NordDesign 2018
August 14 – 17, 2018
Linköping, Sweden

A Review of Augmented Reality Research for Design Practice: Looking to the Future

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Abstract

The rapid proliferation of Augmented Reality (AR) technologies over the past 30 years has introduced new capabilities and opportunities to further support design activities. It is therefore not surprising that there is an increasing body of knowledge on the application of AR within design. However, little work has been performed on consolidating this knowledge to enable the identification of general trends and gaps in the successful application of AR across design activities. This is both critical to design research to ensure that the field provides comprehensive coverage of the potential of AR in design, and for industry who are looking to AR to enhance the productivity of their design processes.

To meet this need, the paper presents a review of the design literature relating to AR and maps this research in relation to the type of AR technology and the stage in the design process. From this review, the paper identifies the AR technologies that show greatest promise in supporting design activity and areas in design that have had little to no research with regards to AR. Through this investigation it was possible to determine that while there are currently some AR technologies aimed at supporting design not all forms of AR technologies are currently being investigated with SAR and HHD having more commercially available platforms than HMDs. More importantly, this review found that not every stage of the design process is currently supported by AR technologies. It appears that the initial and final stages of the design process are the areas that lack the most support. Indeed the Task, Design Specification and Product Documentation stages (first, second and final stages in the design process respectively) are the areas where little to no research has been undertaken. These stages in the design process are thus identified as potential areas for further development of AR technologies to support the growth and acceptance of AR in design.

Keywords: Augmented Reality, Design Process, Review, Design Model, Tools

1 Introduction

Augmented Reality (AR) exists at a mid-point between the digital and physical worlds. Whereas Virtual Reality (VR) completely immerses a user in a world that is entirely fabricated, AR superimposes digital imagery over the existing physical world "augmenting" it (Milgramand and Kishino (1994) as cited in Furht, 2011). Azuma (1997) further defines augmented reality by specifying the presence of two additional features: interactivity in real-time; and, registering in three dimensions. As such, a reflector or holographic sight would not be considered AR as, while it is a combination of digital and physical worlds it is neither interactive nor does it blend in three dimensions.

Designers have historically worked with drawings and physical models to investigate design and communicate their ideas (Sass & Oxman, 2006). Physical models, while time consuming and expensive to create, can give a very good idea of the final result by capturing complex details. Conversely digital design tools can make it much simpler to make modifications and reuse existing models. However digital models lack in realism (Ishii et al., 2004). It becomes apparent that being able to bridge the gap between physical and digital worlds, as is done with AR, could carry considerable benefits.

Therefore, this paper aims to:

1. relate existing studies into AR technologies to design practice;
2. identify areas where major technological development has occurred; and,
3. identify areas that may benefit from additional research.

To achieve this goal, this paper defines both the categories of AR technology (Section 2) and stages of the design process (Section 3) used in the mapping exercise. This is followed by the literature review methodology used to collect and analyse relevant papers(Section 4). The results of the review and mapping exercise is presented in Section 5 and discussed in Section 6. The paper then concludes with the key findings and trends for future AR design research.

2 Categorising AR Technologies

Van Krevelen and Poelman (2010) provide a clear categorisation of AR technologies dividing the field into three major categories. These categories are distinguished from one another by the display technology used to overlay augmented reality onto the physical world. Peddie (2017) similarly discusses an extended taxonomy for augmented reality devices primarily focusing on whether the technology is worn and its technology readiness level. Padzensky (cited in Peddie, 2017) also provides a taxonomy that is based on types of technologies used to achieve AR. This second categorization closely resembles the one provided by van Krevelen and Poelman (2010), especially in its top level division into three major categories.

The categorization used by van Krevelen and Poelman (2010) was selected for this study due to the clear subdivision of the technology based on the method of displaying information, which provides an objective measure that the literature can be mapped to reliably. Figure 1 provides an illustration of the van Krevelen and Poelman (2010) categorization of AR based on the relative position of the technology to the user. The three main categories are: Hand-Held Displays (HHD), Head-Mounted Displays (HMD) and Spatial Augmented Reality (SAR). These are further subdivided based on the type of technology used to achieve AR as shown in Figure 1. Similar technologies, such as projectors, may be used to achieve AR in different configurations.

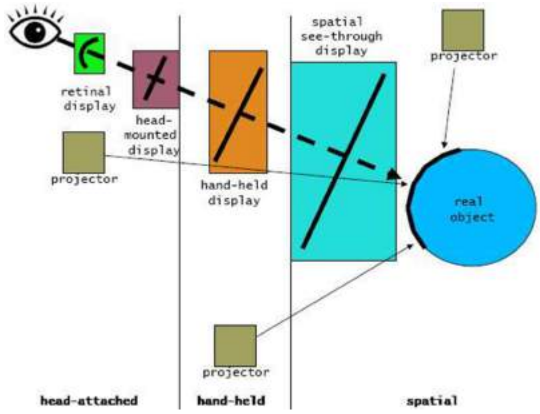

Figure 1. Categorization of AR technologies (van Krevelen & Poelman, 2010)

2.1 Handheld

Hand-Held Devices (HHD) are one of the most common methods for implementing AR due to the ubiquitous nature of smartphone and tablets - they provide a simple, low-cost platform for AR. HHD can be divided into separate subcategories based on how the software creates and overlays digital images onto the physical world. The nature of the HHD's means that the AR is only visible through the device itself, which acts as a window into an augmented dimension and thus requires users to constantly hold up the device to avoid breaking the illusion.

One of the most common methods of achieving this overlay is through the use of visual markers, either QR codes or other visible markings on the objects that are to be augmented. The placement of irregularly shaped and spaced markers breaks-up the otherwise regular surface of the object. One work-around for this is the use of image recognition to detect whole objects. While this eliminates the reliance on foreign markings it adds the difficulty of implementing computer vision into the system but has found use in assembly and maintenance (e.g. Patent 9,448,758 (2012) shown in Table 1).

Another method that has found success is through location-based tracking. Most commonly used in outdoor settings this approach to AR relies on mapping the location of users and then presenting them with images based on their current position. An example of this is Pokémon Go (Table 1).

2.2 Head-Mounted Displays

While there are various technological solutions for wearable AR, Head Mounted Displays (HMDs) can be considered the most developed and available. There are various approaches to HMDs namely: Projection, Retinal, Optical, and Video. In the case of projection, AR is achieved by essentially strapping one or more projectors to the user's head. These projectors then project a digital overlay onto the physical world that is being looked at by the user. Retinal HMDs on the other hand project directly into the user's eyes. By doing so they mix incoming light from the physical world with the light of the projectors this gives the illusion that the digital world has overlaid or replaced parts of the real world.

Optical HMDs instead, function by having a set of semi-transparent screens placed before the user's eyes. Digital images can be projected onto these screens which, due to their semi-transparent nature, will blend them with the incoming light from the user's surroundings. Video HMDs are very similar in function to virtual reality headsets. Like virtual reality headsets, they only transmit digital images by way of a screen. However, where virtual reality means that what the user sees is entirely generated by a computer, in video AR users still see their surroundings as a form of live video feed. AR comes into play when parts of the visuals shown to the user are modified to intersect a digital reality with the physical one.

Commercially available tools include Microsoft's Hololens, LusoVU's Eyespeak, and Google's Google Glass shown in Table 1 (Peddie, 2017). It must be noted that Google Glass has been relaunched (Savov, 2017) after a less than stellar initial launch demonstrating that companies remain convinced of the potential of the technology. The continued development of new devices shows that the technology is still relatively immature and that a dominant design has not yet been established in the market.

2.3 Spatial Augmented Reality

Unlike HHDs or HMDs whose definitions are based on how the technology is positioned in relation to the user, Spatial Augmented Reality (SAR) is defined by the overlay of digital images over a specific physical area. This is achieved either through video, projection, or holographic/optical displays. Video SAR is the superposition of digital images onto a video feed of the real world. This implementation is one of the most ubiquitous forms of AR currently in use. For example, sporting events often overlay important information, such as score, time remaining, names of people, etc. onto a live feed of a match. Whilst, Cave Automatic Virtual Environment (more commonly known by the recursive acronym CAVE) is a platform that allows for more immersive and interactive setups, such as those found in simulators (Peddie, 2017). SPARK (Spatial Augmented Reality as a Key for Co-Creativity) is a further platform that enables the projection of additional features onto physical surfaces to support the development of marketing material (Caruso et al., 2016). These are all examples of Projective SAR.

Another sub-category of SAR is optical SAR, which relies on projecting digital images not onto physical objects but rather onto a semi-transparent material. This partially reflective layer allows users to see objects beyond it as well as any digital images that have been projected. This type of technology has long been used in head-up displays and has more recently been implemented in a number of music performances to allow dead musicians to "play" in live performances (Peddie, 2017).

SAR has found less direct commercial applications from specific companies despite having been the subject of various research projects and studies (Bimber & Raskar, 2005). Unlike HMDs, custom hardware is rarely necessary and off-the-shelf components are often used to put together an SAR system. Although no custom hardware is required, SAR typically requires extensive preparation and setup to ensure that it works effectively. This is potentially a block in the commercial development of SAR platforms and makes them less attractive to potential consumers (Park et al., 2015).

2.4 Summary

In summary, using the categorization provided by van Krevelen and Poelman (2010) it was possible to investigate some of the currently available technologies currently on the market as summarized in Table 1. As can be seen there are multiple commercial offerings currently available in all the major categories, however head-worn solutions seem to have predominately focused on optical technologies.

Table 1. Examples of commercial technologies

AR Technologies							
Head-Worn				**Handheld**	**Spatial**		
Retinal	Optical	Video	Projective	All	Video	Optical	Projective
	Hololens (Microsoft, 2018) Google Glass (Savov, 2017). Eyespeak (LusoVU-USA, 2014).			Patent (9,448,758, 2012) Pokémon Go (Niantic Inc., 2018)	CAVE (Peddie, 2017)	Holographic setups (Peddie, 2017)	SPARK - (Caruso et al., 2016)

3 Classifying the Design Process

For the purpose of this review it was necessary to identify a generic design process model to allow the mapping of AR design studies. Various models for understanding the design process have been proposed and, while the models share similarities, they often differ in the granularity of their analysis of design. Lawson (2005) for example proposes an abstract interpretation showing design as a complex mental process whilst Pahl et al. (2007) present a detailed design planning process. The Pahl and Beitz model is subdivided into six steps or stages that are interconnected, not just linearly but allow for an iterative approach where, should requirements change, or a solution begin to seem unsuitable, designers can return to an earlier stage. The six steps identified are: Task, Design Specification, Concept, Preliminary Layout, Definitive Layout, and Product Documentation.

Pahl et al.'s (2007) model was chosen for use in this review due to its more expansive nature and clear definitions of the various stages of the design process. This allows for better placement of the AR technologies into the design process phases. Furthermore, the reference has a large number of citations and is widely accepted in the research community.

4 Literature Review Methodology

The review identified relevant papers through Google Scholar searches into AR and AR for design. Google Scholar was chosen due to its independent nature from major publishing houses as well as its ability to link to commercial material which enabled the identification of existing technologies currently on the market. Related articles were also queried to collect an initial set of papers. These papers were then placed within the matrix. Search terms included keywords "Design, Mixed Reality, Augmented Reality, Assembly, and Creativity". Only results listed on the first page were taken into consideration. Where empty cells were still present a second search was conducted in an attempt to identify any additional papers that may have been overlooked in the original search. This second search looked at the first two pages of results. Search terms used for this second search revolved around combining the AR technology with the design process phase. In both cases not all papers that were listed as results by Google Scholar were included in the matrix as some papers might mention either design or AR but not in depth or not have it as the focus of the paper.

The references collected were then coded in terms of the technology used and the stage in the design process. Understanding where the reference could be used to support the design process was the more complex of the two tasks. In the event that the reference explicitly stated how the technology could be used to support the design process, the categorization provided by the authors was used. However, many of the references identified tended to showcase the technology more and focus less on potential applications. Furthermore, simply because a reference failed to mention a potential design application, choosing instead to focus on other fields, did not mean that it could not be used for design purposes as well. In the interest of clarity and transparency each reference used has been provided with a brief summary to better understand the logic behind the categorization into a specific design process stage in addition to describing the original intended purpose should it not have been originally intended for design. It is important to note that some references have a one-to-many-relationship with the stages of the design process.

5 Results

The review resulted in 21 papers being identified and Table 2 lists the papers that have been compiled for the mapping exercise. The summaries give a brief explanation of the research conducted within each resource. This provides a basic understanding of the reasoning behind the categorization of each resource both for the type of technology used as well as the design process stage(s).

Table 2. Brief overview of references used in creation of comparison matrix

Reference	AR Technology	Summary
(Ong, Zhang, Shen, & Nee, 2011)	Head-worn: Optical	Review of different AR technologies. Analyses technologies for design review, manufacturing and robot programming. Of particular interest is the design review section which matches the Definitive Layout stage through the use of Optical HMD.
(Tawara, 2011)	Head-worn: Video	Development of a system for visualization of CT/MRI scan data allowing users to manipulate 3D models and see cross sections. Also allows for manipulation of 3D models in real time. Such a system could be used for either Concept or Preliminary Layout stages.
(Kaufmann & Csisinko, 2011)	Head-worn: Video & Optical	Development of a 3D modelling environment for use in teaching. Two technologies are investigated: both an optical and a video HMD. Use of a primitive shapes and basic implementation of geometry as well as simple mechanics suits the Concept stage as it allows for a simplification and subsequent analysis of the problem.
(Ma, Fan, Gausemeier, & Grafe, 2011)	Head-worn: Video & Optical	Overview of prototypes of AR technologies currently in use or under development in industry. Use scenarios include AR as an aid in assembly of components and as a prototyping tool to explore layouts.
(Poh, Nee, Youcef-Toumi, & Ong, 2005)	Head-worn: Video	Discussion of a potential architecture for the development of an AR based CAD system. Use of markers for drawing and measuring in digital space. Preliminary Layout stage.
(Valentini, 2009)	Head-worn: Video	Manipulation and interactive assembly of virtual objects through the use of AR headset and gloves to detect hand movement. Virtual assembly of basic parts and simple manipulation of objects indicate function at the Preliminary Layout Stage.
(J. Park, 2008)	Head-worn: Video	CAD visualization system for the setup and assembly of models. Smaller models can be manipulated and modified as well as reassembled. Preliminary Layout Stage.
(Radkowski & Linnemann, 2009)	Head-worn: Video	A setup for realistic lighting and colour rendering for CAD models in AR. Due to the fine detail finishing this appears to fall under Definitive Layout.
(Hua, Brown, & Zhang, 2011)	Head-worn: Projective	A review of projective HMDs showcasing different technologies available for development as well as potential applications. Majority of applications suggested are for visualization or basic manipulation of objects suggesting suitability for a Preliminary Layout stage.
(Xin, Sharlin, & Sousa, 2008)	Handheld	3D sketching interface for portable tablet PCs. Markers are used to define a sketch space which is then drawn in through the tablet interface by the user. The basic designs being generated and the creation of working principles suggests that this

		application would be best suited for the Concept or Preliminary Layout stages depending on the specific use made by the designer.
(Liestøl, 2011)	Handheld	Analysis of situated simulations as a method for displaying architectural buildings. Used to simulate and visualize ancient structures in their historical locations where otherwise only ruins can be seen. Low modifiability with high degree of accuracy in representation makes this application best suited to Definitive Layout stage.
(Stutzman, Nilsen, Broderick, & Neubert, 2009)	Handheld	Development of MARTI (Mobile Augmented Reality Tool for Industry) platform developed specifically for mass market use in industrial settings. MARTI is designed for aid in assembly and setup of machinery as well as other fine tuning aspects as the user input is less required and the system is more geared towards giving instructions. This makes the system best suited for Definitive Layout as well as Product Documentation.
(Zhang, Ong, & Nee, 2010)	Handheld	Virtual panel for the visualization of CNC machining pathways. The system is geared towards assisting users follow specific pathways for machining. This makes it most suited for the Definitive Layout stage.
(Smparounis, Mavrikios, Pappas, & Xanthakis, 2007)	Spatial: Video	Virtual and Augmented Reality tool for collaborative design. The AR part consist of both an online and offline interface that permits the visualization of a room wherein designers can make changes collaboratively to the layout by moving set pieces around. Preliminary Layout stage.
(Marner et al., 2011)	Spatial: Projection	Discussion of how SAR can be applied to Design Specification, Concept, Preliminary Layout and Definitive Layout stages of the design process. Various techniques for SAR and potential applications, both present and future are described here including how SAR can be implemented without having to rely on a pre-existing physical model.
(Marner, Thomas, & Sandor, 2009)	Spatial: Projection	SAR applied to user interface and finishing design. Due to the nature of SAR a semi-final physical model for projection is required. As such this is best suited for Preliminary and Definitive Layout stages.
(Löchtefeld, Krüger, & Rohs, 2011)	Head-worn: Projection Spatial: Projection	Investigation of how pico-projectors may be used to develop new applications for SAR and head-worn projection systems. A number of potential applications, from games to map design and augmentation are suggested as potential avenues for exploitation of the technology. Due to the relative simplistic nature of the augmentation and the ability to present sketches and render them interactive this seems best suited for the Concept stage.
(Marner & Thomas, 2010)	Spatial: Projection	Presentation of a new technique for real-time simultaneous modelling of both physical and digital worlds. Use of foam physical prototypes with projection that can be cut and modified as guided by the projection for additional flexibility. This supports the Concept stage in the design process.
(Israel, Wiese, Mateescu, Zöllner, & Stark, 2009)	Spatial: Projection	An investigation of how CAVE can be used to combine 2D and 3D sketching for designers in the Concept stage.
(Calife, Bernardes, & Tori, 2009)	Spatial: Projection	Discussion on the creation of Robot Arena, an AR platform to aid in the development of games in combination with existing physical robot models. Useful for Preliminary stage design as it allows or setup and organization of initial concepts.
(Irlitti & Itzstein, 2013)	Spatial: Projection	Discussion of how new techniques can be used for constraint driven design using SAR resulting in the creation of a prototype, named SARventor. This approach to SAR best suits the Definitive Layout stage.

			Design Process Stages						
			Task	Design Specification	Concept	Preliminary Layout	Definitive Layout	Product Documentation	Total
techn ologi	-	Retinal							0
		Optical			(Kaufmann & Csisinko, 2011)		(Ong et al., 2011) (Ma et al., 2011)		3

		Video		(Tawara, 2011)	(Kaufmann & Csisinko, 2011)	(Poh et al., 2005) (Valentini, 2009) (J. Park, 2008) (Ma et al., 2011)	(Radkowski & Linnemann, 2009)		7
		Projective			(Löchtefeld et al., 2011)	(Hua et al., 2011)			2
	Handheld	All			(Xin et al., 2008)	(Xin et al., 2008)	(Liestøl, 2011) (Stutzman et al., 2009) (Zhang et al., 2010)	(Stutzman et al., 2009)	6
	Spatial	Video				(Smparounis et al., 2007)			1
		Optical							0
		Projective		(Marner et al., 2011)	(Löchtefeld et al., 2011) (Marner et al., 2011) (Marner & Thomas, 2010) (Israel et al., 2009)	(Marner et al., 2011) (Calife et al., 2009) (Marner et al., 2009)	(Marner et al., 2011) (Irlitti & Itzstein, 2013) (Marner et al., 2009)		11
		Total	0	2	8	10	9	1	

Table 3 presents the comparison matrix generated using the sources from Table 2. It shows where each specific research output might contribute to the design process

Table 3. Comparison matrix

AR technologies			Task	Design Specification	Concept	Preliminary Layout	Definitive Layout	Product Documentation	Total
			Design Process Stages						
AR technologies	Head-worn	Retinal							0
		Optical			(Kaufmann & Csisinko, 2011)		(Ong et al., 2011) (Ma et al., 2011)		3
		Video		(Tawara, 2011)	(Kaufmann & Csisinko, 2011)	(Poh et al., 2005) (Valentini, 2009) (J. Park, 2008) (Ma et al., 2011)	(Radkowski & Linnemann, 2009)		7
		Projective			(Löchtefeld et al., 2011)	(Hua et al., 2011)			2
	Handheld	All			(Xin et al., 2008)	(Xin et al., 2008)	(Liestøl, 2011) (Stutzman et al., 2009) (Zhang et al., 2010)	(Stutzman et al., 2009)	6
	Spatial	Video				(Smparounis et al., 2007)			1
		Optical							0
		Projective		(Marner et al., 2011)	(Löchtefeld et al., 2011) (Marner et al., 2011) (Marner & Thomas, 2010) (Israel et al., 2009)	(Marner et al., 2011) (Calife et al., 2009) (Marner et al., 2009)	(Marner et al., 2011) (Irlitti & Itzstein, 2013) (Marner et al., 2009)		11
		Total	0	2	8	10	9	1	

From

AR technologies			Task	Design Specification	Concept	Preliminary Layout	Definitive Layout	Product Documentation	Total
			Design Process Stages						
AR technologies	Head-worn	Retinal							0
		Optical			(Kaufmann & Csisinko, 2011)		(Ong et al., 2011) (Ma et al., 2011)		3
		Video		(Tawara, 2011)	(Kaufmann & Csisinko, 2011)	(Poh et al., 2005) (Valentini, 2009) (J. Park, 2008) (Ma et al., 2011)	(Radkowski & Linnemann, 2009)		7
		Projective			(Löchtefeld et al., 2011)	(Hua et al., 2011)			2
	Handheld	All			(Xin et al., 2008)	(Xin et al., 2008)	(Liestøl, 2011) (Stutzman et al., 2009) (Zhang et al., 2010)	(Stutzman et al., 2009)	6
	Spatial	Video				(Smparounis et al., 2007)			1
		Optical							0
		Projective		(Marner et al., 2011)	(Löchtefeld et al., 2011)	(Marner et al., 2011)	(Marner et al., 2011) (Irlitti & Itzstein,		11

					(Marner et al., 2011) (Marner & Thomas, 2010) (Israel et al., 2009)	(Calife et al., 2009) (Marner et al., 2009)	2013) (Marner et al., 2009)		
		Total	0	2	8	10	9	1	

Table 3 it is possible to see that not all stages of the design process have been supported by AR applications. The most glaring omission is the Task stage, where no sources could be identified, but also the Product Documentation and Design Specification stages with only 1 and 2 sources respectively. Additionally, Retinal Head-worn and Spatial Optical technologies seem not to have received much implementation as no sources could be identified for these technologies. It should however be noted that for the case of Spatial Optical technologies there have been implementations, as mentioned in section 2.3. However, no design applications were found in any of the papers investigated.

6 Discussion on the future of AR in Design

The lack of support for design process stages at the beginning and end of the design process could potentially be explained by the relative lack of perceived added benefit provided by AR. Task definition is often performed on the basis of specifications laid out by the client or technical limitations due to technology and requires less visualization to understand. Similarly, for the end of the design process the documentation is ideally performed by collating information collected over the course of the design process and while AR systems could play a role in aiding the recording of data to later be used for collating they are not strictly necessary for the collation itself. However, it could also be argued that the increase in international teams and thus the need for remote working may bring forward the need for an improvement in these fields.
Most of the technologies discussed have been used in the matrix, with the exception of Spatial Optical, and Head-worn Retinal. This is likely a result of the technological difficulties of implementing these systems (Peddie, 2017). The competition they receive from similar systems, such as Projective or Video based solutions, has also likely not helped the development of these systems. It appears that there has been a considerable body of work in the development of technologies for Concept, Preliminary Layout, and Definitive Layout stages across most technologies with Handheld, Head-worn Video and Spatial Projection seeing the largest level of investigation.

It should also be noted that many of the references investigated did not present products that were market ready. Even solutions that are supposedly prototypes in industry, such as the car layout visualization system described in Ma et al. (2011) in use by Volkswagen, or AR systems used to aid technicians during assembly (Ma et al., 2011), are prototypes that have not yet been fully integrated in the design process.

For the field of AR to advance, many of these ad-hoc solutions would have to mature into products that can be acquired and used by design professionals. Once this step is undertaken it will be possible to gauge the true impact of AR on the design process. Perhaps new methodologies will become possible thanks to the greater process efficiency made possible by the use of AR. Of particular interest is the paper by Marner and Thomas (2010) wherein a new system for SAR is proposed that allows the modification of the physical prototype as well as the virtual one. This would help defeat the major drawback of AR platforms when compared to VR platforms, namely the reliance on unchanging models, especially in the field of projection.

7 Conclusion

In conclusion, it appears that while there are some AR technologies already commercially available - either at this current moment in time or that are due to be fully released in the near future - AR as a tool for design is still not fully explored. As noted in
Table 3, there are entire parts of the design process that have little or no AR technologies

			Design Process Stages						
			Task	Design Specification	Concept	Preliminary Layout	Definitive Layout	Product Documentation	Total
AR technologies	Head-worn	Retinal							0
		Optical			(Kaufmann & Csisinko, 2011)		(Ong et al., 2011) (Ma et al., 2011)		3
		Video		(Tawara, 2011)	(Kaufmann & Csisinko, 2011)	(Poh et al., 2005) (Valentini, 2009) (J. Park, 2008) (Ma et al., 2011)	(Radkowski & Linnemann, 2009)		7
		Projective			(Löchtefeld et al., 2011)	(Hua et al., 2011)			2
	Handheld	All			(Xin et al., 2008)	(Xin et al., 2008)	(Liestøl, 2011) (Stutzman et al., 2009) (Zhang et al., 2010)	(Stutzman et al., 2009)	6
	Spatial	Video				(Smparounis et al., 2007)			1
		Optical							0
		Projective		(Marner et al., 2011)	(Löchtefeld et al., 2011) (Marner et al., 2011) (Marner & Thomas, 2010) (Israel et al., 2009)	(Marner et al., 2011) (Calife et al., 2009) (Marner et al., 2009)	(Marner et al., 2011) (Irlitti & Itzstein, 2013) (Marner et al., 2009)		11
		Total	0	2	8	10	9	1	

proposed to support them. Furthermore, some AR technologies have not yet been adapted to be used to support design. One example of this would be the Spatial Optical AR which, while available for other applications, it has not yet been adapted for design. This paper attempted to collate existing studies and technologies, mapping them against the design process stages to aid future researchers and technology developers understand where the current gaps are: i.e where AR technology has not yet evolved to aid the design process. In doing so, it found that the Concept, Preliminary Layout and Definitive Layout stages of the design process are the areas currently most investigated while the Task, Product Documentation, and Design Specification stages are least investigated.

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