applied sciences

Review

XR Technology Deployment in Value Creation

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Featured Application: Enabling business-process and industry-agnostic identification of XR technology deployment use cases through a taxonomy of value-adding deployment purposes.

Abstract: With increasing computing power and data transmission performance of information technologies, the application scenarios for Extended Reality (XR) technologies in industries are growing. Despite the ongoing scientific investigation of industrial XR applications for over 25 years, these technologies are still considered emerging. Within this paper, we present an industry- and business-process agnostic approach for classifying the deployment purposes of XR technologies in value creation. We identified two major research streams regarding the role of XR technologies in value creation: (1) the research initiatives focusing on business-process-specific use case analysis and (2) industry-oriented research reviews. This results in limited identification of suitable application scenarios for new use cases and restricted transferability of the existing use case to future deployments. First, we provide a qualitative analysis of the current research streams. Then, in the second step, by abstracting the XR technology from the existing business processes and the industry-specific context, the generic purposes for XR technologies in value creation are identified and defined. The summary of these deployment purposes results in a taxonomy that enables the identification and transfer of potential use cases of XR technologies in value creation.

Keywords: value creation; extended reality; virtual reality; augmented reality; mixed reality; technology deployment

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Citation: Krodel, T.; Schott, V.; Ovtcharova, J. XR Technology Deployment in Value Creation. *Appl. Sci.* **2023**, *13*, 5048. https://doi.org/10.3390/app13085048

Academic Editor: Shana Smith

Received: 14 March 2023
Revised: 15 April 2023
Accepted: 16 April 2023
Published: 18 April 2023

1. Introduction

For decades, various fields of research such as information technology, psychology, communication, engineering, and economics have explored the relevance of virtual worlds for their respective domains [1–5]. As a result, the umbrella term Extended Reality (XR) emerged, containing all forms of combinations of real and virtual surroundings and encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [6,7]. All forms of XR that frequently appear in literature share the following understanding [8–12]:

- AR is created by overlaying the user's real environment with virtual objects.
- MR is a coherent interaction between real and virtual users and objects.
- VR is a computer-generated simulation of a situation where the user can only interact with virtual objects in real time.

Due to the possibility of transferring larger amounts of data in shorter times, the miniaturization of computing power, and the widespread availability of devices for displaying virtual content, XR technologies are becoming increasingly relevant for companies [13]. In addition to numerous scientific studies on the concrete use cases of companies in various industries and different business areas such as production, development, employee training, or marketing, the increasing relevance of these technologies can also be observed on the consumer side [8]. While the research field of XR has been investigated for more than 55 years [14] and systematic investigations on the applications of XR in the business context have been performed for more than 25 years [15], the field of XR technologies is still considered emerging [6,16]. The primary reasons for the low adoption in the business context are technological complexity, hardware costs, appropriate user experience design, and the requirement for more hardware maturity for the underlying requirements [17,18].

There is a contradiction between the relevance of XR technologies for business and their actual adoption in use cases. Technology has no value in a business context, as the value can only be realized through a business model [19]. To embed technology in a business model, it can be deployed in value creation as a core resource or for the execution of business processes [20]. Current research deals with two types of approaches. On the one hand, research reviews investigate the distribution of technologies in different business processes across various industries (e.g., [7]). Implementation reports examine concrete technology setups for concrete business processes (e.g., [21]). While the reviews provide an understanding of existing use case distribution, implementation prerequisites, possible obstacles, and success factors, identifying new use cases for value creation is limited [22]. On the other side, implementation reports are strongly connected to the underlying context and structure of value creation, limiting the transferability of the implementation reports [23]. The research question is, therefore, for what axiomatic purposes can XR technologies be used in value creation, independent of industry and the context of the underlying value creation, in order to initiate a deployment?

A taxonomy will be derived to provide a solution to this research question. Taxonomies are suitable for developing a theoretical basis from various research streams [24]. By applying the methodology according to Nickerson et al., deployment purposes are derived in an iterative procedure suitable for the domain of information systems (IS) [25]. The foundation for achieving this is a selected database of reviews and implementation reports with a varying focus on industry, technology setup, and the value creation process acquired with the structure of a value chain, according to Porter [26]. The XR deployment purposes aim to enable the identification of use cases in existing value creations and to prepare the implementation of the XR technology use cases.

2. Theoretical Foundations and Background

2.1. Extended Reality Technologies

XR is an extension of the physical reality generated by technologies and therefore based on technologies to computer-generate immersive experiences [7,9]. XR technologies consist of hardware systems that create a feeling of immersion for users [27]. This requires hardware input units for tracking users and the environment, creating output for addressing the users' senses, enabling the interaction between users and XR, and running the corresponding software [28–30]. Second, XR technologies contain tools and methods for designing and implementing software systems in the underlying context [31]. Especially in the context of XR technologies, the evolution speed and extensive feedback integration throughout the solution lifecycle require agile software development methods [32]. A core software technology for XR is independent development environments (IDEs). IDEs provide a set of development concepts, techniques, computer-aided tools, and graphical user interfaces (GUI) to reduce the time and effort of the development process, functional composition, and integration of solutions [33,34]. Software development kits (SDKs) are compilations of tools and software technology modules to ease the creation of software solutions. Common SDKs for mobile devices are ARKit from Apple for iOS devices and ARCore from Google for Android devices [35]. Third, XR technologies for content creation contain tools and methods to create user-centric designs for XR experiences, prioritizing human behavior, capabilities, and needs [36]. Furthermore, they have tools and methods to prepare the three-dimensional content to be displayed in XR scenes by creating and assigning properties such as geometry, materials, textures, animations, colliders, and physical relations to relevant data [37].

2.2. Value Creation

Value in the underlying industrial context is created in a value chain, defined as a company's "[...] collection of activities that are performed to design, produce, market, deliver, and support its product [...]" [26]. The value creation core activities of logistics, operations, marketing and sales, services, and support activities are defined generically to be applicable in different industries and contain technology to a certain extent [26]. Value creation can be regarded as converting technological input into economic output through the structure of a company's value chain, value offering, and value distribution within a value network [38]. Furthermore, value creation means the subsequential creation of use value and the realization of exchange value between organizations [39]. An organization's value creation depends on the structure of its value chain as well as its resources and capabilities [40]. It is related to all factors of the delivery of an offering to potential customers, regardless of whether the customer is another value creation organization or an end-customer [41]. Next to the resources and activities of a company, partnerships are additionally considered an integral part of the value creation of a company [42]. With the set, the structure, and the governance of value creation activities, the exploitation of new business opportunities is enabled [43,44]. However, the operation of value creation requires an orchestration of processes and resources to ensure financial viability to distribute the created value [20]. Overall, the relationship between technological innovation and a company's value creation performance correlates through monetizing technology potential in productivity and customer engagement [45].

2.3. Existing Research on XR Technology Deployment in Value Creation

2.3.1. Research Strategy

This paper aims to develop a taxonomy for the use of XR technologies in value creation. The term XR is utilized inconsistently in current research, and the deployment in value creation varies in the scope of the technology's comprehensiveness [46]. Therefore, the research strategy to comprehend the existing research landscape differentiates the term XR into VR, AR, and MR. These terms have already been analyzed in different research projects through taxonomies from a general perspective [47,48], for educational use cases [49], and from a technological perspective [50]. Secondly, the understanding of the term value creation within the context of XR technologies must be shaped. To provide a foundation for taxonomy development, the research initiatives to be included are to be identified with Porter's value creation activities, which are as follows [26]:

- Logistics (in- and out-bound)
- Operations
- Marketing and sales
- Services
- Support activities (i.e., firm infrastructure, human resources, technology development, and procurement)

This research structure intends to provide a cross-section of existing research initiatives to reveal the generic purposes of XR technology deployment in value creation. Numerous research approaches and reviews for XR technologies for value creation have already provided insights into their application fields, with varying degrees of focus. General reviews without focusing on one of the mentioned value creation activities provide insights into adoption requirements [6], cross-industry use cases [51], industry-specific value chains [52], or the distribution of applications in the development, manufacturing, commissioning, maintenance, and decommissioning of products [53].

Next, it is to be depicted how the XR technology deployment in value creation is investigated within the scope of each value-creation activity. In logistics, XR technologies can be applied in various use case scenarios, especially in the intra-logistics areas due to their requirements for specific hardware [16]. In operations, XR technologies are examined in relation to manufacturing, both for the fundamental challenges of their use [30] and their diffusion in specific application scenarios such as product design [54], assembly tasks [29], and manufacturing systems [55]. In the context of operations, it is further investigated what value is added through the XR deployment [56]. Furthermore, XR systems in operations are investigated for their capability to link them to other value creation activities, such as the technology development [29]. Concrete investigations on use case implementations in operations show technology-focused tools and systems with the underlying process integrations [23]. From a marketing and sales perspective, XR deployment research focuses on technology distribution [57] as well as on approaches for understanding [5] or enhancing the customer experience during the purchasing process [58]. The support activities of value creation are investigated in terms of how XR technologies can optimize the process of technology development, how the development of the firm's infrastructure can be enhanced [59], and how the human resource activities of training [60,61], and the organization of collaboration [62,63] can be improved. The use of XR technologies in purchasing is not yet extensive since the application scenarios are covered by XR technology in the sales activities of the upstream value chain [64].

The following section analyzes the representative research initiatives for the value-creation activities that provide characteristics for the purpose of their deployment, differentiated in their research character by research reviews and implementation reports.

2.3.2. Research Reviews

Depending on the performance of the XR technology setup, the XR system can provide varying experiences in terms of immersion and interaction [1,4,28]. Therefore, the focus of research reviews varies from individual technology manifestations (e.g., a particular configuration of a non-immersive VR setup) to an entire XR technology group (i.e., VR, MR, or AR) to a holistic view of XR. Secondly, the review shows different levels of comprehensiveness regarding use case scenarios for value creation. As mentioned, value creation links to core and support activities and their organization and execution to create added business value. Reviews about the deployment of XR technologies can therefore be focused on the overall value creation of an industry [30], for complementing a value creation activity itself [16] or improving the execution of an activity [29]. Table 1 lists selected reviews on XR distribution in value creation with different levels of comprehensiveness in XR technologies and use cases.

2.3.3. Implementation Reports

The second research stream focuses on the detailed description of implementation projects. The research field suggests concrete initiatives where XR technologies are implemented. Same as in the research reviews, the implementation reports show different focuses in terms of technology comprehensiveness as well as use case comprehensiveness in the context of value creation. While the reviews showed a more comprehensive perspective, the implementation reports suggest concrete technology system setups [5,23] or dedicated approaches for operating XR technologies. Also, the comprehensiveness of the use case is characterized by a concrete activity in the value creation, such as development [59], manufacturing [23], sales [58], or the organization of the activity performance [62]. Table 2 summarizes selected implementation reports.

Table 1. Research reviews on XR technologies in value creation.

Source	Technology Comprehensiveness	Use Case Comprehensiveness	Summary
[6]	XR	Generic	Generic prerequisites for adopting XR technologies
[57]	VR and AR	Retail	Identification of fragmented research landscape and future research agenda
[30]	AR	Manufacturing	Technological, organizational, and environmental challenges for AR deployment in manufacturing
[52]	VR	Tourism	Significance and potentials of VR for the tourism value chain
[54]	VR	Manufacturing	Relevance of VR for product design and challenges for deployment and suggestion of an implementation process
[55]	XR	Industrial	Key technologies and applications of XR in industrial system engineering
[56]	AR	Industrial	Benefits, challenges, development, industrial distribution, and purposes of AR in industry
[60]	XR	Construction safety	Synthesizing current research characteristics, existing use cases and trends for future development
[65]	AR	Design and manufacturing	Presentation of relevant AR applications for manufacturing and future importance of AR
[51]	AR	Generic	Distribution of AR technology characteristics and potential use case scenarios across industries
[63]	XR	Collaboration	Training, design collaboration and remote collaboration as major XR use cases in the field of collaboration
[29]	AR	Assembly tasks	Comprehensive summary of AR assembly system setup as well as training, simulation, and planning as application fields
[16]	AR	Inhouse logistics	Long-list of potential use case scenarios for AR in inhouse logistics

Table 2. Implementation reports on XR Technologies in value creation.

Source	Technology Comprehensiveness	Use Case Comprehensiveness	Summary
[5]	CAVE VR	Sales-oriented customer analysis	VR-based study to analyze customer behavior
[66]	VR configuration	Design review process	System suggestion for deploying VR in design review process
[59]	VR model creation	Plant design review	Rule-based system to automatically transfer CAD data to VR for design reviews
[23]	Web VR	Manufacturing task planning	Web VR-based tool for executing planning of task execution in a dynamic context
[13]	AR content creation	Employee guidance in manufacturing	Methodology for converting manuals to AR content in production environment
[67]	AR application	Maintenance task performance	Concept for collaborative assistance in maintenance processes through AR
[62]	VR engine enhancement	Generic collaboration scenario	Method for enabling synchronization in a segregated immersive collaboration environment
[61]	VR setup	Generic learning scenario	Setup for VR-based e-learning with multiple users
[58]	XR	Point-of-sales modelling	Framework for enhancing customer touchpoints through VR and AR
[21]	Adaptive AR system	Assistance in maintenance task execution	System for AR-assisted support in executing maintenance tasks with adaption to user requirements
[68]	VR system	Reviewing product design	VR-based system for collaborative product design review
[69]	AR paradigms	Customer engagement	Guidelines for AR deployment with the focus on customer engagement

The reviews are designed to record and aggregate individual research initiatives and provide an overview of a defined target area. The review-based XR research provides an ex-post overview of the deployment [60]. Most reviews aggregate the major challenges [30], success criteria, and future research agendas [57]. The application of the results for practical deployment is restricted due to the required applicability of the findings for future initiatives. The research stream of implementation reports shows detailed approaches to the execution of XR technology deployment projects [68] but is limited to specific XR technology setups [59] in specific business processes [23]. The technology-focused reports that suggest concrete setups and technological solutions to concrete activities within the value creation lack transferability due to both specifications in technological and use case comprehensiveness.

3. Methodical Approach

Drawing back on the various technological and value creation-related comprehensiveness levels, the listed reviews and implementation reports are utilized as a foundation and database for the methodology. To enable the identification of new use cases and the transfer of XR technologies for new use cases, a taxonomy of purposes for XR technologies in value creation will be derived. According to Nicherson et al. [25] and Oberländer et al. [70], a proven and commonly established approach is taxonomy development. This has been applied to various topics in information systems [71], digitally enhanced value creation [72], and in the context of XR technologies [50]. With the scope of combining practical insights from use case-oriented implementation reports with theoretical review-based findings, the taxonomy approach seems suitable [73]. The procedure is illustrated in Figure 1.

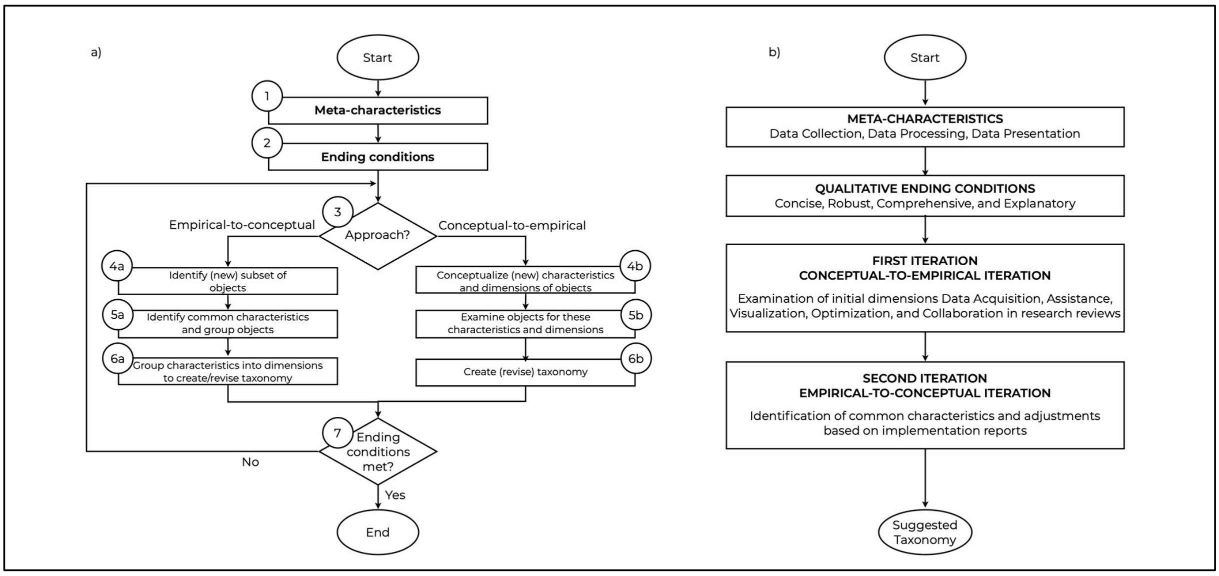

Figure 1. (**a**) Taxonomy development method according to Nickerson et al. [25] (p. 10), and (**b**) Applied procedure to derive an XR deployment purpose taxonomy.

The approach for deriving a taxonomy is iterative [25]. At first, the given domain's meta-characteristics and the end conditions for the iteration must be defined. The meta-characteristics can be interpreted either based on the technological characteristics or the characteristics of the value creation use case. Intending to propose a business process-independent taxonomy, the meta-characteristics are to be defined based on the common technology characteristics of XR system configurations. Based on this, the conceptualization of the initial taxonomy is to be performed. With the iterative approach, the ending conditions are to be considered. They can be either qualitative or quantitative; for the underlying qualitative approach, the focus should be on the taxonomy to be concise, robust, comprehensive, and explanatory [25]. Figure 2 shows the meta-characteristics of the taxonomy development approach.

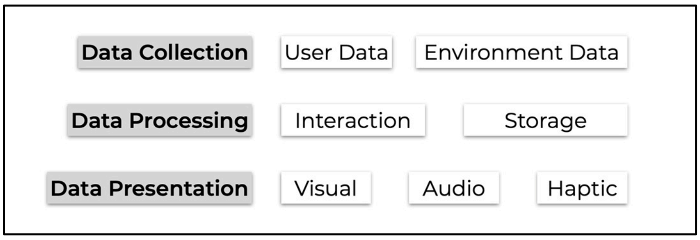

Figure 2. Meta-characteristics for the taxonomy [27–30].

An activity in value creation is a business process consisting of tasks to produce a business outcome [74]. To understand the purposes of XR technologies being used in value creation, the fundamental tasks they can fulfill should be considered for the initiation. These can be derived from the components of the XR technology setup. Thus, each XR technology setup has a data collection unit, a data processing unit, and a data presentation unit [27–30]. The data collection is achieved through the input units of sensors, which capture the environment, user, and position of the user in the environment [28,30]. The data processing simulates the user's interaction with the environment and stores relevant data collected from the system and presented to the user [28]. Data presentation is realized through output units that visualize content for the user and can be enhanced with audio and haptic signals to increase immersion [75–77]. The data collection capability of XR technologies can be deployed to acquire relevant data as an outcome for the business context. The data presentation capability of XR technologies can be embedded in the physical process performance, and thus, the execution of the activities can be assisted. Additionally, the data presentation capability can deliver a detailed visual impression of the performance of tasks in value creation. By iteratively collecting, processing, and presenting data in the context of value creation, the overall task execution can be optimized for efficiency. Additionally, the data collection, processing, and presentation can be deployed to organize the collaboration between different users across spatial and temporal boundaries.

With the wide variety of comprehensiveness in XR technologies and value creation use cases, an empirical-to-conceptual approach consists of a certain complexity, complicating the approach of deriving value-creating purposes independent from the underlying context. With relevant research reviews already providing an overview of the research landscape, the first iteration should be performed with a conceptual-to-empirical approach. In this approach, the initial characteristics are defined independently of technological and value creation properties based on the literature, research reviews, and their abstraction. A generic definition of the characteristics for deployment purposes follows this. In the second iteration, the defined purposes are validated empirically rather than conceptually. The implementation reports are used to validate the initially defined deployment purposes and identify relevant characteristics for extending the dimensions of the deployment purposes.

4. Deployment Purposes of XR Technologies in Value Creation

4.1. Data Acquisition

XR technologies have the capability to capture data with either their tracking system or the input devices of the selected setup [28–30]. The two major data types can be acquired from the user or the environment.

Furthermore, the content can be designed accordingly to enable the user to enter the required data or to acquire data by interacting with the solution or the provided content [78]. Bigné et al. executed a VR-based analysis, observing the users in a simulated environment with observation and tracking systems to acquire consumer behavior data and identify the buying action triggers [5]. Within the context of Digital Twin (DT) data in a production environment, the input unit of an AR solution supports monitoring the

DT's physical element [79]. Further application scenarios of AR technologies suggest their deployment for monitoring processes through data recording, documentation of process execution or damages, object recognition, barcode and QR code scanning, object measurement, and automated inventory recording [16]. AR technologies are additionally deployed to monitor the workers' performance and count orders to be loaded on trucks in the shipping process [80]. It can be subsidized that XR technologies that generate both AR and VR are utilized to acquire relevant data for value creation.

Data acquisition in the context of XR technologies can be understood as collecting data from an individual or an ecosystem relevant to value creation. This includes acquiring environmental data, data from process flows, or data from the user itself. The collection can be either through hardware technologies, i.e., tracking systems, or through the user experience design, which enables users to provide data to generate value-adding information for value creation.

4.2. Assistance

XR technologies can be deployed for the user in a process flow or the user's perception of a technology-enhanced experience [8]. XR technology deployment can furthermore be classified in perceptual presence, behavioral interactivity, and technology embodiment from the customer perspective to distinguish their capability to assist (i.e., support or enhance) the core customer experience [8].

A significant field of XR technology deployment for assistance in value creation appears in the form of AR to support industrial processes. Especially in terms of assistance, the deployment of XR technologies as AR experiences for industrial applications has a focus on guiding the performance of manual activities, mostly independent from the industrial sector [56]. Wang et al. reviewed the scientific literature on existing use cases in AR-based assembly systems that guide the user and highlight the relevance of context awareness and the interactivity of AR solutions for assembly guidance to add value by assisting the user [29]. Li et al. executed an analysis to provide a classification of VR and AR applications in construction safety that add value through assistance for safety inspections and building assessments by reducing users' effort to access required information through the inspection process [60]. Siew et al. introduced a system framework that enables AR for adaptive support assistance, which consists of a specific AR technology setup with a haptic tracking methodology and demonstrates the viability of a maintenance system based on AR [21]. The value added is generated through the scenario by providing feedback to the user for adaptive support and assisting with the manual process tasks, improving execution speed and error avoidance. Gatullo et al. introduced a methodology to optimize the text documentation of attachments to translate them into two-dimensional graphic symbols and map them with AR's help to support humans during maintenance work [13]. The methodology focuses on the technology aspect of content creation and enables the automated conversion of existing analog manuals into AR content. By providing the user with the manual content through AR, the user is assisted with the manual process execution. Furthermore, the framework offers a content-authoring concept to assist in the administration of the provided solution [13].

The purpose of assistance through XR technologies in value creation can be aggregated to provide value-relevant data and information to the user. In this context, XR technologies are deployed so that the user can perform his manual process activities by providing data and performing his physical work process. Thus, the focus is on the empowerment of the execution, which distinguishes this category from visualization.

4.3. Visualization

Visualization is central to any XR technology composition [77]. Thus, because of these technologies, there are countless possibilities for depicting details and designs in three dimensions for the users. Of course, as in the assistance already described, showing content is a major component of this deployment purpose. The focus within assistance is rather on adding information to a manual flow and supporting the user, with less emphasis on graphical fidelity. The value-creating aspect of visualizing content in value creation is virtually presenting the future appearance of a physical state or product in a highly detailed manner to enable and improve the decision-making process [54].

In terms of visualization, XR technologies that generate AR overlay virtual content within the real world [78,81]. Based on this understanding, Yim and Park analyze AR-based product presentations and nominate a potential utilization of AR for virtual try-ons [82]. The visualization aspect is the superimposing of a computer-generated representation of products on a user's body reflection through an image. The value-generating benefit results from the superiority of the simultaneous visual representation of user and product over the traditional 2D product representation on the web [82]. Heller et al. list 26 different use cases across industries that apply AR to provide the user with a visual impression by simulating the appearance of a physical product in reality [83]. The utilization of XR technologies for VR is a mature tool for visualization in product design and manufacturing, especially for detailed previewing of a future physical state [54]. Choi et al. further reviewed VR applications in the manufacturing industries [84]. They pointed out that the visualization aspect of VR adds value by intuitively depicting a situation to convey relevant information with the right details to the user [84]. Especially in the context of design reviews, concepts exist that provide realistic prototypes and product impressions while reinforcing the relevance of VR visualization for improved decision-making [66].

XR technology deployment for the purpose of visualization is the use of XR technologies for the immersive, interactive, and intelligent presentation of content relevant to value creation prepared for a target group relevant to value creation. This primarily includes the three-dimensional presentation of content to the user. Visualization with the help of XR technologies enables the user to perceive details through the three-dimensional depiction as well as through interaction, which would not be possible without XR technologies. Therefore, the value-adding component enables early-stage decisions, either on a product design or on the buying action of an end-customer itself.

4.4. Optimization

XR technologies offer possibilities to optimize value creation by enhancing existing activities or simulating additions in future activities [5,36]. This leads to improvements in value creation by reducing the effort required to physically create situations to determine or convey knowledge or by adding a virtual component to a physical situation.

Therefore, XR technologies appear in various studies focusing on optimization, where XR technologies are deployed along the value creation to achieve improvements. Pantano and Servidio demonstrate how the point-of-sales can be optimized through XR technologies by enhancing the in-shop experience for a potential user group, i.e., retail customers [58]. Besides, XR technologies can be deployed for optimized consumer engagement through increasing affordance, increasing sociability, and targeted offering of artifacts [69]. Damiani et al. identified the internal and external improvement of value creation through the new interaction possibilities given by XR technologies, realizing improvements in the process of conveying knowledge to a decision-maker [55]. In terms of interaction, XR technologies can optimize existing value creations by providing missing elements for the accessibility, interaction, and simulation of a DT [85]. XR technologies furthermore provide possibilities to execute preliminary process simulations, unleashing potential within value through the avoidance of creating real scenarios and accelerating the overall execution [10]. Another optimization use case is the simulation of the spatial relationship of components through a user experience to optimize the training of the manual skills of the users [86]. Furthermore, XR technology can optimize the product assembly planning processes, which is enabled by giving a virtual layout of a production setup and thus improving the planning process [65]. Additionally, the combination of three-dimensional depiction and the high level of interactions possible in a virtual environment enables the efficient utilization of resources and therefore provides an optimization within the dynamic scheduling of tasks [23]. Additionally, Li et al. mention the relevance of VR in the construction safety domain, as it can be utilized for preliminary hazard identification and safety training and education [60]. The avoidance of creating the physical situation through material-intensive construction and the early-stage recognition of required changes before the physical setup provide an overall optimization to value creation in the construction industry.

The deployment of XR technologies is achieved by improving or enhancing processes through optimized knowledge transfer, improved interaction possibilities, autonomous simulation in XR, and the automated extraction of knowledge from it. This can be achieved by simplification through XR technologies for handling complex procedures. XR technologies can be deployed to present content target group-oriented for further training or for the simulation of real situations that enable the creation of new knowledge and experiences.

4.5. Collaboration

Another key area of XR deployment in value creation is collaboration through XR technologies. In particular, the characteristics of XR system compositions provide a high degree of immersion and the interaction of multiple users in one or more virtual spaces, which have a high potential to enable collaboration across spatial and temporal boundaries [87].

Vasarainen et al. identified the potential for value creation through XR deployment for collaboration by providing virtual access to physically inaccessible scenarios or increasing the efficiency of existing analog collaboration scenarios [63]. Mayer et al. introduced a method to enable the locally distributed asynchronous collaboration of multiple parties in immersive environments, allowing the collaborators to avoid inconsistent scene states within their individual scenes [62]. In terms of VR, Monahan et al. provide a solution for a collaborative e-learning environment, accessible with multiple mobile and web-based VR devices [61]. Peng et al. developed a concept for web-based VR technology that enables collaboration between technicians and product designers through communication, coordination, control, and integration within the product validation process [68]. The benefits of value creation are improved maintainability and reduced development times, resulting in reduced overall costs [68]. Deploying XR technologies for AR provides major benefits for value creation by enabling multiple people to view, discuss, and interact with 3D models [51]. Masoni et al. furthermore created a concept for remote maintenance, connecting trained operators off-site with unskilled people (e.g., clients) on-site in real-time, avoiding sending maintenance experts on-site, and enabling an increase in the number of key accounts that can be served by one maintenance expert [67].

The XR technology deployment purpose of collaboration can be understood as enabling multiple people from one or more value creation organizations to work together through XR technologies. This includes bridging spatial and temporal distances to increase productivity by saving time and the efficient transfer of relevant information and know-how via XR technologies; the value-adding role of XR technologies in the context of collaboration thereby resides with the creation of both synchronous and asynchronous interaction between stakeholders.

5. Discussion

5.1. Interrelations of the Proposed Taxonomy

The five dimensions are formed from the existing basis of research reviews and implementation reports as the application purposes data acquisition, assistance, visualization, optimization, and collaboration. It can be seen that both VR and AR are included in each deployment purpose through the XR technologies. Figure 3 summarizes the dimensions and characteristics of the XR technology deployment purposes.

While data acquisition in AR is more likely to be achieved through the input units, it is the user experience in VR that generates data about user behavior. Assistance is more represented by AR use cases, especially in industrial AR applications [53]. Since every deployment purpose depicts data in a certain way to the users, visualization means visual fidelity and a high level of detail. While AR primarily represents a non-real product in reality that offers visually added value, the interactability with the three-dimensional model in VR adds value to value creation. The optimization through XR can be user- or activity-oriented. Thus, the possibilities of XR technologies can optimize the user through knowledge transfer, i.e., training. On the other hand, XR technologies can improve the process side by virtualizing process steps and simplifying them through virtualization and simulation of future states. While data acquisition, assistance, and visualization focus on the performance of a value creation activity, the deployment purposes of optimization and collaboration focus on the organization and administration of supporting or main activities as an integral part of value creation.

In principle, a taxonomy can be hierarchical [88]. The derived deployment purposes are not mutually exclusive, and some are linked to each other from a technical point of view. Each deployment purpose requires the capability of data acquisition to a certain extent. Visualization is also basically included in each purpose, as any XR technology setup requires a visualization unit. However, it is only in the foreground in the visualization itself through detailing. Overall, it can be seen that, from a technical point of view, the purposes of deployment build on each other in an interrelation of the dimensions and characteristics given. From the value creation perspective, however, it is necessary to examine which purpose is fulfilled by the technology deployment. From this economic perspective, there is no hierarchical relationship between the purposes.

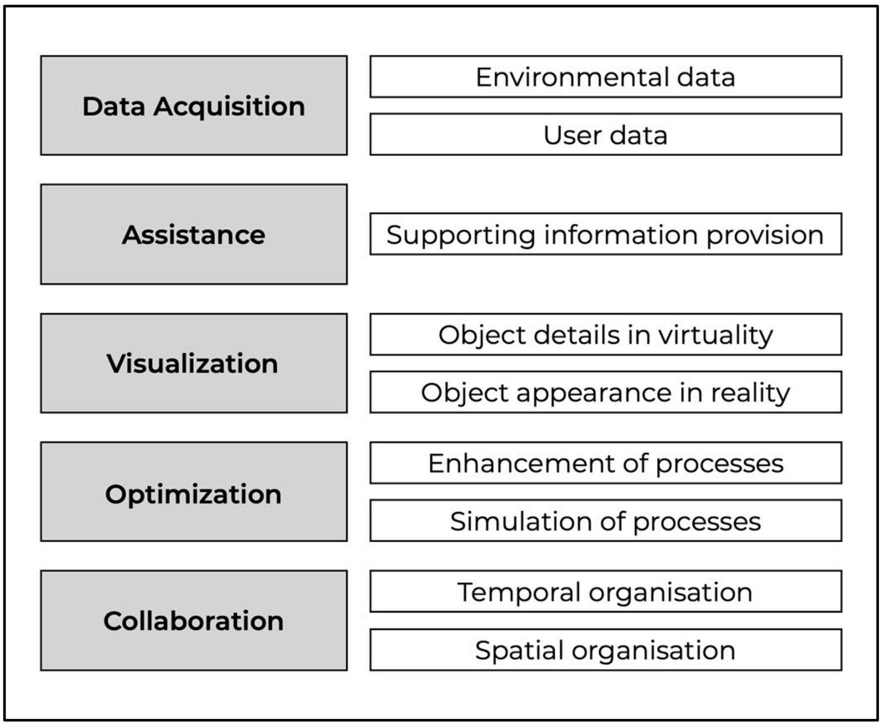

Figure 3. Summary of dimensions and characteristics of the XR deployment purposes.

5.2. Value-Added through XR Deployment Purposes

For the deployment of XR technology, e.g., the process of acquiring non-available data for value creation can be the major purpose from a business perspective. Figure 4 depicts an applied example utilizing the XR technology setup with the ARKit to acquire relevant measurement data that can be processed within a user experience to add value within the value chain of the user. The application scenario shows an iPad application that uses AR to generate the necessary data to prepare a quotation for a facade renovation project. A commodity device with an associated SDK is used to acquire the measurements of façade components. Within a user experience, the acquired measurements of the façade components can be processed and enhanced with details, such as excesses and tolerances.

An overall measurement can be created by adding the count of façade elements within the user experience. This provides the necessary data for a price indication as quickly as possible on-site. The value within the value creation is primarily added by faster decision-making for the user. Additionally, the material manufacturer can use the acquired data on a meta-level and improve the planning capabilities for future demand. This optimizes production capacities as well as delivery times. The application scenario proves that a technologically low-tech XR setup can already deliver added value in the sales process by stringently using the deployment purpose of data collection.

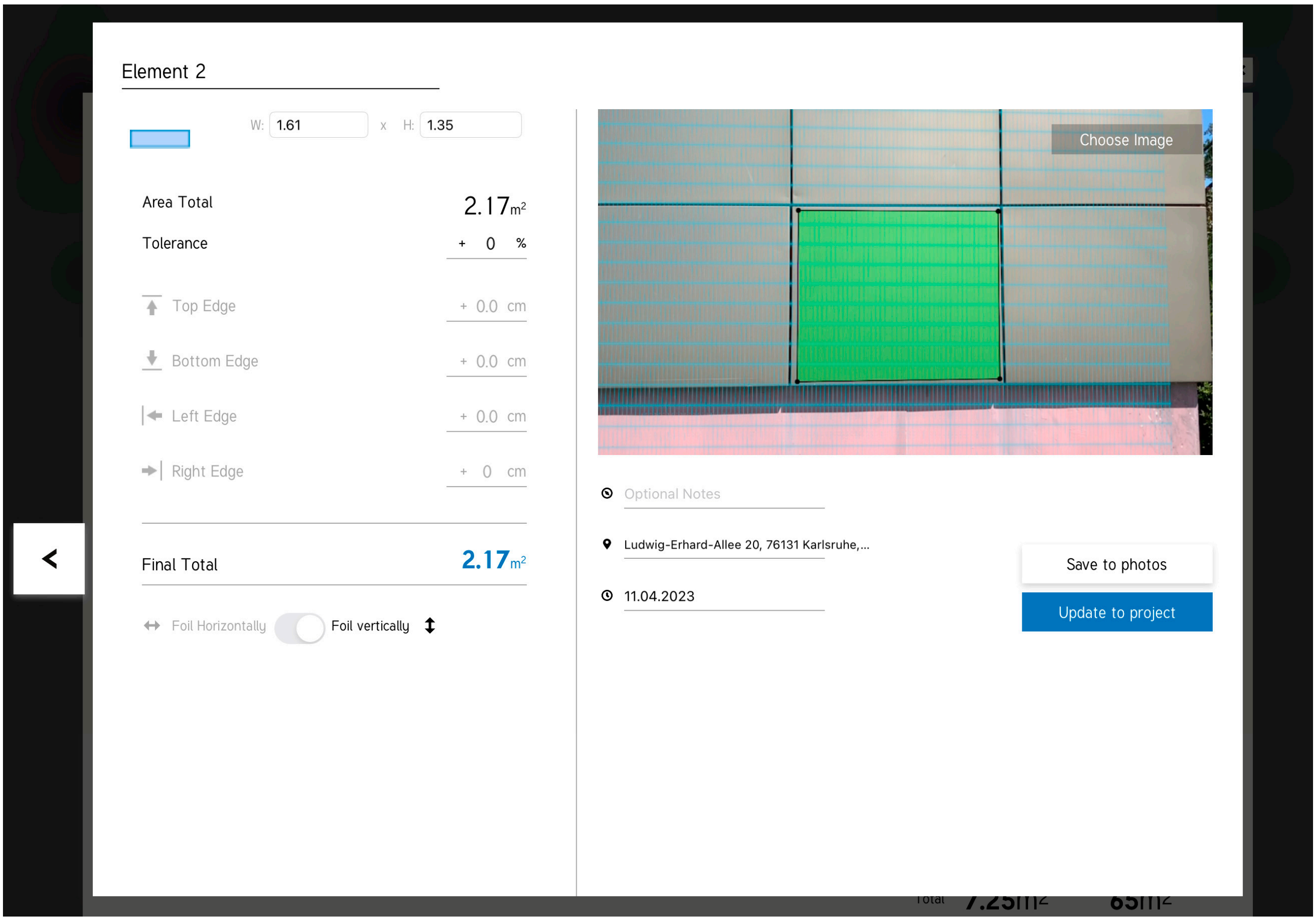

Figure 4. Application scenario showing the post-processing of acquired data from an AR application collecting measurements (industrial project reference).

5.3. The Role of the Taxonomy in the Execution of an XR Solution

The presented taxonomy offers a set of purposes that can provide potential solutions for value creation. However, it does not provide a methodological approach to deploying an XR solution itself. To turn the deployment purposes into XR solutions, the taxonomy can be used in the context of a design thinking approach [89,90]. After understanding and defining an existing issue, the taxonomy can be applied to uncover and develop potential XR-based solution approaches [91]. Subsequently, these approaches are to be tested and implemented [91]. In particular, dedicated approaches propose a methodical approach for implementing an XR solution based on the identified deployment purpose for these steps. These can range from generic approaches deploying information systems for business transformation [92], approaches describing the required activities and the ecosystem for deploying XR technologies [93], to approaches describing the technological process of developing and configuring XR solutions from the initial requirements over the proof-of-concept to the value-adding XR solution [94]. In the larger context of the state of research, the presented paper takes a supporting role in the initiation phase of a deployment with the above-mentioned methodologies.

6. Conclusions

This paper proposes a taxonomy for deployment purposes of XR technologies in value creation. Based on research reviews and implementation reports, five dimensions with a total of nine characteristics were identified according to Nickerson's methodology. While they are interrelated from a technological perspective, they can be classified without overlap from an economic perspective. From a value creation perspective, the taxonomy simplifies the identification of new use cases and the transfer of an existing use case to a new value creation. This can be obtained using the taxonomy for solution identification, e.g., in the scope of a design thinking process. With the help of the purposes, an industry-independent approach supports identifying a use case and solving an issue in underlying value creation. The identified solution can then be applied within the framework of a deployment methodology. In addition to the business-process agnostic character of the taxonomy, the deployment purposes are industry-independent. Thus, these purposes can furthermore be applied in related industries without business value-added intent. For example, data acquisition can also be used for educational deployment purposes or medical use cases without generating specific economic value.

Due to the required hardware, software, and content setup, deploying an XR solution generally requires a significant initial investment, and the solution's scalability might be restricted within a given value creation. Based on the purpose-oriented deployment of XR technologies, sub-components of a technology setup can be deployed to add value without requiring a full XR technology stack. For instance, the sensory system of an XR technology stack might be sufficient in value creation to acquire relevant data for improving the organization of the value activities without requiring a dedicated three-dimensional visualization unit, as shown in the industrial project reference in Figure 4. Summing up, the deployment purposes show that within the context of value creation, XR technologies can be deployed for value addition even with a low-fidelity technology setup.

The limitations of the derived taxonomy result, on the one hand, are from the qualitative selection of reviews and implementation reports. With the variance in technological comprehensiveness and industrial processes, the value chain model was applied to identify the common denominator of the deployment purposes [26]. Furthermore, the taxonomy suggests suitable purposes from an economic perspective for implementation but does not provide information about a systematic approach to introducing XR technologies into value creation. It can be used to derive new use cases by addressing a pain point in a value chain or transferring a best practice from another value chain through abstraction. Theoretically, any number of use cases can be derived from it. The accuracy of the taxonomy should be investigated in further research by analyzing and comparing the deployment purposes of different use cases and technology setups. Future research can also focus on distributing the purposes across different value creation steps and industries. A quantitative study on how XR technology setups are deployed in existing value creations could provide insights into drafting a purpose-based solution. Subsequentially, which XR technology configuration fulfills which purpose to simplify the technical implementation could be investigated. Furthermore, it should be investigated what kind of added value the individual deployment purposes deliver and how this can be validated and quantified from an economic point of view. It should be distinguished how the value of XR technologies is manifested. The value can occur in terms of use value (e.g., productivity) and exchange value (e.g., provision of new services with new revenue streams for value creation). As a subsequence, the empirical investigation of the value impact adds more insights into successfully deploying XR technologies in value creation.

Author Contributions: Conceptualization, T.K., V.S. and J.O.; methodology, T.K.; software, T.K. and V.S.; validation, T.K., V.S. and J.O.; formal analysis, T.K.; investigation, T.K.; resources, T.K. and V.S.; data curation, T.K.; writing—original draft preparation, T.K., V.S. and J.O.; writing—review and editing, T.K., V.S. and J.O.; visualization, T.K.; supervision, V.S. and J.O.; project administration, J.O.; funding acquisition, J.O. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by the KIT-Publication Fund of the Karlsruhe Institute of Technology.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We acknowledge support by the KIT-Publication Fund of the Karlsruhe Institute of Technology.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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