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Technology Acceptance of Augmented Reality and Wearable Technologies

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Abstract. Augmented Reality and Wearables are the recent media and computing technologies, similar, but different from established technologies, even mobile computing and virtual reality. Numerous proposals for measuring technology acceptance exist, but have not been applied, nor fine-tuned to such new technology so far. Within this contribution, we enhance these existing instruments with the special needs required for measuring technology acceptance of Augmented Reality and Wearable Technologies and we test the new instrument with participants from three pilot areas in industry, namely aviation, medicine, and space. Findings of such baseline indicate that respondents in these pilot areas generally enjoy and look forward to using these technologies, for being intuitive and easy to learn to use. The respondents currently do not receive much support, but like working with them without feeling addicted. The technologies are still seen as forerunner tools, with some fear of problems of integration with existing systems or vendor-lock. Privacy and security aspects surprisingly seem not to matter, possibly overshadowed by expected productivity increase, increase in precision, and better feedback on task completion. More people do have experience with AR than not, but only few on a regular basis.

1 Introduction

Technological innovations such as brain stimulation, simulations, sense making, augmented reality and virtual reality are making possible major changes in the following:

the nature, depth and scope of human experiences; our capacity to re-experience and constructively reflect upon our own experiences; our ability to share actual experiences; our capacity to synthesize partly-false memories that combine fragments of our direct experiences and synthesized third-party experiences. One indicator of this trend is recent work about people who lose or gain a core sense (e.g., “Notes on Blindness, a feature film and virtual reality experience”, <http://www.notesonblindness.co.uk>).

Sensory-focused work like that can be useful in assessing the social context, development and dynamics of changes in science and technology and thus being better able to empathise in some way with the initiators, developers and prospective users of a given scientific or technological innovation, for example by providing ways to share and to communicate the experiences and feelings of people who are in need of a particular innovative technology.

A consequence of that empathetic approach is being able to extend how we identify and measure the degree of ‘fit’ between a technology and its users’ needs and wants. Numerous proposals for metrics for technology acceptance and behavioural intention to use were made in the past to help assess success of then-new information and communication technology before committing to and investing into its introduction [1-7].

The metrics and associated Technology Acceptance Models (TAMs) developed at a particular time reflect the insights, experiences and concerns of that time’s expert communities, and the development and dynamics of the associated science, technology, society and culture. Technology innovations such as Virtual Reality (VR) and Augmented Reality (AR), can help to benchmark and predict success (and failure), but as acceptance is not independent of usage culture (think ‘home office’), fashion trends (think ‘themes’), and paradigm shifts (think ‘mobile computing’), revisions had to be proposed over time.

The current third generation of AR does not only provide adaptation to location/viewpoint and not only links content with computer vision to physical objects [8], but provides immersive experience where human vision (and other senses) are manipulated in a way that very believable illusions seem to alter reality.

Wearable Technologies (WT), such as smart glasses, watches, or armbands, use embedded systems to fit accessories and garments with computing facilities. They play an important role as delivery devices for such immersive experience.

The combination of AR and WT is currently subjecting computing as we know it to further transformation – quite likely more than just a little disruption in usage culture, with nearly 1M AR Smart Glasses sold in 2015 and 10M expected for 2016 and mass markets of > 1B predicted for 2019–2023 [9, 10].

AR/WT solutions are not conventional software systems (like desktop software, web, or mobile application), but have different, non-standardised form factors as well as different user interfaces.

Within this contribution, we first investigate the suitability of the generic models acceptance models for benchmarking acceptance of AR/WT solutions, tending to the particularities of such emerging technologies.

Moreover, we investigate whether from the application context – not for home use for leisure or life, but in a workplace context in aviation, medicine, and space contexts – specific constraints on AR/WT acceptance can be identified. The three application

areas are explored within the research project (removed for blind review). Each application area is represented in the project by an industrial partner company.

We do so, because both, AR and WT as well as their application in these work contexts are emerging fields and remain widely unstudied: Existing studies look either into hardware [11], regardless of the application, or they are validation studies of effectiveness and efficiency of use [12], not acceptance.

The rest of this article is organized as follows. First, we describe the methodology for constructing scales, a two-stage approach of using experts to gather feedback on the scale items to select those that are on scope and that can be included in a questionnaire run by participants from the three pilot areas of the (removed for blind review) project (in aviation, medicine, and space). We report the results from the scale construction first to then report the results from the participants of the pilots. We discuss what this baseline benchmark means with respect to the introduction of AR and WT in an industrial context (and potential required interventions). An outlook on open problems and future plans for iterative measurements using the resulting model concludes the article.

2 Methodology

In order to build a model of what drives acceptance and use of technology in the context of maintenance and repair operations in aviation and space as well as training on operating procedures (of imaging equipment in the health sector), we collected items from existing technology acceptance models.

This included items from UTAUT, TAM-3, UTAUT-2, and TPB (see Section 3), as well as additional items from the generic literature on user experience. We enriched these items in focus groups with technology as well as ergonomics experts with items specific to industry needs.

As Section 4 will report, this resulted in a pool of 91 statements, many of which belonging to groups of items, investigating the same construct, but asking for different aspects or using different phrases to express the same statement. The statements are formulated in a way so that they can be rated with a 7-point Likert scale, ranging from strongly disagree to strongly agree, including a neutral ‘neither agree or disagree’ in the middle. This pool of items to draw from was too large to ask for from participants in the target groups directly (a set of 15–20 would be deemed appropriate).

In order to test reliability and measure internal validity of the constructs and items in the model, we asked 15 subject matter experts from a project consortium partnership to provide ratings for all items of the pool. With that, we measured the correlation (Pearson’s r) across the responses with the sum scores of all items to assess that each item is actually measuring what we are interested in, testing for discriminatory power of the item [13]. The general assumption of this is that in total the chance for error is less likely than with a single item [13]. If responses to an item do not correlate with the sum scores of all items’ responses, then it is very likely to not measure aspects of acceptance and use of technology, but rather something else. This analysis step allowed sorting out those items not correlating high with the sum score.

Subsequently, we calculated the item-to-item correlations to identify further those items loading onto the same construct. If the correlation between two or more items is high, one or a subset can be selected.

Then, Cronbach's α was measured to estimate interrater reliability, comparing the reliability for the full pool as well as the final subset selection.

Finally, the resulting questionnaire was run with 33 participants from three industrial partner companies (removed for blind review) (Norway), (removed for blind review) (Italy), and (removed for blind review) (Italy) in the areas of aviation, medicine, and space in order to assess the current level of user acceptance of AR and WT in those industries.

3 Existing models of acceptance

Venkatesh et al. compare eight models and integrate their constructs into the Unified Theory of Acceptance and Use of Technology (UTAUT), consisting of 31 items in four core determinants of intention and usage, namely Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC), see Figure 1 [6]. Moreover, they identified four additional moderating variables, i.e., gender, age, experience, and voluntariness of use.

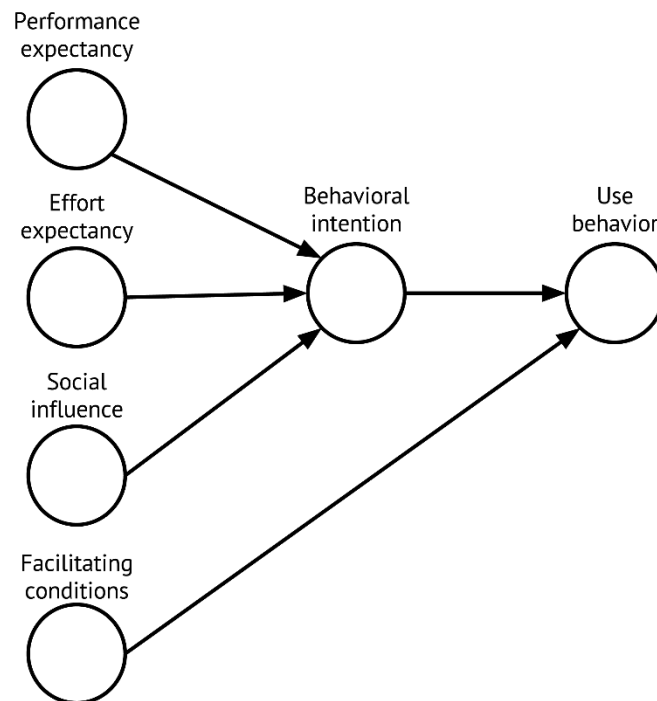


Fig. 1. Direct and indirect determinants of user acceptance and usage behaviour, redrawn from [6]

UTAUT thereby integrated constructs from the theory of reasoned action, the technology acceptance model, the motivational model, the theory of planned behaviour, a model of PC utilisation, social cognitive theory, and a combi-model. The model was validated and accounted for 70% of the variance in usage intention, outperforming the models it built on. Even though the results are very promising, the authors demand that “future research should be targeted at more fully developing and validating appropriate scales for each of the constructs” [6], while at the same time asking for “alternative measures of intention and behavior”. They particularly stress the importance of further investigating the relation of individual and organisational technology acceptance (p.470) and propose to further align success factors relevant in these two social spheres.

One of the very established precursor models, is the Theory of Planned Behaviour (TPB) [14]. Key constructs in TPB are Attitude Towards Use (ATU), Subjective Norm (SN), and Perceived Behavioural Control (PBC). The model is still being applied in recent years. For example, Teo and Lee use it to explain about 40% of the variance in intention to use technology among student teachers [2], finding, however, PBC not to have any significant path from PBC to intention (and a rather small effect for Subjective Norm).

Venkatesh et al. propose an extension to UTAUT, adding Hedonic Motivation (HM), Price Value (PV), and Habit (HT) as constructs [1]. Price Value is especially important for consumer contexts, where costs define expectation of experience. Habit is automated, learned behaviour. Hedonic Motivation, also known as the “fun or pleasure derived from using a technology” [1], picks up on research into user experience [4]. Beyond the items proposed, various uX authors recommend additional constructs for assessing the experiential quality, in particular usability, utility, affective quality (AF), or aesthetic experience [4, 15, 7].

Finally, Venkatesh and Bala propose the third version of the Technology Acceptance Model (TAM-3), comprising Subjective Norm, Image (IMG), Job Relevance, Output Quality, Result Demonstrability, Computer Self-Efficacy (CSE), Perceptions of External Control, and Computer Anxiety (CANX) to moderate Perceived Usefulness and Perceived Ease of Use that then drive Behavioural Intention (BI) and actual Use Behaviour [5].

4 Item pool generation and reduction

An expert panel was used to select items from the existing models introduced in Section 3 that were considered likely to be relevant for studying technology acceptance of AR and WT, casting the net widely. Moreover, the expert panel included additional items, resulting in a pool of 91 Likert statements plus six Use Behaviour (USE) questions, varying the delivery devices.

The pool of 91 statements (and six different types of usage frequencies) were rated by the board of 15 subject matter experts using a 7-point Likert agreement scale each. The data table lists participant responses (rows) against items (columns), containing numeric value from 1 (strongly disagree) to 7 (strongly agree). For the first analysis

step, sum scores for each row were calculated and each item vector was correlated with the sum score vector using Pearson's product moment coefficient r .

Results show that there are several items that do not correlate (directly or inversely) with the sum score (Fig. 2). There are 12 items in total correlating with the sum scores on a level higher than 0.7, a total of 36 items on a level higher than 0.6, and 45 items with a correlation value higher than 0.5.

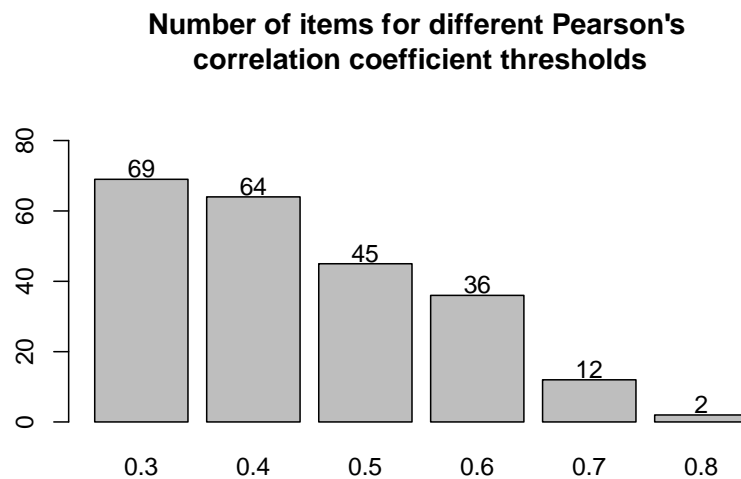


Fig. 2. Number of items for different correlation thresholds.

Since the sum scores are composed of all items, including items that may not directly measure what we intend to investigate, we decided to select a threshold of 0.6 of the absolute correlation as acceptable for identifying whether items are on scope. The sum scores indicate that the other constructs either measure something completely different or are not independent of other influences.

Next, we turned to item-to-item correlations and their groupings. The **Fig. 3.** visual representation clearly indicates that there are groups of items that are related, as expected since we adopted several groups of items from the existing technology acceptance models (Fig. 3). The figure displays the correlation matrix [16] of the items graphically, indicating the correlation value via the size (area) of the circles and additionally colour shade as well. The order of the items in the plot is determined using a hierarchical cluster analysis (hclust, package: stats) [17], so items close to each other along the diagonal are tend to correlate more highly.

The triangles visible along the diagonal (and the rectangles within) in the figure indicate that there are groups of items belonging more closely together. This confirms already visually, that there are indeed groups of questions amongst the 36 items selected for a sum score correlation of 0.6 that may load on the same aspect. This potentially will allow picking just one of the items in each group (instead of posing all of them).

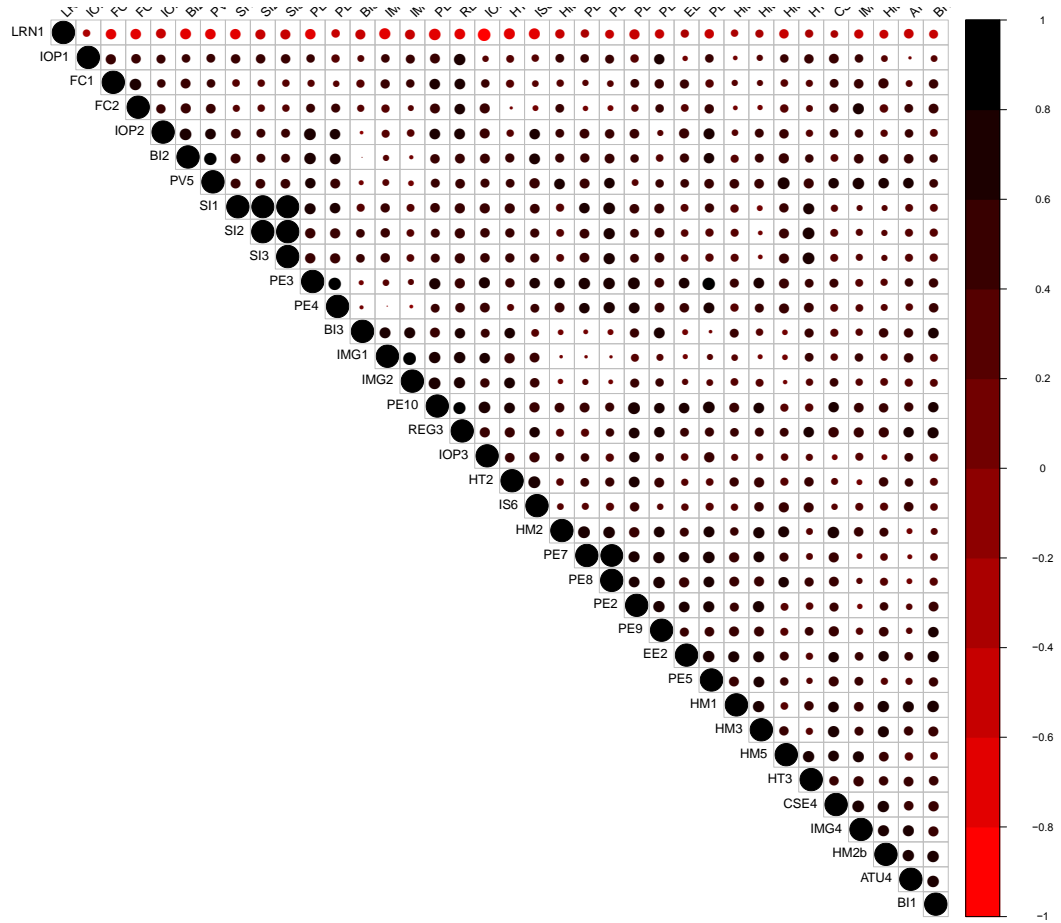


Fig. 3. Item to item correlations (selected 36 items)

5 Selection of items

Investigating the excluded items, i.e., the ones not in the 36-item selection (with correlations to the sum scores above 0.6), shows the following particularities.

Anxiety (group CANX) does not correlate with the sum scores. This may have to do with the selection of our test participants. This group of items is likely to be more relevant in an everyday use context and it may not be so relevant in a work context. Workers also may prefer management by objectives that are way within their capability. We can't separate whether anxiety would be personal or work related and this is better to explore qualitatively in an interview context, in which we can separate between personal use and work use (and the anxieties connected to it).

Questions about management support (such as DM1) are too early to ask, as in most contexts right now AR/WT are in prototype or exploratory use (if at all) and such question would need real exposure in daily routine.

Questions about integration with legacy systems do not work. This is likely to have to do with competence of people asked, as system integration is not their job, nor within their knowledge. Similarly, the lack of exposure or exploratory use of AR/WT is a problem among this group of questions.

The question about appeal of the workplace to younger people is out of place: respondents may not know this.

Questions about content and content experience (in dropped items in IOP) could not be answered. Maybe end-users do not see this separation between content and system as we do.

The lack of correlation with sum scores of questions on privacy may be a result of lack of exposure (or infrequent daily use). Questions also do not differentiate by target group of data (and their level of exposure), this would have to be further specified.

The target group cannot answer statements on value for money.

For both the full pool as well as the selected 36 items, the standardized Cronbach's α , as a measure of internal consistency, is similarly high (0.96 for the full pool, 0.97 for the 36 items).

Analysis of the 36 included items and their item groups provides the following. Several items correlate highly within their group and a choice can be made for the phrasing with more clarity or for the aesthetically more pleasing formulation (see Table 1).

Table 1. Item grouping (black background: selected)

| ITEM | COR | ANALYSIS |
|------|------|---|
| ATU4 | 0.63 | Better question compared to the two items before, as this is future oriented (and not about past exposure) |
| BI1 | 0.71 | Expected to group, but inter item correlations (0.4, 0.6, 0.01) is not very strong. Preference for BI2 over BI1/BI3, because it is not dependant on current use of AR/TW. |
| BI2 | 0.69 | |
| BI3 | 0.6 | |
| CSE4 | 0.71 | Covers the other three CSE items, no need to ask the other (less well working) questions. The other three items are more about supports that may not be in line with modern software design approaches (self-explanatory, no need for extended IT support, etc.). |
| EE2 | 0.61 | This question works best amongst this group of EE items and clearly loads on sum scores. More technical than the other questions - good in our technology context. |
| FC1 | 0.65 | These two items are working well, no need to ask the other FC items (correlate with 0.74, keep FC1 as it is the more broadly formulated one). |
| FC2 | 0.62 | |
| HM1 | 0.63 | Expected that we can only ask one of these HM items - they are very similar. |
| HM2 | 0.61 | |
| HM2b | 0.67 | |

| | | |
|------|-------|---|
| HM3 | 0.63 | |
| HM5 | 0.67 | Badly phrased, drop. |
| HT2 | 0.7 | Two of the four HT items correlate with sum scores. HT2 and HT3 correlate with 0.5, but HT2 is better formulated (less bound to previous exposure). |
| HT3 | 0.72 | |
| IMG1 | 0.65 | Three of the four IMG items correlate higher with the sum score. Expect two more to drop out with group analysis: IMG1 vs. IMG2: 0.91, so keep IMG1. |
| IMG2 | 0.62 | |
| IMG4 | 0.69 | |
| IOP1 | 0.66 | Three of the 10 IOP items correlate highly with sum scores. Integration questions about existing integration could not be answered. Questions about content / content experience could not be answered. Maybe end-users do not see this separation between content and system as we do. IOP1/2/3 do not correlate (0.45, 0.23, 0.57). Drop IOP1, as interoperability is a difficult word. |
| IOP2 | 0.64 | |
| IOP3 | 0.68 | |
| | | |
| IS6 | 0.69 | Only item left in this group. |
| LRN1 | -0.78 | Reverse item. |
| PE2 | 0.71 | Very close, pick PE4 as it is more different from the other PE items. |
| PE3 | 0.74 | |
| PE4 | 0.62 | |
| PE5 | 0.69 | These are novel, AR/WT functionality related questions. The task completion questions can be grouped. Reduce error and increase precision express the same. |
| PE7 | 0.6 | |
| PE8 | 0.65 | |
| PE9 | 0.73 | |
| PE10 | 0.87 | |
| PV5 | 0.74 | Drop this question: out of context, cannot be interpreted anymore without the other PV items. |
| REG3 | 0.87 | Should have been an inverse item, but isn't, so: drop. |
| SI1 | 0.71 | Similar, picked one of the three well loading items. |
| SI2 | 0.7 | |
| SI3 | 0.7 | |

6 Final questionnaire

The final set of statements contained 20 items from different constructs/models (Table 2).

Table 2. Final metric scale

| CODE | STATEMENT |
|------|--|
| ATU4 | I look forward to those aspects of my job that require me to use AR & WT. |
| CSE4 | I could complete a job, if I had used similar technologies before this one to do the same job. |

| | |
|------|--|
| EE2 | My interaction with AR & WT is clear and understandable. |
| FC1 | I have the resources necessary to use AR & WT. |
| HM2b | I like working with AR & WT. |
| HT2 | I am addicted to using AR & WT. |
| IMG1 | People in my organization who use AR & WT have more prestige than those who do not. |
| IMG4 | I use AR & WT solutions, because I want to be a forerunner in technology exploitation. |
| IOP1 | Interoperability is important for AR & WT. |
| IOP2 | I am worried about vendor lock in with AR & WT. |
| IOP3 | Integration costs of AR & WT with other software systems in use are high. |
| IS6 | I would find it useful if my friends knew where I am and what I am doing. |
| LRN1 | Learning curve for AR & WT is too high compared with the value they would offer. |
| PE10 | With AR & WT, I immediately know when a task is finished. |
| PE4 | Using AR & WT increases my productivity. |
| PE8 | AR & WT increase precision of tasks. |
| SI1 | People who are important to me think that I should use AR & WT. |
| BI2 | I will always try to use AR & WT in my daily life. |
| UF1 | Please choose your usage frequency of AR/WT |

7 Current level of Technology Acceptance

The final resulting questionnaire now allowed us administer another survey with participants from the pilot companies, which gives us a 'baseline' of what drives technology acceptance, use, and all the other success factors. We have run the questionnaire with the aim to draw an equal share of participants for each pilot area (deleted for blind review) is looking at (about 10 each). Additional people across the project consortium contributed.

Most of our participants are male and from the age group of 25–44, with only a few being younger or older. Respondents come mainly from the space industry and the educational field, with additional participants from transportation, R&D, manufacturing, and medicine. Participants added maintenance, media, IT consulting, and telecommunication service provider to the list of industries offered. Within these organisations participants are mainly researchers or end-users, with some participants being managers, developers, or trainers.

The variables of the technology acceptance model are presented and discussed below (Fig. 4). The respondents generally look forward to using AR/WT (ATU4) or are neutral about it and plan to use AR/WT in their daily life (BI2). They are rather neutral about learnability of AR/WT for being similar to existing technologies (CSE4), but agree that their interaction with AR/WT is generally clear and understandable (EE2).

Participants do not necessarily have the resources available (FC1) to use AR/WT (some do, some don't), but the majority likes working with AR/WT (HM2b) without

feeling addicted to it (HT2). They don't see AR/WT as prestigious tools (IMG1) but rather a tool for forerunners (IMG4).

Interoperability is seen as a highly relevant issue (IOP1) and participants are slightly worried about vendor lock-ins (IOP2). They fear high integration costs for AR/WT solutions (IOP3).

Participants are rather neutral about privacy and security aspects, i.e. the use of AR/WT for informing others about current activity or location (IS6). In addition, they are neutral about the learning curve needed to adopt AR/WT (LRN1).

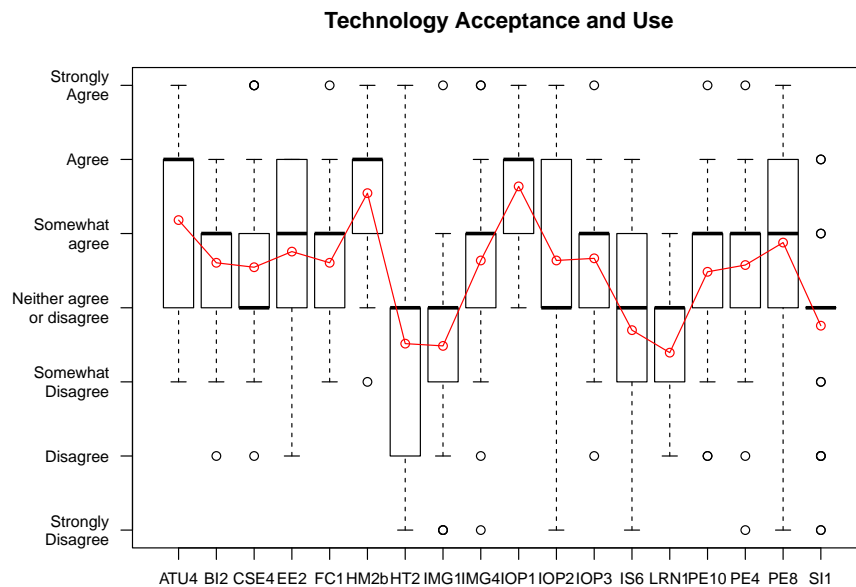


Fig. 4. Variables of the technology acceptance model

With respect to performance expectancy, participants are slightly inclined to believe in an increase of productivity (PE4), an increase of precision (PE8), and the advantage of feedback on task completion (PE10).

Participants are rather neutral about social influence of other people on the use of AR/WT (SI1).

The majority of participants has no experience in the use (UF1) of AR/WT (never: n=14), some use AR/WT rarely (once/month: n=7; once/two weeks: n=6). Only a few people use AR/WT on a regular basis (daily: n=1; several times a week: n=5).

We tested the reliability of the developed questionnaire with a split half reliability test [13]. This means calculating the correlation between the sum scores of odd-column items versus the sum scores of even-column items, resulting in a Pearson's r value of 0.77.

Since 'limiting' the number of items for the halves to half the full set, the underestimation can be corrected with the Spearman and Brown formula: $rs = 2 * rs_{1,2} / (1 +$

rs1,s2). This results in rs of 0.87, which is above the recommended value of 0.80 [13]. The standardised Cronbach's α is 0.86 (same with the raw α).

Testing the predictive quality of the sum scores against BI2, the behavioural intention to use shows a correlation effect of 0.6075 (Pearson's r), which is highly significant with a p-value below 0.001.

8 Conclusion

Within the study presented in this article, we have extended and applied a metric scale to assess technology acceptance, including key factors determining success. In particular and beyond existing models, we have added constructs and items for interoperability, learnability, and privacy, all items that in this phase of emergence of an AR/WT market deserve special attention.

In the industries screened, it is clear that specific attention has to be paid to equipping users with the resources needed, in particular with the devices. Device management will be an issue, also for managing update and upgrade procedures. Integration with legacy systems is of big concern, so in the introduction of AR/WT, interfaces have to be created ensuring that any new solution fits seamlessly in into the existing pool of hard- and software.

It is important to ensure solutions meet expectations with respect to hedonic quality and performance gains. Hopes are high that an increase in productivity, precision, live feedback will be delivered by solutions that are fun to use. If these expectations are not fulfilled, acceptance will suffer. This clearly demands thorough user experience and usability/utility testing. For an overview on the according methodology see [18].

We found a lack of social influence and, at the same time, expectations about AR/WT being used by forerunners. This indicates potential for supporting the introduction with social communities, with key personnel leading by example. We expect that with more widespread use of AR/WT peer pressure will rise.

The lack of concern about privacy is surprising, indicating lack of exposure. To avoid legal consequences to arise ex post, we recommend to elaborate individual policies for privacy and data security in joint consultation with providers, management, and employee representatives.

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