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Augmented reality for user validation in product development: utilizing the theory of technological mediation to assess a case study

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This paper assesses a case study that utilizes the development of a coffee machine to determine where and how augmented reality (AR) can be used as validation in a company's user-centred design (UCD) process. The aim of the case study is to digitalize part of the prototyping process by inserting existing CAD models into an AR environment. The AR spectrum is defined according to the xReality framework by Rauschnabel et al. (2022). The theory of technological mediation by Verbeek (2008) is defined according to the xReality framework and is used to reflect on the user validation results of the developed AR environment. The unique contribution of this thesis is the establishment of theoretical possibilities directly into practice. This project provided the client, with no knowledge of the extent of AR, a validated tool that can be integrated at a low threshold into their workflow.

Augmented reality, User validation; Mediation theory; xReality framework; User-centred design

1. Introduction

This paper summarizes the master thesis project constituting a case study of a coffee machine for a client company's user-centred design (UCD) department.

The case study includes an analysis of the coffee machine's current design and user interaction (UI). The coffee machine analysis and concept remain confidential. This analysis concludes with a coffee machine design developed to the rough concept level in the form of a CAD model. The UI of the coffee machine is formulated in a Use Flow: the sequence of steps a user must follow to brew a single serving of coffee. This Use Flow and CAD model are used as the case to test the developed AR tool.

The AR tool is the augmented reality (AR) environment developed for testing of digital prototypes. This environment holds the CAD model of the coffee machine and is created to hold the elements that allow for AR interaction for the user. The AR tool is used in collaboration with Microsoft's HoloLens2 to immerse the user in the AR environment.

To assess the impact of AR on user testing, the theory of technological mediation applied to the xReality framework is used.

2. xReality framework

The "xReality framework" by Rauschnabel et al. (2022) is used to define the extended reality spectrum [1]. Extended reality (XR) is an umbrella term that is used for any digital form or integration of reality, both virtual reality (VR) and augmented reality (AR). The scope of this paper focuses entirely on AR, excluding VR.

Rauschnabel et al. (2022) refer to augmented reality (AR) as "a combination of digital information with the real world that is presented in real-time" [1]. The continuum within the AR spectrum is further defined by opposite poles of local presence: assisted reality and mixed reality. Assisted reality describes the form of AR where the purpose of the virtual objects is to enhance the user's understanding of the physical environment. The local presence of virtual objects is clearly artificial in assisted reality. For example, a cyclist wearing AR glasses can view directions hovering above the road. In contrast, mixed reality defines the seamless merging of the virtual objects with the physical world as realistically as possible. The local presence of virtual objects is seen as being in the real environment in mixed reality. For example, a user views their room through AR glasses and sees a digital animal is integrated behind real objects. This AR spectrum is used in alignment with mediation theory to determine how a change in the technology can influence the user's experience.

3. Mediation theory

The aim of the exploration of AR for user validation is to test the practical implications for the client company. To further extend the academic relevance of this research, mediation theory by Verbeek (2008) is used to reflect upon the use of augmented reality in the context of user validation [2]. This introduction describes the theory of technological mediation and its three dimensions.

Founded by Peter-Paul Verbeek, mediation theory in technology is an approach designers can use to anticipate the possible relationships that the user will have with the product [3]. Meaning instead of designing the product for use, the designer focuses on designing for the relationship between the product and user, while keeping in mind the possible impact it can have on the user experience [4]. In the context of this master thesis, AR replaces the physical prototype with a digital prototype. This adds another dimension to the user-product relationship: a user-product-AR experience relation. What would have been a user-coffee machine relation is further complicated with a user-coffee machine hologram relation and a separate relation comparing the two experiences. This added question of - how does user validation via AR deviate from traditional user validation – is excluded from the scope of this research. This difference is of value and is recommended to be further researched with another case study.

The relation between the user and holographic coffee machine is the focus for this research. Technological mediation in the user-hologram context will be used to reflect on the user testing results. To do so, the three dimensions of technological mediation are defined as follows:

- categorizing the types of **relations** between the user, the HoloLens2, and the world

- identifying **contact points** where the design of AR interaction impacts the users
- and identifying the types of **influence** present.

The aim of the reflection is to better understand the role AR plays in the human-product relationship.

4. Case study

The coffee machine design is used as a case to test the developed AR tool. This tool is tested with colleagues at the client company to assess the applicability of AR in user validation.

4.1. Coffee machine design

The coffee machine is an existing design of a single-serve brewer. An analysis was conducted to assess the user interaction and redesign the UI in terms of convenience. The steps a user must follow to brew a single serving were formulated in a Use Flow. The coffee machine was redesigned to match this Use Flow. The Use Flow and CAD model of the redesign are used as input in the AR tool and testing. The redesign process of the coffee machine was done according to the UCD workflow of the client company. This aided in decision making concerning the development of the AR tool.

4.2. AR tool

The AR tool consists of an augmented reality environment constructed in Unreal Engine. This environment is built for combability with the HoloLens2. The HoloLens2 is an AR headset from Microsoft that tracks the wearer's hands. The AR tool utilizes this tracking by adding AR interaction to CAD models. As a result, a user wearing the HoloLens2 can see a hologram of the coffee machine and interact with it similarly to a physical prototype; buttons can be pressed, the coffee mug can be placed on the drip tray, and the machine lid can be opened and closed. These functionalities allow for testing the Use Flow, from the redesign analysis, in AR.

4.3. User validation

The AR tool was validated with users via two tests: the Usability Test and the Design Test. Twelve colleagues from the client company participated as users in individual testing sessions. Prior to the tests, the users followed the Microsoft tutorial to get acquainted with the HoloLens2 and AR interaction. The Usability Test assessed the Use Flow; the users executed the first steps of brewing a single serving. The Design Test assessed variations in the colour and geometry with the press of a button. Throughout the tests, users were encouraged to speak aloud their thoughts and frustrations.

4.4. Conclusions from user testing

The following conclusions were drawn based on the results of the user testing combined with the author's own interpretations.

- Although the AR environment is capable of more complex (and close to real life) interactions, the simpler interactions are better received by users.
- Overcoming the unrealistic aspects (floating holograms) is easier for users than overcoming the realistic aspects that glitch.
- AR can be an in-between step of CAD modelling and rendering or prototyping, bringing realism to the beginning of the design process.
- AR brings research and decision making forward in development by allowing exploration of the product in 3D, giving a better impression of texture, size, flexibility of components, which can lead to design changes before the physical prototypes are made, helping avoid costs
- Prototypes at the AR fidelity level require less time and resources than physical prototyping.

5. Mediation theory in user validation for AR

The following sections explain the three dimensions of mediation theory and how they are used with the xReality framework to reflect on the role AR plays in the user-product relationship of the case study.

5.1. Dimension 1: relations

By placing the four main types of relations on the xReality continuum, the organization helps define the context the user testing aims to orient concerning the user and hologram.

Verbeek expands on the work of Don Ihde, who categorizes the relations into four general categories: embodiment, hermeneutic, alterity, and background relation [5]. These four types of relations describe the different interactions between the user, technology, and world. To aid in reflection, these four relations are placed on the augmented reality continuum of the xReality framework (Figure 1.).

- In **alterity relations**, the world is in the background when the user interacts with the HoloLens2, which the user is completely focused on. In this relation, the level of local presence is at the lowest.
- Within **embodiment relations**, the user sees the world through the technology. In the context of AR, this relation is placed on the lower end of local presence.
- In a **background relation**, the technology is the context the user is experiencing, in contrast to actually being the experience. Here, the level of local presence is higher.
- For **hermeneutic relations**, the technology is part of the world, the user sees the product representing the world. The level of local presence is at its highest.

Verbeek already categorizes wearable devices as its own relation: augmentation, which combines embodiment relation with hermeneutic relation [6]. However, this assumption is without context of the AR device application. The context, purpose, and product are strong factors in AR device use that influence the type of relation. As a result, it is impossible to agree with Verbeek's assumption on a general basis and should be evaluated in every instance where AR is used.

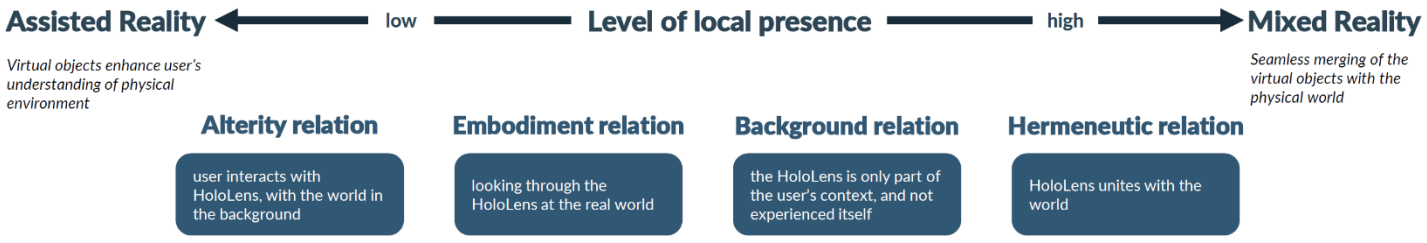

Figure 1.; Mediation theory relations applied to the xReality framework, AR spectrum.

The purpose of exploring the HoloLens2 (HL2) for user validation for the client is to use the technology as a tool to bring the product and its use context into view, not as a novel product in itself.

The goal was to facilitate an embodiment relation between the user and holographic brewer in the testing sessions. This means the user sees the world through the HoloLens2. During the Design Test, an embodiment relation can be used to describe the user's experience 90% of the time. This is because this test had no issues or bugs that took the user out of the experience, as seen in the Usability Test. The success of achieving this relation for the Design Test was surprising. It was anticipated that the lack of grounding, or floating of the hologram, would be too far from reality for users to believe. In contrast, the users received the floating hologram from the Design Test more positively than the Usability Test.

The remaining 10% of the Design Test is categorized as a background relation. A background relation has a higher level of local presence compared to embodiment. Here, the HoloLens2 is only part of the user's context, and not experienced itself. This 10% is based on the test start-up the user experiences. The test begins with the user already wearing the HoloLens2. The user then must wait until the test is streamed to the device. After the stream is successful, the user needs to move their head around to locate the holographic brewer. Once the user orients with the floating hologram, the test can begin. This initial start-up process can take about 15 seconds or up to a minute. At this time, the user is consciously aware of the HoloLens2 on their head but does not interact with it. Here, augmented reality is not experienced itself, but is within the user's context. Apart from the initial start-up, the remainder of the test is continuously categorized as an embodiment relation.

The Usability Test consists of 50% embodiment and 50% alterity relations. The problems in user interaction and holographic feedback caused the user to be at the lowest level of local presence, an alterity relation. Here the user focuses on their interaction with the HoloLens2, and the world is pushed to the background. This happened in every user test. The opening of the chamber lid requires a movement that differs from how the user would perform the same action with a physical prototype. Because of this, there was a large learning curve to this specific interaction.

The remaining 50% of the Usability Test indeed achieved embodiment in the relation. Users were initially taken aback at the realistic presence of the hologram, saying "the feeling that this an actual thing standing in front of you is actually quite good". After the initial learning curve was overcome, the interaction between the user and brewer was smooth. The use of the QR code as a means to ground the brewer to a surface aided in the initial start-up realism that is lacking in the Design Test.

5.2. Dimension 2: contact points

To help further reflect on how the HoloLens2 shapes user validation, mediation theory specifies the four types of contact points where the product impacts the user. These contact points are essentially the connection the user has with the technology. Dorrestijn divided the human body into four types: to the hand, before the eye, behind the back, and above the head [7]. These contact points are used to identify the impact AR has on the users.

"To the hand" constitutes the user physically interacting with the HoloLens2. This contact point is minimal in terms of influence. The user places the device on their head and adjusts the fit before continuing with the tests. There were no comments from the users concerning comfort or discomfort, weight, or pressure related to wearing the HL2. One user commented "I wouldn't want to wear it for longer than 15 minutes probably", but this has yet to be tested. It can be concluded that the physical interaction between the user and the HL2 had no significant impact on the user testing sessions.

"Before the eye" contact point concerns the user interacting with the holograms given by the HL2. This was the most prominent and influential contact point. This interaction determined the success of the tests. Due to the nature of augmented reality, it is strongly recommended to categorize interactions within the "before the eye" contact point. This contact point concerns such detailed interaction: pinching, poking, twisting wrist, translational movement and other actions made by the user trigger the holograms in different ways: translation, rotation, free movement, and more. The conclusion derived from reflecting on this contact point is that the interaction is highly complex and requires further testing and assessment.

"Behind the back" contact point means the physical environment impacts the user actions. This was seen more than expected. The tests were set up to ensure no physical obstruction would hinder the results. However, some "behind the back" contact points were still experienced. In the Usability Test, about 20% of the users who picked up the mug or coffee filter lost contact with the hologram. They had pinched the hologram and moved it very quickly. This sometimes caused a displacement of the hologram, causing it to pass through the table where the user could see it but not retrieve it. Holograms can be projected through walls and other obstacles, so it is vital to ensure the test is set up with the testing room in mind.

"Above the head" covers the impact of the HL2 on the user's way of thinking. Due to the steep learning curve, about 30% of users doubted their own actions when an issue occurred. This was a common thought among the users with no XR experience. Whether the problem was on the user or hologram/ testing side, the impact was still there. It is important for user validation in AR to avoid this contact point. The users should feel comfortable and confident during testing to give the most accurate and helpful feedback, whether it is for digital or physical prototyping

5.3. Dimension 3: influence

The types of influences the HoloLens2 could have on the user testing will be categorized based on visibility, being hidden or apparent, and force, being weak or strong [8]. Coercive, persuasive, seductive, and decisive are the types of influences defined. All types of influences were present in the testing sessions.

- **Coercive influences** are both apparent and strong. Verbeek using the example of cars that require buckled seatbelts before driving [6]. This type of influence was not present in testing but in the initial tutorial. When a new user puts on the HoloLens2, the device prompts the user to calibrate their eyes for a better experience.
- **Persuasive influences** are apparent but weak. Verbeek explains how energy meters measure but don't prevent overconsumption [6]. This influence is seen in the button interaction of both tests. When the user approaches a button with their forefinger, a white square hovers over the button to highlight it. This indicates to the user an action is needed but does not force the user to do anything. When the user proceeds to press the button, the white square translates backwards with the button.
- **Seductive influences** are both hidden and weak. Verbeek uses the example of coffee machines being deliberately placed for congregation of employees [6]. The placement of the UI buttons in the Design test is considered to be a seductive influence. A user action can be triggered by many things in the HL2. The choice of a button triggers the user's poking reaction that they would normally do with a physical button. These buttons were deliberately placed for the user to explore variations in the design.

- **Decisive influences** are hidden but strong. Buildings without elevators require people to take the stairs [6]. The interaction of the Usability Test was limited to the coffee filter and mug control, the opening and closing of the chamber lid, and the interactive buttons. It is possible to make each component of the brewer interactive. Instead, the remaining components were deliberately kept fixed. This required the user to explore only the parts that moved, which forced them to follow the first steps of the Use Flow.

5.4. Mediation theory conclusion

By being aware of the background relation in the start-up of the Design Test, a designer can understand how to change the testing session to avoid this disparity. This can be done by ensuring the holographic brewer is in position before the user puts on the HoloLens2. The alterity relation occurring in parts of the Usability Test make it clear to the designer where the AR interaction can be improved to achieve a complete embodiment relation. The contact point "before the eye" is too broad to reflect on the HL2 impact in detail. This covers most of the user testing interaction and requires further definition to better categorize this impact. All the user actions and hologram reactions are what make up this contact point. The categorization of the types of influence aided the reflection by identifying where and how strongly the test affected the interaction.

This reflection uses the theory of technological mediation and its three dimensions to assess the impact of AR on the User Testing sessions. This reflection provides context to the practical application of AR and how user testing can be shaped by different relations, contact points, and types of influence. These conclusions can be used to design for the relation between the user and the holographic product to be tested. Mediation Theory is used to define a basis for reflecting on the relations between the user and immersion brewer hologram.

6. Impact

This case study is used to reflect on the application of mediation theory to the xReality spectrum. The use of AR in user validation provides context to the user-product relation in the augmented reality world. This work attempts to define technological mediation in augmented reality by focusing on user validation. This research can be further developed in many aspects: deeper AR specification, broader XR exploration, and definition of technological mediation in augmented reality.

6.1. Deeper AR specification

The reflections made on mediation theory in AR can be explored deeper by repeating the case study for more iterations. The reflections can be incorporated back into the AR tool and follow up with another round of user testing. This can give insight into how making changes to the three dimensions can influence the user validation.

6.2. Broader XR exploration

The XR spectrum also covers VR. It is interesting to develop a similar tool to the case study and test with users. Mediation theory can then be reflected on in VR, the conclusions of which can later be used to compare to AR.

6.3. Definition of technological mediation in AR

This case study provides a practical reflection of the mediation theory applied to augmented reality. The four relations are placed on the xReality framework to aid in orienting the level of local presence in relation to the AR technology. The use of contact points to define the user-hologram interaction brings to light the "before the eye" point requires its own framework to assess the influence of AR in user validation.

8. Conclusion

The case study utilizes a coffee machine concept as means to explore augmented reality as a form of user validation. The results from the user testing sessions give insight into practical application of AR in digital prototyping of the client company. The case study concludes with a final advice to the company to utilize the HoloLens2 as a form of user validation in terms of in-house testing, early in the product development process. This is based on the observation that the application of the HL2 has proven to be feasible in prototyping. Mediation theory and the xReality framework set a basis for reflecting on the influence AR has on the user-product relationship. The conclusions drawn from the testing results can be used for further research into technological mediation of he extended reality spectrum.

The impact of this thesis proves to the client that the initial barrier has been overcome within this research. The unique contribution of this thesis is the establishment of theoretical possibilities directly into practice. This project provided the client, with no knowledge of the extent of XR, a validated tool that can be integrated at a low threshold into their workflow.

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