Affordances of Augmented Reality Systems for Co-Located Collaboration

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Abstract

This paper aims to identify relevant affordances towards an augmented reality system for organizational practices of co-located collaboration. As augmented reality is a means to visualize and author information, such an artifact could enable intuitive sharing of information. It can be shown that single aspects are reflected in literature, missing so far is a comprehensive description of relevant affordances for such an artifact.

The concept of affordances is increasingly used in information research, as it enables to define design principle based on the action goals of the user. Addressing the lack of clear formulation guidelines of affordances, a proposal is presented of how affordances can be formulated to reduce uncertainty and ambiguity.

This paper makes two major contributions: (1) it introduces how augmented reality systems can contribute to organizational practices of co-located collaboration and (2) illustrates how affordances can be utilized to derive requirements for such systems from interviews.

Keywords: Augmented Reality Systems, Affordances, Collaboration.

1. Introduction

Different settings of collaboration rely on different means of communication, which can be synchronous/asynchronous and within the same place or different places (Bafoutsou & Mentzas, 2002). For a co-located (same place), synchronous (same time) setting, it is quite intuitive to rely on personal meetings. Meanwhile, e-mails still seem to be the preferred means to communicate in an asynchronous (different time) and remote setting (different place). Examples of communication for same time/different place circumstances are phone calls and video conferences, while different time/same place situations can involve post-it notes or fixed screens (Bafoutsou & Mentzas, 2002). In the latter case, there is particularly limited flexibility and personalization with the current means of communication, e.g., people passing by a fixed installed screen will see the same information. These shortcomings can potentially be addressed by Augmented Reality (AR). Augmented Reality Systems (ARS) are a recent addition to digital information systems (Li et al., 2017). An ARS can be applied in addition to conventional information systems in collaboration settings. The possibilities and implications are not yet clear, as the technology is rapidly evolving. For example, the tracking technology, which is a vital part of AR, becomes more intuitive and sophisticated. Leveraging 3D positioning e.g., via Simultaneous Localization And Mapping (SLAM) does not require anymore a perfect 3D reconstruction of the environment nor AR markers (Polvi et al., 2016).

While there is still some way to go for the user not to be tasked with tracking activities at all, ARS can already increase flexibility and personalization of collaboration. For example, AR content can be placed anywhere and be limited to specific recipients only. Immersive technologies, like ARS, can play a role in all time/space collaboration scenarios, like expanding video communication with AR Remote Meeting Systems (Schopf & Jonas, 2022). Especially in asynchronous co-located settings however, there is a notable inadequacy of conventional collaboration means compared to the possibilities of emerging ARS, as AR annotations enable completely new ways to collaborate (Irlitti et al., 2017). It is therefore surprising that asynchronous AR applications for collaboration have not yet been more addressed in research (de Belen et al. 2019) and shall therefore be the focus of this paper.

A vignette of a site supervisor collaborating with colleagues is helpful for a better understanding of the scenario of different time/ same place. It also demonstrates the various difficulties associated with this kind of collaboration, which requires regular means of communication: A site supervisor who at present times conducts an inspection walk generally annotates findings on paper to type a report afterwards via e.g. Microsoft Word in the site office. He then sends out the report per mail to colleagues for them to address the respective findings at the respective location. This supervisor cannot leave his findings at these locations, as unauthorized persons could draw the wrong

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conclusions. In addition, adverse conditions at a construction site or overcrowding of information could decrease the effectiveness or efficiency of such communication when posted physically (e.g., post-it notes). An ARS, affording mobility in information sharing, that also affords sharing personalized and persistent information, could potentially increase the efficiency of the activities completed by the supervisor. This could be achieved by sending an automated e-mail to relevant colleagues when posting AR information about a finding at the respective location. This AR information can be pictures, audio files, text comments, etc. which are then 'floating in mid-air' at the respective location. While these colleagues are immediately informed and guided to the location, they can then intuitively consume the AR information left behind by the supervisor, to understand what needs to be done. A report, including a timestamp on activities, can easily be created by exporting the digital content from the respective information system.

Such systems are not in broad usage yet. The motives driving the adoption and use of AR are still not yet fully understood (Steffen et al., 2019). Steffen et al. (2019) assert that AR is adopted by users since Virtual Reality (VR) and AR enable (i.e., afford) activities that are impossible or advantageous compared to the traditional activities afforded by well-known physical reality. Physical reality on the other hand has advantages over AR and VR for example in the haptic richness and the sensory vividness it provides (Steffen et al., 2019). In light of the COVID pandemic, new ways to collaborate across time without the need to be at the same place at the same time might be an example for a valid advantage and motive to use AR, as if could decrease the risk of infection.

The concept of affordances can help to pinpoint further differences and thereby to understand the motives of adoption. It can therefore be used to analyze potential improvements in organizational practices of co-located collaboration with AR.

The origin of the concept of affordances stems from Gibson (1977). He used the term to describe how animals directly perceive what an object can be used for. Information system research adopted this idea and terminology to provide a useful bridge between the analysis of IT properties and the explanation of IT effects (Markus & Silver, 2008). Our intent is to identify the affordances that enable the design of an artifact to facilitate organizational practices of co-located collaboration.

There are two guiding research questions for this paper:

1. *Which affordances should be considered in the design of an ARS to facilitate organizational practices of co-located collaboration?*
2. *How can these affordances be derived and formulated?*

In addressing these questions, the paper makes two major contributions. Firstly, it introduces how ARSs can contribute to organizational practices of co-located collaboration, thereby describing new ways to collaborate especially in mobile and asynchronous settings. Secondly, it illustrates how affordances can be utilized to derive requirements for such a system from interviews. Therefore, we offer a proposal to formulate affordances and illustrate our approach to define affordances.

In the next section, the paper presents the relevant background of AR for collaboration and relevant frameworks of affordances. The section thereafter details the research methods followed by the case interpretation and findings. Finally, the paper concludes with the discussion of limitations and contributions of this study.

2. Theoretical background

AR stands out as technology that can be used for co-located, asynchronous collaboration settings that present a large number of opportunities for collaboration (Irlitti et al., 2017). AR is defined as any system that 1) combines real and virtual content, 2) is interactive in real time, and 3) is registered in three dimensions, so that virtual objects would cover real objects if situated in front of them (Azuma, 1997). Collaboration involves the coordinated interaction of participants that are committed to a common mission and are willing to share the knowledge necessary to fulfil that mission (van Leeuwen & Fridqvist, 2006).

Irlitti et al. (2017) discussed the opportunities of an asynchronous system and claimed that existing research has considered production and consumption of AR information as separate actions. However, the combination between creating and consuming AR information interchangeably is key to effective collaboration, as it enables bidirectional communication and thereby knowledge exchange (Irlitti et al., 2017). Although individual goals and motives in work practices can vary widely, we can assume that organizations generally aim for their employees to collaborate more efficiently, effectively, and enjoyably (Grudin & Poltrock, 2012). A system that supports the realization of such goals is perceived as useful, which leads to increased adoption of this system (Sabherwal et al., 2006), making voluntary adoption in work practices a key metric to measure its success. This is relevant for the evaluation of these systems and the concept of affordances provides a theoretical lens to examine how information systems relate to behavioral routines manifested in work practices (Leonardi, 2011).

While Gibson (1977) originally proposed this concept in the realm of ecological psychology, it is not the material properties (features) of an object that is perceived but what the object affords. For example, a chair with the material properties of a horizontal surface, made from aluminum, might afford sitting for a weary person passing by with the goal of resting, but for an American wrestler, it might afford hitting an opponent with the goal to win a fight. Affordances allow to examine how individuals with certain action goals interpret the material properties of information systems with the objective to fulfil these goals. This is why affordances can be employed in evaluating the use of information system technology (Leonardi, 2011).

It is important to note however that affordances create the potential, but not the necessary and sufficient conditions, for goal-oriented actions (Markus & Silver, 2008). Affordances enable evaluating how users of information systems address their respective action goals and values (Markus & Silver, 2008). This does not yet fulfill the requirements of Sutton & Staw (1995) to be considered an "affordances theory" and is still seen as a concept by most researchers (Evans et al., 2017). Evans et al. (2017) for example considered it a process concept that facilitates theoretical and empirical research.

The concept can also be reversed, such that the blockage of a passage can be considered an anti-affordance, meaning the prevention of interaction (Norman, 2013). For affordances to be effective, they must be discoverable, which can be supported by including signifiers in the design of an artifact. These signifiers indicate what actions are possible and how they should be executed and need to be perceived to function (Norman, 2013). The signifiers are realized by the material properties of an artifact and are addressing aspects that are intrinsic to the technology in terms of matter and form (Seidel et al., 2018).

According to Markus and Silver (2008), affordances describe the action possibilities allowed by material properties existent in information systems. The affordances emerge when these properties are interpreted as affording action possibilities within the context of their use. Affordances therefore are not the material property itself but a relationship. Whether an affordance exists depends upon the (material) properties of both the artifact and user (Norman, 2013)

As such, it is worthwhile to verify whether the identified properties of a design system are indeed affordances or material properties. One of the major challenges to use of the affordances concept relates to their identification and the process by which affordances can be separated conceptually from material properties, user characteristics/properties, and the environment in which they are used (Markus & Silver 2008).

The framework of affordances by Evans et al. (2017) defined three criteria with the goal to establish a commonly accepted definition of an affordance, as there are inconsistencies in its use. This paper will evaluate relevant affordances according to these criteria:

A. Confirm proposed affordance is neither the object nor a feature of the object

While features are static, affordances are dynamic, emerging from the relationship of the user, the object, and its features. Evans et al. (2017) mention, as an example, a smartphone's built-in camera as a feature enabling the affordances of recordability.

B. Confirm the proposed affordance is not an outcome

While affordances invite behaviors and outcomes, they are not the outcome itself. Evans et al. (2017) used the example that viewing profile pictures via social media is not an affordance but the outcome of visibility and searchability that social media affords.

C. Confirm the proposed affordance has variability

According to Evans et al. (2017), affordances have a range, which means they are not binary and possess unique features. This means that scales could be developed to address how individuals perceive the variability of specific affordances.

After an affordance is determined to meet the criteria as proposed by Evans et al. (2017), the question emerges of whether there are means of categorization for the respective affordances to verify that all available categories are addressed. The framework of affordances for VR and AR by Steffen et al. (2019) provides these means. According to Steffen et al. (2019), examining AR through the lens of what it affords is useful for three reasons. First, affordances help examine user goals. Second, affordances are relatively generalizable and constant across specific implementations. Third, affordances are particularly apt for describing AR technologies because they have been extensively applied to information technology (IT) artifacts.

The framework proposes a set of primary affordances, motivating virtual representation of content and thereby explaining the usage of VR and AR. According to Steffen et al. (2019), these primary affordances serve to:

- Diminish negative aspects of the physical world
- Enhance positive aspects of the physical world
- Recreate existing aspects of the physical world
- Create aspects that do not exist in the physical world

Steffen et al. (2019) defined sub-affordances without the claim to be complete. This paper aligns the identified affordances to these primary affordances and considers identified sub-affordances by Steffen et al. in its research. As knowledge about relevant affordances for the use of ARSs in collaboration remains limited (Steffen et al., 2019), we aim to contribute to a better understanding of this issue.

3. Research Method

To answer the question how ARS can facilitate organizational practices of co-located collaboration, we apply an open approach to research, for a deep understanding of processes from the user's perspective (King et al., 2018). Thereby, we focus on an asynchronous setting of collaboration and communication, where there seems to be a noticeable advantage compared to conventional collaboration means (Irlitti et al., 2017). Most scholarly works focus on synchronous collaboration scenarios regarding time as a dimension (Ens et al., 2019), which suggests that a qualitative explorative research approach based on interviews is a suitable strategy to develop insights in this research field (Yin, 2018). We address this by examining the affordances of an ARS for organizational practices of co-located collaboration.

Whilst many scholarly articles, like Seidel et al. (2013) aim to analyze information systems currently in use in terms of the affordances they provide, the intent of this article is to lay the foundation for a deliberately designed ARS with affordances. This enables a well-founded start into a design process, based on derived affordances.

We have taken a multi-stage approach to this exploration of affordances for asynchronous collaboration, as shown in Figure 1. Summarizing the detailed steps, this approach is divided into four stages: a) coding, b) paraphrasing c) consolidating, and d) verifying.

This open approach supports the assessment of real-life experiences in the context of interview partners active in construction (Miles, Huberman, & Saldaña, 2013). The interview partners are selected from an organization that is an industrial engineering and software company with a global operation scope that is active on many medium- and large-scale construction sites. Construction sites are chosen as suitable setting due to the complexity of collaboration centering around fixed locations.

Data was collected in 2019 and 2020 in the form of seven semi-structured interviews and four workshops, to create a basic understanding of collaboration in building management and construction sites. The interviewees and workshop participants were nominated by the organization based on their relevant experience and willingness to participate. Their roles were e.g., commissioning engineer, (chief) technical field assistant, personnel planner, and managers of site personal. Two persons were interviewed jointly.

Secondary data from documentation material such as reports helped the researchers to deepen their understanding of the context and to triangulate preliminary findings. To utilize the interviewees' knowledge effectively and ensure comparability, an interview guide allowed open responses within a predefined field of interest. The questions were directed toward the role and activities of the respondent, daily routine, current tools in use, stakeholders and collaboration, as well as ideas of how to improve knowledge sharing and collaboration in the future.

All interviews, held in German or English, were audio recorded and transcribed verbatim for analysis. Based on Gioia et al., (2013), an inductive category development was employed. The research question asked for affordances that facilitate organizational practices of co-located collaboration. Therefore, we identified in the interviews e.g., collaborative activities, issues, ideas, applied tools, and stakeholders as relevant for further analysis and coded the interviews accordingly. Using a formative check of relevance, the analysis was continued not based on all initial codes but reduced to three.

By (1) coding the results of the interviews and workshops according to Corbin and Strauss (1990) with the codes "Activity", "Problems", and "pot. Affordances", a set of potentially *relevant interview sections* were identified. These sections described some type of collaboration activity or problem within a construction site or indicated ideas about what an AR collaboration tool could afford. The *relevant interview sections* were reduced to those that were potentially applicable for an affordance provided by an ARS. Only activities that could be addressed within the technological boundaries of an ARS were pursued. For example, manual activities like moving objects or mechanical works were eliminated, as ARS can only be used to share information.

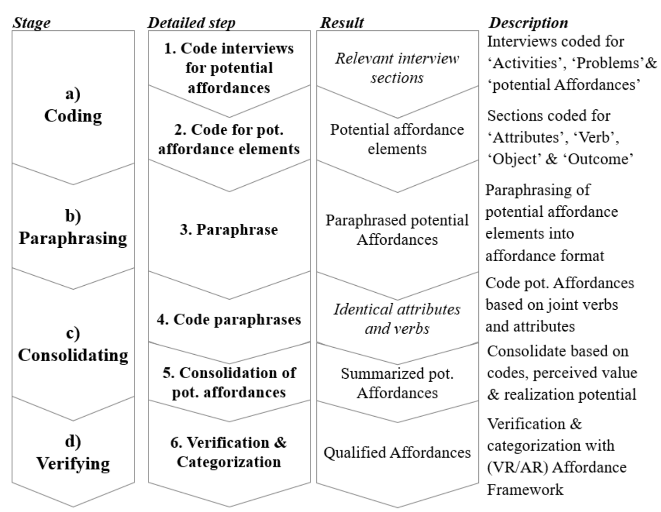

Figure 1. Research approach to derive qualified affordances from interviews.

The *potential affordance elements* of these sections were coded in a second step (2) with the codes "pot. Affordance Attribute", "pot. Affordance Verb", "pot. Affordance Object", and "pot. Affordance Goal/Outcome", which will be explained in the findings of this paper. In a subsequent step (3), the sections, including their elements, were paraphrased into *paraphrased potential affordances.*

These *paraphrased potential affordances* were (4) coded in a second cycle based on identical attributes and verbs, like 'information sharing'. In a fifth step (5), the affordances were consolidated based on the joint attributes and verbs of the codes from stage four, arriving at *summarized potential affordances*.

The *summarized potential affordances* were verified in a sixth step (6) with the conceptual framework of affordances by Evans et al. (2017), mapped to the framework of affordances for VR and AR by Steffen et al. (2019), and verified by the literature.

4. Findings

In this qualitative study, we seek to define which affordances enable the design of an ARS artifact to facilitate organizational practices of co-located collaboration in complex settings that happen at different times. Our study reveals six such qualified affordances and increases the understanding on the application possibilities of ARS, which we verify and illustrate.

To reduce the ambiguity and inconsistencies in how affordances are used (Evans et al., 2017), we claim there is a need of more detailed formulation principles for affordances. In line with the reasoning of Chandra et al. (2015) for the formulation of design principles, we propose this formulation of affordances:

[Artifact] allows [defined user] to [affordance attribute] [affordance Verb] [affordance object] in order to [action goal/outcome]

Leaving out one of the elements leads to a generalization, reducing the distinctness of the affordance. It also can be set to one specific value, detailing the scope of description.

In this case, the intent is to use <u>one</u> specific ARS as an artifact, providing a constant for *[Artifact]*, which is the *subject* of the evaluation. Also, the action goal is to collaborate more efficiently, effectively, and enjoyably, which we summarize with 'collaborate efficiently'. This provides a constant for the affordance element *[action goal/outcome]*. We identified and paraphrased 99 such *paraphrased potential affordances.*

Consolidating the affordances (step 5), based on the codes from step 4, shows that *pot. Affordance Verbs* (words that show an action) for a collaborative ARS center around 'sharing' and the *pot. Affordance Objects* (the thing/person that the action is done to) around 'information'. This is not surprising, as collaboration centers around the exchange of information to achieve common goals. Examples from later used quotes are: 'create digital protocols', 'get a status update' and 'explain modifications'.

This entails that all activities are based on the 'sharing' *(verb)* of 'information' *(object)*, specifying <u>one</u> *[affordance verb]* and <u>one</u> *[affordance object]*, which results in two more constants in this analysis. As the [defined user] are manifold, the key differentiator of the intended affordances for an ARS are therefore *[affordance attributes]*. Such *[affordance attributes]*, which are a quality, character, or characteristic, can also be adverbs, adverbial phrases, or instrumental cases. As a result, we claim that affordances must be specified by the affordance element *[affordance attributes]* for ARS to be actionable.

Our finding after coding, paraphrasing, consolidating, and verifying were the following six qualified affordances:

*1. The ARS artifact allows [defined user] **mobility in** information sharing in order to collaborate efficiently*

*2. The ARS artifact allows [defined user] **personalized** information sharing in order to collaborate efficiently*

*3. The ARS artifact allows [defined user] **persistency in** information sharing in order to collaborate efficiently*

*4. The ARS artifact allows [defined user] **richness of** information sharing in order to collaborate efficiently*

*5. The ARS artifact allows [defined user] information sharing **via external Knowledge Base System interfaces** in order to collaborate efficiently*

*6. The ARS artifact allows [defined user] information sharing **via push/pull notifications** in order to collaborate efficiently*

Attributes that failed to meet the three threshold criteria for affordances of Evans et al. (2017), like integrity of data, intuitiveness of use, workflows, information security, and collaboration, were not included in the overview. For example, we consider *intuitiveness of use* to be a feature that needs to be designed into the user interface and not an affordance.

The following section provides detailed explanations of the resulting affordances, including reference quotes from the interviews and the *paraphrased potential affordances*:

1. The ARS artifact allows [defined user] **mobility in information sharing** in order to collaborate efficiently

The artifact should enable mobility, e.g. by an intuitive way to including new locations at which information can be shared (that is without time-intensive scanning of the environment). A respective quote from the interviews read: "Walking over the construction site? This, I do daily. I would even say that most part of the day I'm outside" (Person A). Such quotes and others lead to the paraphrased potential affordance: *[Artifact] allows the Technical Field Assistant to create digital protocols in rough conditions directly onsite in order to avoid print out and later re-creating the protocol in digital format*.

In this context it is relevant to note that most affordances considered by themselves alone could be provided by other means, like a 2D protocol application on a mobile tablet. However, logging geo-referenced AR annotations into a standard 2D protocol that is created automatically with the push of a button, fulfills the goal to collaborate efficiently with ARS by making that information shareable.

2. The ARS artifact allows [defined user] **personalized information sharing** in order to collaborate efficiently

Due to the many stakeholders associated with a construction site, it is relevant to tailor communication exchange to a specific recipient or group of interested persons. For example, the electricians could collaborate between different shifts and keep relevant information among themselves, or a site-supervisor could address a specific issue that needs to be solved by a particular person or group of persons. "From the construction supervisor, I receive all the information that is relevant to me" (Person B). Such quotes and others lead to the paraphrased potential affordance: *[Artifact] allows the Construction Supervisor to [affordance attribute] get a status update of what happened in the other shift in order to understand what still needs to be done and what activities need to be continued.*

Personalization also enables confidentiality of information exchange, as not all information should or can be shared with all the stakeholders of a construction site. An ARS affording to share information in a confidential or restricted manner is therefore required. "It is possible that there is confidential information shared between project management and site staff that should not go to the customer" (Person B).

Personalization also avoids information overload. On large construction sites with many different companies and stakeholders, it is required that there is not too much information cluttering the site. "What if anybody can post digital information everywhere—isn't there an overflow of information when so many people work on a construction site?" (Person N). To illustrate the material properties of an artefact that enables such personalization, the artefact could employ AR-layers that overlay information on the real world only for those with access rights to the respective AR-layer.

3. The ARS artifact allows [defined user] **persistency in information sharing** in order to collaborate efficiently

The persistence of information on a dynamic construction site with potentially harsh environmental conditions is relevant to avoid loss of information and subsequent issues. "And often the customer says, 'last time you promised me this and that, and it is not documented anymore'" (Person B). Such quotes and others lead to the paraphrased potential affordance: *[Artifact] allows the Construction Supervisor to [affordance attribute] create a summary of protocols in order to have a consolidated daily report.*

Therefore, it is also possible to overcome space-time linearity, as it becomes possible to view places as they previously existed via AR pictures, persistently annotated at the respective locations. Due to the creation process on construction sites, this view of the past (documentation) could improve collaboration. The timestamp that is automatically set when creating digital (AR) content is one simple example that reduces ambiguity in collaboration.

4. The ARS artifact allows [defined user] **richness of information sharing** in order to collaborate efficiently

Although text protocols are widely used, documentation of specific issues is done with pictures. Affording the exchange of "rich" information, e.g., pictures, videos, or holograms, could improve communication for collaboration. "Pictures are very important to better explain modifications in customer discussions. We use drawings, diagrams, and anything else there is…" (Person B). Such quotes and others lead to the paraphrased potential affordance: *[Artifact] allows the Service Commissioning Engineer to explain modifications etc. via drawings, diagrams etc. in order to efficiently communicate with the customer.*

This would also enable depictions of the nonexistent, the possibility to include three-dimensional holograms, virtual pictures, virtual videos, to facilitate communication. "You can bring the digital twin of your product to the construction site" (Person M).

5. The ARS artifact allows [defined user] **information sharing via external knowledge base system interfaces** in order to collaborate efficiently

Different yet similar is the affordance to access other knowledge base systems. Here, the differentiator of the affordance verb "information sharing" is achieved by the (instrumental) adverbial phrase, the interface to other knowledge base systems. These can be enterprise resource planning systems (known as ERP) or a project management software like Teamwork Projects, Jira, etc. Construction projects are subject to constant change regarding their engineering and design due to aspects like change requests. Moreover, the update of information should always be possible. This is done via the product change management (PCM) system. Using AR to have one single interface to all required knowledge base systems, also geo-referencing relevant information to make it intuitively accessible at relevant locations, could enable several action goals/outcomes. The worker could keep the systems up to date with new entries as well as learn about past entries. Person B, answering the question about possible improvements, noted "it would be great if I can receive updates on all info that are relevant to me, what has been changed, what was modified…" (Person B). Such quotes and others lead to the paraphrased potential affordance: *[Artifact] allows the Service Commissioning Engineer to access WINCC via VNC Viewer [affordance attribute] in order to get relevant data for starting the gas turbine.*

6. The ARS artifact allows [defined user] **information sharing via push/pull notifications** in order to collaborate efficiently

In this sixth affordance, the (instrumental) adverbial phrase also differentiates it from the other information sharing possibilities. Sending and receiving visual notifications is a preferred method of collaboration (Cidota et al., 2016). On a construction site, for example, information about issues and problems between the supervisors and the customer is done daily. Currently, the process is complicated with several media conversions but could be facilitated by e.g., creating a push notification whenever a respective AR-item, representing a safety hazard, is placed somewhere. Person E described a current process: "You first create a word file, then a PDF which is digitally signed, to confirm who wrote this. And then it is forwarded to the customer, and he must answer as well via PDF when he solved the problem" (Person E). Such quotes and others lead to the paraphrased potential affordance: *[Artifact] allows Commission Engineer to [affordance attribute] digitally sign & send Site Observation Notes in order to communicate issues to the customer.*

5. Discussion

We identify a comprehensive set of six qualified affordances for an ARS to facilitate organizational practices of co-located collaboration in complex settings. This is likely relevant for collaboration in other scenarios that have similar conditions. These conditions are (a) many involved stakeholders, (b) relevant local context, (c) constant changes of the environment, (d) a complex environment, and (e) the need to collaborate over an extended period. This could be for example, the preparation and execution of large events, the management of cities, defense-, and policing activities, maintenance services and shop floor activities.

Asynchronous AR applications for collaboration have not yet been comprehensively addressed in research (de Belen et al., 2019), where scholarly works focus mainly on synchronous collaboration (Ens et al., 2019). To relate the identified affordances to existing literature, some examples shall be described based on such selective findings to better illustrate the benefit of a comprehensive set of affordances, compared to describing them individually.

Mobility in information sharing (affordance no. 1), for example, is critical to collaborative work (Luff & Heath, 1998). Paper documents, which are regarded as an outdated artifact, can be substituted for new technologies that enhance support for the documentation, evaluation, and management of work sites (Luff & Heath, 1998). However, this is not a given, as described by Luff & Heath (1998) in their work wherein a mobile application used to substitute paper documents ultimately hindered user mobility. It is required that ways in which users interact with colleagues on site is evaluated alongside how they use current and new artifacts to provide the corresponding affordances. An ARS that is not only enabling mobility, but also has e.g., the capacity to convey information cues, also called media richness (Daft et al., 1987), can bring additional benefit. While sensory richness is a disadvantage of AR compared to the physical world (Steffen et al., 2019), *richness in information sharing* (no. 4) should facilitate collaboration. A problem on a construction site can, for example, be demonstrated and discussed with a "digital twin"/hologram of the respective construction instead of using a two-dimensional drawing to try solving a three-dimensional problem.

Easy access to localized information should facilitate co-located collaboration. This enables the artifact also to be 'community-integrated' to a greater degree (Maceachren, 2000). Without broad adoption in the respective work environment, localized information sharing will likely be unable to fulfil its potential. To increase adoption, different modes of collaboration must be allowed, such as informal meetings, wherein low interactivity might be sufficient (Slater, Mel ; Wilbur 1997). The ability to bring new objects to the virtual space and affording their *persistency* allows for such infrequent *information sharing* and across-time collaboration (no. 3), building up a community knowledge base.

Another reason to support the adoption of ARSs is the value that localized knowledge provides to the user. This can be supported by a central authority (Maceachren, 2000), which can promote and facilitate participation and add relevant localized information updates, e.g., indicating safety zones and regulations at specific locations. These AR information updates might depend on algorithms based on data, like the air quality or best route to safety (White et al., 2019). Such data can be provided via *external knowledge base systems*, and an artifact should afford *information sharing via* such systems (no. 5), as elaborated previously. In particular, safety *information* should be *shared via push/pull notifications* (no. 6), alarming the user immediately. Notifications can also organize and structure collaborations and substitute letters and phone calls. Cidota et al. (2016) analyzed for specific settings in which users preferred visual notifications over audio and no notifications. They analyzed this however in an artificial setting, without mobility, persistency or complex surroundings.

"Ambient computing," which considers, for example, the current position, surrounding, time of day, date, etc., can provide the context for *personalized information sharing* (no. 2) (Schubert & Koch, 2002). Personalization is also relevant for confidentiality, trust, and privacy in collaboration (Bertino et al., 2006). Both can make content more valuable and lead to increased adoption. They are further a key benefit of ARS compared to conventional means of communication, such as signs and post-its.

To evaluate the affordances on their potential contribution to adoption of the intended artifact, aligning them to the framework of affordances for VR and AR (Steffen et al., 2019) could give an indication. The affordances identified in this research can be allocated, with some interpretation and ambiguity, to the aforementioned primary affordances of Steffen et al. (2019). They could therefore be considered "sub-affordances". Using the "sub-affordances" by Steffen et al. (2019) as an example, we argue however that e.g. "overcoming space-time linearity" with an ARS is an outcome and not the affordance. The respective affordance would be richness in information sharing, as the visualization of holographic content could be used to display "objects or environments that existed in the past or have not yet come into existence" (Steffen et al., 2019). Mapping the identified affordances around information sharing to the "primary affordances" of Steffen et al. (2019) is, however, not intuitive and can be interpreted differently by different researchers, thereby limiting the applicability of the model. For example, affording *persistency in information sharing* (no. 3) could be interpreted as "diminishing the negative aspects of the physical world," as digital information is not prone to adverse weather conditions like physical notes would be. It could, however, also be interpreted as "[enhancing] positive aspects of the physical world," as the information remains available as long as required.

Considering affordances, a hierarchy could be required. Some affordances are more complex, with the requirement for further levels or attributes, such as the concepts of communication and collaboration, which require knowledge sharing (van Leeuwen & Fridqvist, 2006). Steffen et al. (2019) define sub-affordances in their framework, such as 'collaboration', but do not continue towards an extended hierarchy, for example, by highlighting lower-level affordances required of an AR system to enable collaboration. Collaboration can even be argued to be an outcome. We claim that a hierarchy of affordances will likely be required to move from an affordance concept to an affordance theory by increasing the predictability of applying it as research lens.

It is important to note that affordances emerge and evolve with changing technological and organizational features (Zammuto et al., 2007). Continuing innovations will create additional options for affordances and a need to constantly assess and improve the understanding of ARSs as well as the functional affordances potentially originating from their interpretation and use (Seidel et al., 2013). Specific affordances, like richness in information sharing that is based on the media richness theory, can be challenged. Regarding the media richness theory, some researchers have produced results consistent with theory (Kraut et al., 1994). Others found in their research that users adapted their work practices to available media with no impact on performance (Grudin & Poltrock, 2012). We use richness of information in a way that it summarizes the possibilities to virtually collaborate via pictures, audio, video, holograms etc., which might be interpreted differently by other researchers.

6. Conclusion & Outlook

Based on a qualitative study from a construction site, this paper proposed six qualified affordances to use ARSs for organizational practices of co-located collaboration. Therefore, a method was applied which explained how affordances can be derived, interpreted, and verified from interviews, offering the possibility to transfer the approach to other settings. To reduce uncertainty and ambiguity, a proposal detailing how qualified affordances can be formulated was presented.

Due to the interpretive nature of this research, it cannot be claimed that the phenomenon of an ARS for digital enterprises has been explored exhaustively. As with any research in a specific empirical field, we need to acknowledge that results, as well as the application to the described approach, may be interpreted differently in different settings. The generalizability of the findings may be limited due to the selection of interviewees.

However, care has been taken to relate the findings to existent theories.

The procedures applied have been described and documented in detail to ensure a clear chain of evidence. While available resources limited the analysis to one content coder, multiple viewpoints and interpretations are considered. The findings of the analysis are corroborated by involving more than one researcher in performing and reviewing the interpretation and analysis, allowing for consensus-building discussions. Through these measures, we believe enough evidence from multiple participants and different sources was collected to increase confidence in the conclusions drawn from the analysis.

The present findings have several managerial implications. First, it becomes apparent that an ARS can combine several affordances that facilitate co-located collaboration. It might therefore be worthwhile piloting within organizational practices of collaboration. Second, we illustrate the process to derive relevant affordances from interviews, which enables a well-founded approach to the design of a new artifact. Third, such an artifact is likely generic enough to consider facilitation of collaboration in other relevant scenarios that have similar conditions as described before.

Considering the COVID pandemic, it could be interesting to explore related changes in adoption behavior, as asynchronous ways of collaboration need to be explored more often, e.g., due to attendance constraints. There might also be additional or alternative affordances to be identified when focusing on scenarios other than the construction environment as a starting point for the use of an ARS.

It will be necessary to investigate further how affordances can be deliberately considered in the design of an ARS. It is required in a further step to identify specific material properties that will allow such affordances to facilitate information sharing and collaboration. Evans et al. (2017) state that there is no singular way to operationalize or identify affordances. We claim that only a detailed description of affordances, i.e., in the way that we proposed, can provide operational clarity in using affordances as a basis for design principles. The creation of these qualified affordances should follow a clear process to avoid deriving misleading or unclear affordances. This could contribute to the creation of an affordance theory. Our findings further elucidate the possibilities that ARSs offer and enable the purposeful design of ARSs for organizational practices of co-located collaboration.

12. References

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