020) Rapaccini et al. (2014) Suárez-Warden et al. (2015) Terhoeven et al. (2018) Wang et al. (2014) Wang et al. (2022) Wang et al. (2013) Wu et al. (2013) Yeh et al. (2012)
Economic features	Zaher et al. (2018) Bosch et al. (2020) Kodeboyina et al. (2016) Wang et al. (2014)
Organisational features	Rasimah et al. (2011) Wang et al. (2016) Cabero-Almenara, et al. (2019) Lo & Lai. (2019) Gavish et al. (2015) Loch et al. (2016) Werrlich et al. (2017) Daling et al. (2020) Stigall et al. (2019)

	Scott et al. (2020) Alves et al. (2019) Masood et al. (2020) Terhoeven et al. (2018) Masood & Egger (2020) * Al Haderi et al. (2018) * Kamel (2010) * Cho (2007) ** Nikas et al. (2007) ** Hua (2007) **
Trust features	Wang et al. (2007) Cheng et al. (2013) Teizer et al. (2013) Lu et al. (2022) Huang & Yao. (2021) Gu et al. (2010)

* Related to top management support

** Related to organisational size

Expanded TAM

Technological features in terms of AR adoption in renovation and maintenance projects are associated with different attributes of information quality and system quality. Information quality refers to reliability and accuracy of the AR technologies, while system quality refers to easiness and simplicity of using these technologies. Considering information quality, multiple studies highlighted that the accuracy of AR technologies and quality of outputs is of utter importance (Lu & Deng, 2021; Thomas & Alex, 2020; Chu et al., 2018; Elshafey et al., 2020; Min et al., 2020; Terhoeven et al., 2018; Belletier et al., 2021). As inaccurate information can lead to dislocate renovation-demolition operations, leading to the increased time and cost for employment and corrections.

System quality associated mainly with hardware and software limitations and time required for setting up AR technologies were commonly discussed by former studies (Bosch et al., 2020; Chu et al., 2018; Wang et al., 2014; Gavish et al., 2015; Gu & London., 2010). Hardware limitations are mainly related to barriers, which are not designed to be used for long working hours (Cralsén & Elfstrand, 2018) and processors being overheated after continuous use for a long period of time (Cralsén & Elfstrand, 2018). While the software limitations refer to difficulties in making connections between AR technologies, simulation tools present relevant digital information and embed it into the real physical environment The setup time is the other influential variable, affecting users' acceptance of AR technologies. The setup time depends on whether users have experience of using AR technologies and are familiar with managing hardware and software limitations.

Users' experience related to the information and system quality have a significant influence on their perceived ease of use and perceived usefulness e (Chismar & Wiley-Patton, 2003; Lin, 2007; Mohd et al., 2005; Wang et al., 2009). The following hypothesis are therefore posited:

H 1- Information quality has a significant positive effect on perceived ease of use.
H 2- Information quality has a significant positive effect on perceived usefulness.
H 3- System quality has a significant positive effect on perceived ease of use.
H 4- System quality has a significant positive effect on perceived usefulness.

Economic features refer to affordability and cost saving potential. Former studies have different and sometimes contradictory attitudes related to the cost of AR technologies. For instance, Kodebonya et al. (2016) discussed that the high cost of AR technologies limits the adoption of them in renovation and maintenance projects. While Zaher et al. (2018) and Bossh et al. (2020) stated that AR technologies are cost-effective solutions since adoption of these technologies leads to the reduction of cost for employment and corrections. According to Yusoff et al., (2020) perceived cost can affect users' purchase and use intention. Hence, the following hypothesis is considered:

H 5- Affordability and cost-saving potential has a significant positive effect on perceived usefulness.

Organisation features in terms of AR adoption related to users' possibility to receive adequate education and training to be able to utilise these technologies (Wang et al., 2016; Cabero et al., 2019; Lu & Lai, 2019). Because training can indeed facilitate the use of AR technologies in renovation and maintenance projects. Furthermore, it assists users to realise the usefulness of these technologies (Gavish et al., 2015; Loch et al., 2016; Werrlich et al., 2017). Accessibility to adequate education and training is mainly affected by top management support and organisational size. Top management support refers to the determination of top management in using AR technologies and the domain in which these technologies are exploited (Al Haderi et al., 2018). The top management commitment in allocating resources and designing strategies for adopting AR technologies can promote users' personal developments (Al Haderi et al., 2018).

Organisation size shapes mainly the availability of resources to be used for educating and training users. Former studies have different attitudes about the effects of organisational size on users' acceptance of AR technologies. According to Cho (2007) also Nikas et al (2007), larger organisations spend further resources and efforts to facilitate the adoption of AR technologies, since these organisations deal with greater businesses and have more economic resources. In the country, small and/or medium-sized organisations have more flexibility and are more likely to adopt AR technologies (Hua, 2007). Former studies discussed that knowledge acquisition due to training has a significant effect on the perceived ease of use and perceived usefulness (Gavish et al., 2015; Loch et al., 2016; Werrlich et al., 2017). The following hypothesis are therefore posited:

H 6- training has a positive significant effect on perceived ease of use.
H 7- training has a positive significant effect on perceived usefulness.

Trust features in terms of AR adoption in renovation and maintenance projects are mainly associated with safety and security risks. According to Wang et al. (2007), Cheng et al. (2013), and Teizer et al. (2013), adoption of AR technologies for detecting the location of hidden objects and visualisation of data contributes to the enhanced safety in construction sites. On the other hand, Huang (2021) and Gu et al. (2010) highlighted concerns related to security, confidentiality, and privacy. Trust features can be more illustrated when renovating high-secure buildings, such as banks, governmental offices, military facilities, embassies, and consulates. The following hypothesis is therefore considered:

H 8- Trust features have a positive significant effect on users' intention.

Additional hypotheses are posited to describe the relationship between perceived ease of use and perceived usefulness. Former studies discussed that a technology including AR technologies can be perceived useful when they are easily utilised in a project (Venkatesh & Davis, 2000; Legris et al., 2003), that clarifies the effect of perceived ease of use on perceived usefulness. Further improvements in perceived ease of use and perceived usefulness enhance users' intention in using AR technologies, which lead to actual technology use (Liao et al., 2018; Venkatesh & Davis, 1996). Thus, the following hypotheses were considered:

H 9- Perceived ease of use has a significant positive effect on perceived usefulness. H 10- Perceived ease of use has a significant positive effect on users' intention.

H 11- Perceived usefulness has a significant positive effect on users' intention.
H 12- Users-intention has a significant positive effect on actual use.

Figure 3 shows the extended TAM, developed to evaluate determinants of users' acceptance of AR technologies in renovation and maintenance projects. The extended TAM comprises technological, economic, organisational and trust features. In addition, it illustrates how these features affect perceived ease of use and perceived usefulness, thereby shaping the actual technology use. The arrows show hypothesised relationships in the direction of arrows.

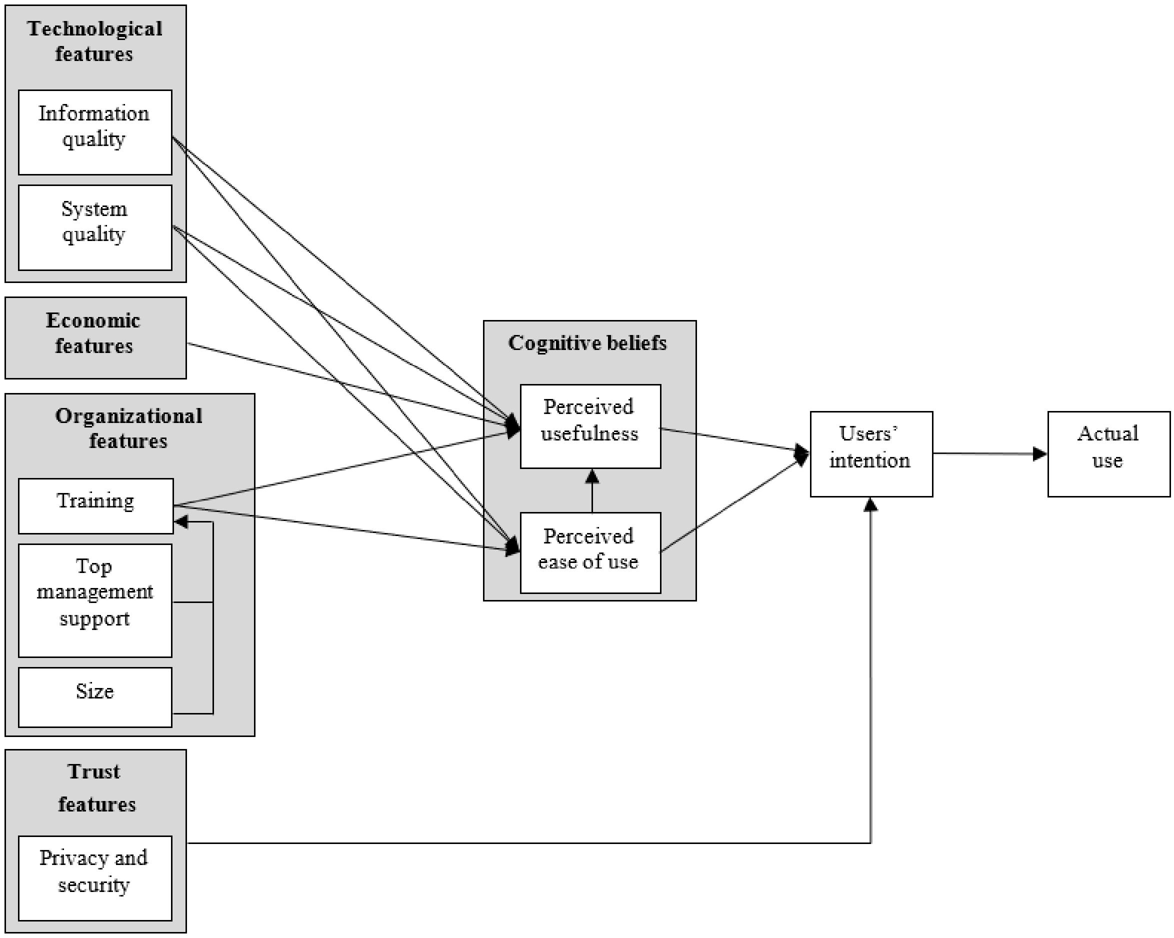

Figure 3: The extended TAM

Conclusion

The government of Sweden set ambitious goals to be 50% more energy efficient by 2030, while achieving net zero carbon emissions by 2045. The building and service sector accounts for 21% of the total greenhouse gas emissions in 2019 in Sweden. Although great attempts have been made to reduce the energy consumption and emissions of greenhouse gases in this sector, the energy renovation and maintenance rate in Sweden is very low. This occurs due to various challenges associated with owners' lack of awareness regarding the existence of new technologies, high investment cost, long payback period and difficulties in quantifying the actual energy savings. To manage the abovementioned challenges, the government of Sweden offered an array of solutions such as financial aids, tax-deduction, free energy consultancy, and training programs for experts. Another challenge in performing energy renovations and maintenances is the lack of technical drawings and documentation of information about material specifications and structure systems of existing buildings. Adoption of augmented reality technologies in renovation and maintenance projects can be beneficial since these technologies present digital information about the hidden objects and embed the digital information into the real physical environment so that both can simultaneously be experienced by users. However, the level of AR adoption in renovation and maintenance projects is still very low.

This paper evaluated the determinants of users' acceptance of AR technologies by expanding the technology acceptance model (TAM). A systematic literature review was therefore conducted to specify external variables, which affect the users' acceptance of AR technologies. The most influential external variables comprised technological, organisational, economic and trust features. Technological features were associated with different attributes of information quality and system quality, while organisational features included top management support, organisational size, and training. Economic features were related to affordability and cost of AR technologies. Trust features in terms of AR adoption in renovation and maintenance projects were related to privacy and security risks, more specifically in high-secure buildings.

Application of TAM for evaluating determinants of users' acceptance of a technology can be criticised since this model has inherent limitations (Salovaara & Tamminen, 2009). To evaluate the degree to which technological, organisational, economic and trust features affect actual use, one should design surveys to gather information about users' acceptance of AR technologies. But users may have various comprehension about survey questions (Salovaara & Tamminen, 2009). For instance, a user may focus on initial costs of adopting AR technologies, while the other one concentrates on economic benefits being made by adopting these technologies. To manage any such limitation, survey questions should be designed in a way to comprise users' possible comprehensions. In addition, users may have different perceptions in various timeframes (Liu, 2018). Performing longitudinal surveys can indeed help to manage changes in users' perception.

In addition to TAM, Different theories have been previously used to technology, organisation, environment framework (TOE) and unified theory of acceptance and use of technology (UTAUT) were used to evaluate determinants of users' acceptance of a technology. However, these theories have various limitations. According to (Dedrick & West, 2003), TOE has no clear structure and should be further developed to be used in evaluating users' acceptance of a technology (Dedrick & West, 2003). The limitation of UTAUT is mainly associated to its inflexibility since this theory cannot be used in different contexts (Al-Gahtani, et al., 2007). TAM overcomes the above-mentioned limitations and can be used in different field of studies (McCoy et al., 2005). The expanded TAM will be later used to evaluate determinants of users' acceptance of AR technologies in renovation and maintenance projects in Sweden.

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