

THE DEMOCRATIZATION OF AR:
PROSPECTS FOR THE DEVELOPMENT OF AN AUGMENTED REALITY APP IN THE
REALM OF SPATIAL DESIGN

by

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PROSPECTS FOR THE DEVELOPMENT OF AN AUGMENTED REALITY APP IN THE
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Abstract

Despite the growing popularity of augmented reality technologies in many different industries, there is still an untapped opportunity for its implementation in the realm of interior design. Consumer needs and demands evolve constantly, and with that comes the need to develop augmented reality applications that focus more on the users' experiences and specific preferences. This research paper presents a framework for creating a mobile AR design application that will allow its users to explore the home designing process with their own hands. A SWOT analysis of the current AR applications in the field is provided to justify the need for the novel invention. Overall the research aims to democratize the AR technology, making it more accessible to the general consumer and adding value with features missing from the current augmented reality app developments in the design sphere. The paper also presents opportunities for future developments of the application that would further enhance the user experience.

Keywords: augmented reality; user experiences; interior design; mobile application; virtual reality; democratization of technology; SWOT analysis;

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Introduction

In 2016, we witnessed the emergence of many innovative mobile applications using augmented reality and hardware products to increase this technology's efficiency (Boyajian, 2016). According to many researchers, we can expect it to develop with even higher speed and new directions. Very soon, the extended reality technologies could become an integral part of our personal and work lives. Currently, augmented reality (AR) has explicitly been utilized in many different fields ranging from health services to education, online shopping, design, entertainment, and many others. This growing usage of AR and the changing needs of the consumers has largely informed this research thesis. For this project, I would define augmented reality as an enhanced visual experience of any interior environment, which gives the user a realistic representation of how an item would look like in a given space.

This primary research project aims to explore the current mobile AR applications in the realm of interior design. More specifically, the thesis paper would question how a future mobile application could be improved to suit the consumer needs better through a proposed framework for the development of an augmented reality mobile application. The future development of such an application would be an innovative approach to home redesign and will provide broader access to the AR technology. It will also allow the users to redecorate their homes in real-time without the need to use VR/AR headsets (which could have some limitations described later in the paper) without compromising the application's functionality.

The paper covers different aspects and will provide valuable knowledge about AR and its future use in spatial design regarding non-professional users. Since my research showed there are still many limitations in the mobile AR applications that aid people in designing their homes, it would be valuable further to explore the idea of AR and spatial design. This paper would serve as a foundation for the possible future development of a new AR application that will facilitate the designing process by providing more features and better usability. That will enhance the user's

interactive experience with the app. Moreover, it will also help them redecorate their homes without the need to buy external hardware (AR/VR headsets) or to have unique developers' knowledge to design virtual environments.

This paper begins with a literature review that outlines the theoretical framework that guided the project and provides short reasoning behind the choice of AR instead of VR. The next section describes how marketers have been utilizing AR to advertise and products since this aspect is also valuable to explore for the project's purposes. The review will also focus on AR with specific regards to spatial design and some related practices that already exist. Finally, the review summarizes an extensive study conducted by Siltanen et al. in 2013 that explores the user expectations from an augmented reality application for Interior design. It would serve as a solid basis for understanding the general consumers' and interior design enthusiasts' wants and needs from such an application. The paper continues with the proposed methodological framework and the structure of the project. That part includes a SWOT analysis of ten existing Android and IOS-based mobile interiors AR applications. A thorough evaluation of the research will follow this section. The paper continues with an outline of the project structure, i.e. the theoretical proposal of an app that aims to improve the users' experience and provide access to a broader range of consumers.

The research paper will explore AR in terms of the software and not the hardware. The reason for that is that every mobile device contains a processor, sensors, GPS, a display, a camera, a microphone, and others, which is all the hardware needed for an AR development. Lastly, paper prototypes of the proposed app will supplement the paper for a more comprehensive visual representation. Finally, the paper concludes with a summary of the thesis and a comment about future development opportunities.

Research Motivation

As a person interested in interior design and technology industries, I recognize a growing demand for digital media to visually enhance our spatial environments and give us a more practical and user-friendly way to decorate our homes. I began this research by posing the question: How can current AR solutions be improved to reach more people and provide better functionality and experience for the users? My research showed that customers are not prone to use the current solutions such as VR/AR headsets because they are an external and expensive device (Viet et al., 2009). Hence it was valuable to explore how developers can improve the functionality of the app and the more valuable features that need to be implemented. The use of mobile augmented reality for interior designing specifically still has many drawbacks—discussed in this paper— as well as low adoption from the users (Pampattiwar et al., 2016). My goal for this project is to demonstrate that this technology can be used in its full potential to provide the users with a semi-immersive experience without compromising on quality and features. Due to the technology's complexity and the lack of resources to develop a functioning prototype, the paper will be supplemented only with a paper prototype. Its goal is to give an idea of the main features and options for customization that I am proposing.

Literature Review

Democratization of AR (Theoretical Framework)

A central theme of this thesis is the concept of democratization of technology refracted through the current work's prism. Technology democratization refers to the need for people from a broad range of backgrounds and work fields to access and benefit from new technological advancements such as AR (Tenekedjieva, 2019). The paper aims to bring the designing process closer to the general consumer, provide easier access to the AR technology, and improve the overall user experience. Currently, if consumers wish to redecorate their space, they either have to hire a professional, or they have to do it themselves. Many different mobile applications could help with the process, but the ones available are not sufficient for complete and accurate design experience, as proven later in the paper. Another choice that people have for a better visual cue is the VR headsets. However, they do not allow the user to alter the environment but only preview the pre-made design. (Sidiq et al., 2017).

A central thinker of technology philosophy, Andrew Feenberg (1991), argued that democratizing technology requires extending the technological design to incorporate other desires and values. If this is successful, it can be a tool to increase inclusiveness (Veak, 2006). Feenberg argues that this must be achieved through consumer intervention in a freed design process (Feenberg, 1999). That means that people's expectations from certain technologies should be placed at the forefront when designing new tools and services (Feenberg, 1991). When human needs and wants are satisfied, that would further mean that more people would be able to access new technological tools and services. Comprehensive research performed by Siltanen in 2013 outlines the wishes and desires of non-professional consumers from an interior design AR application/service. Consequently, my research showed that the current accessible solutions are dissatisfactory in many regards using Siltanen's research as a basis.

Additionally, Thomas Friedman (1999) argued that the era of globalization was marked by the democratization of technology, the democratization of finance, and the democratization of information. Technology has been crucial in these systems, enabling the accelerated expansion of access to advanced information and resources and transforming how people interpret and seek such access (Friedman, 1999). Finally, Gartner has placed technology democratization on the ten strategic trends in technology for 2020 (Panetta, 2019). It is defined as 'easy access to technical or business expertise without lengthy and expensive learning and focuses on four primary areas - app growth, data and analysis, design, and information (Panetta, 2019).

Klaus Schwab, the President and Executive Chairman of the World Economic Forum, wrote a book titled *The Fourth Industrial Revolution*. He defines the term "Fourth Industrial Revolution," which is used to examine the impact of new technologies in the early 21st century on almost the entire spectrum of human development (Schwab, 2017). It also illustrates that when sets of innovations arise and converge, they could cause changes beyond the marginal efficiency gains (Schwab, 2017). According to Schwab, the implications of ongoing research, innovation, and marketing — and the introduction of new technologies well beyond the services that make our lives simpler — represent a profound set of social identity changes and a transformation of how we view the world. Technologies usually represent their designers' beliefs, and both reflect and constrain their users' desires (Schwab, 2017). Schwab (2017) adds that technology ethics must be taken into account at all points of its creation and implementation. Doing so should be seen as functional, accessible, and vital to the future of technology we want. However, to date, those who have benefited the most from innovations have been customers capable of affording and navigating the digital world (Schwab, 2017). With that comes the threat to the democratic usage of innovations and services as people who are unable to access or use them cannot fully benefit from them. Ultimately, by putting people first and empowering them, we need to shape a future that works for us.

Why AR and not VR?

For the project, it is essential to outline the advantages of augmented reality over virtual reality and why it would be the more suitable technology for an interior design application. The main difference between AR and VR is the level of virtuality that they provide. In Augmented reality, the users can see computer-generated objects on top of a real-world environment. On the other hand, virtual reality provides a fully immersive virtual experience.

The International Journal of Computer Science and Mobile Computing from 2017 outlines a few key differences between AR and VR relevant to the current project. According to Sidiq et al. (2017), the users' engagement with a virtual world has brought a new realm of study that deals with the "dualistic interaction between mind and body" or how the user and the virtual world communicate with each other. The study points out that the feeling of being present in the world can be a psychological condition related to the mediated and unmediated experience. In virtual reality, the user does not feel or accept the existence of his surroundings and reacts as if the real world is not there, whereas, in augmented reality, the user can sense and recognize his environment and respond accordingly to it (Sidiq et al., 2017). As a result of the different immersion levels, the augmented reality applications and devices that support them are slowly becoming more commercially successful as they do not disconnect people from the real world altogether (Sidiq et al., 2017).

The other significant difference between AR and VR is in the devices that support them. Users usually access VR through an OHMDs (optical head-mounted displays) that entirely blocks the vision (Greenwald, 2018). Virtual reality OHMDs are also associated with VR-induced nausea and vomiting, which may be a problem for certain people (Sidiq et al., 2017). In comparison, the devices that utilize AR allow the users to change their location and perform various other tasks while being partially virtually engaged. As a consequence, researchers expect AR to have a more

significant impact on the business market, despite being behind VR on the current growth curve (Sidiq et al., 2017).

Overall, AR is more suitable than VR for an interior design application for two main reasons. The first one is that the more sophisticated VR headsets are not commonly available for home consumers and could be quite expensive (Viet et al., 2009). ARs' ability to work on mobile devices eliminates the need for an external device. The second reason is that VR presents an already designed space for the user to observe, while AR allows users to change the environment in front of their eyes as they wish and then to preview the result. These benefits, alongside other crucial ones, are highlighted in Table 1 below.

AUGMENTED REALITY VS VIRTUAL REALITY	
Augmented reality (AR)	Virtual reality (VR)
AR is a combination of real and virtual worlds	VR creates entire virtual world
It lets people interact with both real and virtual worlds and distinguish between the two	It's hard to differentiate between what is real and what is not
Generally, it is experienced by using a smart-phone, laptop or tablet	This is experienced by wearing VR headsets (mounted or handheld-controlled)
The purpose of AR is to enhance experience by adding virtual components such as digital images and graphics as a new layer of interaction with the real world	The purpose of VR is to create its own reality that is completely computer-generated
Users remain in the real world	Users are transported into a new world
It adds relevant information to the existing real-world view	It incorporates heavy graphics to create a virtual environment
It is mostly used for demonstrations, interior designing and mapping	It is used in games, medicine, military, etc
Users maintain a sense of presence in the real world	Senses of users are under the control of the system
Users can move, rotate, scale and manipulate 3D objects in real world	Users can move, rotate and scale 3D objects in virtual world
Users are present at the location of experience	Users are not at the location of the experience
Users can physically move in the environment	Users cannot physically move in the environment

Table 1 – Comparison of the main differences between AR and VR.

Augmented Reality - An overview

This section provides a brief overview of the main types of realities to understand the concept of "augmented reality better," and its interaction with other types of realities (see Fig. 1). Milgram and Kishino (1994) define the reality-virtuality continuum in which AR is considered part of the mixed reality. The figure shows that mixed reality includes both augmented reality and augmented virtuality and examines the phenomena of mixing real and virtual objects in real-time. The goal is to create mixed environments where real and virtual (digital) objects interact with each other in real-time (Antonova, 2015).

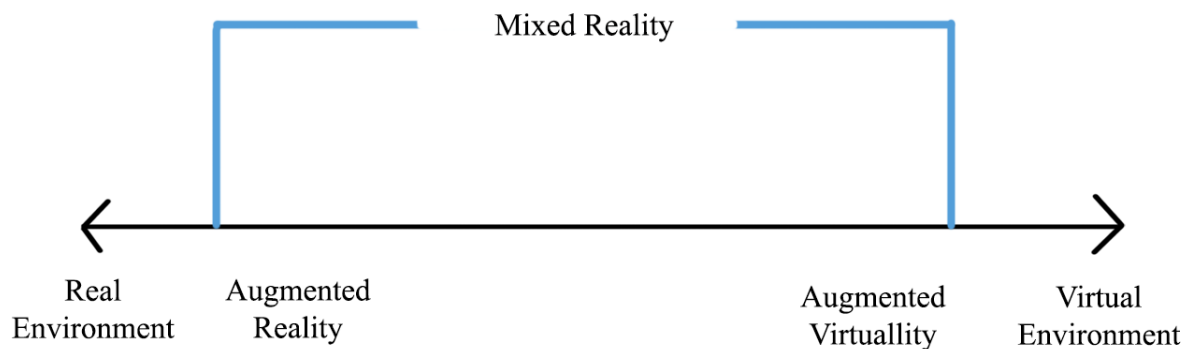


Fig 1 – The reality- virtuality continuum

Academics believe that the term was first introduced in the first half of 1990 by Thomas Caudell, who was then one of Boeing's leading engineers (Poetker, 2019). In the 90s, augmented reality technology aims to inform and facilitate the users as much as possible by providing them with additional information about the qualities and abilities "invisible to the naked eye" that an object or product possesses (Poetker, 2019).

Augmented reality is a set of technologies in which the screen of a tablet, phone, or other device mixes the real world with certain virtual content. In particular, augmented reality relies on techniques developed in virtual reality, interacting with the virtual world and having a certain

degree of interdependence with the real. In this way, AR unites the real and computer-generated world and allows certain virtual information to be added to actual objects.

Currently, most consumer-grade AR hardware systems are geared towards enterprise-grade solutions for large businesses (Mealy, 2018). Moreover, many current-generation AR headsets are sold in development mode where "preorder kits are available for developers but not at a scale for mass consumption" (Mealy, 2018), which means that they are neither easy to access nor to use by the general consumer. One of the higher-profile head-mounted displays (HDMs) on the market, Microsoft's HoloLens, is a standalone headset that does not require a wired connection to an external device. (Mealy, 2019). According to many professionals in the field, HoloLens has the potential to become available for mass consumption. However, the price of the current generation and the FOV (field of view) are the main factors keeping it out of the hands of everyday consumers for now and is only suitable for enterprise-level AR experiences (Mealy, 2018). Another AR headset on the market is Meta 2, which unlike the HoloLens, requires a wired connection to a computer, which substantially limits the movements of the user; however, according to its developers, it provides a larger FOV (Mealy, 2018). Like Microsoft's solution, Meta 2 is considered an enterprise-level device as not many consumers currently have it (Mealy, 2018). Lastly, Magic Leap One is a smaller standalone headset that became available for developers in 2018 (Mealy, 2018). According to the headset's official website, it is geared towards enterprises and more giant corporations ("Reality is Just Beginning," n.d.).

This short overview of some of the more popular AR headset systems clearly shows that despite their advantages, such as more immersive experience and realistic graphics, the devices are not widely available or are too expensive to be accessed by an everyday user. On top of that, they often require the consumer to have developer skills to create different virtual environments, which poses another burden for the adoption of mass consumption. All of this justifies the need to develop an AR design application that is available on every smart device, and consumers can use without special developer skills or bulky and expensive hardware solutions.

Nonetheless, there are other examples of current AR apps in different industries that positively impact different sectors while disturbing the norms. One such example is Sephora's AR makeup application called Virtual Artist. The application scans the users' facial features and then allows them to apply different makeup products on their face. Sephora is an excellent example of a cosmetic company that enhances the user's shopping experience through new technologies rather than relying only on department store sales. According to the company, the Virtual Artist feature has had over "8.5 million visits and 200 million shades tried on," proving its success (Rayome, 2018).

Another successful example is HomeDepot's mobile AR application that allows the users to preview 3D renderings of different products directly in their home. According to Forrester Research, Home Depot's mobile app has been assessed as the leading retailer mobile application because of its functionality and user experience (McKinnon, 2020). Lastly, IKEA was the first furniture retailer to release a mobile application with AR that allows the user to snap a picture of the room and virtually place new furniture. Since it's the pioneer in the mobile interior AR apps, it will be discussed in more detail later in the paper. All of the examples mentioned above serve to show that augmented reality has the potential to alter any industry from cosmetics to home decorations and change the way people purchase and experience new products.

Mobile AR apps and Marketing

The development of an AR mobile application for interior design, which is more accessible and functional for the mass consumer, would target two user groups. The first is the person looking to redecorate their home and purchase new pieces of furniture. At the same time, the other target users are the furniture manufacturers and resellers trying to advertise their product in front of the consumer. That would be the main way the app generates revenue by charging the furniture dealers with a monthly subscription and selling advertisement space. The current state of affairs does not

leave the option for an entirely free application. On the consumer side of the spectrum, there could also be a subscription fee that would provide full access to all of the applications' features.

For this project, augmented reality will be considered in terms of the pre-purchase stage because AR has the most significant impact on this stage (Fill, 2009). At this stage, the consumer chooses to make a final purchase decision, and in this sense, AR can "put" the product in the hands of the customer, thus enabling him to test the specific product as if he already "owns" it. By spending more time with the respective branded product, customers have been proven to be more inclined to buy it (Owyang, 2010). The above-mentioned aspect benefits both of the target user groups.

To provide the context of how AR began to be used for marketing, I will outline some of the ways in which it was initially utilized for advertising purposes. Companies in the automotive industry were amongst the first to use AR for advertising (Spies et al.,2009). The companies printed individual leaflets, which, once recognized by a webcam, showed a three-dimensional model of the advertised car on the computer device screen. Later, this approach spread to various marketing niches, from computer games and movies to shoes and furniture. The available QR code, which is a barcode similar to that found on the packaging of commercially available products, is also an example of Augmented reality: a (black and white) image that contains readable data from the camera to a mobile phone. As a more complex example of Augmented reality, we can mention the testing of clothes, shoes, glasses, and others online. For this purpose, the AR application must be launched on a mobile phone, tablet, or computer placed at the point of sale, but it is also possible to do so through the store's website. Through Augmented reality applications, consumers receive much more information, making it easier for them to decide to purchase a branded product.

Notwithstanding the above, some of the existing developments, which explore the topic of augmented reality in the context of marketing, consider AR only as a promotional tool (Woods,2009) and not as a lasting marketing opportunity that can be used by companies. According to Owyang (2010) and Clawson (2009), augmented reality contributes to developing positive

relationships between consumers and the brand and influencing the purchase decision. Since over the next few years, digital media specialists are expecting AR to grow exponentially, and because so far we have only seen 5 to 10% of what AR can be used for (Woods, 2009), companies need to know what direction to follow in order to achieve a positive result from the use of augmented reality as part of their marketing programs.

Related Practices in Spatial Design

One of the related industries that benefit the most easily from the technology of augmented reality is architecture - including interior design, landscape architecture, installation art, and others. Architects utilize AR's full potential from futuristic presentations to clients to impressive pavilions during exhibitions and events. Since presenting a new design to the investor can be quite tricky, most architects have moved from 2D drawings to 3D models. For example, ARki is a tool for visualizing architectural models in real-time. It combines AR and architecture, providing three-dimensional (3D) images with varying degrees of interactivity. It is used both for design and presentation. It works by converting standard 2D images or models into 3D visualizations (Shavel, 2020). There are various functions, such as analysis of the construction and selection of building materials. Users can capture and record architectural models' variants in the form of 3D images or movie clips, and so on. ARki can be used with any system, which works with the operating systems of IOS / Android (Grozdanic, 2018).

SmartReality is another mobile application for AR. It uses the mobile device's camera to add an interactive building information (VIM) model to the printed circuit board, and that is how the app is creating the 3D visualizations of the project (Grozdanic, 2018). Users can zoom to show structures layers through a single button press to pass through various project stages and record images and videos from their work.

The engineering company Aecom uses mixed-reality technology to help architects and engineers of different geolocations visualize models of large and complex construction projects.

Thanks to the Microsoft HoloLens technology, the team members can see 3D models of the projects projected as a hologram. When they "walk" through the image, specialists can notice irregularities and eliminate them (Mposso, 2019). The technology connects to a network system and collaboration software from the company, specializing in developing Trimble construction and location software. Aecom uses augmented reality technology in Denver, London, and Hong Kong (Mposso, 2019).

AR in Interior Design: Why is there a need for it?

Mobile AR applications used for indoor design have a beneficial effect on enhancing users' spatial perception and design preferences, as they give almost realistic results in the representation of space (Siltanen et al., 2013). This thesis was developed based on the hypothesis that people have a hard time redesigning their homes without external visual cues and that some of the current AR design solutions are still not entirely effective. Since smartphones are one of the most widespread devices (Tsirulnik, 2017), it would be valuable to develop a practical mobile AR application that could facilitate the general consumer's designing process and enable more people to access the innovative service.

Another benefit of people to re-decorating their homes by themselves is the emotional connection they build with any given space. The places we inhabit play a vital role in our psychological behaviour, with much of our lives spent indoors. In reality, environmental psychology is the relationship between individuals and the spaces they occupy (Ackerman, 2020). The lighting, colours, dimensions, acoustics, and materials all address the individual's senses and create a continuum of sensations and practices (Ackerman, 2020). Our home environment can have a tremendous impact on how we behave or what we feel from inducing warmth and protection, determining well-being, or creating a healthy and productive working atmosphere. Therefore, design and innovative interventions should be considered according to the occupants' social and psychological needs (Ackerman, 2020). The development of an AR design application will allow

people to make decisions that speak to their connection with space. That way, regardless of whether the design is good or bad, it will be emotionally connected to the person who has designed it.

Currently, professionals and consumers use a variety of virtual designing tools and services available online. Siltanen et al. 's (2013) study have shown that home design services help users determine what types of "building products and decoration materials to pick for a home in addition to furniture, household appliances, and home electronics to choose for an aesthetically pleasing home environment "(p.547). More often those services allow the user to model their space based on a "ready-made 2D floor plans or 3D models". (Siltanen et al., 2013). Viyanon et al. (2017) also support my initial hypothesis by asserting that visualizing how a specific furniture item would look like in a room before purchasing is hard for many customers. In addition to that, Pampattiwar et al. (2016) note that people are busier with their work lives in today's world and that substantially limits their time to visit various furniture stores and pick new furniture. According to his study, companies have found a new difficulty with "fulfilling the customers' contentment of decoration of their room without an imaginary view of how the place would appear." (Pampattiwar et al., 2016, p.17789). Moreover, printed catalogues containing only textual information and images "do not provide any interaction for the user" and have become less and less useful for selling purposes. According to Pampattiwar et al. (2016), human imagination also adds a burden to the proper visualization of a room - hence it is hard to imagine the size of an item, the colour, and how well it integrates with the existing environment.

Since AR is a technology that overlays virtual objects onto the real world, its application in spatial design and architecture is undeniable. Another critical aspect of the customer's journey to buying new furniture is the resistance to purchasing online, as lacking full product information makes the purchase decision risky (Kim & Forsythe, 2008). Many researchers claimed that AR compensates for the lack of objective product information and the inability to imagine products by creating 3D augmented experiences (Macintyre et al., 2001; Lu & Smith, 2007; Pantano & Servidio, 2012; Papagiannidis et al., 2017). Papagiannidis et al. (2017) also turn the attention to the sensory

shopping experience in terms of visual, audio, and textual cues that gives the consumer a direct contact with the desired product and helps them with the decision making (Papagiannidis et al., 2017). Thus, AR not only gives a near-real representation of products but it also provides a powerful stimulation of the shopping experience that allows for a better evaluation of the products (Kim & Forsythe, 2008) as well as persuades people to buy items with more certainty (Poushneh & Vasquez-Parraga, 2017; Papagiannidis et al., 2017; Pantano et al., 2017; Oh et al., 2008). The overall shopping experience becomes an enjoyable and appealing experience (Papagiannidis et al., 2017; Yim et al., 2017; Li et al., 2001), with the aid of 3D visuals of an item (Fiore et al., 2005).

Moreover, the quality of the visuals created by AR can alter the buyer's behavioural intention (Pantano et al., 2017). That is important for retailers as the higher quality, positive experiences with AR technology use increase the customers' willingness to purchase more products from companies supporting AR applications (Poushneh & Vasquez- Parraga, 2017). Thus, augmented reality enhances the visual perception of furniture items and enriches shopping experiences (Poushneh and Vasquez-Parraga, 2017).

User Expectations

My evaluation of the existing interior AR applications is based on a mind mapping method obtained from a field study conducted in 2013 by Sanni Siltanen et al. In the study, the characteristics of mobile applications are analyzed quantitatively. The study provides a comprehensive overview of the specific needs consumers, prosumers, and design professionals have from an interior design service. In the following paragraph, I provide a summary of the study's findings, which would be referenced later in the paper.

The study provides valuable information about the users' needs and expectations from an interior design AR application. Siltanen (2013) studied two focus groups - non-professional users and professional designers to determine what each group would expect from the app and whether there are common grounds. The research ultimately shows that some expectations between the two groups are similar, while others differ. The study results are summarised in a mind map that shows all of the preferred features in an interior application. The mind map is illustrated in Fig. 2 (Siltanen, 2013), and according to it, the red flags represent the priority features in the application while the rest are second priority expectations. It is important to note that these preferences could shift with future technological advancements. Some of the study criteria include the user interface, virtual size, colour and texture intervention, interaction with existing furniture, photorealism, social media sharing features, and trademark support. All of the criteria are also featured in the mind map and the effectiveness of the current AR applications.



Fig. 2 - Mind map with user preferences.

Research Methodology

AR technologies are still very new, and the applications built for interior design are, therefore, primarily for entertainment purposes and do not concern any mass adoption aspects. Besides this, there are still several interior AR applications which are not entirely optimized for the end-users today. Most of these applications promise their consumers that by seeing features such as design, scale, colour, and texture, they can purchase branded furniture and decoration items that they check using AR technology—each of these applications shares commonalities with differing features, benefits, and drawbacks.

The research sample consists of Android and IOS-based interior design AR applications with embedded visual markers or markers with 3D models of virtual furniture and decorations. The evaluation criteria for the applications intended to be tested were established in conjunction with the results from the field study by Sanni Siltanen et al. in 2013. The mobile applications included in this research had been qualitatively determined in the analysis through the SWOT method, including the strengths, weaknesses, and opportunities. The threats are excluded due to irrelevance.

The research focuses on an assessment from the end-user perspective. It aims to find the shortcomings of the indoor mobile AR applications built for the general consumer. It is therefore intended to contribute to the development of mobile AR apps, which are expected to occupy a significant position in interior design in the future. The ultimate goal is helping everyday consumers benefit from the advantages of AR systems and improve their spatial perceptions and understanding. The work included searching in 'Apple's and 'Google Play' virtual stores for 'AR interior design' and selecting the applications with the most downloads and user reviews. The search resulted in the discovery of ten indoor AR applications with a relative number of downloads higher than one thousand. In the next step, the applications were downloaded on Android and IOS mobile devices and tested for their primary functions.

The following paragraphs will discuss each assessed application separately, outlining their strengths, weaknesses, and opportunities. The information derived from the research is summarised in Table 2, shown in the evaluation portion of the paper.

1. Ikea Place

Ikea place is a mobile application released from Ikea in 2017. It allows its users to try Ikea's products through AR technology. Digitally, users can use AR to visually check the decorative products and furniture in the company's catalogue. The software is for Ikea products only, so that the product inventory of any other brand is not affiliated. The customers will see all aspects of the products that they want to check and adjust properties, such as colour and texture. The app uses the Turnkey catalogue as a reference, with mobile device options for Android and IOS platforms.

Strengths

Since Ikea has a sizeable global store network, having a product for consumer testing with AR is comparatively higher. The online database is relatively large, consisting of more than two thousand Ikea products. Users can point their device in the desired spot in their space and preview the given product's virtual 3D models. Another feature of the app is the option to save favourite products, share selections on social media, and make purchases through Ikea's website. The application uses the device's camera to scan the room and automatically scale the product according to the dimensions of the space. Another feature of the app is its 'visual search' option, which allows the users to point their device to a piece of furniture that they like, and the app automatically recommends an Ikea product that looks similar to it. In terms of interface, the application is quite simple. According to Don Norman, to achieve high-quality user experience in any product or service, there must be a "seamless merging of the services of multiple disciplines, including engineering, marketing, graphical and industrial design, and interface design" (Norman & Nielsen, n.d.). He also points out the importance of "simplicity and elegance" of the product/service that

makes it enjoyable to use and own (Norman & Nielsen, n.d.). In these regards, Ikea Place provides both ease of use and proper functionality. It only has three buttons - the user's profile, browse collections, and recommendations. Screenshots from the applications' interface are shown on image one below. Lastly, the application can link furniture to the IKEA store and let the user buy the item that they like, which further enhances the user experience.

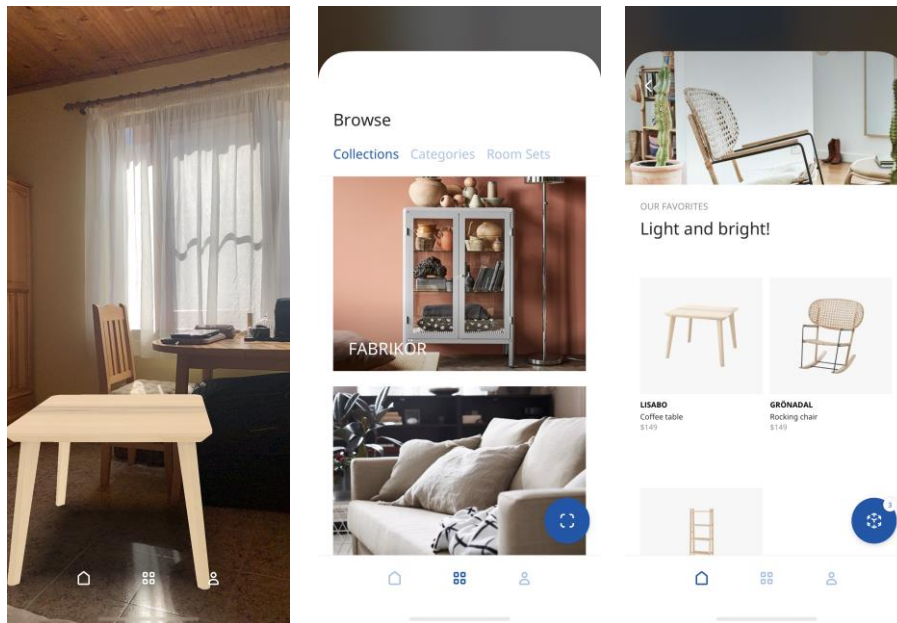


Image 1 - Ikea Place's User Interface.

Weaknesses

One of the significant disadvantages of the application is that the specific place where the user wants to test the furniture has to be empty and well lit without any visual obstacles. As a result, the user cannot preview more bulky furniture such as a wardrobe, for instance, on the place of their old furniture item. That means that one can only see the product when isolated from the other furniture pieces in the room. Thus, the user does not have a correct representation of how the product will look at the place of the old furniture. Additionally, the set of products includes mainly larger furniture items such as storage solutions, sofas, coffee tables, and armchairs. That substantially limits the user's options for redecoration. Lastly, the interface does not show any

options for the products when one clicks on them, and it is also hard to rotate an item as there are no visual cues on the screen on how to swipe the display.

Opportunities

One of the things that could be done in the future to make the app better is to expand the items included in the catalogue. Including more types of furniture and decoration items such as rugs, lamps, artworks, and others will allow people to preview even their room with more sophisticated items. The application provides an excellent opportunity for IKEA, to expand their AR catalogue and allow the shoppers to preview more items for their homes. Another useful feature to include would be the ability to place furniture on top of another old furniture. For that purpose, the app should have the feature to mask out the floor, ceiling, and walls by gathering the dimensions of the room, or through a diminished reality software discussed later in the paper. Since most of the app's catalogue items are large, it would be hard to move the real furniture in the room if one wants to preview how a new one would look in its place instead. However, the application is not developed for full redecoration but rather for viewing how IKEA's products would look like in real life - in terms of scale, shape, material, and colour.

2. Decor Matters

Strengths

Decor Matters is another mobile application that supports AR view and offers its users the ability to preview new furniture before purchasing it. The users can rotate and flip the furniture piece so they can experiment more with its placement. Then, they can capture the space and then add other furniture pieces to see how different styles would go together. Another one of their features is in an AR ruler, developed with ARKit that offers an easy way to get any room's dimensions. Furthermore, Decor Matters' users can benefit from the Artificial Intelligence algorithm that helps with the design's automation and gives product recommendations according to the user's preferences. Currently, the application provides information for the products of over thirty brands with two options to design - over a template or a picture of the user's real home. Lastly, the

application can buy products directly from the app, making the shopping experience easier once the user picks their favourite item.

Weaknesses

At this stage of the app development stage, the AR camera offers an unimpressive experience as the offered items for real-time preview are only five and randomly selected, as you can see on image #2. The application has a selection of 3D models which the user can overlay on top of the room's picture. However, that does not provide any realism nor interactive experience. Another drawback of the application is the lack of focus on one main goal that it seeks to fulfill. The interface is cluttered and hard to navigate (image # 3) with several different options that seem confusing to the user. These include a page with challenges that resemble a home redecoration video game, inspiration design board, user posts with hashtags similar to Instagram (image # 3), the option to shop, design, and a personal profile page. Another drawback is that the application is supported only on IOS, limiting the number of users that can access it. The loading time for many of the products is longer than expected. Overall, the application does not focus on the use of AR for interior design, and it has only featured it as an add on to its other main features.

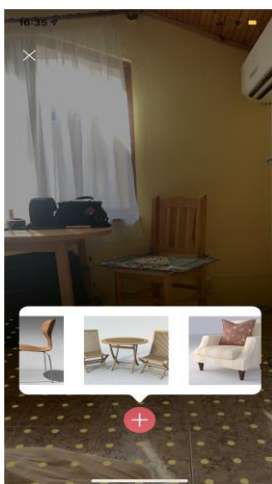


Image 2 - DecorMatters' selection of items for preview in the AR camera.

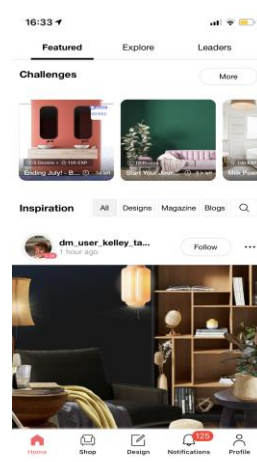
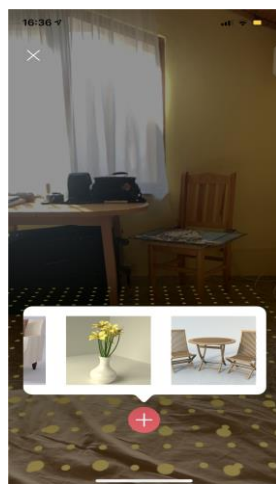


Image 3 - On the left- DecorMatters's interface on the right - DecorMatters's feed feature

Opportunities

The application can offer its users a more personalized experience due to its utilization of Artificial Intelligence. That would mean that if the developers include a more extensive product variety for the AR camera, it could automatically suggest products based on space's current design even if the user lacks understanding of the basic design principles. Another opportunity of the app has its options for shareability and community building within the app. It is currently featured as an option; however, it is not fully developed and well functioning since it's not the primary app goal. With a proper accent on that feature, people will be able to share and discuss design ideas with each other, which will more or less encourage their creativity and desire for decoration and design. With all being said, DecorMatters is one of the newer apps in the design domain, and hopefully, in the future, it will become more competitive with an improved AR and community building functions.

3. Homestyler

Strengths

First, Homestyler is available on both IOS and Android, which, as mentioned earlier, gives access to the app for more users. Compared to IKEA Place, for instance, Homestyler has a much more comprehensive selection of products ranging from sofas and wardrobes to rugs, plants, and small home decor and lighting fixtures. That is due primarily to its brand support from big furniture retailers such as Ikea, Target, Crate & Barrel, Pier 1, and others. The catalogue is easily organized by rooms (image # 4), making the overall user experience easy to navigate. It has four options for design - getting a picture from the phone's gallery and design on top, taking a picture instantly of the space, designing over empty room templates, and using the AR camera. Once in the AR camera view, the user can access the catalogue with only one click (image # 4), which adds to the intuitive user interface. The app also has a community section, as well as a product catalogue. Unlike the previously discussed app, DecorMatters, the different features are organized right onto the home screen, separated from one another, which provides a better understanding of each of the features

(image # 5). Lastly, the application gives hand gesture directions for the user to move and scale the furniture. Overall, the application has an easy to use interface and a satisfactory level of realism.

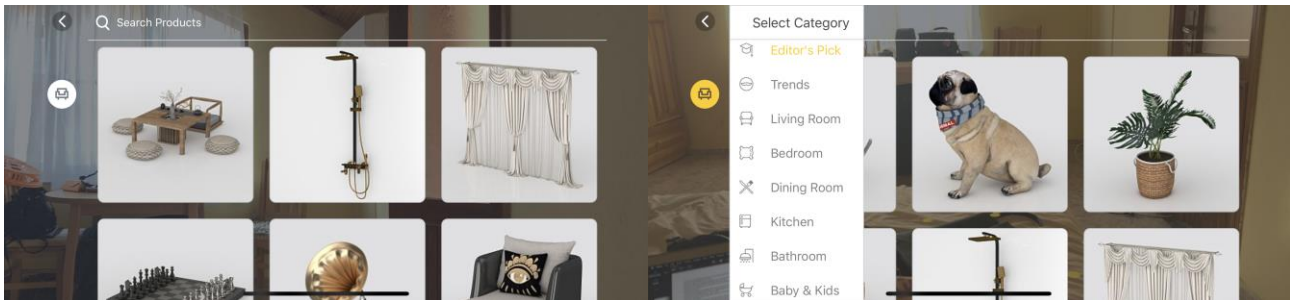


Image 4 - Homestyler's AR camera on the left | Category organization on the right.

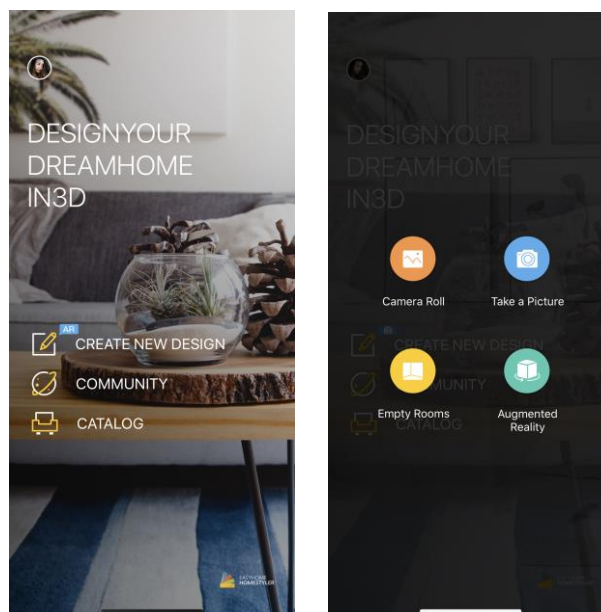


Image 5 - Homestyler's main menu organization.

Weaknesses

Compared to the application mentioned above, Homestyler's overall performance is relatively better, except for a few notable drawbacks. In the first place, the hand gesture guide appears only when the user is in room template mode. Whenever one enters the AR camera, the only guide shown is how to scan the floor (image # 6.1), and it is not clear what gesture would rotate the object in a different direction. Moreover, the application has a hard time scanning the floor properly, and it takes several times, especially if the room has other rectangular items such as

a table or a bed in it (image # 6.2). Similarly to DecorMatters, the application compensates for the lack of proper AR experience with an option to add 3D models to a photograph of the room.

However, that substantially limits the user and is not feasible for a home re-decorating solution.

Lastly, as seen on image # 6.2, the objects are not responsive to different lighting situations, which could mislead users and not allow them to see the proper colour of the product.

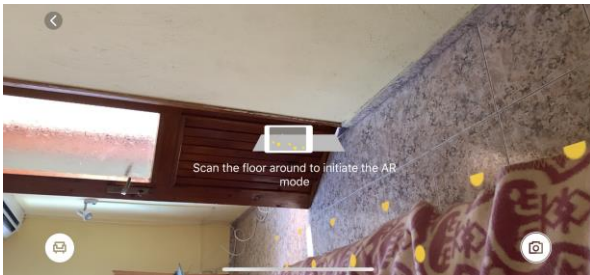


Image 6.1- Homestyler's AR camera guide.



Image 6.2 - Homestyler's 3D object rendering

Opportunities

Since the application has already implemented a good variety of features, it can become one of the leading design apps if it fixes the minor issues with visual marker scanning and provides more realistic lighting. Its community page is also nicely structured and could ultimately drive more people to use it because of the ease of navigation and the contests feature that provides interest and desire to make new designs.

4. SayDuck

Strengths

SayDuck was released far back in 2012 when Augmented Reality had become reachable for the masses because of the release of the iPhone 4S (Toromanoff, 2019). The current version is much more advanced and has several improvements. Users can choose from a range of more than 10 000 products from 150 world-leading interior brands. Among that, the application has some essential features. It can now recognize whether a person is walking through the virtual object in front of the camera and hiding it. That slightly improves the immersion of the experience. Along with that, the app blurs the virtual objects whenever the user moves to match the camera feed's blurriness. The

application also is capable of holding the focal point on only one spot, keeping everything outside more blurry. Another function that aims to improve the realism is that when it is dark, the app matches the image noise accordingly and reflects light from the 3D models according to the lighting conditions in the room (image # 7). Users can also place several objects simultaneously on the camera canvas, which gives a better idea of how the room would look like if it had several new items. Moreover, customers can precisely measure the distance between the objects exactly as they please. Last but not least, users can use the app to purchase furniture directly and check out through Apple Pay. That provides flexibility and ease of use since people do not have to visit external websites to shop for the items that they like. According to Toromanoff (2019), the app is "designed with minimal technical or 3D knowledge requirements, to let anyone leverage 3D and AR, from the Sales team to the Development team members".

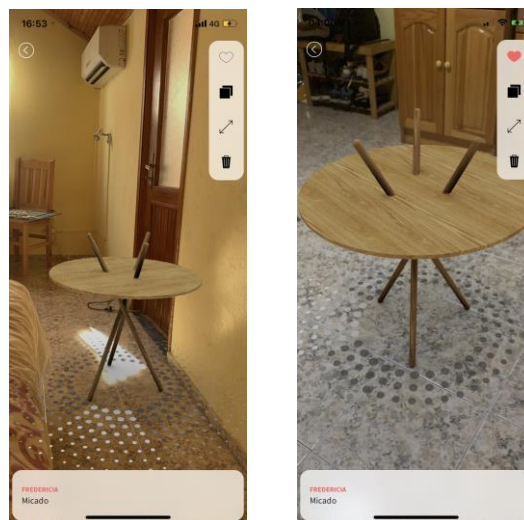


Image 7 - SayDuck's user interface in different lighting conditions.

Weaknesses

Despite its undeniable strengths, SayDuck also has weak spots that would require further development. In the first place, similarly to some of the previous examples, the app is supported only on IOS operating system. Second, the user interface has borrowed a lot from IKEA Place's design, which does not benefit the app's company as it loses authenticity and identity. The lack of an option to save a specific design and continue on it later is also disappointing. The application

also does not support different products' variations, which does not let users change properties such as colours and materials. Besides, even though the catalogue is quite extensive, the products are still predefined so that customers are not able to match and choose products according to their tastes. According to Sayduck, it supports direct purchases through the app; however, many of the products are not supported for direct purchase yet (image # 8). Lastly, the application does not have social media support, which does not encourage shareability and design community building. Similarly, to all of the applications examined so far, Sayduck cannot overlay 3D models on top of old furniture and cannot save the design. The only provided option is to organize the products is into collection and favourites.

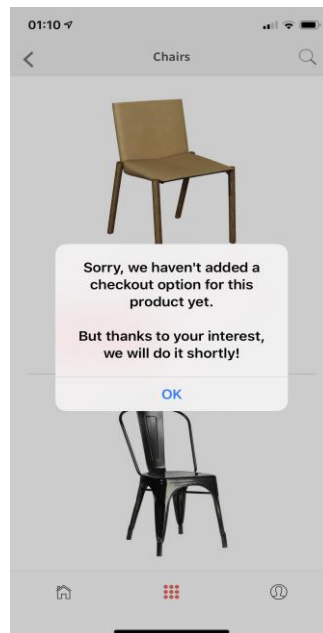


Image 8 - SayDuck - Error message for the unavailable product.

Opportunities

Unlike most other design applications that usually redirect the user to a new page to buy a particular product, Sayduck is already making steps towards more facilitated e-commerce. That holds many potentials since people generally prefer to use one unified application throughout the whole buying experience. If the developers of the application feature more products available for direct purchase, that would most likely attract more users. Another feature that gives Sayduck an

edge is the efforts made towards higher realism and immersion, which would ultimately drive more interest towards the app.

5. RoOomy

Strengths

RoOomy is yet another interior design application. Likewise, some of the applications mentioned above, it provides different options to design - creating a 3D scene from a 2D image, selection of sample rooms, and AR camera. Unlike Sayduck, this application has a function to save and share the designs via email or social media. The gallery offers products from a wide range of furniture retailers including but not reduced to Amazon, Pottery Barn, and Wayfair. One interesting feature is the ability to measure the whole room, and then the app creates a 3D space in which to put furniture such as tables, chairs, floors, curtains, and much more. There is also the option to select different colours and styles for every interior. Then there is the option to view more info, which gives the user the ability to buy the product.

Weaknesses

Similarly to some of the previous applications, roOomy is currently available only for IOS users. One of the first weaknesses is that unlike SayDuck, it does not show whether an item would fit in a given space. If space is not enough, the application just positions it over the other furniture in the room (image # 9.1) Another issue discovered during the testing of the app is that it is almost impossible to finish a whole room without running into a problem with the renderings. When the user places an item at the spot they wish and then adds another item, both become attached and move as one, and then if one tries to delete one of the items, the other one gets deleted as well. That could potentially cause frustration for the user as that way he/she cannot see how their room would look like with more new items. Besides, the app can show different perspectives of the room if one rotates the camera. However, that options seem not to be working correctly as whenever one tries to circulate the room, the camera bugs out, and the control of angling is lost, which eventually causes issues with the precision. Finally, the application gives a poor performance in terms of realism as it

does not show the colours and textures of the items with the light of the space (image # 9.2) properly.

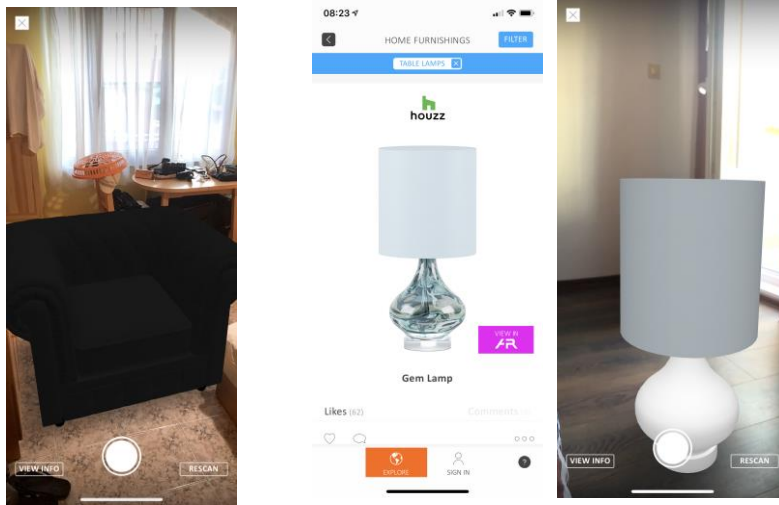


Image 9.1 - RooOmy's 3D object placement. **Image 9.2** - RooOmy's light representation

Opportunities

The application already has built-in functions that allow the user to preview home furnishings in 3D space. It can be improved if it is combined with artificial intelligence to tell the user whether space would be enough or not in any given room. That would improve the shopping experience and spare the time that the user will lose for testing items that do not fit in their space.

6. Amikasa

Strengths

One of the first things that a person notices about Amikasa is the pleasing user interface. It is designed to be not only pleasing to the eye but also very intuitive and easy to understand (image # 10). Another strength of the app is that it shows guidance on every step of the design process, helping new users. The app also can purchase by linking the user to the product's website. It also lets its users change the colour and texture of most of the products in the catalogue.

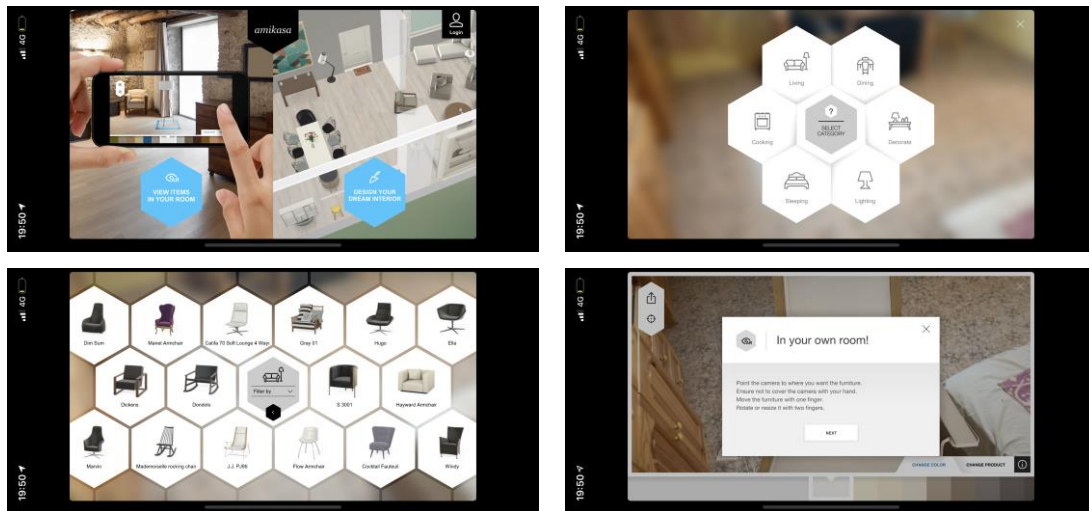


Image 10 - Amikasa's intuitive user interface.

Weaknesses

Out of the apps reviewed so far, Amikasa is the most limited in terms of options and features and has many weak spots. In the first place, the application seems to crash and get glitchy quite often. That interrupts the experience and loses the progress of the design. Moreover, there is a sharing function that takes a screenshot, and the user can send it via email; however, currently, it does not work (image # 11.1).

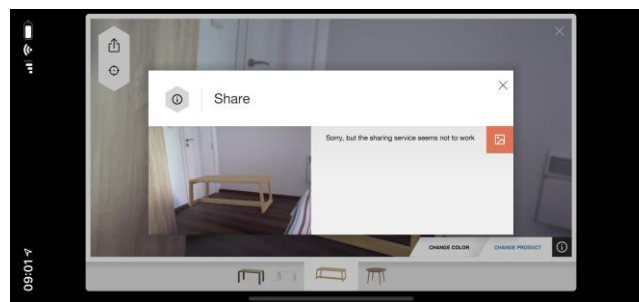


Image 11.1 - Amikasa- not working sharing feature.

One significant flaw is that the app does not allow adding more than one item in the room, nor keeps it there if one goes back to the catalogue. That is a significant issue since users cannot design a whole room with the app, but rather preview products one by one in 3D. Also, the application does not lock the scale of the products; it allows the user to make them as small/big as he/she wishes (image # 11.2). This function is redundant since users

need the real dimensions of the products and not the size they would wish them to be. The variety and choice of furniture are limited in all categories (for reference image # 12).

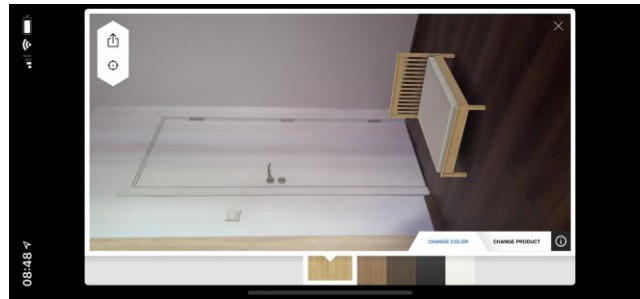


Image 11.2. Amikasa - unrealistic scale of the furniture.



Image 12 - Amikasa's product choice in the chair section.

Opportunities

As discussed above, currently, Amikasa has many flaws with its functionality and performance. It could become a great 3D product catalogue since it has a convenient interface and nicely organized categories. Since many interior principles were omitted from the app's design, I believe it will not be developed into a fully functional interior design application.

7. Intiario WL showcase

Strengths

Intiario WL Showcase app is an augmented reality viewer for interior spaces. One can easily visualize any item at scale, and in the exact configuration desired or even create whole arrangements from favourite items. It has a built-in configurator that lets the user change properties such as size, material, or fabric and see how they fit the interior. The app is available for IOS and

Android, which gives it an edge compared to some other applications. It has the option to build virtual walls and to measure a room (image # 13).



Image 13 -Intiario WL Showcase. Wall building feature.

Weaknesses

The application takes much time to load and then to scan the surface. It also crashes often, similarly to Amikasa. It has a minimal product selection ranging from 5-10 items per room category. The user interface is hard to use, especially the option for virtual walls, as it does not allow the users to make any modifications on top of the wall. If the user tries to place wall art or mirror on the wall, it automatically shows it as if it is placed on the floor, as seen on image # 14, without the option to rotate it vertically.



Image 14 - Intiario W.L. Showcase. The wrong representation of wall art.

Opportunities

One of the more exciting features of the app is the ability to build virtual walls. If that option is made to work correctly and allows the users to paint new colours and place wall art and windows on top of it, that would improve the experience with the app. It could also add another dimension to the designing process: adding an accent wall where there is no space and seeing how it would look if there were a wall.

8. MYTY AR

Strengths

Myty AR is another interior application that utilized Augmented Reality to showcase products in 3D. There is a specific Brands & Designers section, where users can check out catalogues from their favourite brands and explore projects from successful furniture designers. It also features an Inspiration Gallery with thousands of photos of beautiful interiors that could spark the user's creativity. The search bar has filters that could help with styles, colours, and furniture types. Another option is the ability to add items to a list of favourites. The app has social media support to capture the design and share it with friends.

Weaknesses

Like all of the apps discussed previously, MytyAR prompts the user to scan the floor as shown on animation, and then it allows to place objects on it. Nonetheless, it takes many trials to scan the surface properly, and the application regularly shows an error message while doing so (image # 15). Also, the user interface is confusing because when one navigates to the 'brands' tab, the products are organized by the brands that created them, and if one wants to see products only from one category (e.g., armchairs) the user has to locate a small icon on the top right corner which filters the items. There is also an option to map a room by pointing the phone at each of its corners. However, when one does so, the app does not prompt the user to do something different with the outlined space. As such, this function becomes redundant.

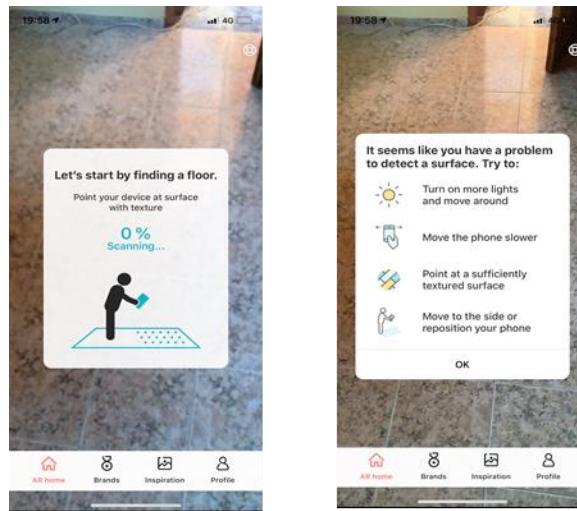


Image 15 - MytyAR - Error message for surface scanning.

Opportunities

Myty AR puts emphasis not on the product categories but on the specific brands that created them. That creates the opportunity for smaller companies that produce furniture to be included and popularised through the application. That way, it could focus only on showcasing products about their brands and target customers for which the origin of their furniture is in the first place. The application also has the room mapping function, which, if it becomes developed more, could become a way of erasing the existing furniture and creating a blank canvas with the same dimensions on top of which the user can begin designing.

9. Roomle

Strengths

Roomle takes a slightly different approach to the way it lets its users design their homes. The app's AR camera allows the user to draw with anchor points the room correct to scale (image # 16). Then, the application generates a floor plan based on the scanned measurements. There is also the option to draw the floor plan with fingertips giving the user more flexibility as to which one to choose. After the user creates the plan, he/she can start furnishing it. Roomle also has the option 'try before you buy' with a catalogue of more than 2500 3D furniture items that users can view in the room. The application provides good realism and allows the user to move closer and look at the

product from every angle. Users can view the complete 3D plans from every angle. The app is also available on both IOS and Android. Lastly, the app gives the option to purchase products directly from them.

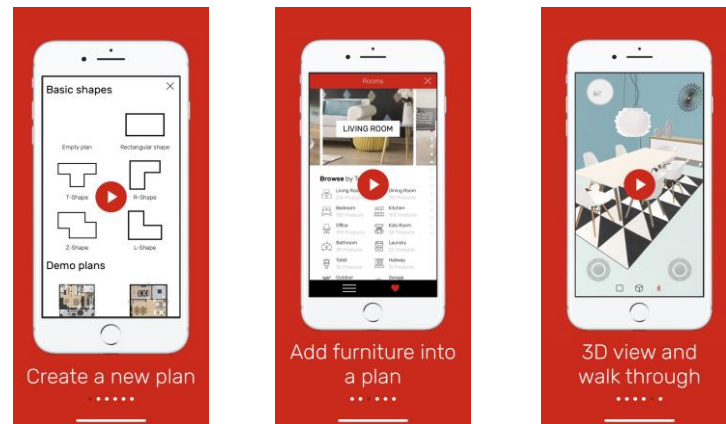


Image 16 - Roomle's User Interface.

Weaknesses

Roomle is offering two options for use - free and subscription-based. One of the drawbacks is that the free version has minimal functionality and does not allow the user to truly test the app and see if it works as expected. That version of the app allows for the creation of an only one-room plan. There is no option to change the wall colour or the flooring of the room. Since they are essential to design elements, it would have been valuable if developers include that function. Also, there is no virtual ruler that lets the user measure space without scanning the whole room again. Finally, Roomle crashes at times without saving work.

Opportunities

Roomle provides an excellent base for designing a whole space from scratch. With its walk-through option, it could elevate the design experience if it fixes the errors and missing functionalities. It can become competitive with the other apps if it adds more functions in the free version and allows for changing the wall colours and floorings.

10. InteriAR

Strengths

InteriAr uses marker-less detection of surface, which is extremely precise and efficient for placing the virtual furniture in the room. It has the option to capture the finished design and share it through social media. It also allows furniture brands to add their products to the catalogue adding direct links to the shops. Before making the final purchase, the user can choose the colour, size, and texture of the desired product.

Weaknesses

One of the major weaknesses is that furniture choice is minimal, with only around ten to fifteen items per product category. That does not allow the user to browse through more options and designs. Moreover, even though the application supports colour change that is only available for specific items and not all of them. The interface is not user friendly as the AR camera constantly shifts the floor surface, which changes the position of the virtual furniture (image # 17). There is no option to lock the products in place once satisfied with their position. When the camera is moved away from the subject, it changes position and starts floating into the room.

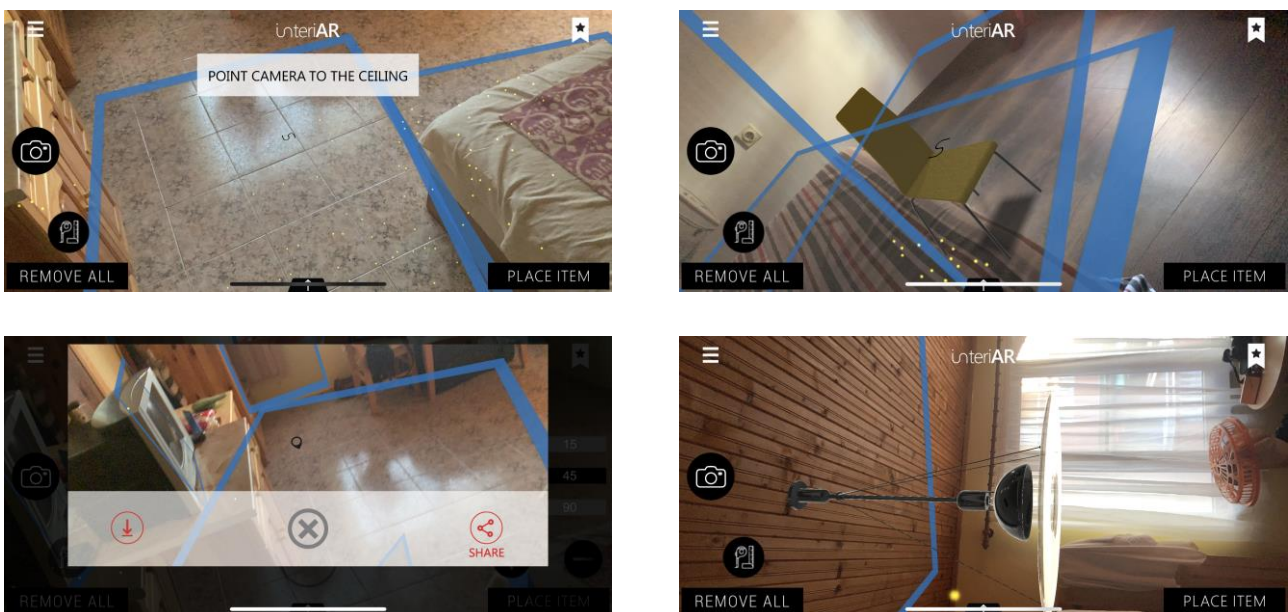


Image 17 - InteriAR's user Interface.

Opportunities

The application bears the opportunity to develop the marker-less tracking, which should be more precise and accurate to life. Besides, that does not offer many different functions than the applications mentioned earlier and is still very limited in many regards.

Evaluation of the Examined Applications

Application	Platform	Tracking System	Space Modeling Option	User Interface	Virtual Object Size Control	Photo-realism	Interaction with existing Furniture	Product Variety	Social Media Support	Operation Recordability
IKEA PLACE	IOS/ ANDROID	VISUAL MARKER	NO	EASY	YES	HIGH	NO	GOOD	NO	NO
DECOR MATTERS	IOS	VISUAL MARKER	NO	HARD	YES	MEDIUM	NO	LIMITED	NO	NO
HOMESTYLER	IOS/ ANDROID	VISUAL MARKER	YES	EASY	YES	MEDIUM	NO	LARGE	YES	NO
SAYDUCK	IOS/ ANDROID	VISUAL MARKER	NO	EASY	YES	LOW	NO	GOOD	NO	NO
ROOOMY	IOS	VISUAL MARKER	NO	HARD	YES	LOW	NO	GOOD	NO	NO
AMIKASA	IOS	VISUAL MARKER	NO	EASY	YES	MEDIUM	NO	LIMITED	NO	NO
INTIARO WLSHOWCASE	IOS/ ANDROID	VISUAL MARKER	YES	HARD	YES	LOW	NO	LIMITED	YES	NO
MYTY AR	IOS/ ANDROID	VISUAL MARKER	YES	EASY	NO	HIGH	NO	GOOD	YES	NO
ROOMLE	IOS/ ANDROID	VISUAL MARKER	YES	EASY	YES	HIGH	NO	LARGE	YES	YES
INTERIAR	IOS/ ANDROID	marker-less	NO	HARD	NO	MEDIUM	NO	LIMITED	YES	NO

Table 2 - Summary of the examined features of the existing interior AR applications.

Table 3 summarises some of the features of the AR interior apps that I examined. It includes ten applications and is based on their current situation as of 20.07.2020. The comparison table is partially grounded on the mind map developed in Siltanen et al. 's (2013) study. The different criteria include; the platform that supports the given app, the option to model the space; usability and interface, control of the 3D model, realism, interaction with existing furniture, variety of the offered products, social media connectivity, and the option to record the design process.

As seen from the table, seven out of ten apps are working on both IOS and Android, while the remaining three are only supported on the IOS platform. Out of all of the researched applications, only one (InteriAR) is markerless while the rest are using a visual marker to load the 3D space. Only four of the apps allow the users to create a space with blank virtual walls, and those are Homestyler, Intiario WLSHOWcase, Myty AR, and Roomle. Although, as seen from the more detailed information about each of these apps above, that function is not a central goal and does not work correctly. It also became evident that most of the apps, six to be precise, are relatively easy to use. Their interface is suitable for a wide range of users - from amateurs to semi-professionals. However, DecorMatters, Roomy, IntiarioSHOWcase, and InteriAR were confusing and had too many features that distract the user.

All of the apps, except MytyAR and InteriAR, allow the user to change the furniture's size. Other properties such as colour and texture are available only for SayDuck and Amikasa, while the rest do not support that. On the contrary, most of the apps have highly photorealistic 3D models with three of them with low realism, mainly due to wrong lighting or texture representation (IntiarioWLSHOWcase, Roomy, and SayDuck).

Another important feature the ability of the AR interior app to interact with existing furniture and to be able to replace it with the virtual 3D model. That could happen in different ways. One of them is by virtually masking out the existing walls, ceiling, and floor based on the dimensions of the room. That, in turn, would generate a blank canvas on top of which the user would have full control of the design and not on just a single piece of furniture. The other way of achieving a similar effect is through diminished reality, a software that masks out the existing furniture where needed while keeping the central elements such as walls, floor, ceilings as they are. This method is discussed in the projects' structure portion later. It would be useful because if people want to keep certain items in their room while removing only one or two, they will be able to do so. In the best case, the user should have the option to choose whether to clear out the whole space or only some items from it. Currently, none of these options are available in the examined

applications. Because these features are missing, all of the apps require the space to be empty for optimal results. That substantially limits the design experience and is not feasible for home renovations.

In terms of product variety, the results of the study showed that varies among all of the applications. DecorMatters is the application that offers the least product choice of only five items. Along with it, Amikasa, IntiarioWLShowcase, and InteriAR also have a minimal choice of furniture items ranging from 10-20 products by furniture category. The rest provided a satisfactory variety of product choices and categories, with Homestyler having the most comprehensive variety. In all of the applications, decoration items such as artworks and rugs were very limited.

The applications' trademark support and the option to buy furniture directly from the applications are not included in the comparison table. Nonetheless, I discuss these features in the following paragraphs. Most of the examined applications offer products from real furniture brands. The brand choice in some of them is quite limited - for example, DecorMatters and IntiarioWLShowcase. While Homestyler and InteriAR do not offer products from real brands. That highly restricts the choice that the user has and makes the application substantially ineffective for buying purposes. While in others such as Homestyler, SayDuck, and Ikea Place, the variety is much larger, and the user can pick from more different items. Ikea Place is the only application that offers products only from its brand since it has international recognition and more exposure to its store network. Roomle and Myty AR also have broad support from furniture brands.

In terms of buying furniture directly from the apps, the only ones that support that feature are Ikea Place and SayDuck. The rest, except DecorMatters and Homestyler, direct the user to a link of the products that they have picked. Usually, the links lead to the companies websites, where the users can easily buy furniture according to the brand's terms. Not being able to buy directly from the apps is a significant deficiency since that would make the experience much easier for the consumer.

Half of the applications support sharing the finished designs with friends through social media - Homestyler, IntiarioWLSshowcase, Myty AR, Roomle, and InteriAR. The rest of the surveyed applications do support that function. With regards to operation record-ability, i.e., the option to save the scene for later adjustments, only Roomle supports that functions since it allows the user to create a scene from scratch.

As a result of the AR apps testing for interior, I discovered that an application that is user-friendly, widely accessible, and has the basic features listed above is still not made. Although some of the applications have many more features, they are still not developed enough to satisfy the users' expectations completely. Hence, new applications that are helping people with their interior design through AR currently have an immense potential for development.

Project Structure

This section will outline the features that I am proposing for a future AR interior app based on the research of the current solutions and the user expectations outlined in Siltanen et al. 's (2013) study. The main ideas will be supplemented by paper prototypes of the app created with Adobe XD. Since the application is intended to be used on mobile devices, the hardware will not be discussed.

1. Full Redecoration of a Space Through Diminished Reality

AR applications in interior designs are usually used to avoid any physical effort in the real environment. Nevertheless, when the apps render 3D visualizations on top of the existing objects that cause AR processing problems since it cannot replace the real surroundings. Thus, another software is needed to solve that problem. 'Diminished Reality' is a technique that would be able to 'erase' the existing furniture and allow AR to place the new furniture in the room. There are two categories of diminished reality - observational and in-painting, which are simply different techniques for achieving the same result. Observational DR utilizes pre-captured images of the background scene in order to generate the visual reduction of elements.



Fig. 3 - An example of a diminished reality technique in AR.

On the other hand, in-painting tries to paint over the objects by gathering visual information from the surrounding areas (Bardi, 2018). The latter is less accurate but can serve as a more general way to achieve DR when no prior information of the scene is available (Bardi, 2018). For this project, in-painting would work better since it will use the walls as a target area to gather the visual data and fill the objects that the user wants to replace with new ones.

According to Seppa et al. (2007), the diminished reality technique is particularly valuable with regards to interior design with virtual objects. In-painting also called a visual repair process, is when the software fills up parts of the image that are lost with 'healthy' areas from the scene. Fig. Three illustrate how would Diminished Reality works in the context of interior design with AR. As seen on the image, the existing armchair is filled up with visual information from its surrounding area and that lets AR to place another object on top of it. This feature is crucial for the success of an interior design app. It gives the user much more freedom to design and redecorate without having to remove bulky furniture physically. In comparison, the applications existing now require an empty room to provide realistic representations of the furniture.

For this project, I developed a paper prototype with Adobe XD, images of which will be included in each of the following paragraphs. As mentioned earlier in the paper, it would be better if the user has the option to choose whether to mask out only one furniture item or to mask out the whole room. As seen on img. 18.1, the app would first ask the users to choose how to begin their new design - either with a blank wall or by removing only one piece of furniture by tapping on it. That way, users will have much more freedom to explore different designs that either starts from blank walls or simply improve the existing interior. Img. 18.2 showcases how the app would diminish all of the existing furniture while image. 18.3 shows how space would look with only one item masked out. The last image (18.4) illustrates how the room would look like with the new piece of furniture, the white wardrobe in the given case.



18.1

18.2

18.3

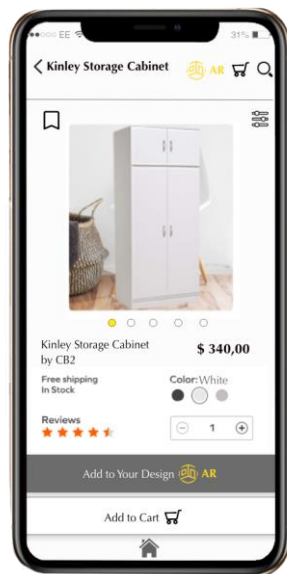
18.4

Image 18 – The AR camera view of the application.

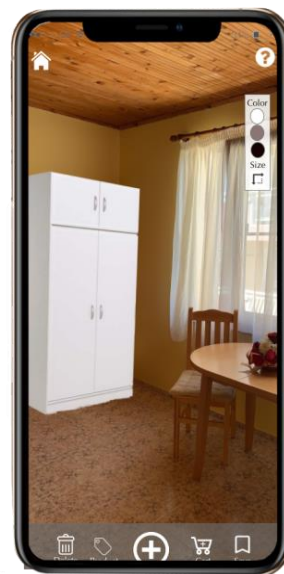
2. Customization of the furniture

Colour and texture are parts of the central design elements of an interior. As such, it is crucial to have them in an app that aims to aid with the design process. As evident from the research

of the current applications, most of them did not have options to change the colour and texture of an item, and those who had that function were quite limited. Since, it is better if the app works with real furniture retail companies, it could gather information directly from them about their colour and texture offerings for every item that they provide in the app's catalogue. That will increase the options that users could choose from and let them get more creative with the colours. An illustration of the idea can be seen in the image (19.1 and 19.2) below.



19.1



19.2

Image 19 – Product customization options within the app.

In my concept, the users will be able to preview the manufacturers' colours on the product page first (img. 19.1) and other information about the item, such as price, brand, ratings, and availability. Once the users add the item to their design, pop up selector will appear on the screen (img.19.2) that will show the available colours again as well as a small size button that will help the user determine whether an item will fit into the given space by providing the actual dimensions of the product. The pop-up selector will allow users to access the size and colour properties of the item while in the AR camera view without returning to the product page.

3. Broader Product Choice / Categories

Another aspect missing from most of the examined application is the variety of furniture and decorative items. A design app should have enough choice to suit as many different creative tastes as possible. A product choice of around forty to sixty items per category would fulfill that goal. The furniture's organization is another dimension to this feature. There could be general themes based on the design style such as Art Deco, Modern, Rustic, and others and then as subcategories, the different rooms and indoor spaces, and lastly, the furniture items themselves - e.g., beds, wardrobes, cabinets, decoration, and others. An added feature would be searching via a specific brand - e.g., Lexington, Herman Miller, Knoll, and smaller furniture retailers. That would add even more value for users who prefer to have their furniture from one retailer over another. Such an organization would make it easier for the user to navigate the items in the style that they want, to achieve a unified look at their redesigned space, and have the freedom to choose the brand of the products. A prototype of the catalogue is shown on image 20.2 while image. 20.1 is an introductory screen that would show the first time the user downloads the app for a quick introduction to the offered brands. It is important to note that the retailers illustrated in image 20.1 are only used for an example. The app would offer products not only from the big furniture manufacturers but also from smaller artisan furniture makers. That would provide a level ground for an advertisement for different companies regardless of their size and popularity, as well as more diversified product choices for the user.

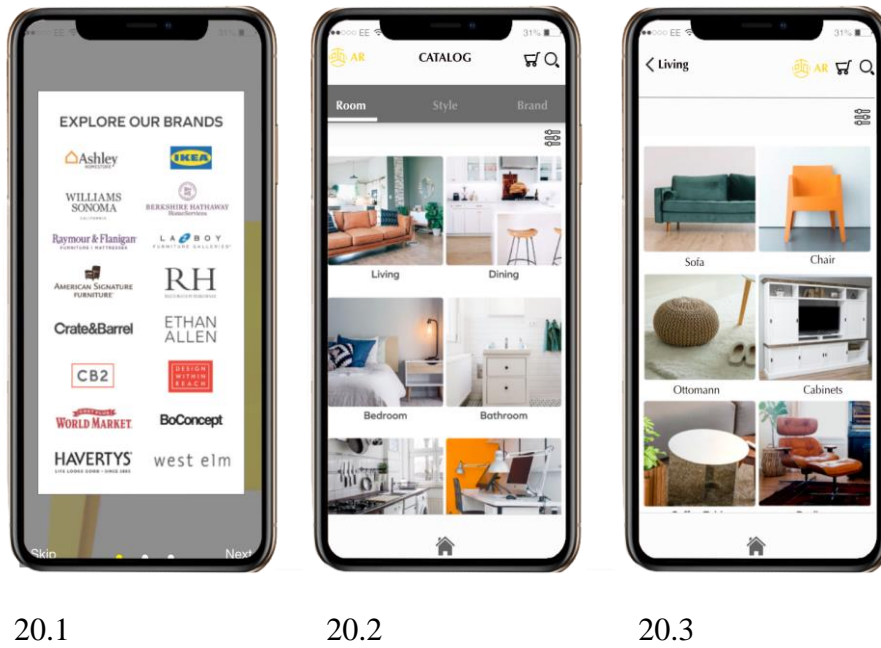


Image 20 – The organization categories from which the user can choose from.

4. Lighting improvement

Lighting is the ultimate property that gives objects their appearance in any given environment. The available apps struggle to adjust the light and shadows of the 3D models to match the real conditions of a challenging lighting environment. That is limiting for the users since they always have to design in well-lit spaces.

There are five types of lighting for 3D objects (ambient, shadows, ambient occlusion, specular, physical rendering), and if all of them are incorporated together, that will achieve the most realism in the virtual image (Bardi, 2019). Without going into much technical detail, it is worth mentioning that specular is the most important property because it shows how the light is reflected, passes through, or emits its light (Bardi, 2019). Also, physical-based rendering uses light properties derived from the real-world environment to generate the light values in the 3D scene, which could be a particularly useful method to project light onto third-party 3D objects supplied by the manufacturers. In that way, regardless of the 3D object, the app will be able to adjust its lighting based on the surrounding scene.

In terms of achievability, currently, Unity 3D' AR engine is very advanced and capable of replicating even the most complicated lighting conditions. If developers embed those properties into

the 3D rendering, they would give much more realism to the scene and provide an overall better user experience. Another dimension to lighting is the option to see how different lighting fixtures would illuminate a room - a feature not present in any of the mentioned applications.

5. Change of wall colours / ceiling colours / floor coverings / windows

As of the present day, AR interior apps mostly do not have the option to change the colours of the walls to add different floorings and to change the windows. That means that up until now, users could only preview the furniture in their room but not change the environment altogether. Since floors, walls, and windows take up much of the space in any room, they are also significant elements of the interior and are worth considering for integration in the app. That feature was only available in Roomle - the app that gave the option to design floor plans from scratch and then preview them in 3D. There should also be the option to add two kinds of flooring into one space. That would be valuable if the living environment is an open plan. In these cases, floors play a role in dividing the space into different sections. For the app to achieve that, it should be able to scan the whole room - from the floor to the ceiling and differentiate between them. The prototype images of the wall colour change are 21.1, 21.2, and 21.3.

The feature will work similarly to the diminished reality option. Once the room is scanned, the user will just have to tap on the walls, ceiling, or floor in order for the colour/texture selector to appear. Once the user taps on the desired colour, the app will show the available brands and their colour offerings, as seen on the flooring change example (image. 22.1, 22.2, and 22.3)

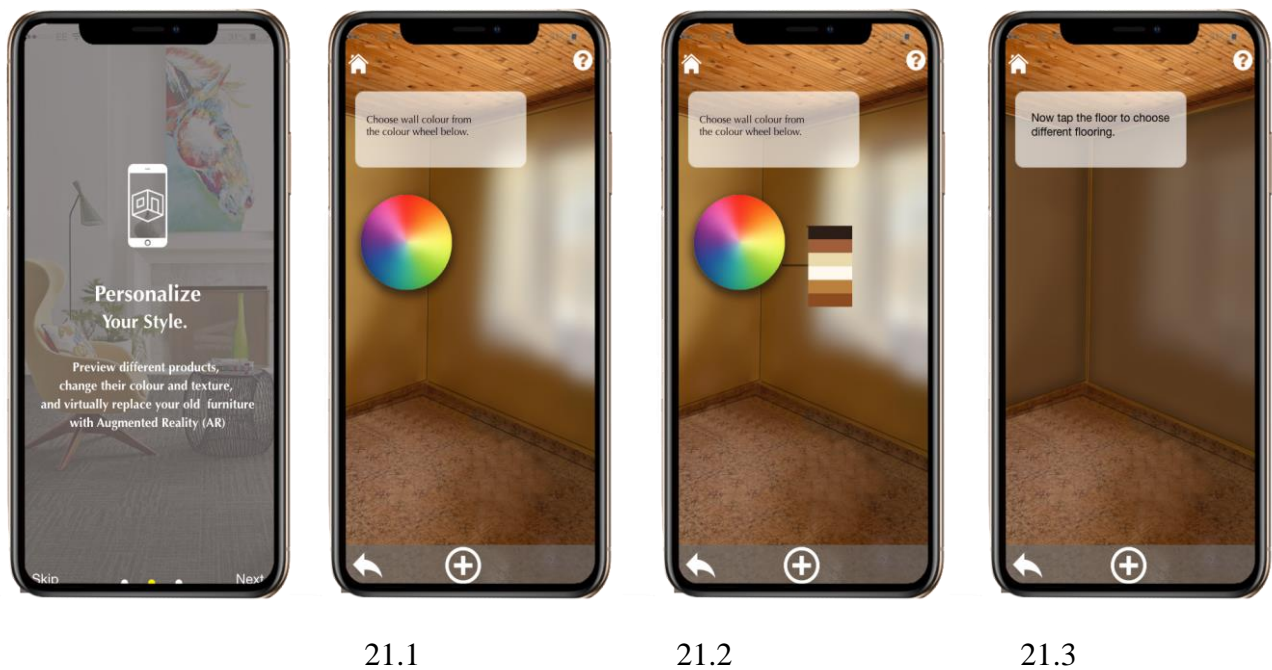


Image 21 – Wall colour change option.



Image 22 - Options for different flooring

After the user chooses a new colour for the walls and new flooring, a new prompt will appear on the screen to change the ceiling as well (img. 23.1, 23.2). However, the changes are not meant to be made in this exact order; the users will be able to change whichever design element they desire at any step of the designing process. As you can see in image 23.3, the room is completely upgraded and ready to place new virtual furniture in it. The small back arrow on the bottom left of the screen allows the user to undo unwanted changes at any point in the design experience.

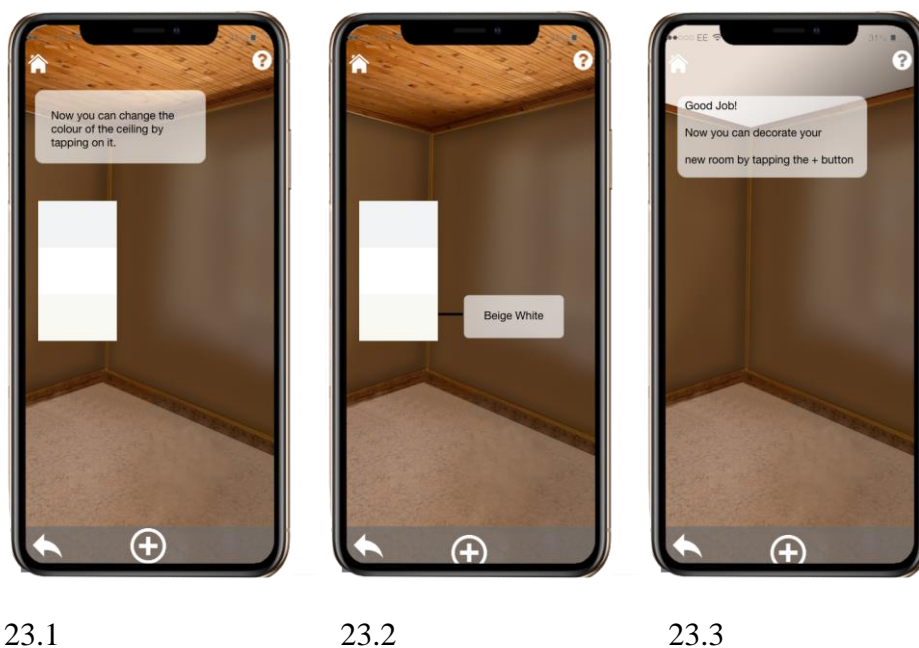


Image 23 - Ceiling colour change.

6. Option to save the design

Another function missing from all of the applications, except Roomle, is to save the design progress and continue at a later time. This function would be especially crucial for more complex interiors where more time is needed to create the space. That function can be connected with a user profile where people will be able to keep their designs and access them from different mobile devices. It will add another level of convenience because with the current apps when the user opens

up the app, he/she has to start all over again. While with the option to save, that would not be a burden.

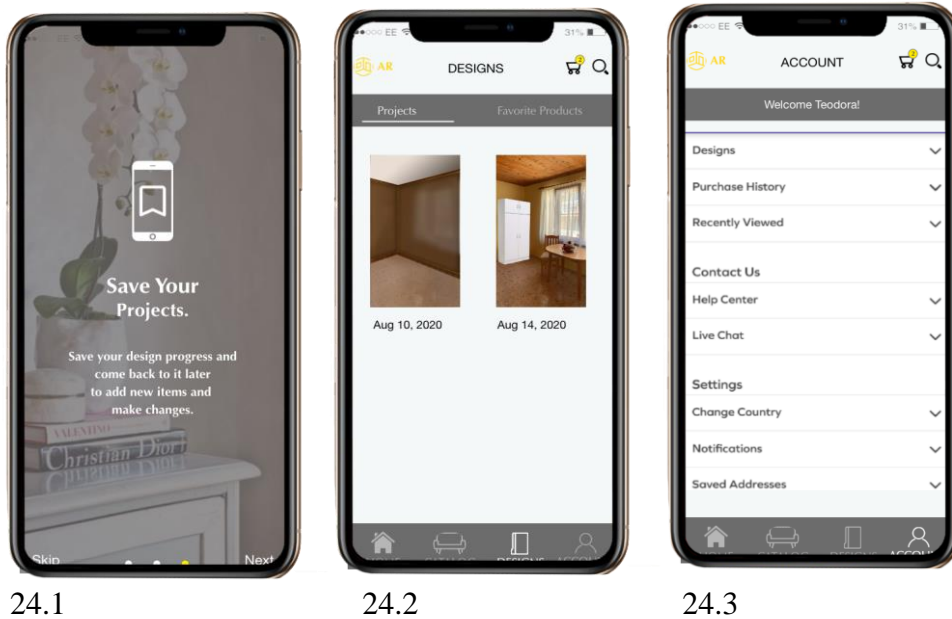


Image 24 – Save the design option.

Image 24.1 is an introductory screen that would appear the first time the app is downloaded to highlight the save feature. Image 24.2 shows the saved designs page, which includes the date on which the design was created and a preview image of the room. Users can also find their designs through their accounts' page (image 24.3) and their favourite products and app settings

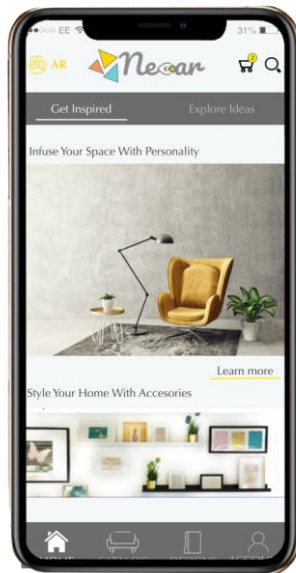
5. Improved User Interface (UI)

With the integration of more features, the user interface complicates as well. At least that was the case with the examined application, which have tried to implement more functions. The results are usually either cluttered interfaces that are counterintuitive for the user or too simple, providing very little to hardly any customization options. To achieve a simple yet complex user interface design, one needs to be guided by the rules for UI design. According to Babich (2019), UX architect and writer, there are '4 golden rules' for the creation of successful UI design - place users in control of the interface, make it comfortable to interact with a product/service, reduce cognitive load, and make user interfaces consistent. Those considerations would ensure the smooth

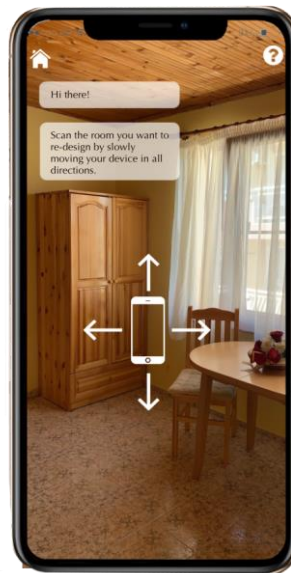
usage of the application and encourage users to come back to it more often (Babich, 2019). For the project, the prototypes I developed have a clean look with bright colours and intuitive buttons/menus (Img. 25.1).



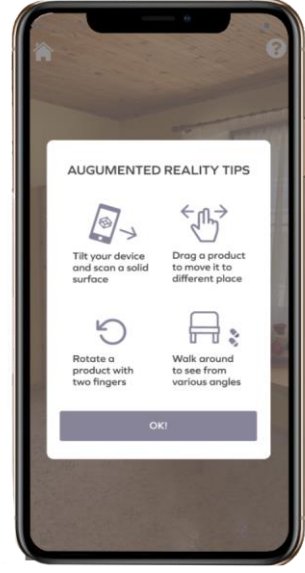
25.1



25.2



25.3



25.4

Image 25 – The app's interface

Image 25.2 shows the application's home screen, which is simplified to the main menus and options. It features quick access to the AR camera on the top left corner, recommendations for different designs in the midsection of the page, and the main menus on the bottom (Home, Catalogue, Designs, Account). All of the screens in the AR camera view are designed to show helpful messages and graphics that would guide the users when they first use the app. An example can be seen in image 25.3 and on some of the prototypes shown in previous sections. Lastly, a designated help button on the top right corner shows additional tips for proper usage of the app (img. 25.4).

Concluding Thoughts and Future Opportunities

This major research paper aimed to explore and evaluate the current mobile augmented reality apps in the interior design sphere to propose a mobile application that would make the design process more engaging and accessible for the general consumer. Specifically, the paper explored how the future's mobile apps can be improved to suit the users' needs better. The work further aimed to democratize technology by proposing an application that would eliminate many of the current burdens which prevent people from using augmented reality in its most effective way.

Several theorists, outlined in the literature review of the paper, agree that technologies can serve a more significant cause than only solving everyday issues - namely, to democratize access to advanced technological tools. Concerning this project, the goal of the interior mobile application is to access more people who would otherwise have to use services that are either expensive or have other drawbacks discussed in the paper. Some of the current solutions include hiring a professional designer, using a paid desktop software such as LiveHome 3D and FOYR, using VR phone headsets, or the available AR mobile applications.

To evaluate the current situation of the mobile augmented reality application for interior design, it was required to test ten applications with the highest download rate. I assessed them qualitatively based on different criteria. The research proved that there are still many drawbacks and malfunctions of the current AR design apps. These include a poor user interface, lack of crucial functions, problems with realism, and minimal variety of the products. Moreover, some of the applications lacked support from real furniture retailers, while others had limited support. The applications that had a simple user interface lacked many crucial functions, while those with more functions were complicated. For that reason, most of the examined applications could be used only for entertainment purposes and not for a complete redesign of a space.

As a result of all of the evaluations, it was evident that there is a need for an AR design application that would fulfill the needs of the users without compromising on quality, functionality, and access. Another expectation from a user side, as evident from Siltanen et al. 's (2013) study,

was the ability to render 3D models on top of the existing furniture and to be able to replace it virtually. My research showed that this would be possible with the integration of software that diminishes reality - i.e., erases virtually the existing furniture and allows the user to place a new one on the same spot.

After evaluating the current situation with mobile design apps, I proposed a theoretical framework for developing a more functional mobile app that would eliminate the limitations of those apps. The proposed features included a more compelling user interface, replacing the existing objects with virtual ones, trying out different lighting fixtures, changing the flooring and wall colours.

A useful future addition to these features would be the integration of artificial intelligence that would provide a more personalized experience. According to Abhay Parasnis (2019), EVP and CTO at Adobe, "AR, combined with AI, can be a killer combination of experiences unlike anything seen before." That holds for interior design because AI could improve the user experience tremendously compared to the use of only AR. There are several ways in which that could happen. One of them is including the ability for automated recommendations based on the room. That way, the user will be able to click on a particular area in their space, and the AI algorithm would recommend an item that would fit with the rest of the existing furniture. That could be helpful for people with less creativity or experience with design. The creation of AR experiences that seem convincing requires that the 3D renderings, the lighting, the materials/textures, and the objects to behave according to real-world rules (Abhay Parasnis, 2019). By utilizing AI and machine learning, "the 3D design tools can handle time-consuming tasks and create photorealistic results that previously required costly photoshoots or hours of creative work" (Abhay Parasnis, 2019). That is an added benefit of integrating artificial intelligence into the application because it will add to the realism.

Moreover, AI could serve as initial automated setup of the preferences of the person using the app. Since users already have many choices to make, such as brand, colour, styles and others, AI

could automate a portion of the decision making right from the start and make the design process more efficient. As mentioned earlier in the paper, one of the benefits of the app is to make the person feel emotionally connected to space they are designing regardless of whether the design itself is "good" or "bad." However, since the artificial intelligence aspect is quite complex and involves many different decisions before it is perfected, it would probably be incorporated into the app at a later phase and not right from the start.

The paper also touched upon the relation between marketing and AR and whether AR can serve as a tool to drive more sales and engagement with a given company. The research showed that the more users are immersed in the virtual experience, the more likely they will purchase from the app. That means that such an application would benefit not only the consumers but also the retail furniture companies, which are finding new ways to advertise their products.

In the future, digital media specialists predict that mobile augmented reality applications will be prevalent and widespread (Cipresso, Giglioli, Raya, & Riva, 2018). Thus, it is essential to think about how they can be improved, made more easily accessible, and user-friendly. In the scope of this work, it is evident that the use of AR technology in the realm of interior design could be a very effective method for redesigning one's environment in the future. Although AR is still a new technology and is still not accessed by many due to the higher prices of the headsets and lack of knowledge to design AR experiences, it can grow fast and become advanced quickly. Augmented reality is a technology that will have a role in the way people are perceiving and thinking about their living spaces.

Nowadays, technologies are not merely a tool that makes our lives easier - they serve a much bigger role in shaping our social identity and transforming how we view the world. An application that allows people to almost fully change their living spaces with virtual 3D renderings could substantially alter the design process by making it easy to access by everyone. It will also place the agency and freedom in the hands of the person who designs the space, eliminating any miscommunications that could happen through the work with a professional.

In conclusion, further app development must be completed to include all of the features needed for a functional and easy-to-use AR design application. To date, the consumers that can access and develop virtual environment have benefited the most from the new technological advancements (Schwab, 2017). In that way, the democratic usage of technology and resources is undermined as many individuals lacking access cannot take advantage of it. The future development of such an application would be an innovative approach to home redesign. It will democratize the use of AR, bringing it closer to the general consumers and letting them benefit from that technology. Finally, it will make the design process more accessible, pleasant, and useful without the need for expensive hardware or specific developers' knowledge.

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