Value Creation with Extended Reality Technologies

A Methodological Approach for Holistic Deployments

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Kurzfassung

Mit zunehmender Rechenkapazität und Übertragungsleistung von Informationstechnologien wächst die Anzahl möglicher Anwendungsszenarien für Extended Reality (XR)-Technologien in Unternehmen. XR-Technologien sind Hardwaresysteme, Softwaretools und Methoden zur Erstellung von Inhalten, um Virtual Reality, Augmented Reality und Mixed Reality zu erzeugen. Mit der Möglichkeit, Nutzern Inhalte auf immersive, interaktive und intelligente Weise zu vermitteln, können XR-Technologien die Produktivität in Unternehmen steigern und Wachstumschancen eröffnen. Obwohl XR-Anwendungen in der Industrie seit mehr als 25 Jahren wissenschaftlich erforscht werden, gelten nach wie vor als unausgereift. Die Hauptgründe dafür sind die zugrundeliegende Komplexität, die Fokussierung der Forschung auf die Untersuchung spezifische Anwendungsszenarien, die unzureichende Wirtschaftlichkeit von Einsatzszenarien und das Fehlen von geeigneten Implementierungsmodellen für XR-Technologien.

Grundsätzlich wird der Mehrwert von Technologien durch deren Integration in die Wertschöpfungsarchitektur von Geschäftsmodellen freigesetzt. Daher wird in dieser Arbeit eine Methodik für den Einsatz von XR-Technologien in der Wertschöpfung vorgestellt. Das Hauptziel der Methodik ist es, die Identifikation geeigneter Einsatzszenarien zu ermöglichen und mit einem strukturierten Ablauf die Komplexität der Umsetzung zu beherrschen. Um eine ganzheitliche Anwendbarkeit zu ermöglichen, basiert die Methodik auf einem branchen- und geschäftsprozessunabhängigen Wertschöpfungsreferenzmodell. Darüber hinaus bezieht sie sich auf eine ganzheitliche Morphologie von XR-Technologien und folgt einer iterativen Einführungssequenz.

Das Wertschöpfungsmodell wird durch ein vorliegendes Potential, eine Wertschöpfungskette, ein Wertschöpfungsnetzwerk, physische und digitale Ressourcen sowie einen durch den Einsatz von XR-Technologien realisierten Mehrwert repräsentiert. XR-Technologien werden durch eine morphologische Struktur mit Anwendungsmerkmalen und erforderlichen technologischen Ressourcen repräsentiert. Die Umsetzung erfolgt in einer iterativen Sequenz, die für den zugrundeliegenden Kontext anwendbare Methoden der agilen Softwareentwicklung beschreibt und relevante Stakeholder berücksichtigt. Der Schwerpunkt der Methodik liegt auf einem systematischen Ansatz, der universell anwendbar ist und den Endnutzer und das Ökosystem der betrachteten Wertschöpfung berücksichtigt.

Um die Methodik zu validieren, wird der Einsatz von XR-Technologien in zwei industriellen Anwendungsfällen unter realen wirtschaftlichen Bedingungen durchgeführt. Die Anwendungsfälle stammen aus unterschiedlichen Branchen, mit unterschiedlichen XR-Technologiemerkmalen sowie unterschiedlichen Formen von Wertschöpfungsketten, um die universelle Anwendbarkeit der Methodik zu demonstrieren und relevante Herausforderungen bei der Durchführung eines XR-Technologieeinsatzes aufzuzeigen.

Mit Hilfe der vorgestellten Methodik können Unternehmen XR-Technologien zielgerichtet in ihrer Wertschöpfung einsetzen. Sie ermöglicht eine detaillierte Planung der Umsetzung, eine fundierte Auswahl von Anwendungsszenarien, die Bewertung möglicher Herausforderungen und Hindernisse sowie die gezielte Einbindung der relevanten Stakeholder. Im Ergebnis wird die Wertschöpfung mit wirtschaftlichem Mehrwert durch XR-Technologien optimiert.

Abstract

With increasing computing power and data transmission performance of information technologies, the possible application scenarios for Extended Reality (XR) technologies in industries are growing. XR technologies are hardware systems, software tools, and content creation methods to create Virtual Reality, Augmented Reality, and Mixed Reality. With the ability to demonstrate content to users in an immersive, interactive, and intelligent way, XR technologies can leverage business potential through productivity increases and business growth opportunities across industries. However, despite the ongoing scientific investigation of industrial XR applications for more than 25 years, XR technologies are still considered emerging. The primary reasons are the underlying complexity of the domain, research focusing on the investigation of application scenarios in specific use cases, the insufficient economic viability of deployment scenarios, and a lack of suitable implementation models for XR technologies.

Realizing the value of technologies can be achieved through their integration into the value creation architecture of business models. Therefore, this thesis presents a methodology for the deployment of XR technologies in value creation. The main goal of the methodology is to enable the identification of suitable deployment scenarios and to provide guidance with a structured deployment process for managing the complexity of the deployment execution. To ensure holistic applicability, the methodology is based on a value creation reference model that is independent of industry and business processes. Furthermore, it refers to an encompassing morphology of XR technologies and follows an iterative deployment sequence.

Thus, the value creation model is represented by an existing value potential in the value creation, value chain, value network, physical and digital resources, and a subsequent value-added realized through XR technology deployment. XR technologies are represented by a morphological structure with application characteristics and required technological assets. Deployment follows an iterative sequence that describes applicable agile software development methods for the underlying context and considers relevant stakeholders. The focus of the methodology is on a systematic approach that can be applied universally, taking the end user and ecosystem of the considered value creation into account.

To validate the methodology, XR technologies were deployed in two industrial use cases under real economic conditions. Each use case originates from different industries, with different XR characteristics as well as different forms of value chains, to demonstrate the universal applicability of the methodology and highlight relevant challenges in the execution of XR technology deployment.

Using the proposed methodology, companies can deploy XR technologies in their value-creation processes using a target-oriented approach. It allows for detailed planning of the process, profound selection of application scenarios, assessment of possible challenges and obstacles, and targeted involvement of the relevant stakeholders. Consequently, value creation is optimized with economic added value through XR technologies.

Table of Contents

Table of Figures

List of Tables

List of own Publications

- Krodel, Tim, Vera Schott, and Jivka Ovtcharova. 2023. “XR Technology Deployment in Value Creation.” *Applied Sciences* 13 (8): 5048. https://doi.org/10.3390/app13085048.

- Krodel, T., V. Schott, A. Mayer, and J. Ovtcharova. 2023. “Impact of XR-Enabled Collaboration in Businesses - an Economic, Ecological, and Social Perspective.” In *AI and Business, and Innovation Research: Understanding the Potential and Risks of AI for Modern Enterprises (in Press)*, edited by Bahaaeddin Alareeni and Islam Elgedawy, Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-42085-6.

- Krodel, Tim. 2022. “The Metaverse - What It Takes to Be Successful in the next Generation of Business Models.” Whitepaper. June 30, 2023. https://ili.digital/wp-content/uploads/2023/02/ILI.DIGITAL_Metaverse.pdf.

List of Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
APK	Android Package Kit
AR	Augmented Reality
B2B	Business-to-Business
B2B2C	Business-to-Business-to-Consumer
B2C	Business-to-Consumer
BI	Business Intelligence
BPMN	Business Process Model and Notation
CAD	Computer-Aided Design
CAP	Capture Analyze Present
CAVE	CAVE automated virtual environment
COTS	Commoditiy Off The Shelf
CPU	Central Processing Unit
CTE	Combinatorial Technology Evolution
DevOps	Development and Operations
DFD	Data flow diagrams
DOF	Degrees of Freedom
DPI	Data Programming Interface
DT	Digital Twin
ERP	Enterprise Resource Planning
FBX	Filmbox
FoV	Field of View
GPU	Graphics Processing Unit
GUI	Graphical User Interface

HHDs	Hand-Held Device
HMD	Head-mounted Display
IDE	Integrated Development Environment
IoT	Internet-of-Things
IS	Information Systems
ISA	International Society of Automation
IT	Information Technology
LiDAR	Light Detection And Ranging
MAR	Mobile Augmented Reality
MES	Manufacturing Execution System
MR	Mixed Reality
NICE	Novelty, Lock-in, Complementarities, Efficiency
OBJ	Object
ODT	Omnidirectional Treadmill
OEM	Original Equipment Manufacturer
OSS	Open Source Software Development
PDM	Product Data Management
PLC	Program Logic Controller
PoC	Proof-of-Concept
PoV	Proof of Value
R&D	Research and Development
RBV	Resource-based view
RE	Real Environment
RQ	Research Question
SaaS	Software as a Service
SAR	Spatial Augmented Reality
SCADA	Supervisory Control And Data Acquisition
SDK	Software Development Kit
SQA	Software Quality Assurance

STEP	Standard for the Exchange of Product model data
SWOT	Strenghts, Weaknesses, Opportunities, Threats
TAM	Technology Acceptance Model
UCD	User-Centered Design
VE	Virtual Environment
VIP	Value-Information-Process
VR	Virtual Reality
WAVE	Wirtschaftlichkeitsanalyse für Virtual Engineering
XP	Extreme Programming
XR	Extended Reality

1 Introduction

In 1935, Stanley G. Weinbaum published the novel "Pygmalion's Spectacles", describing a pair of glasses that transport the user into a non-existing world indistinguishable from reality (Weinbaum 1935). The concept, which was fictional then, is remarkably similar to the head-mounted displays that are widely used today. Thirty years later, Ivan Sutherland described in "the perfect display", his vision of a window into the virtual world (I. Sutherland 1965). Three years later, he developed a concept combining graphic displays with computers to create virtual environments and, with the help of a tracking system, make them tangible in correct three-dimensional visualization (I. E. Sutherland 1968). By varying how virtual content can be displayed, Sutherland is referred to as the founder of the Extended Reality (XR) technologies for both reality variations, Virtual Reality (VR) and Augmented Reality (AR) (Biocca 1992).

Since then, VR and AR have been investigated from a research perspective for decades in various fields, e.g., information technology, psychology, communication, engineering, or economics (D. Bowman and McMahan 2007; Biocca 1992; Steuer 1992; Jezernik and Hren 2003; Bigné et al. 2016). With increasing technical development, new possibilities for visualizing information and creating three-dimensional experiences have emerged. XR technologies are becoming increasingly relevant for companies because of the possibility of transferring large amounts of data rapidly, the miniaturization of computing power, and the growing availability of devices for displaying virtual content (Gattullo et al. 2019).

1.1 Motivation and Research Problem

Numerous scientific studies on concrete use cases for internal processes exist in the business context. Yet, the increasing relevance of these technologies can also be identified on the consumer side (Flavián et al. 2019). It can be observed that the recently occurring dynamics in science and business affect the relevance of XR technologies for companies leading to the necessity to investigate the interrelations between business and XR technologies from a scientific perspective.

Technology Diffusion

First, the increasing diffusion of devices among end-users and improved accessibility affect the adoption of XR technologies in businesses. For example, Apple created a stir by entering the XR domain with the announcement of their head-mounted display “Vision Pro”, which, according to Apple, represents the start of the spatial computing era (Apple Inc. 2023). This follows a trend that predicts a significant diffusion of XR technology devices. For example, it is estimated that the global sales volume of VR and AR devices will increase from 11 million to 105 million units between 2016 and 2025 (Counterpoint 2022). Furthermore, the maturity of associated technologies that positively affect the adoption of XR technologies grows. Thus, recent break-throughs in Artificial Intelligence (AI) will ease the deployment of XR technologies, for example, through the automated creation of virtual worlds and an improved interaction in XR (Hirzle et al. 2023).

Business Potential of XR technologies

In addition to the increasing prevalence of relevant technologies, the predicted economic potential of XR also indicates its growing relevance for companies. The total market volume for XR, i.e., devices and content, is estimated to be almost USD 860 billion by 2030 (Precedence Research 2022). Moreover, the indirect productivity potential across all industries is assumed to be significant, amounting to USD 1,500 billion in

Overall, there is a contradiction between technological development and advancements, market potential, and the actual adoption of XR technologies in business. The research problem emerges from the deviating economic potential of XR technologies and the scientific evaluation of the maturity of XR technologies. To resolve this research problem, this thesis develops a methodology to tackle the aforementioned challenges and enable the value-adding deployment of XR technologies in companies.

1.2 Research Objectives

To address this research problem, the underlying research follows a value-driven perspective, as the adoption of technologies depends on their usefulness, i.e., the value the technology can deliver to a company (Davis 1989). Technology has no economic value, as it can only be realized within the framework of a business model (Chesbrough 2010). Thus, the question arises as to how XR technologies can be integrated into a company's business model. Due to the significant productivity potential, it is, therefore, necessary to investigate how XR technologies can affect and enhance the origination of value, i.e., value creation.

Given the existing challenges of adopting XR in companies, the main objective of this thesis is to develop a systematic methodology for companies to deploy the XR technology in their value creation. In doing so, companies should be able to deploy them holistically. Therefore, the methodology should therefore map the deployment execution from the initial identification of a deployment opportunity to the operation and scaling of the XR technology solution. This should provide a dedicated planning capability for companies. In this context, the methodology should furthermore scope the deployment across company borders to consider the integration of the surrounding value chain, i.e., possible partners, customers, and suppliers. In addition, the methodology should global productivity gains (PwC 2019). Even if these figures seem speculative, the direct revenue potential and the indirectly realizable efficiency gains motivate companies to engage with XR technologies.

Lack of Adoption Speed

Even though the technological and economic indicators might be promising, it has been repeatedly shown that technical developments progress faster than companies need to adopt them, and thus the economic potential of these technologies remains mostly unused (Ovtcharova 2010). A viable innovation is considered a technical invention with a significant value-added (Horn 2005). The field of XR has been researched for more than 55 years, whereas research on applying XR in the business context has been ongoing for at least 25 years (I. Sutherland 1965; Curtis et al. 1998). However, XR technologies are still emerging in the industrial application context due to their lack of viability (Chuah 2018; Wei Wang et al. 2020). There are significant hurdles for companies deploying XR technologies.

Adoption Challenges of XR technologies

The primary reasons for the low adoption in the business context are technological complexity, hardware costs, appropriate user experience design, and lack of hardware maturity for the underlying requirements of the business use case (Perkins Coie LLP. 2018; Dimensional Research 2018). In particular, the costs of creating virtual assets or developing software applications for automatic visualization of physical assets are labor intensive and, thus, related to significant investments (Nayyar et al. 2023). Additionally, the technological complexity of creating and operating XR technology solutions requires specific knowledge and advanced information technology resources (Rokhsaritalemi et al. 2020). Another limiting factor is the need for a sophisticated user experience to empower users with the advantages of XR technologies and avoid phenomena like cybersickness (Chardonnet et al. 2021).

be applicable for value creation independent of industry and business process, thus allowing universal applicability.

Main Objective

> Development of a systematic methodology for companies to deploy XR technologies in value creation with the capability to:
>
> - holistically map the execution sequence of the deployment
> - holistically deploy in the value chain of the value creation
> - deploy regardless of industry or business processes

As previously mentioned, XR technologies are complex. To enable a systematic deployment, this methodology should provide guidance to manage the complexity of XR technologies. With XR as an umbrella term for various reality forms, a proper perspective must be selected. Thus, a targeted classification of XR technologies must be formulated, which on the one hand, has the granularity to represent all technology fields and possible reality forms. On the other hand, a suitable abstraction of the technologies and reality forms must be performed to carry out the deployment without restricting complexity.

Research Objective I

> Handling the complexity of XR technologies by classifying XR with:
>
> - a suitable granularity for mapping all XR manifestations
> - a suitable abstraction for complexity reduction

With the significant investments for companies to deploy XR, resulting from technology provisioning costs as well as initialization and operation of the XR solution, the pressure to create value-added arises for any XR technology deployment. Thus, regarding the holistic approach of the methodology, particular attention should be directed to the type of value that can be generated through XR in the value creation process and how this value can be realized.

Research Objective II

> Determining the potential value added through XR technology deployments regarding:
>
> - Type of generated value-added
> - Realization of the generated value-added

This methodology should consider the execution process of technology deployment in value creation, with an emphasis on enabling companies to adopt XR technologies. This study aims to provide a systematic approach. Therefore, the different purposes of XR technologies in value creation must be investigated and integrated into the methodology. In addition, the implementation procedure must be considered. The methodology should demonstrate how the implementation can be performed step-by-step while focusing on users and providing agility to adapt the execution plan according to changing requirements throughout the deployment process.

Research Objective III

> Executing the XR technology deployment systematically with:
>
> - regards to XR technology purposes in value creation
> - agile, adaptable, and user-centric execution steps

Overall, the proposed methodology should demonstrate practical applicability. For this purpose, a verification of the scientifically derived methodology in industrial application scenarios is pursued. In doing so, knowledge that influences the design of the methodology is gained. Eventually, the practical applicability should be proven under actual economic conditions, and the implementation challenges should be presented tangibly.

1.3 Research Strategy and Thesis Structure

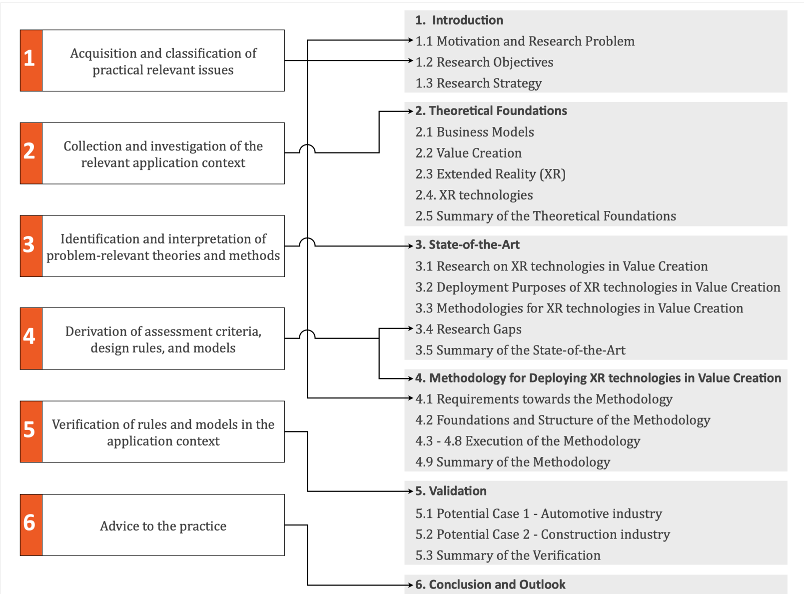

Figure 1.1: Research strategy and thesis structure derived from (Ulrich 1984)

The research strategy and structure of the thesis to achieve the research objectives and address the identified research problem are described below. With the application-oriented character resulting from the research problem as well as the overall goal of real-economic applicability, the structure of this thesis follows the application-oriented research strategy according to Ulrich (Ulrich 1984). Figure 1.1 depicts the research strategy resulting in the structure of the thesis.

As stated in **chapter 1**, this thesis assumes that adopting technology in a business context depends on the potential value that can be realized within the framework of a business model, particularly through integration in the value creation of business models.

To derive of the problem identification and the research gaps, the concept and the development of the term business model will be presented in the theoretical foundations of **chapter 2**. Based on this, the term value creation, especially in association with value chains, is explained, and the relevant sub-terms are described. Next, the term XR is defined in the theoretical foundation. The relevant characteristics of the different manifestations are described by discussing the development of VR, AR, and MR as subterms of XR. In this thesis, XR is understood as the experience generated by XR technology. These technologies are outlined in the categories of hardware systems, software development, and content creation. This forms the basis for the analysis of the state-of-the-art and the development of the methodology.

Subsequently, the scientific state-of-the-art of XR technologies in the context of value creation are presented in **chapter 3** to identify the research gaps. First, the existing research characteristics of XR technologies in value creation is identified. Based on the existing research streams, the deployment purposes of XR technologies in value creation are derived by developing a taxonomy according to the approach of Nickerson et al. (Nickerson et al. 2013). Subsequently, current methodologies for deploying VR, AR, and MR will be analyzed and evaluated with respect to the research objectives. Given the interdisciplinary nature of XR technologies, methodologies from related research areas have also been presented to form a substantiated basis for the methodology. The depicted state-of-the-art is then subsumed, and the identified research gaps are transferred into requirements for the methodology through research questions.

Chapter 4 describes the methodology for deploying XR technologies for value creation. Initially, the requirements for the methodology are determined by the research objectives of chapter 1.2 and the research gaps identified in chapter 3.4. A morphology for XR technologies is constructed based on the characteristics of the XR technologies presented in chapter 2.4 and the determined XR deployment purposes in chapter 3.2. In addition, a value creation reference model is defined as the starting point for the deployment methodology, which provides the basis for the deployment regardless of industry and business process. Third, a deployment sequence is defined, which specifies the phases of an XR technology deployment in value creation. Additionally, relevant deployment stakeholders were nominated and characterized. The steps of the methodology for executing the deployment are then described using the respective methods, approaches, and frameworks.

The methodology is then applied in **chapter 5**, using two different scenarios based on the economic conditions of two industries. The application scenarios focus on different target groups with varying requirements in differently arranged value chains. Both scenarios require different forms of XR, i.e., VR and AR. In this context, a universal application of the methodology is demonstrated within these two scenarios. Furthermore, the challenges of XR technology deployment are made tangible.

The implications from chapter 5 also show the limits of applicability and the need for future research. This is collected in the summary and outlook of **chapter 6**. After an overview of the research results, the research objectives, the research questions, and the requirements for the methodology are compared and conclude this thesis.

2 Theoretical Foundations

The following section defines the basic terms used in the research approach. First, an examination of the term business models is required. It specifies what value and what understanding is assumed for the research strategy. Second, the chapter will concretize the creation of value, especially in the context of value chains, as well as business processes and resources. Third, the term XR is examined and explained as a foundation for the derivation of the methodology. For this purpose, the evolution of the term is discussed, and the major differentiation criteria of today's understanding are elaborated. Finally, XR technologies, that is, hardware systems, software tools, and content creation methods to create XR, are presented, and the major characteristics of these technologies are explained to provide the foundation for the methodology.

Given the research objectives outlined in **chapter 1.3**, this chapter aims to map the background to the research problem. The terms value creation, XR and XR technologies are to be presented in a scientific context. Thus, on the one hand, this chapter contributes to the fulfillment of **research objective II** by mapping the complexity of the respective fields and preparing the management of the complexity by structuring the context and interrelationships of both value creation and XR technologies. In addition, it contributes to **research objective II** by defining the understanding of value for this thesis and outlining value creation mechanisms.

2.1 Business Models

The first appearance of the term business models dates back to the 1950s, when it was not yet clearly defined. (Bellman et al. 1957). However, it is stated that the term business model was initially a buzzword and understood as ambiguous until it gained scientific popularity in the 1990s with the emergence of Information Technology (IT)-driven businesses (DaSilva and Trkman 2014). The definition and shaping of a common business model understanding has been going on since. As the discussion of business models appears in different research fields, the research landscape is fragmented, and a unified understanding has not yet been presented (Wirtz et al. 2016). The following section summarizes the relevant research approaches identifying a pattern to be utilized as a base understanding for this research purpose. One of the first relevant definitions of a business model appeared with the rising relevance of the internet and was provided in the context of e-commerce by Amid and Zott (Amit and Zott 2001). They defined:

> *"[…] the business model construct as a unifying unit of analysis that captures the value creation arising from multiple sources. The business model depicts the design of transaction content, structure, and governance so as to create value through the exploitation of business opportunities."* (Amit and Zott 2001)

Chesbrough and Rosenbloom underlined the context of business models with the internet and offered the six operational core functions of a business model, i.e. (Chesbrough and Rosenbloom 2002):

- Value proposition articulation
- Market segment identification
- Value chain structure definition
- Cost structure and profit potential estimation
- Value network description
- Competitive strategy formulation

Richardson suggested the business model as an integrated framework with a focus on the strategy design and execution process of a company. The framework consists of the value proposition, the value creation, and delivery system, and the value capture. With this aggregation of previous concepts of the business model, Richardson linked the business model concept to the field of business strategy. (Richardson 2005)

Morris et al. derived a business model framework from existing research approaches. The framework consists of six questions to be answered regarding value creation, target groups, competence sources, competitive positioning, money generation, and future vision (Morris et al. 2005).

Osterwalder et al. summed up the existing components in the field of business models and presented one of the most practical utilized frameworks within this context. The so-called Business Model Canvas provides a structured template for both new and existing businesses to shape their strategy execution and identify new business opportunities (Osterwalder et al. 2010). For the holistic description of a business model, Osterwalder et al. distinguished in the Business Model Canvas the four main areas of customer, offer, infrastructure, and financial feasibility into a total of nine core components, as shown in Figure 2.1.

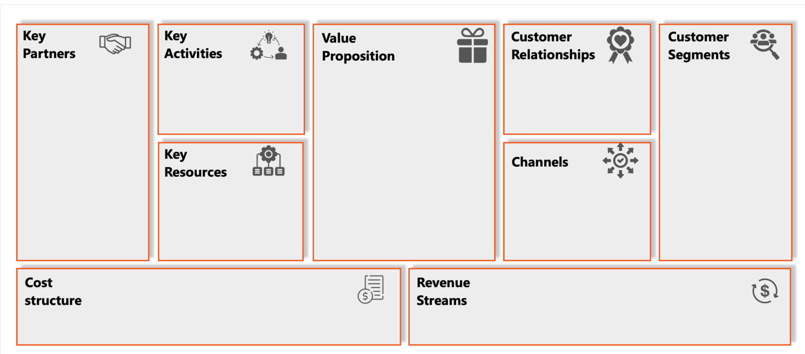

Figure 2.1: Business Model Canvas (Osterwalder et al. 2010)

With the St. Gallen Model, Gassmann et al. defined their Business Model Navigator with the relevant components of the existing approaches. Four questions were determined to create a concrete understanding of a business model, consisting of the target group (Who), the offer to the target group (What), the process of value creation (How), and the economic value itself (Value) (Gassmann et al. 2013). With the Business Model Navigator, Gassmann et al. executed a cross-industry validation and identified 55 patterns of business models distinguished by their framework.

Baden-Fuller and Haefliger stated that there is a relevant but complex bi-directional connection between technology and business models. While the need to develop an existing business model more efficiently will shape the direction of development and technological innovation, new technologies can also affect the shape of an existing business model and enable the appearance of new business models (Baden-Fuller and Haefliger 2013).

Looking at the scientific discourse of the past decades, repeated attempts have been made to interpret the context of the term and make it tangible against various backgrounds. The similarities between these approaches can be observed in two ways. On the one hand, the business model is not to be equated with the strategy of a business, but rather to be understood as a link to operational execution. Second, the concept of value is at the forefront of both approaches. In summary, the common denominator of business model understanding is the offering of value, capturing value, and creating value. For this reason, the understanding of value and its creation in the business context is examined in the following section.

2.2 Value Creation

Value is widely spread in different research fields and viewed through a variety of academic lenses. From social aspects, psychological perception, ecological impact, and economic research fields, value can be analyzed, interpreted, and understood differently.

Regarding business models, value and value creation are central elements of all presented frameworks in **chapter 2.1**. Table 2.1 sums up how the given frameworks recognize the notion of value, the understanding of the process of value creation, and identifies which components are viewed as crucial in the value creation of a business model.

Table 2.1: Value and value creation in business models

Author(s)	**Notion of Value**	**Understanding of Value Creation**	**Components for Value Creation**
Amit and Zott (2001) / Zott and Amit (2010)	New wealth	Exploitation of new business opportunities	• Set of activities • Structure of activities • Governance of activities
Chesbrough and Rosenbloom (2002)	Technology based offering for users	Conversion of technological input into economic output	• Structure of value chain • Creation of offering • Distribution of value • Value network position
Richardson (2005)	Willingness to pay for a firm`s offering	Creation and delivery of value to customers and source of competitive advantage	• Resources & capabilities • Value chain, activity system and business processes • Value network position
Morris et al. (2005)	Offering to customers	All factors related to the offering	• Product/Service mix • Role of firm in delivery
Osterwalder et al. (2010)	Quantitative (e.g., price) or qualitative (e.g., experience)	Company-centric aspects of creating a defined value proposition.	• Key resources • Key activities • Key partnerships
Gassmann et al. (2013)	Financial viability	Building and distribution of a value proposition	• Mastering processes • Orchestration of resources
Badner-Fuller and Heafliger (2013)	Monetization of technology through firms	Relation between innovation and performance of a firm	• Technology development • Customer engagement

The value is seen by all frameworks at least as a quantifiable result for a target group from the value creation. This target group can be internally integrated within the value creation and externally positioned in the business model ecosystem. Moreover, most frameworks consider value creation a process-oriented construct in an ecosystem around a firm. Thus, value creation focuses on the transformation of resources in a flow of activities by different stakeholders (Table 2.1).

Regardless, the introduced frameworks provide neither a unified understanding nor a clear definition of the term value. For this reason and to create a clearer picture of value creation, a more differentiated consideration of the term is necessary. Bowman and Ambrosini identified that value consists of both subjective and objective components (C. Bowman and Ambrosini 2000):

- The subjective **perceived use value** depends on how the receiver (e.g., customer or organization) might see and be willing to pay for a good or service.
- The objective value component that is **realized exchange value** while exchanging a good and therefore making it quantifiable throughout the transfer. The quantification is the monetary amount for the sold use value reduced by the costs for the generation.

Bowman and Ambrosini further elaborate that value creation is the subsequential creation of use value and the realization of exchange value between organizations. The people within the organization must actively perform actions on both tangible and intangible inputs to generate new use values that can be realized in (C. Bowman and Ambrosini 2000). The concept of how the value is generated is explained through the simplified flow shown in Figure 2.2.

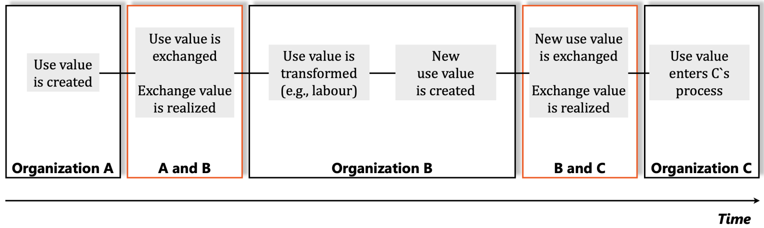

Figure 2.2: Value creation flow (C. Bowman and Ambrosini 2000)

Lepak et al. used this understanding of use and exchange value to explained that the source of value creation can originate from different layers. The three different layers distinguished by Lepak et al. are (1) individuals, (2) organizations, and (3) society (Lepak et al. 2007). At the social level, for example, according to Lepak et al., value is created by, e.g., the prevalence of a competitive situation or by the setting of specific incentives. At the organizational level, on the other hand, the activities that create value are, e.g., Research and Development (R&D) activities and the generation of knowledge. On the individual level, an individual's skills and motivation create value. Despite this, the different dimensions of value are directly linked. Thus, the value capture of the individual contributes to the value creation of the organization, and the value capture of the organization contributes to the value creation of the society. (Lepak et al. 2007) It is relevant for the research targets to understand the interplay of value levels as XR technologies can add value both on the individual and the organizational level.

Based on the previously defined understanding of a business model consisting of the design elements “content”, “structure”, and “governance”. Zott and Amit later introduced the NICE framework to describe the source of value creation within a business model (Amit and Zott 2001; Zott and Amit 2010). From the perspective of the activity system of a company (as well as its environment) as the elementary basis of the business model, the value creation lies in the so-called design themes of the activity system, to which extent the activity system can be shaped. The design themes are (Zott and Amit 2010):

- **Novelty**
  Novel integration, connection, or monitoring of activities
- **Lock-In**
  Making it difficult for third-party stakeholders (e.g., customers) to leave the system of redeeming created value
- **Complementarities**
  Releasing synergies through the combination of activities
- **Efficiency**
  Improving the flow of existing activities to reduce costs for value creation

In summary, it becomes evident that in terms of value creation, the literature focuses on the linkage of processes (activities) to turn the input of resources into value. After presenting the terms value and value creation, the following chapters should elaborate on the linkage of the processes, i.e., the value chain, the terminology of business processes, and the resources.

2.2.1 Value Chains

One of the most cited frameworks for understanding, explaining, improving or designing existing or new activities in a business is the value chain model by Porter. It is defined:

> *"[…] as a system of interdependent activities, which are connected by linkages."* (Porter and Millar 1985)

Furthermore it is the representation of a firm's:

> *"[…] collection of activities that are performed to design, produce, market, deliver and support its product."* (Porter 1985)

Figure 2.3 depicts the generic model of a value chain.

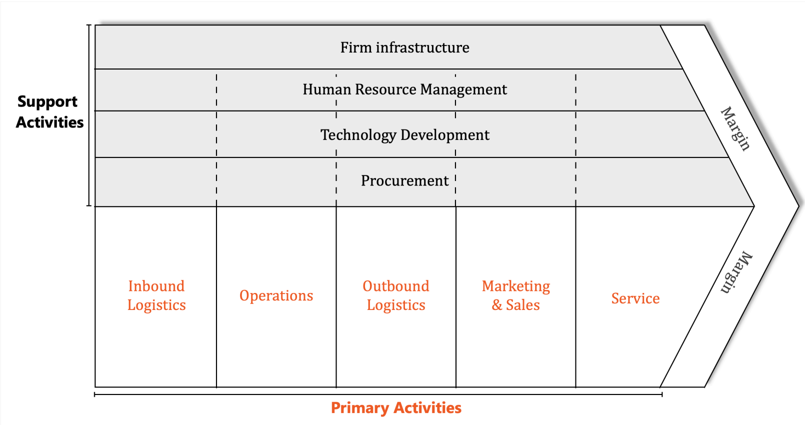

Figure 2.3: The Value Chain Model (Porter and Millar 1985; Porter 2001)

The Value Chain model consists of value activities, that distinguish between primary and support activities. While primary activities are directly related to the targeted output of the value chain (e.g., direct handling, production, or marketing of a physical product), support activities are value contributions to enable the execution of primary activities. Value activities are generically defined as applicable to different industries and contain technology to a certain extent (Porter 1985). Furthermore, a value activity consists of physical and non-physical components, while it requires processes and creates information during the actual task performance. Therefore, the framework emphasizes the relevance of information technology in any business model and illustrates the potential for competitive advantages through technology (Porter and Millar 1985)

Beyond the Value Chain model, Porter states that a firm's value creation is a linkage between multiple value chains. These value chains belong to different participants, as reflected through the roles “Supplier”, “Business Unit”, “Channel” and “Buyer”. All linked value chains of these participants result in a value system. (Porter 2001) This understanding allows to depict the complexity of various business models, understand the cross-company value creation flow, and identify potentials for leveraging competitive advantages through technologies.

Based on this understanding, Walters and Lancaster define the value chain linkage as:

> *"a business system to create customer satisfaction (i.e., value) […]"* (Walters and Lancaster 2000).

They state that all activities in a value chain are reasonable only if customer satisfaction exceeds the effort required to execute the respective value activities. Managing value chains is divided into the two disciplines of information management and relationship management. Furthermore, they state that the discipline of supply chain management is complementary to that of value chain management. The strategic scope of interface relationship management is highly significant for the efficient value chain management. (Walters and Lancaster 2000)

2.2.2 Business Processes

The various aspects of the value chain are described in the previous chapter as a set of linked value activities and some frameworks already use the term of processes within their value creation definition (Gassmann et al. 2013; Richardson 2005) it is necessary to highlight the major components of the business processes research field for the research purposes in the following chapter. Therefore, the following section explains the origin and meaning of processes in general, demonstrates the relevance for value creation, and concretizes the term and research field of business processes.

Activities and processes are occasionally used as synonyms. However, there is a difference in both terminologies. A process is defined as:

> *„[a]ny sequence of pre-defined activities executed to achieve a pre-defined type or range of outcome."* (Talwar 1993)

While the activity itself solely describes the act of performing a task, a process has a clear purpose as per definition. Therefore, in terms of value creation, a value-, main- or support activity can be seen as a process given that the purpose of the activity is contained in the prefix of the terminologies. Additionally, there is an evident connection between a process and the value itself. The Value-Information-Process (VIP) framework in Figure 2.4 presented by Solaimani and Bouwman, shows how the information layer of a business model transmits the value of a process flow (Solaimani and Bouwman 2012).

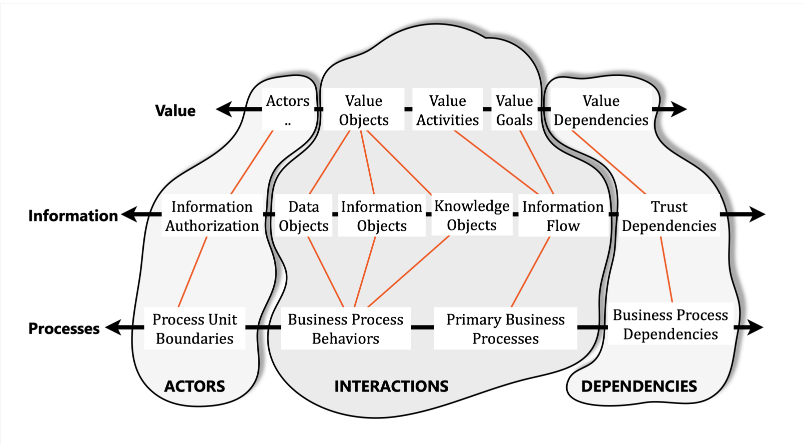

Figure 2.4: VIP Framework (Solaimani and Bouwman 2012)

Al-Debei and Avison stated the existence of coherence between business strategy, business models, and the so-called business processes. They highlight that with the increasing emergence of digital business, the linkage between business processes and the business strategy is achieved through the business model. (Al-Debei and Avison 2010) This also coincides with Richardson's understanding that the business model is part of the field business strategy and the link between strategy and execution (Richardson 2005). Figure 2.5 shows the hierarchy and overlapping points of these elements.

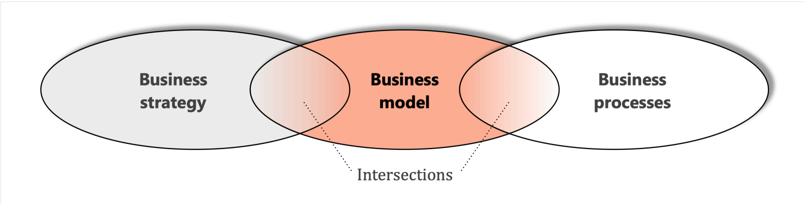

Figure 2.5: Business strategy, business model, and business processes (Al-Debei and Avison 2010)

The findings of Solaimani and Bowman as well as Al-Debei and Avison, highlight the role of processes as the operational layer with a crucial role for value creation. While neither distinguishes between processes and business processes, understanding a process needs to be concretized in the business context. In particular, the process definition from Talwar is generic. It needs to be adopted from the organizational business view by empathizing with how a process is executed and the focus of the output on a specific market. Therefore, a business process, contains of (Davenport 1993):

- Work activities
- Sequential arrangement
- Temporal and local distribution
- Fixed starting and ending point
- Specified inputs and outputs
- Performance dimensions of quality, cost, time, and customer satisfaction

Summing up the interplay between business models and business processes, the business model defines the value that must be strategically created. In contrast, the business processes explain, how the value is created at an operative level (Solaimani and Bouwman 2012). The research field of business processes contains two major research streams, business process management, and business process modeling, which are explained below. Furthermore, and regarding this thesis's research target, a third upcoming stream of the process virtualization will also be added to the explanation.

Business Process Management

Due to the linkage of inter-company value chains of different stakeholders, business processes require their own management approach. The business process management approach follows a systematic and structured method of (Elzinga et al. 1995):

1. Process selection
2. Process description
3. Process quantification
4. Process improvement selection
5. Implementation

It includes the analysis, improvement, and monitoring of fundamental activities such as marketing, communication, and other core elements of company processes (Zairi 1997). The overall goal is to improve the quality of products and services by using dedicated methods, technologies, and software. It, therefore, requires combining knowledge from both fields, IT and management. (van der Aalst 2004; van der Aalst 2013)

Business Process Modeling

Compared to business process management, the business process modeling stream focuses on specific methods to depict the activities, states events, flows, and others within a business process and is also seen as a part of software development (Recker et al. 2009). As business process management requires a process description, both research streams have common targets and depend on each other. However, business process modeling is directly linked to the actual process execution and, therefore, is more technically focused.

Business process modeling methods evolved over decades and started with mathematical paradigms such as the Petri Nets (Petri 1962) with the purpose of the abstract depiction and execution of a process itself. Over the years, methods developed with more intuitive graphic modeling approaches have targeted the application of improvement initiatives (Phalp 1998; Recker et al. 2009; van der Aalst and ter Hofstede 2005). The methods evolved from illustrative computer-drawn flowcharts (Knuth 1963), throughout data flow diagrams (DFD) (Ward 1986), over the event-driven process chains (Keller et al. 1992; van der Aalst 1999) to the wide-spread utilized Business Process Model and Notation (BPMN)(White 2004).

Of course, countless derivates and business process modeling methods are to be distinguished on a technical level. However, to connect both fields of XR technologies and value creation, especially frameworks on a more generic level are suitable for the research approach. Therefore, the Capture-Analyze-Present-Framework (CAP) is furthermore mentioned, as it is a framework that provides business process modeling guidance without a particular prescription of notations (Phalp 1998). It, therefore, allows a holistic understanding of a value chain with the scope of creating additional value through XR technologies.

Process Virtualization

The relatively young and less common field of process virtualization is to be mentioned in this section, as a third relevant stream for business processes. As it is not only part to understanding, depicting, managing, and improving the processes for deploying XR technologies, the process virtualization theory provides a basic understanding of the differences between physical and virtual processes (Overby 2008). Thereby, it creates an understanding of the requirements for virtual process execution. The process virtualization theory understands a physical process as an interaction between people or between people and objects. The theory speaks of a virtual process or process virtualization as soon as the physical component is missing or removed. The crucial requirements for the successful virtualization of a process lie in the morphology of the process in terms of (Overby 2008):

- "Sensory": the acquisition of the process status
- "Relationship": the relation between virtual and physical interaction
- "Synchronism": the temporal linkage within the virtual process flow
- "Identification & Control": the authoring of the virtual process

In summary, **chapter 2.2.2** illustrates the role of processes as the operating entity for the execution of a value creation. The linkage between value-creating processes and business strategy is ensured through a business model. Understanding the process is decisive for the value created, which is provided through an information layer. The business process is a concrete manifestation of the process and is characterized by a sequential arrangement and existing performance dimensions. Business processes require an approach to management and depiction, i.e., modeling. In addition, a business process can be analyzed and designed using defined criteria for its suitability for virtualization.

2.2.3 Resources

As previously summarized, the value creation within business models, is highly dependent on the operational setup of the business processes. Analyzing the frameworks from Table 2.1, it becomes apparent that next to the business processes, resources are a core component of value creation on the other hand (Richardson 2005; Osterwalder et al. 2010; Gassmann et al. 2013). With the business processes utilizing input to generate a specific output and the output of one business process as the input of the following business process in the sequence of a value chain, it is relevant to focus on the resource aspect.

Furthermore, there are theories around value creation that focus more on the static assets of an organization than on the dynamic process view of a company. The basis for this is Schumpeter's theory of economic development through innovation (Schumpeter 1934). Within this theory, Schumpeter states that technology plays a crucial role in advancing the act of combining resources in a new way and therefore being a source of value creation. Furthermore, Porter stated that:

> "[…] *every value activity uses some technology to combine purchased inputs and human resources to produce some output."* (Porter 1985)

Based on Schumpeter's view, the so-called resource-based view (RBV) of industrial organizations has developed as a theoretical research stream (Russo and Fouts 1997). It states that the economic competitiveness of a company and its business model is based on holding and building up resources that are not available to other organizations (Barney 1991). Resources are an integral component of the value-creating system and contain all firm's (Daft 2010; Barney 1991):

- Assets
- Capabilities
- Technologies
- Knowledge about organizational processes
- Firm attributes

Within the RBV, these resources are distinguished into physical, organizational, and human resources and are linked to the value creation through capabilities (Grant 1991). Furthermore, the dynamics of the capabilities of an organization are vital for integrating resources within a value creation. It is considered that those dynamic capabilities are individual for each organization yet provide similar patterns in the form of so-called best practices across organizations (Eisenhardt and Martin 2000).

Considering the dynamics of the capabilities within an organization, it is required to investigate the role of humans within the proposed research initiative. As the term, human resources is widely spread in industries and even as the name of a core value creation process, it is misleading in the context of technology-based innovation (Porter 2001). As the value of a technology depends on the extent of the user's capabilities in applying resources, the terminology resourceful human with a focus on the human intelligence and needs is more appropriate for investigating a value-adding technology deployment within a value creation context (Ovtcharova et al. 2015).

2.3 Extended Reality (XR)

Extended Reality (XR) is an umbrella term that encompasses combinations of real and virtual surroundings in varying degrees and combines Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)(Chuah 2018; Fast-Berglund et al. 2018; Rauschnabel et al. 2022). For the underlying research scope, this thesis is based the following definition of XR:

> XR is the experience of an extension of the physical reality generated by technologies and therefore based on technical capabilities to computer-generate immersive experiences. (Fast-Berglund et al. 2018; Stanney et al. 2021).

As the term encapsulates VR, MR, and AR, the following section summarizes the history of these terms as well as their understanding.

2.3.1 Evolution of XR

Due to the increasing emergence of technologies for the combined representation of "Real Environments"(RE) and "Virtual Environments" (VE), Milgrim and Kishino formulated the "Virtuality-Reality Continuum" in 1994. The goal was to holistically depict the varying forms of XR generated by XR technologies, classify existing concepts, and show possibilities of the clash between real and virtual worlds. (Milgram and Kishino 1994) Figure 2.6 depicts the virtuality continuum.

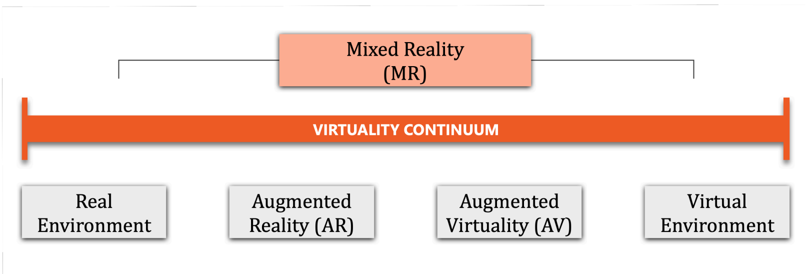

Figure 2.6: Virtuality-Reality-Continuum (Milgram and Kishino 1994)

Milgrim and Kishino intentionally established the term Mixed Reality (MR) with a certain lack of clarity to cover as many concepts as possible that cannot be classified within their "virtuality continuum" (Milgrim and Kishino 1994). Furthermore, the term VR is not displayed on the initial virtuality continuum. As a result, VR, AR, and MR have been used inconsistently in both practice and science (Jeon and Choi 2009). Since then, the literature has discussed the understanding of VR, AR, and MR and defined the terms in various dimensions (Flavián et al. 2019; Collins et al. 2017; Stanney et al. 2021). However, all three forms of XR that appear frequently share the following common understanding (Stanney et al. 2021; Flavián et al. 2019; Farshid et al. 2018; Collins et al. 2017):

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

Regardless, the term MR must be considered more closely under the prerequisite of the interaction between the real and the virtual. The term MR varies in the literature and is not clearly defined yet (Speicher et al. 2019). Thus, in the case of the generation of AR, the simple depiction of a virtual object in the real world is already to be regarded as interaction. Likewise, the presence of a human user in a generated VR is also to be understood as interaction. Consequently, both AR and VR are to be understood as MR in different degrees of the interaction design.

2.3.2 Characteristics of Virtual Reality

Until the 1990s, the term VR was usually equated with technologies and was defined as hardware and software systems used to create an illusion of presence in a VE (Biocca 1992). With the focus on technologies representing a VE, various solutions have resulted in an inconsistent understanding. Steuer pursued the approach of separating the meaning of VR from technology and defining it based on "tele-presence" - the experience of presence with the help of a communication medium. (Steuer 1992) Bryson extended this understanding with technological elements and understood VR as the use of computers and human-computer interfaces to create the effect of an interactive and three-dimensional world that provides a strong sense of presence (Bryson 1996).

Slater and Wilbur identified that the feeling of presence is subjective and can vary from one user to another (Slater and Wilbur 1997). To classify VR systems objectively, Bowman and McMahan focused on immersion and interaction to exclude the subjective reaction of an individual (Slater 2003; D. Bowman and McMahan 2007).

> *Immersion* is the ability of a VE to generate the user's perceptual image through virtual cues and remove stimuli from the physical world and directly dependents on the performance of a VR system. (D. Bowman and McMahan 2007; Biocca 1992)

VEs can provide different degrees of immersion depending on the underlying use case, requirements, and system restrictions. VR is divided into non-immersive experiences, semi-immersive experiences, and fully immersive experiences depending on the characteristics of the components, generating the VE (Craig et al. 2009).

Interaction is the second component of the "human-VE-interaction loop" after Bowman and McMahan.

> *Interaction* is the ability of a VE to allow the user to communicate via the computer with the scene and the stored data model. (D. Bowman and McMahan 2007)

Through this abstraction, Bowman and McMahan separated the application effectiveness of VR technologies from the feeling of presence. Furthermore, they showed that different use cases require another degree of immersion to successfully use VR technologies.

Besides "immersion" and "interaction", the subjective component of the individual within the VR system is reflected by the individual's ability of imagination. Feature to depict a human-centered understanding of VR with the so-called "3 I" (Burdea and Gouffet 2003; Häfner et al. 2013).

However, an individual's imagination is subjective and can only be verified to a limited extent. To depict VR holistically, it is, therefore, logical to assess the VE`s intelligence. The dimension of intelligence is, therefore, more suitable to describe and classify the XR experiences.

> *Intelligence* is the ability of the VE to react and adapt to the varying contexts of the user's interaction with semantic capabilities. (Ovtcharova 2020; P. Häfner 2020)

Figure 2.7 depicts the three dimensions to characterize XR experiences.

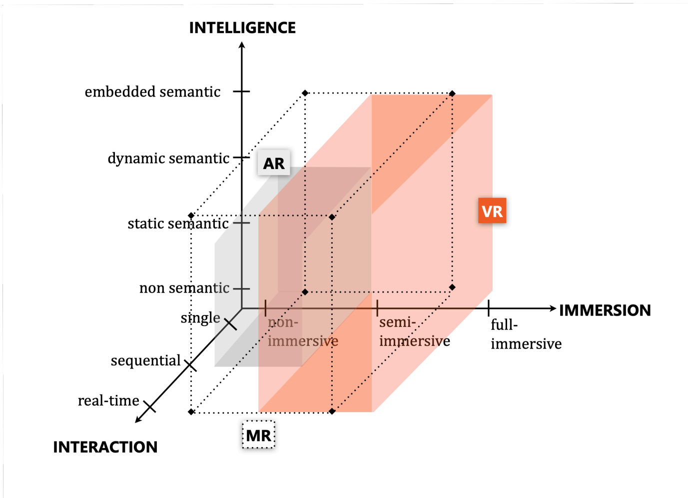

Figure 2.7: Three dimensions of XR (Ovtcharova 2020)

2.3.3 Characteristics of Augmented Reality

While VR is a widely discussed term and various studies have been conducted from both technological and psychological perspectives, the strongly related term of AR has a straightforward understanding with plenty of research analyzing the technological execution and use cases in industries.

AR is generated through the technological provision of local virtuality (Van Krevelen and Poelman 2010). Therefore, AR is created through technologies in which a real world scene is enriched by virtual objects (Milgram and Kishino 1994). Azuma understood AR as a variation of VR and, based on Milgrim and Kishinio's virtuality continuum, formulated the three core characteristics of AR, which are considered the common understanding of AR in the literature (Azuma 1997; Azuma et al. 2001):

- the combination of real and virtual, i.e., intelligence.
- real-time interactivity, i.e., interactivity.
- three-dimensional depiction, i.e., immersion.

AR can therefore be described with the same performance dimensions of VR, depicted in Figure 2.7. In terms of the definition, this combination is equal to the augmentation of the reality. Interaction is a prerequisite for AR to display the virtual content in the proper position to ensure the correct three-dimensional depiction. Furthermore, the interaction can range from a simple registration of the real environment through the AR system to a highly interactive experience for the user with a frequent manipulation of the virtual content (Craig 2013).

AR can viewed as a medium provided through technologies that empower the interaction between humans and between humans and machines (Craig 2013). The primary purpose of AR is when a user needs to perceive his real environment, which can be supported by displaying data and information within this scene (Egger and Masood 2020).

2.4 XR Technologies

After clarifying the emerging umbrella term of XR in **chapter 2.3**, the following section will explain recent developments and the state-of-the-art regarding XR technologies. In general, this study is based on the understanding that XR is a perceptual extension of the physical reality of a user (**chapter 2.3**). XR technologies have generated this extension. Depending on the composition and maturity of these technologies, the reality can be extended in various ways.

To depict a holistic picture of XR technologies, the following section divides XR technologies into the main categories of hardware systems, software development, and content creation. Hardware systems include all the physical components of a system composed of XR technologies, both in direct physical contact with the user and not accessible to the user. Software development is related to all coding-related technologies for developing the front- and Back-end for an XR technology deployment. Even though the content might not seem to be the technology itself, it is considered a crucial part of XR technologies, as content creation and authoring are highly technical and require sophisticated tools and skills.

2.4.1 XR Hardware Systems

XR hardware to generate VR is utilized when a feeling of immersion or the sense of presence in a simulation is generated for users (Sherman and Craig 2003). In general, the system setup requires hardware units for (Craig et al. 2009):

- Enabling interaction for the user
- Determining the position of the user in the system through tracking components
- Creating visualization, audio, and, if necessary, further output devices for addressing additional senses
- Running the corresponding software and the physical simulation of the XR and for translating the simulation into graphic representations and, if necessary, other forms of sensory perceptions.

Depending on the configuration of the VR hardware system setup, systems have a varying performance spectrum in terms of immersion as well as in terms of costs. System configurations can be distinguished into non-immersive, semi-immersive, and fully immersive systems according to the characteristics of single components (Craig et al. 2009). Furthermore, single devices can fulfill the functionalities of multiple component categories.

XR technology compositions to create AR are required when the user perceives his real environment augmented by virtually displayed data or information (Egger and Masood 2020). For the technical implementation of an AR system, hardware units are required for (Wang et al. 2016; Egger and Masood 2020):

- Creating an interaction for the user through a user interface
- Positioning the data and information to be displayed through a tracking system
- Recording the environment through a sensory system
- Mapping data and information into reality through visualization technology
- Data processing, calculating, and preparing the contents to be displayed.

Looking at the units of the XR technology setups for both VR and AR, it becomes evident that they follow the pattern of the human-machine interface loop consisting of output units, input units, and PC structures. Figure 2.8 displays the model.

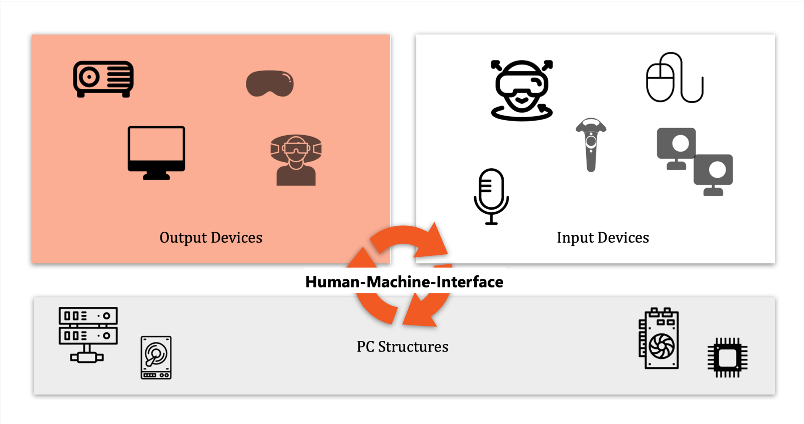

Figure 2.8: Human-Machine-Interface loop (Ovtcharova 2020)

The output units of XR technologies are those that provide visual, tactile, and audio cues to the user. The input units capture data from both the user and the environment through dedicated interfaces for data input and a sensory system that tracks the data required for the XR system composition to generate XR. The processing unit (i.e., PC structures) is considered the base layer that unifies and aligns input and output units while running the required software and algorithms. The following section elaborates on the relevant technologies behind the different technology units.

2.4.1.1 Output Units

The output units are in direct contact with the user and stimulate his senses. For the feeling of immersion, the visual stimulation is in the foreground. Therefore, a major focus in terms of output is the visualization technology to present visual content to the user. Further, tactile feedback and audio stimuli are required to address the relevant senses of a user to create a higher degree of immersion in a multisensory experience (Narbutt et al. 2017; Ramsamy et al. 2006). As already mentioned, a different degree of immersion can be achieved depending on the selected system setup.

Visualization Output Units

XR systems can be classified into non-immersive, semi-immersive, and full-immersive systems (Craig et al. 2009). This relates to the extent to which a user is isolated from external impressions using a visual hardware setup. A wide variety of display technologies exists to provide users with visual (partially) immersive experiences. Figure 2.9 provides an overview of different display devices for creating XR experiences.

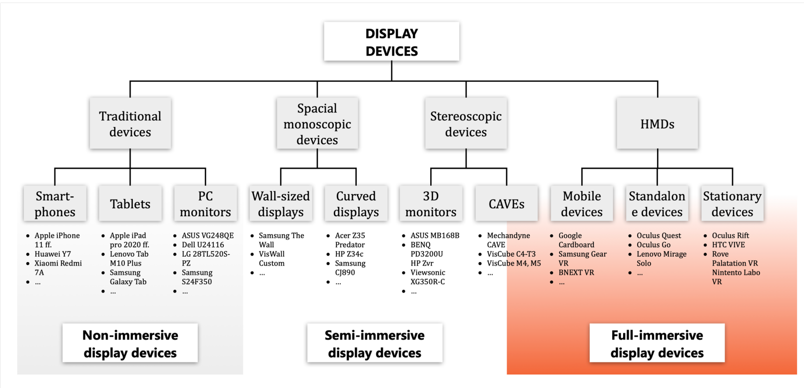

Figure 2.9: Classification of VR visual output devices (Çöltekin et al. 2020)

The first class of traditional display devices contains standard display technologies, such as the displays of mobile devices or TV and PC screens. These devices can be utilized to create a non-immersive VR, the so-called desktop VR experiences (Prabhat et al. 2008). The configuration of a VR setup with traditional displays can be beneficial in terms of costs. In specific cases, it provides a better setup for certain purposes over other displays, as the user can perceive a three-dimensional depiction of content on two-dimensional monoscopic display technology while still being able to perceive their environment (Srivastava et al. 2019).

On the one hand, the semi-immersive visual component is characterized by a specific geometrical form of a monoscopic visualization display. The semi-immersive perception results from the parial isolation of external impressions created through an extensive size or specific shape, e.g., curved displays (Çöltekin et al. 2020). On the other hand, a semi-immersive visualization results from the actual availability of the third dimension in a stereoscopic device. The third-dimension results from the spatial arrangement of multiple screens of a stereoscopic display. The three-dimensional visualization on the stereoscopic device is created by a perspective projection in these three dimensions based on the user's position, which results in a so-called fish-tank VR experience (Ware et al. 1993). Figure 2.10 shows a recent scientific concept setup that utilizes a specific fish tank VR display.

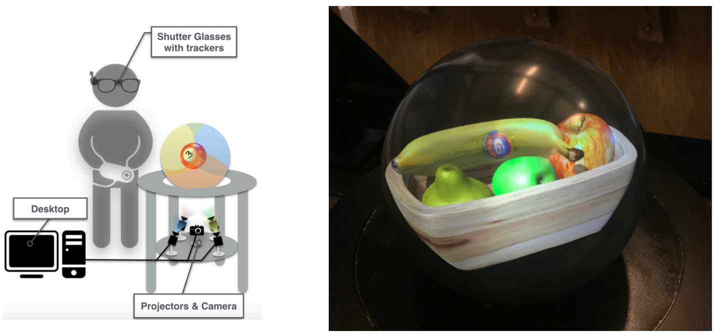

Figure 2.10: Setup and visual appearance of a fish tank VR visualization (Zhou et al. 2019)

Within the example, the stereoscopical character of the setup is not created by multiple overlaying screens but through a spherical display, enabling continuous availability of three dimensions. Especially the glasses on the head that are tracking the users' point of view is highlighting the principle of the fish tank VR concept (Zhou et al. 2019).

Within the full-immersive visualization technologies for XR systems, the two major classes are head-mounted displays (HMDs) and CAVE automated virtual environments (CAVE). HMDs were the first concept of VR visual interfaces that provide the user with an isolated three-dimensional view of a virtual scene based on the user's position (I. E. Sutherland 1968). They have evolved over the years and appear in different morphologies, as suggested in Figure 2.9. Mobile HMDs turn external displays (e.g., smartphones) into VR visual devices by (1) carrying the display in front of the users' eyes, (2) providing isolation against external visual cues, and (3) using analogous optical components such as lenses for creating a three-dimensional depiction of the two-dimensional display technology (celexon 2022). Figure 2.11 shows the low-cost concept from the celexon VR headset for turning regular mobile devices into a VR-capable display unit.

Figure 2.11: Components of the celexon VR headset for mobile devices (celexon 2022)

The first class comprises of standalone solutions and stationary devices. These devices provide a more sophisticated technological setup with integrated displays, tracking systems, audio output units, and input devices for a full-fletch VR experience. While standalone solutions contain all the required units in one device mounted on the user's head, there is no requirement for connection to a processing unit (e.g., a separate PC or console), which increases the user's freedom to move. The advantage of stationary devices, as shown in Figure 2.9 is the capability of calculating more complex 3D scenes with the availability of higher computing power and higher accuracy in position tracking compared to the standalone devices (S. Jung and Jeong 2020). Figure 2.12 shows two examples of the current Meta Quest 2 (standalone) and HTC Vive Pro 2 (stationary) as examples of HMD VR display units. While Meta Quest 2 provides a wireless user experience with all XR technology units integrated, HTC Vive Pro 2 requires both the setup of external tracking devices (i.e., input unit) and an external processing unit for creating the XR experience (Combe et al. 2022).

Figure 2.12: Stand-alone and stationary HMD concepts (meta 2022; HTC 2022)

The second class of full-immersive display devices is CAVEs. In general, a CAVE is a VR interface consisting of projectors that provide multiple users with immersive visualization experiences by projecting three-dimensional content on walls, floors, and ceilings (Juarez et al. 2010). The motivation for the concept results in an approach to avoid immersion issues, which are a restricted field of view, a lack of panorama display capability, a viewer-centered perspective, the missing body representation, and intrusion, i.e., isolation from external influences (Cruz-Neira et al. 1992). Especially the natural moving behavior in a CAVE as well as the possibility of multiple users experiencing the same virtual content in the same location empower a high level of immersion, whereas the other hand the complex setup requires expensive hardware (Manjrekar et al. 2014).

Regarding AR, there are two common classes of visualization concepts, mobile AR (MAR), consisting of HMDs and hand-held displays (HHD) and spatial AR (SAR)(Marner et al. 2014; H. Choi et al. 2019). MAR can be provided to users through various XR technology setups. Figure 2.13 provides an overview of common MAR visualization technologies.

CHARACTERISTICS / DISPLAY	WEARABILITY	IMAGE FOV	ISOLTATION	REAL WORLD REPRESENTATION	CONVENIENCE/ SWITCH TO SMARTPHONE
PHONEAR: VIDEO SEE-THROUGH SMARTPHONE	hand-held	small display: 25° overall: human FOV	No	Live camera video	high (direct usage)
CLOSEDAR: VIDEO SEE-THROUGH SMARTPHONE INSERTED INTO CARDBOARD CASE WITH LENSES	hand-held and closely worn	medium (magnified) Display: 96° overall: 96°	Yes	Live camera video	low (insert phone)
EASYAR: VIDEO SEE-THROUGH SMARTPHONE INSERTED FLIP-ON LENSES	hand-held and closely worn	medium (magnified) Display: 76,5° overall: human FOV	No	Live camera video	Medium (flip on lens)
OPENAR: OPTICAL SEE THROUGH (GLASS-LIKE) DISPLAYS	worn	large (human FOV) Display: 30° overall: human FOV	No	As is	high (direct usage)

Figure 2.13: Classification of Mobile AR visualization technologies (H. Choi et al. 2019)

With the increasing computing power of mobile devices and the improvement of hardware components (camera, depth sensors, etc.), there is a growing commoditization for AR-capable technology (Henrysson et al. 2007). Even though the immersion of mobile device AR is limited as users have to hold the device with a restricted field of view (FoV), PhoneAR experiences can reach a considerable potential without the additional hurdle of high-end device investments as the AR capable phones are available as Commodity-Off-The-Shelf devices (COTS) (H. Choi et al. 2019). Significant limitations of MAR applications running on mobile devices result from high battery consumption through simultaneously required hardware components as well as thermal issues that directly affect the user experience (H. Chen et al. 2018).

The listed display characteristics in Figure 2.13 ClosedAR and EasyAR provide a similar solution to PhoneAR while eliminating the requirement of carrying the device. Therefore, the second relevant type of MAR is HMD-based. Some VR devices offer a dedicated AR functionality and a system for capturing and displaying the real environment to the user (Çöltekin et al. 2020). Further than that, specific standalone AR HMDs are tailored to provide an AR visualization, such as the Microsoft HoloLens and the MagicLeap2, which offer a holistic platform with an industrial focus (Microsoft 2022b; Magic Leap 2022).

SAR, on the other hand (comparable to the CAVE visualization of VR experiences), is focused on the projection of virtual content onto a physical environment with cameras and structured light-emitting projectors. While it is possible to alternate the visual appearance of physical objects and provide information on physical objects, SAR is limited to a restricted environment, and the need for a physical surface as SAR is incapable of creating a three-dimensional hologram “midair” (Marner et al. 2014).

Multi-sensory Output Units

As previously stated, immersion is a performance factor for XR technology configurations. Apart from responding to the user's visual sensory stimulus, the auditory and tactile response is also considered within XR technologies to achieve a high degree of immersion.

The audio aspect of XR technologies enhances the immersive experience of a user by improving the user's connection to the VE with auditive stimulation and transportation of information for orientation (Dombrowski et al. 2019). The technical unit for the output of auditory impulses can range from classic headphones to stereo speakers to multi-channel systems (Dörner et al. 2019).

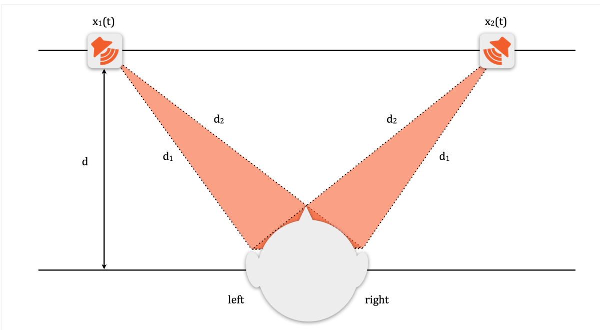

Figure 2.14: Concept of a binaural audio setup with two audio sources (Parida et al. 2022)

One of VE's high-performance audio output technologies is the so-called binaural audio which is the output of sounds perceived by a user as if they were in a specific location (Meghanathan et al. 2021). For this, specific rendering methods for identifying the position and sound emitting direction are required (Bailey and Fazenda 2018). Figure 2.14 shows the concept of a binaural audio setup, generating a "three-dimensional" audio experience from a mono audio source, depending on the relative position of a user to two sound emitters $x_1(t)$ and $x_2(t)$.

The haptic output units for XR technologies setup can also enhance the immersion as well as the guidance of the user through the VE. In particular, in terms of MR, where the physical and virtual boundaries are blurred, haptic feedback towards the user can provide intuitive information such as warnings to avoid physical damage (Dombrowski et al. 2019).

2.4.1.2 Input Units

The input units of XR technology systems fulfill the purpose of tracking and interaction. Input units can be divided into two categories: (1) acquisition of required spatial data and (2) acquisition of user data.

The input of Spatial Data

Various sensors and cameras are used to capture spatial data on the user positioning and environmental scales. Depending on the performance of the XR system setup in terms, i.e., the availability of sensors, the user is provided with three or six Degrees of Freedom (DOF). A system with six DOF allows three linear and three rotational movements to the user (Stewart 1965). To make this possible, the XR system setup must have appropriate sensors to track the user's position within a room and not only their rotatory position on the spatial conditions (XR Association 2020). Figure 2.15 shows the tracking requirements of a 3 DOF system compared to a 6 DOF system.

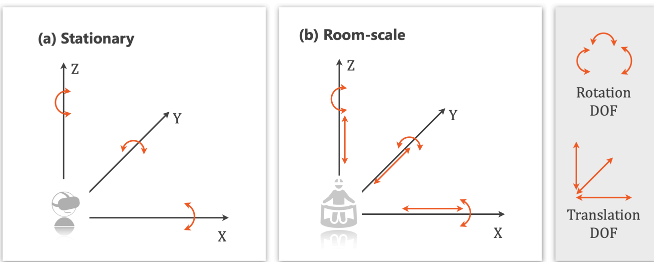

Figure 2.15: Tracking requirements for a stationary and a room-scale VR setup

The so-called stationary system setup (e.g., Mobile VR HMDs) provides a sitting user experience. The system does not provide user position tracking and only captures the head rotation in X, Y, and Z directions to correctly display content to the user (Stanney et al. 2021). A so-called room-scale system has more sophisticated user position tracking in a physical room to enable the user a translatory movement within the space which can be reflected in the virtual content shown through the XR system (Stanney et al. 2021).

In terms of capturing room data and spatial input units for AR, mobile devices use built-in cameras to capture spatial input data from the user and the environment, whereas dedicated AR HMDs provide depth sensing, real-time object recognition, and spatial mapping (Brigham 2017). However, the technology in mobile devices has advanced, e.g., the new generations of Apple devices, iPhone Pro, and iPad Pro from 2020 onwards have a built-in light detection and ranging (LiDAR) sensors (Apple Inc. 2020). This increases the environmental tracking accuracy and the speed of plane detection (Vogt et al. 2021). Furthermore, it enables both a higher level of realism in AR applications through occlusion (i.e., the realistic spatial relationship between virtual and physical objects; see Figure 2.16) as well as industrial 3D scanning applications through AR technology (Tatsumi et al. 2022; Krajancich et al. 2020).

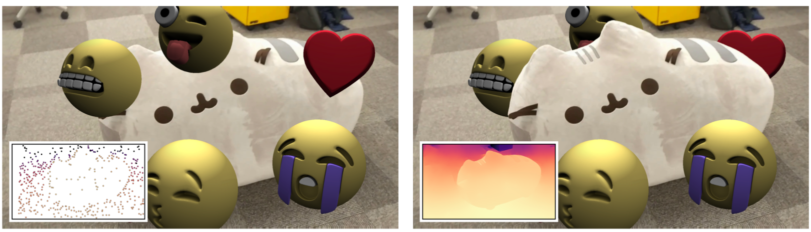

Figure 2.16: Comparison of AR without and with occlusion (Holynski and Kopf 2018)

Input of User Data

Additionally, for spatial data acquisition units, an XR technology setup requires units to acquire data from the user interaction within the VE. To capture this data, the XR technology composition needs to provide interfaces for the user to interact proactively with the system. These interfaces can acquire data from the user's gestures and motions, actions of the user with specific interaction devices (e.g., controllers), or users' speech commands for data input (Stanney et al. 2021).

User gestures in an XR technology environment can be captured using wearables, touchscreens, and computer vision (Y. Li et al. 2019). While wearables such as data gloves provide high accuracy of the user positioning and gesture capturing, the user's embodiment with a physical hardware unit restricts the sense of immersion due to a less natural subjective behavior feeling among users (Dong et al. 2021). Furthermore, user gestures can also be captured in two dimensions using touchscreens. Mobile devices for MAR provide an integrated user data input unit. This has a high degree of user acceptance because the user is accustomed to entering data via the smartphone's touchscreen, even from non-AR-based applications in everyday life.

Regarding VR system configurations, the gesture input via touchscreen is limited to non- and semi-immersive system setups, as the user is excluded from external cues in fully immersive VR systems. A sophisticated software-technological data-entry unit through gestures is a computer vision-based gesture recognition, which adds a semantic context through artificial intelligence (AI) to acquire data from computer vision and spatial tracking of users' body parts (Lin et al. 2014). With recent technological advances in these fields and the more natural user perception, modern XR hardware device setups, such as the Meta Quest 2, provide integrated hand-tracking and gesture data input units (meta 2022; Stanney et al. 2021).

Regarding interaction devices, various VR system setups provide a set of controllers for the user to interact with the VE. The performance capacities of controllers, i.e., the interaction possibilities, depending on the DOF provided through the available sensors capturing rotatory and translatory movement from the controllers (Stanney et al. 2021).

Figure 2.17: Hex-Core-MK1 omnidirectional treadmill (Z. Wang et al. 2022)

Further than the “standard” controller interaction, an XR technology setup can be equipped with specific interaction devices for navigation in the VE, such as omnidirectional treadmills (ODT) (Anthes et al. 2016). The user can intuitively interact with the VE by walking in the VE through the ODT without a spatial variation in his position in physical reality. Figure 2.17 shows an exemplary scientific concept of an ODT VR setup, which enables the user to have an infinite walking experience in a room-scale VR system.

An XR technology setup with user data input interfaces through speech relies mainly on existing third-party solutions, e.g., the mobile OS providers Apple and Google (Stanney et al. 2021). As this technology relies on the recognition of specific words, it can be deployed within an XR technology setup as enhancing feature. Yet, it is neither intuitive nor sufficiently mature to navigate solely within a VE through speech.

2.4.1.3 Processing Units

After introducing relevant output and input units of XR technology hardware, the third layer to be described within the hardware systems of XR technologies is the required computing power for processing (e.g., generating, merging, filtering, rendering, storing, etc.) the relevant data, information, and content of an XR system. Since this is a highly comprehensive topic and beyond the scope of this thesis, the following section will only touch on the relevant processing system components and their interaction to present the current state of the art as a basis for value added XR deployment.

One of the most critical aspects of the performance of an XR technology setup is the minimization of latencies to provide a real-time experience to the user. In general, the generic and highly abstract iteration flow to display a VE through processing hardware is an iteration of (Dörner et al. 2019; H. Chen et al. 2018):

1. Capturing user and environmental data
2. Manipulation of the VE in the Central Processing Unit (CPU)
3. Transferring the generated scene to the Graphics Processing Unit (GPU)
4. Rendering the scene for the user, and
5. Storing relevant data in the database

As described in the previous chapter, XR technology compositions can either have their integrated CPUs and GPUs, relying on the processing units from mobile devices, or entire external processing units such as PCs. Depending on the intended use and application, different system combinations can be the best solution in terms of cost and experience. Regardless of the composition of CPUs and GPUs, it should be noted that the data storage availability requirements are significantly higher than for two-dimensional business applications, mainly because of to the file size of the three-dimensional content to be displayed.

Depending on the use case scenario and the requirements towards the level of detail (LOD) and level of realism (LOR), these iterations require high-performing hardware components for the operational memory

(RAM), the CPU, the GPU, and the efficient interplay of these components (Çöltekin et al. 2020).

To create a performant XR experience in general, the XR processing hardware is only one part of the system to be correctly dimensioned. The entire XR technology composition must be optimized regarding the hardware interplay, an efficient interplay of algorithms (e.g., for rendering and collision detection), as well as the creation of visually appealing yet efficiently manageable three-dimensional content (Dörner et al. 2019).

2.4.2 XR Software Development

After presenting the relevant XR hardware systems, the following section focuses on XR software development in XR technologies. XR software belongs to the research discipline Information Systems (IS) and therefore has a relevant interconnection to software development itself (Chuah 2018). Because XR is strongly related to game development, in addition to a compact summary of software development, the idiosyncrasies of XR development technologies will be highlighted in this chapter.

2.4.2.1 Agile Software Development

Software development generally includes methods for designing and implementing software systems (Mills 1976). After various publications on new methodologies for software development appeared at the beginning of the 2000s, Fowler and Highsmith formulated “The Agile Manifesto” together with 15 experts and stated the following four core values for improving the process of software development (Fowler and Highsmith 2001):

- *„Individuals and interactions over processes and tools. “*
- *“Working software over comprehensive documentation. “*
- *„Customer collaboration over contract negotiation. “*
- *„Responding to change over following a plan. “*

In recent years, various agile methods for software development have been established in practice due to their effectiveness, collaborative empowerment, and target orientation (Edison et al. 2022). Table 2.2 sums up selected relevant agile software development methods with their main definitions, which are common among organizations and, therefore, relevant for the scope of this thesis (Hoda et al. 2018).

Table 2.2: Collection of agile software development methods (Abrahamsson et al. 2002; Edison et al. 2022)

Name	**Sources**	**Definition**
SCRUM	(Schwaber 1997)	*” SCRUM defines the systems development process as a loose set of activities that combines known, workable tools and techniques with the best that a development team can devise to build systems. “*
eXtreme Programming (XP)	(Beck and Andres 2005)	*” XP is a style of software development focusing on excellent application of programming techniques, clear communication, and teamwork which allows us to accomplish things we previously could not even imagine. “*
Development and Operations (DevOps)	(Leite et al. 2020)	*” DevOps is a collaborative and multidisciplinary effort within an organization to automate continuous delivery of new software versions, while guaranteeing their correctness and reliability. „*
Open-Source Development (OSS)	(Abrahamsson et al. 2002)	*“OSS is not a compilation of well-defined and published software development practices constituting a written eloquent method. Instead, it is better described in terms of different licenses for software distribution and as a collaborative way of widely dispersed individuals to produce software with small and frequent increments. “*

Of course, there are numerous other (agile) software development methods. They vary in certain practices, processes, the role distribution of teams, the suitability for software project sizes, organizational conditions, and many other points. The mentioned methods are significant in developing VR and AR applications (Hoda et al. 2018). Especially the XR technology evolution speed and extensive feedback integration throughout the solution lifecycle requires agile software development methods (Mattioli et al. 2015).

2.4.2.2 XR Software Development Environments

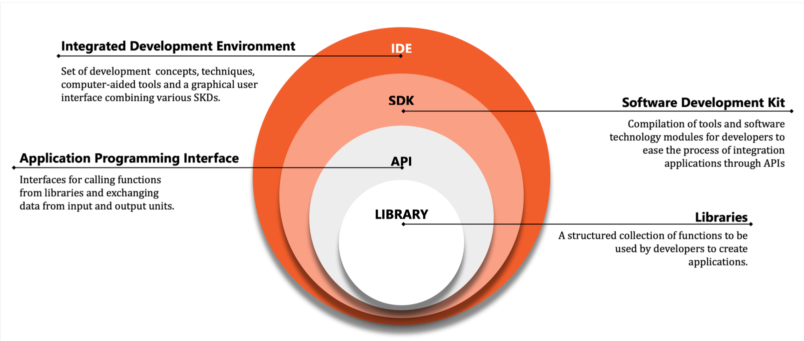

Figure 2.18: Hierarchy of development environments for XR software

Figure 2.18 shows the hierarchy of software development environments relevant to XR software deployment. Each category contains complex interrelations and functionalities. For the scope of this thesis of value creating XR technology deployment, it is relevant to understand the generic concept and the hierarchy of these categories, as well as the challenges and benefits of creating XR software within these environments. The following section provides an overview of relevant examples from science and practice within this hierarchy.

Software solutions were developed for the selected XR hardware setup, depending on the use case scenario and the resulting business requirements. These can range from simple three-dimensional data representations to high-fidelity visualizations with high LOD requirements. This broad spectrum and the need for content interactivity place unique demands on the development environment (XR Association 2020).

Integrated Development Environments (IDE)

XR development is a hybrid discipline that combines software development and game development (Stanney et al. 2021). Therefore, IDEs are a highly relevant field in XR software development. They provide developers with 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 (Konsynski et al. 1984; Chafle et al. 2007).

One highly relevant category of IDEs for XR software development are game engines. With existing modules for AI, physics, scripting, input data processing, rendering, and networking, the UNITY 3D engine provides the required components to create an XR solution with existing modular components (Messaoudi et al. 2015). As a cross-platform IDE with a large community, UNITY 3D is a popular framework for developing XR software solutions (Krauß et al. 2021). Furthermore, UNITY 3D provides a dedicated asset store for developers to buy assets, i.e., predeveloped software components, templates, and tools for specific features (Unity 2022). This increases the speed and the effectiveness of the development process of XR solutions. Restrictions exist for specific business applications as, e.g., the integration of required data interfaces for business solutions in the pre-existing modules, which is time-consuming and error prone. Furthermore, the handling and manipulation of computer-aided design (CAD) data in high-end engineering solutions is not directly feasible (P. Häfner 2020).

A second game engine from this category is the UNREAL Engine offered by Epic Games, providing similar modules for XR software development (Epic Games 2022). While UNITY 3D has a wider variety of possibilities for developers with a higher maturity, UNREAL has an advanced rendering approach for more detailed graphics and better collaboration opportunities due to the sophisticated network communication stack (Hilfert and König 2016). Solutions for UNITY 3D are coded in the coding language C#; UNREAL solutions are based on C++, while they can also be developed graphic-based with so-called blueprints. For deploying advanced VR experiences in CAVE hardware systems, game engines might require middleware software solutions to process the specific data streams of the tracking systems (P. Häfner 2020). Furthermore, the lacking compatibility for CAD data requires extensive effort in creating 3D assets for the content to be displayed (see **chapter 2.4.3**.).

The second category of IDEs for XR software development involves VR engines. Unlike game engines, this category has its origin and its target users in science and engineering. IDEs like TechViz, COVISE, and IC.IDO focus on preliminary visualizations, prototyping, simulations, and collaboration on product-related data (e.g., CAD files) in immersive environments (TECHVIZ 2022; HLRS 2022; Esi Group 2022). These solutions provide direct compatibility and support for advanced hardware setups such as CAVEs. As professional software solutions, some of these IDEs are subject to fees and require the integration in the existing system landscape for the product data. With the focus on industrial development processes, the graphic fidelity is lower than that of game engines.

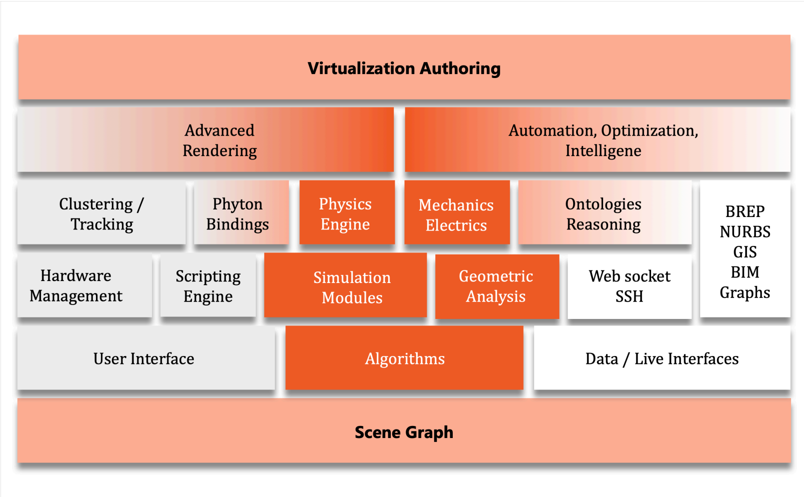

Figure 2.19: Modular system architecture of PolyVR (V. Häfner 2019; P. Häfner 2020)

Another relevant VR engine is PolyVR (V. Häfner 2019). This open-source authoring framework is based on a modular system architecture that supports various use case scenarios and different hardware setups from Desktop VR, and Web VR to HMDs and CAVE systems (V. Häfner 2019; P. Häfner 2020). Figure 2.19 shows the modular architecture of the framework, which can be flexibly used and adapted. In particular, the open-source character of the framework enables a continuous modeling, further development, and improvement of the solution through the scientific community.

Software Development Kits (SDK)

SDKs are widely used solutions for AR software development, especially for MAR. An SDK, like the IDE, is a compilation of tools and software technology modules for developers to ease the process of creating software solutions. Compared to IDEs, SDKs usually do not provide a GUI (Malgaonkar et al. 2015). The two most significant SDKs for mobile devices are ARKit from Apple for iOS devices and the ARCore from Google for Android devices (Berger and Gerke 2022). Both SDKs provide relevant features for developers to display virtual content in the real world, including (Oufqir et al. 2020):

- Motion tracking for user's real-world position
- Plane detection for identifying real-world surfaces
- Light estimation for shading
- Image tracking
- Face detection

Both SDKs differ in some of these functionalities and have advantages and disadvantages depending on the requirements of the use case scenario. The ARKit provides specific features like body detection, depth API, and the occlusion feature in its latest version ARKit 6, which enable developers to provide a high-performance and immersive AR experience for Apple mobile devices (Apple Inc. 2022b).

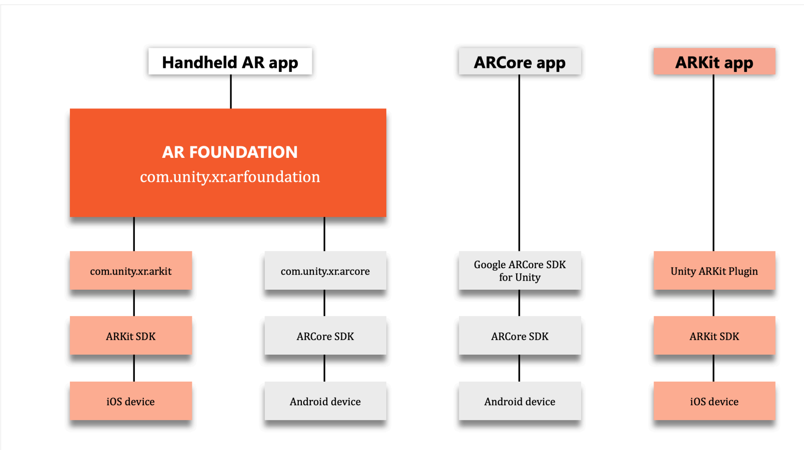

Figure 2.20: Integrative AR foundation for cross-platform development of MAR applications (Unity 2018)

As business-related XR software solutions might aim for the most significant user audience possible, deploying the solutions on both platforms, iOS, and Android, is relevant. As the authoring of the same solution for the two platforms increases the effort and thus the operational costs, cross-platform SDKs are required. UNITY 3D offers the AR Foundation SDK, which integrates all the overlapping functionalities of ARKit and AR Core, allowing development and authoring in one environment for both platforms (Unity 2018). Figure 2.20 shows the integrative role of the AR Foundation SDK. The disadvantages are the lack of functions only available in one SDK and the time delay until the functions of the new versions are also available in the AR Foundation SDK.

Next to AR Foundation, another platform-agnostic AR SDK is Vuforia, which focuses on industrial MAR applications (PTC Inc. 2022). With Vuforia, cross-platform applications for AR can be developed, but requires an acquisition before the SDK implementation, as it is not an open-source SDK (Berger and Gerke 2022). While being advantageous in terms of data compatibility and integration with other systems and features for industrial use cases, the pricing and scarcity of resources to create Vuforia solutions are obstacles to overcome when the solution development is done with this SDK. The deployment of XR software created for mobile devices, such as MAR or VR for HMDs, is executed through dedicated platforms. These platforms are related stores from the device providers (e.g., Google Play Store or AppStore) or cross-platform stores (e.g., Steam). For deploying solutions within these platforms, the created software might be subject to a defined review process according to quality guidelines from the providers. As the review process is executed manually, the time for deployment via these platforms can increase, and improvement iterations must be performed, increasing the deployment costs.

In terms of VR, various HMD providers also offer SDKs for creating XR software. The appearance of associations and cross-platform initiatives as “primers” increases as the VR market suffers from a strong fragmentation (XR Association 2020; Sternal et al. 2019). SDKs such as the

Microsoft MR Toolkit 2 and Valves SteamVR and Open VR are prominent platform-independent SDKs to increase the flexibility and the audience for software providers of XR solutions (Microsoft 2022a; Steam 2022).

Application Programming Interfaces (APIs) and Libraries

To deploy web-based VR and AR experiences, the XR software development requires the utilization of APIs and libraries explicitly. The most elementary form of this category is 3D web visualizers. Among others, this includes WebGL, which is a standardized, openly accessible, and platform-agnostic API. This can be used to publish three-dimensional content via a web browser without requiring specific hardware (Rechichi et al. 2016). In combination with the library three.js, developers can create more advanced 3D experiences, yet only to be considered fundamental XR experiences (three.js 2022). A more sophisticated web based XR experience can be created using the WebXR Device API. This API provides required features for developers to create and host AR and VR solutions for all types of output devices through the web, including modules for creating interactions with various device types (WebXR 2022).

Various APIs and libraries exist for customizing the features of VR and AR experiences within any development environment, such as OpenXR for cross-platform hardware interactions, OpenCV for computer vision, and OpenSG for scene graphics (The Khronos Group 2020; OpenCV 2022; OpenSG 2022). Applying these directly to software projects requires specific coding skills, a high level of coding experience within XR environments, and extensive testing effort to ensure a decent user experience.

2.4.3 Content Creation

In **chapter 2.4**, the varieties of hardware systems are explained, and the software-related features and specifications of XR technologies are highlighted. The third section on XR technologies now addresses the creation of the content reflected via the XR software onto the XR hardware systems to a user. As every XR technology composition of hardware and software addresses a human user, first and foremost, the user experience's design and the human interaction in XR are in the foreground. Additionally, the following section examines the content creation in terms of 3D assets to be displayed within an XR solution.

2.4.3.1 User Experience, User Interface, and Interaction Design

In general, designing solutions for humans refers to prioritizing human behavior, capabilities, and needs (Norman 1988). User-centered design (UCD) is a standardized method, and in terms of interactive systems of hardware and software, an approach to achieve usability and usefulness by focusing on human requirements through ergonomics (ISO 2019). As XR solutions address humans and even more, centralize humans in terms of immersion and interaction, HCD is of crucial relevance for the value-adding deployment of XR technologies.

Molich and Nielsen performed an empirical derivation of heuristics for designing systems that are "[…] *easy to learn and remember, effective and pleasant to use […]"* (Molich and Nielsen 1990). These generic design heuristics are highly relevant to XR content design (Wenting Wang et al. 2019). Table 2.3 lists the heuristics used to meet the usability requirements. These heuristics can be applied to the design of the user experience (UX), i.e., the journey of the user, his perceptions and perceptions while using the XR solution, and the user interface (UI), i.e., the critical enabler for the user to interact with the XR scene (ISO 2018).

Table 2.3: Usability heuristics (Molich and Nielsen 1990; Nielsen 1994)

Usability heuristics	**General description**
Dialogue simplicity	Avoid irrelevant information
Language of user	Use of familiar words and grammar for target user
Minimized memory load	Avoid necessity to remember advice for longer time
Consistency	Unified schemes, layouts and structure of actions and interfaces
Feedback	Information about background system activity

Exit points	Ability to leave scene at any time at a visible spot
Shortcuts	Integrate advanced features for experienced users to increase usage speed
Error prevention	Design to avoid unwanted actions
Constructive error notification	Provide precise messages with guidance to recovery
Error recovery	Enable un-do of unwanted or incorrect actions

Next to UI and UX design, it is required to create an interaction concept for the user that is intuitive to use and provides an immersive experience. For creating a UCD, a unified process is defined and consists of four steps that can be directly applied to the design of XR solutions and experiences (Jerald 2015; ISO 2019):

1. User context analysis regarding tasks, goals, and ecosystem
2. Derivation of user requirements
3. Development of alternative solutions
4. Iterative evaluation and adaption of the solutions

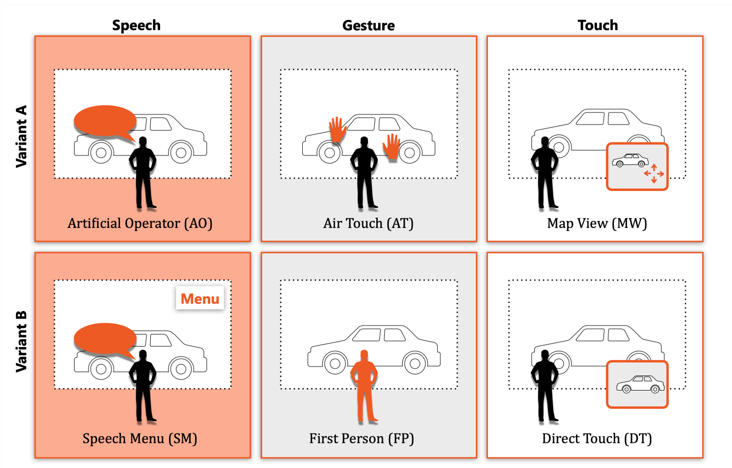

Figure 2.21: Interaction design validation for an industrial VR experience (de Clerk et al. 2019)

The UCD process is generic for products and interactive systems. It applies to XR solution design and should be followed to ensure user centricity within the XR technology deployment. Figure 2.21 shows the setup of a UCD process performed to design an XR solution. This study examines different interaction designs in a VR experience for a design review and illustrates how to design an interaction for users via different input devices. The various techniques are (de Clerk et al. 2019):

- Artificial Operator:
  Free scene navigator reacting to trigger and stop words
- Speech Menu:
  Hierarchal set of pre-defined commands displayed on the scene
- Air Touch:
  Overlaying the scene with an imaginary interface that tracks the user's gestures close to the virtual object
- First Person:
  Tracking users' position and adapting the model perspective accordingly
- Map View:
  Representation of the 3D model on a 2D GUI with navigation buttons and transferring the button trigger to the 3D model
- Direct Touch:
  Representation of the 3D model on a 2D GUI and transferring gestures from the user on the GUI to the model

Although the study is focused on a specific use case, the interaction methods identified and investigated demonstrate the variability of interaction design through hardware systems and software development. The concepts shown can be adapted and deployed for various XR experiences. It is required to assess the capabilities of the target user and the use case and technological prerequisites of the XR technology deployment to compile a suitable interaction design.

2.4.3.2 Asset Creation

Next to the UI, UX, and interaction design, creating an XR experience requires assets. Assets are the objects required to represent a virtual or augmented world. This includes, for instance, 3D models. Such models are either available in a format that cannot be used directly for XR environments or must be created from scratch.

Along the value chain of business models, relevant 3D models often exist as CAD data which can be an essential part of the value creation process. As mentioned earlier, many software environments for XR are incompatible with CAD data. For this reason, existing CAD models must be exported in a CAD exchange format and transformed into a compatible format to be rendered in an XR scene (Lorenz et al. 2016). Therefore, a complex process must be performed to convert the parametric information of the CAD model into a 3D mesh model that can be rendered into an XR scene (Hunde and Woldeyohannes 2022). A typical CAD exchange format is the Standard for the "Exchange of Product model data" (.STEP)-format (ISO 2021). Distinct XR compatible formats are, among others, Filmbox (.FBX)- or Object (.OBJ)-format (Stanney et al. 2021). To prepare the output data from CAD for display in the XR scene, the following properties must be assigned to the target data (Lorenz et al. 2016):

- Geometry
- Materials
- Textures
- Animations
- Collider

Even if some CAD programs can store all this information, these properties get lost during the format conversion process.

There have been various scientific approaches for automating this complex process, such as a rule-based conversion system (S. Choi, Jo, Lee, et al. 2010) or integrative product data management (PDM) approaches (Graf et al. 2002; Stelzer 2010). Also, commercial solutions exist that partially automate this process (CAD Exchanger 2022). However, generating graphically appealing models of decent file size and can therefore be handled, rendered, and transferred without time delay in scene generation still requires human intelligence.

For optimal conversion results and creation of 3D model assets from scratch, a specialist such as a 3D artist is required. The 3D artist works with dedicated 3D modeling software, such as Blender (open source), 3DS Max, Cinema4D, Maya, etc. (Blender 2022; Autodesk Inc. 2022a; Maxon Computer GmbH 2022; Autodesk Inc. 2022b). Within this software, the 3D artist can manipulate the geometrical appearance, reduce the polygon count and the LODs of the models regarding requirements, create animations, assign materials, and create textures to optimize the multi-dimensional trade-off between visible details, realism, file size and XR experience.

Other 3D assets relevant to the content creation of XR experiences are 360° videos or 3D scans that can be deployed within an XR experience for value creation. As XR technology among consumers is more and more distributed, the relevance of sharing 360° videos is increasing, even though the transfer of a massive amount of data a challenge for content creators (Sassatelli et al. 2020). Furthermore, both consumer devices with relevant capabilities and highly specialized hardware for 3D scanning are more and more distributed, enabling XR content creation. However, the quality of content, the post-processing of captured scans, and the amount to data required to transfer are significant challenges for XR experience creation with 3D scans (Vogt et al. 2021).

For faster creation of 3D assets or in case of lacking 3D artist resources, content creators can acquire 3D models on dedicated marketplaces to increase the process execution speed. Platforms like Sketchfab or TurboSquid provide a database with various 3D models in different formats, LoD versions, and are prepared for integration in XR software (Sketchfab 2022; TurboSquid 2022).

2.5 Summary of the Theoretical Foundations

In summary, the concept of business models has existed many years and has gained relevance and substance, especially in relation to the Internet and information technologies. While the understanding of business models varies in scientific approaches, value creation is a common denominator in each approach. Value creation is closely linked to value chains, which depict the interaction between value creation partners and are characterized by resources and processes. In a value chain, value is created using an output (use value) as well as through the transaction of an output between value creation partners (transfer value). On this basis, the methodology development can be carried out with the **research objective III** in mind since **chapter 2.1 and 2.2** can be used to model both the type of value and the realization of value.

On the other hand, XR is an umbrella term for the experiences VR, AR, and MR. While VR is a fully immersive experience, AR overlays the real world with virtual content. MR, in addition to displaying virtual content, is an experience coherently and bi-directionally interacts with virtuality and reality. While experiences are often described in terms of a continuum, it is useful to differentiate the various forms based on the degree of interaction, immersion, and intelligence of the experience. The generation of the XR experiences is performed by XR technologies. These can be divided into hardware systems, software tools and content creation methods. Depending on the composition of these technologies, a differently intelligent, immersive, and interactive experience can be created for the user with the help of the system setup. The understanding of the technology setup to generate an experience for the user, simplifies the deployment of XR for value creation. At the same time, the differentiation of the technologies into hardware, software and content creation enables a holistic mapping of XR experiences. Thus, **chapter 2.3 and 2.4** contribute to **research objective II** of complexity handling.

3 State-of-the-Art

Chapter 2 clarifies and delineates the basic terms used to develop the methodology. Based on the fields of business model and value creation as well as XR and XR technologies, the following section will examine current scientific approaches regarding the state-of-the-art for XR technologies in the context of value creation.

First, it will be shown how XR and XR technologies are currently researched in the context of value creation. Two research streams have been formed, either giving detailed reports for specific application scenarios or holistic reviews showing the distribution of XR technologies in business processes and industries. For this purpose, regarding the **main objective**, research from different industries and business processes along value chains are investigated. To contribute to the **main objective** of holistic applicability and **research objective III** of systematic execution, the XR deployment purposes in current research is derived.

Then, to highlight the current research deficit, existing approaches to XR technology deployment are identified and analyzed based on **all research objectives.** Since the number of deployment methods for XR are limited, further deployment methods of related technologies from the field of information systems are investigated. For this purpose, the sequential application of the **main objective** as well as the systematic execution of **research objective III** will be addressed.

3.1 Research on XR Technologies in Value Creation

Developing a methodology to deploy XR technologies in value creation requires examining the current state of the art of how the various manifestations of XR are investigated and applied. The following section provides an overview of the research structure and forms of studies. The description of the research character is based on Porter's value chain structure for identifying relevant research reports and distinguishes them into research reviews and implementation reports (Porter 1985; Tim Krodel et al. 2023)

Research Reviews

Various researchers have reviewed the current state of the art of XR applications (Fernández del Amo et al. 2018). A significant proportion of the research reports are analyzed and designed to record and aggregate individual research initiatives and provide an overview of a defined target area (e.g., industry or value creation process). The classification of XR technology distribution thereby shows different comprehensiveness in terms of technology and in terms of use case scenarios. Relevant research on XR technologies 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 in total) to a holistic view of XR technologies. The researched use cases vary in terms of their scope in the application context. Thus, the use of XR technologies is investigated from isolated business processes to value creation components (i.e., steps in the value chain) to industry-wide analyses of the diffusion of various XR technologies. Table 3.1 sums up the major reviews of XR technologies (i.e., XR in total, VR, AR, and MR) with different use case comprehensiveness and a given focus on value creation.

Table 3.1: Reviews on XR technologies in value creation (Tim Krodel et al. 2023)

Source	Technology comprehensiveness	Use case comprehensiveness	Major findings
(Chuah 2018)	XR	Generic	Generic prerequisites for adopting XR technologies
(Bonetti et al. 2018)	VR and AR	Retail	Identification of fragmented research landscape and future research agenda

(Egger and Masood 2020)	AR	Manufacturing	Technological, organizational, and environmental challenges for AR deployment in manufacturing
(Guttentag 2010)	VR	Tourism	Significance and potentials of VR for tourism value chain
(Berg and Vance 2017)	VR	Manufacturing	Relevance of VR for product design and challenges for deployment and suggestion of an implementation process
(Damiani et al. 2018)	XR	Industrial	Key technologies and applications of XR in industrial system engineering
(de Souza Cardoso et al. 2020)	AR	Industrial	Benefits, challenges, development, industrial distribution, and purposes of AR in industry
(X. Li et al. 2018)	XR	Construction safety	Synthesizing current research characteristics, existing use cases and trends for future development
(Nee et al. 2012)	AR	Design and manufacturing	Presentation of relevant AR applications for manufacturing and future importance of AR
(Van Krevelen and Poelman 2010)	AR	Generic	Distribution of AR technology characteristics and potential use case scenarios across industries
(Vasarainen et al. 2021)	XR	Collaboration	Training, design collaboration and remote collaboration as major XR use cases in the field of collaboration
(X. Wang et al. 2016)	AR	Assembly tasks	Comprehensive summary of AR assembly system setup as well as training, simulation, and planning as application fields
(Wei Wang et al. 2020)	AR	Inhouse logistics	Long-list of potential use case scenarios for AR in inhouse logistics

Overall, it becomes evident that the review based XR research solely provides an ex-post overview of the deployment. Most reviews aggregate the major challenges, success criteria, and future research agendas. The application of the results for practical deployment is restricted due to the required transfer of findings for future initiatives.

Implementation Reports

The second research stream focuses on a detailed reporting of implementation projects. This research field suggests concrete initiatives, in which XR technologies are implemented. The reports either focus on user-centric paradigms, provide a concrete technological methodology, or advise on how XR technologies can be deployed for specific scenarios. Due to the detailed focus of implementation reports, the research is investigated in specific industry sectors for defined value creation steps with a technology setup and possibly with the evaluation impact. Table 3.2 lists relevant implementation reports that investigate the deployment process and impact of specific XR technology compositions for particular use case scenarios with relevance to value creation.

Table 3.2: XR technology implementation reports with relevance to value creation (Tim Krodel et al. 2023)

Source	**Technology comprehensiveness**	**Use case comprehensiveness**	**Major findings**
(Bigné et al. 2016)	CAVE VR	Sales-oriented customer analysis	VR based study to analyze customer behavior
(S. Choi, Jo, Boehm, et al. 2010)	VR configuration	Design review process	System suggestion for deploying VR in design review process
(S. Choi, Jo, Lee, et al. 2010)	VR model creation	Plant design review	Rule-based system to automatically transfer CAD data to VR for design reviews
(Chung and Peng 2008)	Web VR	Manufacturing task planning	Web VR-based tool for executing planning of task execution in a dynamic context
(Gattullo et al. 2019)	AR content creation	Employee guidance in manufacturing	Methodology for converting manuals to AR content in production environment
(Masoni et al. 2017)	AR application	Maintenance task performance	Concept for collaborative assistance in maintenance processes through AR
(Mayer et al. 2021)	VR engine enhancement	Generic collaboration scenario	Method for enabling synchronization in a segregated immersive collaboration environment

(Monahan et al. 2008)	VR setup	Generic learning scenario	Setup for VR-based e-learning with multiple users
(Pantano and Servidio 2012)	XR	Point-of-sales modelling	Framework for enhancing customer touchpoints through VR and AR
(Siew et al. 2019)	Adaptive AR system	Assistance in maintenance task execution	System for AR-assisted support in executing maintenance tasks with adaption to user requirements
(Peng et al. 2012)	VR system	Reviewing product design	VR based system for collaborative product design review
(Scholz and Smith 2016)	AR paradigms	Customer engagement	Guidelines for AR deployment with the focus on customer engagement

Overall, the listed implementation reports show detailed approaches to the execution of XR technology deployment projects but are limited to specific XR technology setups in specific business processes. Technology-focused reports that suggest concrete setups and technological solutions to pain points lack a dedicated description of the value added.

In summary, both research streams provide valuable insights into the deployment of XR technologies along value creation. The literature from review and implementation-focused research needs to be investigated from a different perspective to aggregate the various research scopes from the value creation perspective of those technology compositions.

3.2 Deployment Purposes of XR technologies in Value Creation

To enable the methodological deployment of XR technologies, the following section will highlight how the various manifestations of XR are utilized in a value-creating manner. Since technology itself does not create value, but rather the utilization of humans unleashes their value, the focus will be on the purpose of use, or rather on the value-creating contribution throughout the usage of the technologies (Ovtcharova 2022).

Therefore, the current research state of XR technologies deployment in value creation, the following section suggests a taxonomy to enable an industry- and business process agnostic identification of value creation relevant deployment of XR technologies (Nickerson et al. 2013; Tim Krodel et al. 2023). Figure 3.1 depicts the derived taxonomy, described in the following sections.

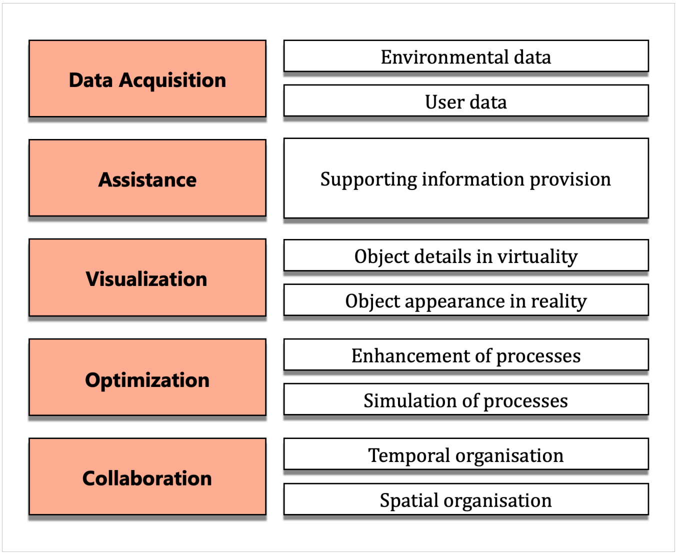

Figure 3.1: Taxonomy for XR technology deployment purposes (Tim Krodel et al. 2023)

3.2.1 Data Acquisition

The first purpose of deploying XR technologies along the value creation is the capability to capture data with either the tracking system or the input devices of the selected setup. (Craig et al. 2009; X. Wang et al. 2016; Egger and Masood 2020). The two major data types that can be acquired are from the user or the environment. Furthermore, the content can be designed accordingly to enable the user to enter required data or to acquire data by interacting within the solution or the provided content. (Fernández del Amo et al. 2018)

In general, every XR solution requires data and therefore acquires data to a certain extent. However, various research initiatives have focused on solutions with the significant purpose of generating data that are being processed to generate value-creating insights.

Bigné et al. conducted a VR-based analysis to capture consumer data. Using VR technologies, a virtual shop experience was simulated for a set of users. By observing the users in the simulated environment with both tracking systems and other analysis methods, data is acquired to help understand consumer behavior in terms of identifying the buying action triggers. (Bigné et al. 2016)

Zhu et al. introduced an AR application to project relevant the Digital Twin (DT) data of a milling machine with the help of the Microsoft HoloLens in a manufacturing environment. Although the major purpose of the proposed solution is data visualization, it also comprises of a control process unit. The input unit of the solution supports monitoring the physical element of the DT. By enriching the data acquisition process, the user is enabled through AR, and the data of the DT are kept up-to-date. (Zhu et al. 2019) Figure 3.2 depicts the framework.

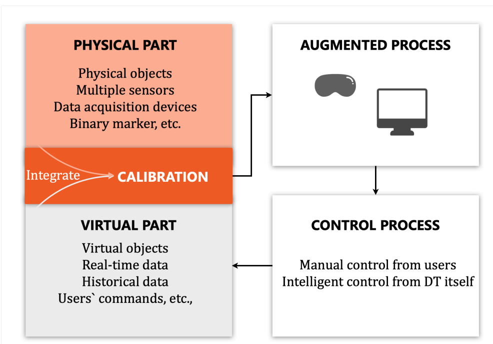

Figure 3.2: Framework for using AR for data acquisition (Zhu et al. 2019)

Wang et al. reviewed various AR applications from research and industry in inhouse logistics and from that place derivate a list of potential use cases for AR in in-house logistics. In terms of data acquisition, Wang et al. highlight the potential of deploying AR technologies and suggests the following scenarios (Wei Wang et al. 2020):

- Monitoring processes through process data recording
- Documentation of process execution or damages
- Object recognition
- Barcode and OR code scanning
- Object measurement
- Automated inventory recording

Furthermore, Stoltz et al. suggest potential AR use cases for acquiring data in warehouse operations, especially for monitoring workers' performance and counting orders to be loaded on trucks in the shipping process (Stoltz et al. 2017).

It can be subsidized that XR technologies that generate both AR and VR are utilized to acquire data for value creation. As a conclusion of the purposes and research use cases, the term data acquisition in the context of this thesis will be defined in the following as the use of the XR technologies to collect data from 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 design of the user experience, which intelligently enables any stakeholder to collect data to generate value-adding information for value creation.

3.2.2 Assistance

The second purpose of using XR technologies in value creation is assistance. The purpose of XR in this context is to support the user in a process flow or in the user's perception of a technology-enhanced experience (Flavián et al. 2019). Flavian et al. suggested a framework to classify XR technology deployment in terms of perceptual presence, behavioral interactivity, and technology embodiment from the customer perspective. The focus of this framework is to classify XR technology appearance forms to distinguish them in their capability to assist (i.e., support or enhance) the core customer experience. (Flavián et al. 2019)

Figure 3.3 shows the variations in technology-enhanced customer experiences.

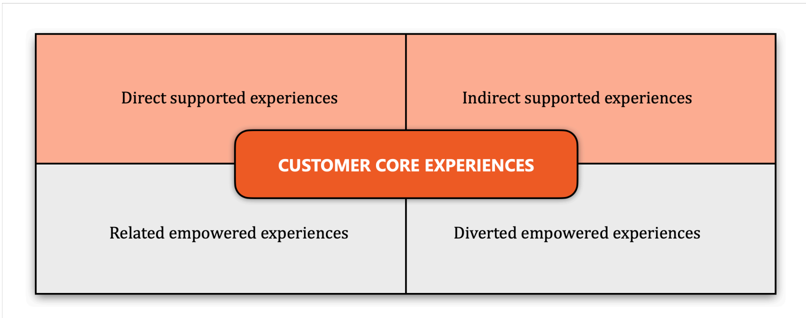

Figure 3.3: Technology-enhanced customer experiences (Flavián et al. 2019)

A large field of XR technology deployment for assistance in value creation appears in the form of AR to support industrial processes. For this purpose, Fite-Georgel defined the term "Industrial AR" (IAR) and investigated studies on the application of AR for the development, manufacture, commissioning, maintenance, and decommissioning of products (Fite-Georgel 2011). Especially in terms of assistance, the deployment of XR technologies as AR experiences for industrial applications has a strong focus on guiding the performance of manual activities, mostly independent of the industrial sector (de Souza Cardoso et al. 2020).

Wang et al. reviewed the scientific literature on existing use cases in AR-based assembly systems that guide users (X. Wang et al. 2016, 2). They highlight the relevance of context awareness and the interactivity of AR solutions for assembly guidance to add value to the value creation process by assisting the user (X. Wang et al. 2016).

Li et al. executed an analysis to provide a classification of VR and AR applications in construction safety. AR applications especially add value through assistance for safety inspections and building assessments by reducing users' efforts to access the required information through the inspection process. (X. Li et al. 2018)

Siew et al. introduced a system framework that enables augmented reality for adaptive support assistance. The framework consists of a specific AR technology setup with a haptic tracking methodology and demonstrates the viability of a maintenance system based on AR. (Siew et al. 2019) The value added is generated through the scenario by providing feedback to the user for adaptive support and assisting the manual process tasks.

Gatullo et al. introduced a methodology to optimize the text documentation of attachments to translate them into two-dimensional graphic symbols and to map them with the help of AR to support humans during maintenance work. This methodology 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 in manual process execution. Furthermore, the framework offers a content-authoring concept to assist in the administration of the provided solution. (Gattullo et al. 2019).

In summary, assistance through XR technologies in value creation can be aggregated to provide value-relevant data and information to users. In this context, XR technologies are used in such a way that the user is enabled in the performance of their process through the provision of data and can perform their physical work process. Thus, the focus is more on empowerment and the core process, which distinguishes this category from visualization.

3.2.3 Visualization

As mentioned in **chapter 2.4.1**, visualization is a central component of any XR technology composition. Thus, because of these technologies, there are countless possibilities for immersive depictions of details and designs in three dimensions to a user. Of course, in the assistance category already described, showing content is a component of the applications. As mentioned, the focus is on adding information to a manual flow and supporting humans with less emphasis on the graphical aspect. In the following, applications under the XR technologies application purpose "visualization" are to be enumerated to embrace the graphic possibilities of visual detailing, thus contributing to value creation.

In terms of visualization, XR technologies that create AR overlay virtual content within the real world (J. Y. Ma and Choi 2007). Based on this understanding, Yim and Park analyze AR-based product presentations and nominate a potential exploitation of AR for virtual try-ons. In this scenario, they defined the visualization aspect as the superimposition 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 users and products over the traditional 2D product representation on the web. (Yim and Park 2019).

Furthermore, Heller et al. listed 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 (Heller et al. 2019). Figure 3.4 depicts an industrial example from the automotive industry, where Porsche exploits AR to provide users with a realistic impression of their car configuration in the real environment.

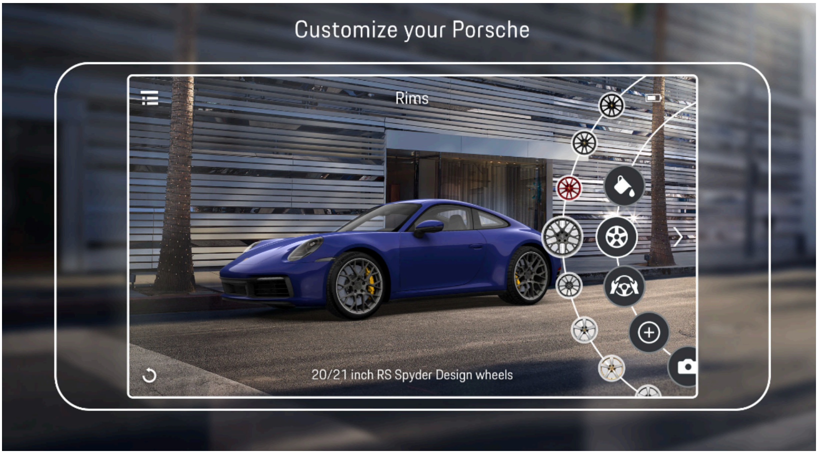

Figure 3.4: Porsche Augmented Reality Visualizer App (Porsche AG 2019)

Overall, AR can make a physically non-present object (e.g., a product) appear as if it was present in the physical reality and enable the user to make visual connections while compromising on visual details. Conversely, VR has various possibilities to present visual details to the user, mainly due to the variance of display possibilities (**chapter 2.4.1**).

Berg and Vance reviewed the utilization of VR in an industry context for VR in product design and manufacturing and identified VR as a mature tool for visualization. The value-creating aspect of visualizing content in an industrial context enables and improves decision-making by preliminary presenting the future appearance in a highly detailed manner (Berg and Vance 2017). Choi et al. furthermore reviewed VR applications in manufacturing industries and pointed out that the visualization aspect of VR adds value by intuitively depicting a situation to convey relevant information to the user. (S. Choi et al. 2015)

An example is another concept presented by Choi et al. to enable VR-based design reviews. It consists of multiple systems depicting the design review process and fulfilling various requirements, from product data management to the depiction of designs. The concept serves the provision of realistic prototypes and product impressions while reinforcing the relevance of VR visualization for improved decision-making.(S. Choi, Jo, Boehm, et al. 2010)

In summary, XR technology deployment for the purpose of visualization should be defined in the context of this thesis as 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 a three-dimensional presentation of the content to the user. Visualization with the help of XR technologies enables the user to perceive details, mainly through the image as well as through interaction, which he would not be able to grasp without XR technologies. Therefore, the value-adding component enables early-stage decisions, either in product design or on the buying action of an end-customer itself.

3.2.4 Optimization

XR technologies offer the possibility of simulating situations by creating virtual scenes or enhancing real scenes. This can lead 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 value creation to achieve improvement.

In terms of XR, Pantano and Servidio demonstrated in a framework how point-of-sales can be optimized through XR technologies. The framework consists of relevant factors that can enhance the in-shop experience for a potential user group, i.e., retail customers. The presence of XR technologies in the physical shop enriches the customer experience, given that the technology acceptance by the user is fulfilled. (Pantano and Servidio 2012)

Damiani et al. reviewed the deployment of XR in system engineering. They identified the internal and external improvement of the value creation through the new interaction possibilities provided by XR technologies. The optimization is realized with the improvement of decision-making by providing information and conveying knowledge to a decision maker. (Damiani et al. 2018)

Furthermore, XR technologies provide possibilities for executing preliminary process simulations to unleash potential within value creations (Farshid et al. 2018). Additionally, XR technologies are deployed in the value creation context to improve the interaction and simulation of the physical component of a DT in a product design context. Tao et al. identified optimization through XR technologies by providing the missing element of accessibility and interaction through AR to the data-driven approach of a DT. VR also provides a virtual simulation environment to optimize the process of validating the product design. Figure 3.5 shows the role of XR technologies as DT enablers for reflecting a product's digital component into the physical world. (Tao et al. 2019)

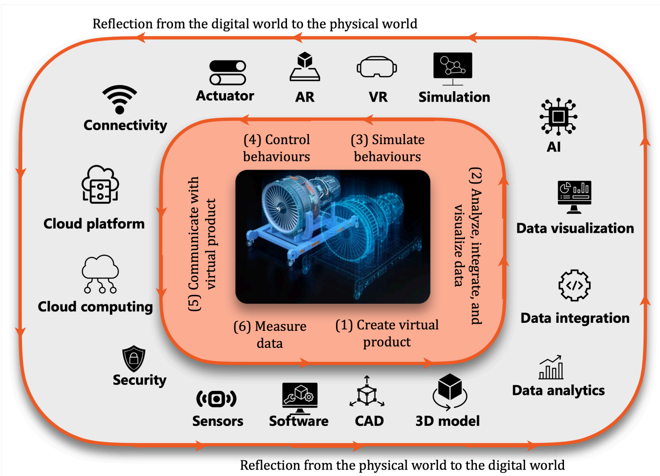

Figure 3.5: The role of VR and AR as enabling technologies for Digital Twins (Tao et al. 2019)

With a focus on AR, Woll et al. demonstrated the concept of an AR-based serious game for manual assembly processes. By simulating the spatial relationship of components through a user experience, the manual skills of the user are trained through the transition of theoretical assembly instructions to practical skills, which can be considered as an optimization. (Woll et al. 2011)

Nee et al. (2012) reviewed AR applications in design and manufacturing and identified the AR deployment within this value-creating processes to optimize the product assembly planning processes, which is enabled by giving a virtual layout of a production setup and thus improving the planning process of it (Nee et al. 2012). Next to the design and manufacturing optimization, Scholz and Smith introduced an AR framework that enables the application of AR for marketers by maximizing consumer engagement through increasing affordance, increasing sociability, and targeted offering of artifacts (Scholz and Smith 2016).

Regarding VR for the optimization of workflows, Chung and Peng presented a concept based on Web VR that enables the dynamic scheduling of tasks in a manufacturing environment. Especially the combination of three-dimensional depiction and the high level of interactions possible in a virtual environment enables the efficient utilization of manufacturing resources and therefore provides an optimization within the deployment of XR technologies for VR. (Chung and Peng 2008)

Li et al. mentioned the relevance of VR in the construction safety domain as it can be utilized for preliminary mock-ups of buildings for hazard identification and safety training and education (X. Li et al. 2018). The avoidance of creating the physical situation through material-intensive construction and the early-stage recognition of required changes before the physical setup provides an overall optimization to the value creation in the construction industry.

In summary, optimization through XR technologies is achieved by improving processes, the possibility of transferring knowledge, improved interaction possibilities, autonomous simulation in XR, and the extraction of knowledge from it. This can be created on the one hand, by simplification through new opportunities utilizing XR technologies for handling complex procedures. On the other hand, XR technologies present content target group-oriented for further training or for the simulation of real situations that enable the creation of new knowledge and experiences. This optimization can be bidirectional. Thus, the possibilities of XR technologies can be used on the one hand to achieve an optimization on the part of the user through knowledge transfer, i.e., training. On the other hand, XR technologies can implement improvements on the process side by virtualizing process steps and simplifying them through virtualization.

3.2.5 Collaboration

A key area of XR deployment in value creation, regardless of industry or value creation setup, is collaboration through XR technologies. In particular, the characteristics of XR system compositions, which provide a high degree of immersion and the interaction of multiple users in one or more virtual spaces, have a high potential to enable collaboration across spatial and temporal boundaries (Ovtcharova 2020).

Vasarainen et al. performed a systematic literature review for collaboration through XR in a working life setting. By assessing relevant literature researching the theoretical and methodological collaborative utilization of VR, AR, and MR, Vasarainen et al. identified 26 relevant studies between 2009 and 2020 with the primary application fields of design collaboration, remote collaboration, and training. The value of XR deployment for collaboration is added on one side by providing virtual access to physically inaccessible scenarios. However, the collaborative value of XR technologies lies in increasing the efficiency of existing analog collaboration scenarios (Vasarainen et al. 2021).

Mayer et al. (2021) introduced a method to enable the locally distributed collaboration of multiple parties in immersive environments, depicted in Figure 3.6 (Mayer et al. 2021).

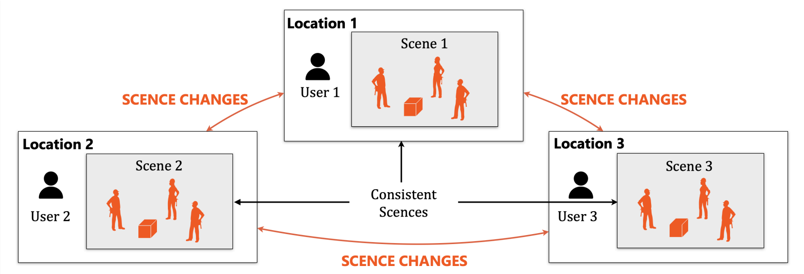

Figure 3.6: XR-enabled Collaboration scenario with synchronization need (Mayer et al. 2021; T. Krodel et al. 2023)

This method allows the collaborators to avoid inconsistent working environments with the setup. The remote collaboration of various parties is achieved by real-time decentralized synchronization through using change lists and consistency controls. The change lists of the distributed environments keep track of what must be synchronized and apply synchronization by executing relevant changes. Consistency is ensured by integrating the various users that maintain and transfer the ownership of objects in the overall system. The resulting forms of collaboration with XR are shown in Figure 3.7.

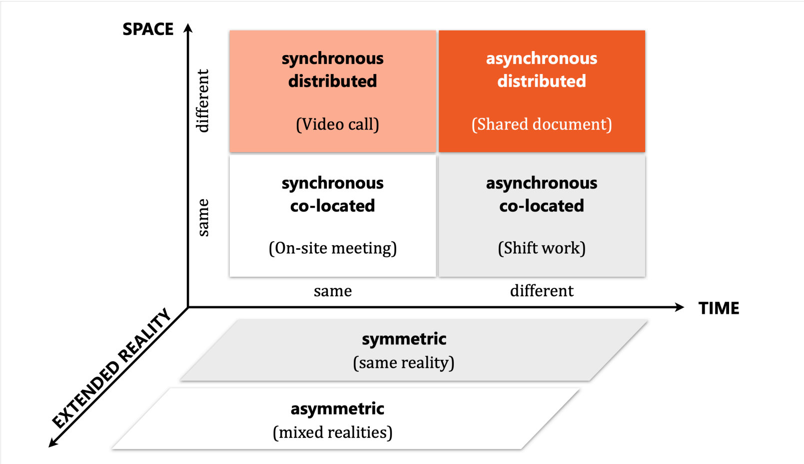

Figure 3.7: Forms of XR-enabled collaboration (Mayer et al. 2021; T. Krodel et al. 2023)

In terms of VR, Monahan et al. provided a solution for a collaborative e-learning environment, accessible with multiple mobile and web-based VR devices (Monahan et al. 2008). Further, Peng et al. devolved a concept for web-based VR technology that enables collaboration between technicians and product designers. The major features are communication, coordination, control, and integration within the product validation process. The reported benefits in terms of value creation are improved maintainability and reduced development times, resulting in reduced overall costs. (Peng et al. 2012)

Regarding AR, van Krevelen and Poelman point out a major potential benefit in their survey: multiple people can view, discuss and interact (i.e., collaborate) on 3D models through AR (Van Krevelen and Poelman 2010) Masoni et al. furthermore created a concept for remote maintenance. The purpose of the concept is to connect trained operators off-site with unskilled people (e.g., clients) on-site. Through the remotely connected collaboration setup, the trained operator supervises the performance of maintenance tasks. Figure 3.8 shows the system architecture of this concept. (Masoni et al. 2017)

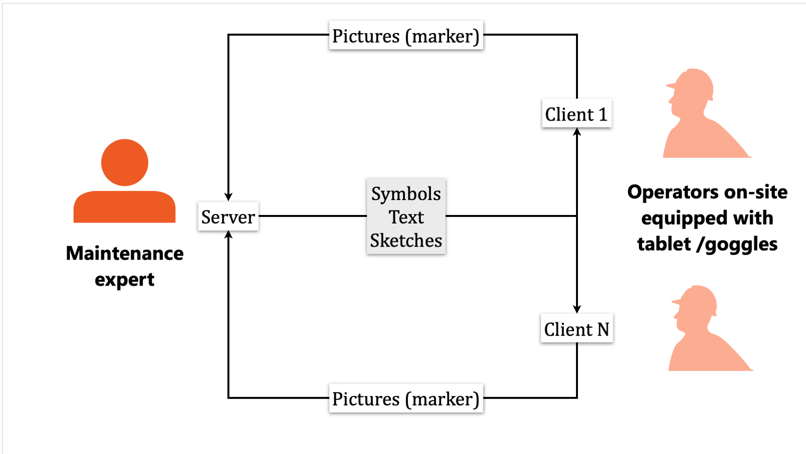

Figure 3.8: System architecture for AR-supported remote maintenance (Masoni et al. 2017)

Next to the avoidance of sending maintenance experts on-site and the increasing number of key accounts that can be served by one maintenance expert; the concept adds value as it is applicable through off-the-shelf mobile and AR technologies. (Masoni et al. 2017)

To summarize the purpose of XR technologies in the context of collaboration, it should be understood as the enablement of 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 as well as the efficient transfer of relevant information and know-how via XR technologies and the value adding role of XR technologies in the context of collaboration thereby resulting in the creation of both synchronous and asynchronous interaction between stakeholders.

3.3 Methodologies for XR technologies in Value Creation

After reviewing the current state of the art of XR technologies and their deployment purposes in value creation in **chapters 2.4 and 3.2**, the following chapter will investigate existing methodologies for deploying XR technologies. With the goal of this thesis to developing a methodology for deploying XR technologies along with value creation, current approaches are to be examined from different perspectives.

Chapter 3.3.1 describes methodologies focusing on the economic aspect of XR technology deployment. In particular, methods that assess the impact on a business or business model are considered to understand and derivate a value-adding deployment methodology.

Chapter 3.3.2 describes methodologies focusing on the deployment of XR technologies itself. It is important to emphasize which prerequisites must be created and which sequence of steps must be taken to enable the rollout of an XR technology composition in the value creation environment.

As already mentioned, XR technologies belong to the research field of IS. Therefore, **chapter 3.3.3** will investigate how related technologies from this field are methodologically deployed in value creation. From this, paradigms can subsequently be identified and transferred that enable the methodological deployment of XR technologies.

3.3.1 Business-related Methodologies for XR Technologies

The first category of XR-related methodologies comprises studies that create a relationship between the deployment of XR technologies and their impact on businesses. Findings and concepts that provide methodological guidelines and recommendations for the economic deployment of XR technologies are also included.

Success Factors for AR Business Models (van Kleef et al. 2010)

Van Kleef et al. performed an empirical analysis for commercial applications for AR in terms of business, users, and technology (van Kleef et al. 2010). The research methodology consisted of the business model ontology from Osterwalder, the user perspective, and a structured literature review for the technological aspect.

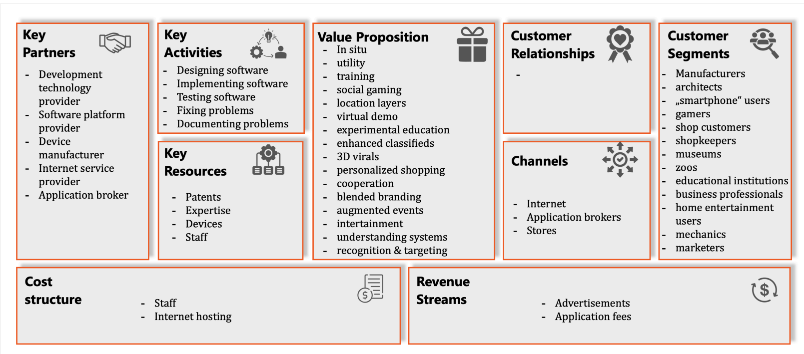

Figure 3.9: Business Model Canvas for AR (van Kleef et al. 2010)

Figure 3.9 sums up the key findings for designing a successful business model with AR in the modules suggested by Osterwalder. The term successful aims to a certain value added to the customer, as economic success is thereby implicated. The business-related findings cover all aspects of the business model, i.e., value proposition, value creation, and value capture. Van Kleef et al. suggested a set of value propositions that can be transported, empowered, or enriched through AR. The value creation segment of the AR canvas is focuses on AR technologies, i.e., hardware and software, as well as partners and resources that can execute and support in this domain. While the customer segments are both business-to-business (B2B) and business-to-customer (B2C), the revenue streams through AR are limited to advertisement and subscription fees.

Regarding the users addressed through an AR business model, the target groups require a certain attitude toward new technologies with expectations towards the performance of the technical solutions. For users, the major adoption criteria are usefulness, usability, fun, and productivity, depending on the business model's B2B or B2C scope.

The adoption of AR business models is being held back from a technical perspective by various constraints, depending on the use case scenario of the AR technology deployment. However, according to van Kleef et al., these are non-critical hurdles that can be overcome with further technological development over time or solved with workarounds.

In summary, the analysis of van Kleef et al. has a broad perspective on business, user, and technological aspects. The compilation of value propositions provides concrete recommendations for deploying AR-based business models. However, it is restricted solely to AR and does not cover the holistic perspective of XR technologies. The aspect of value generation is represented qualitatively and lacks a detailed approach to identify and distinguish the subsequential value. The technology aspect is reflected in deployment obstacles, yet a technological implementation process is not considered in this analysis.

Economic Viability Analysis for Virtual Engineering (WAVE) (Dücker et al. 2016)

Dücker et al. developed a systematic approach to evaluate investment decisions for industrial deployment of VR environments (Dücker et al. 2016). The methodology offers the possibility of making a funded decision about the integration of VR systems based on a structured approach over VR system configuration alternatives, cost- and benefit estimations, and application analysis. Figure 3.10 shows the structure of the so-called WAVE methodology.

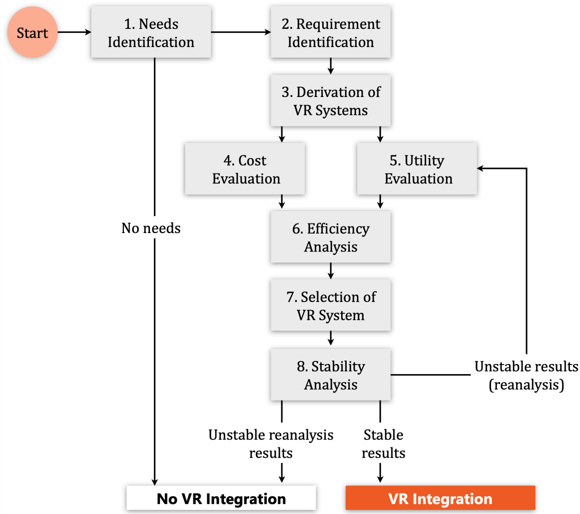

Figure 3.10: WAVE Methodology (Dücker et al. 2016)

After capturing the initial situation in the corporate environment based on a SWOT (Strengths, Weaknesses, Opportunities, Threats) -analysis, the methodology suggests an empirical requirement analysis with relevant stakeholders. The requirements are then transformed into a VR system configuration based on discrete categories representing different levels of technological sophistication. WAVE estimates one-time and continuous costs in different estimation reliability categories based on the system configuration. The benefit is quantified through an empirically weighted utility evaluation in the categories “direct”, “indirect”, and “strategic”. The efficiency analysis provides the best suitable VR configuration based on the cost and benefit estimation. The system implementation goes along with the stability analysis on costs and benefits.

Overall, the WAVE methodology enables the systematic acquisition of requirements and the connection of these business-related requirements to the technical VR system variations. Furthermore, cost quantification is possible in terms of concrete monetization. This structured approach provides funded information to decide for utilization in value creation. The limitations of this methodology include the limitation to VR. However, WAVE can be transferred to XR by adding additional cost and benefit data.

ROI Increase for XR Technologies (Bogan et al. 2018)

Regarding the ROI of XR deployments, Bogan et al. conducted a study that focused on military training methods. The goal of this study was to provide a methodology to derive actions to increase the ROI of XR technology investments. The approach was to monetize the effectiveness, which is resulting cost savings through XR technologies in training scenarios. Bogan et al. suggested using media analysis to capture training requirements prior to XR deployment to increase the chances of success in the endeavor. The methodology consists of seven steps (Bogan et al. 2018):

1. Caption learning objectives
2. Identification of appropriate media options, i.e., XR technology setup
3. Estimation of project execution time
4. Estimation of costs for development, implementation deployment, and maintenance
5. Fidelity analysis for functional requirements, training needs, and performance objectives
6. Hidden cost analysis
7. Delivery options with source data, training plan, and tech setup

Bogan et al. stated that the ROI for XR technology investments can best be improved by new training methods, replacing ineffective training methods, and supplementing existing methods. Furthermore, XR training methods can collect valuable data on the training experiences that cannot be directly quantified. Bogan et al. emphasized the importance of using agile project methods during implementation to ensure successful project implementation and increase ROI.

The proposed methodology considers a holistic spectrum of XR technologies. Bogan et al. also focused on the extensive acquisition of requirements that affect the business impact of the deployment. Furthermore, Bogan et al. provided several real-world case studies with concrete cost savings figures. The use case scenarios and the substantial numbers from the case study are focused on training in military use case scenarios and do not provide systematic insights for generic implementations. The positive impact on the XR Technology ROI is only caused by cost savings rather than by exploring new business opportunities. The project setup recommendations for deploying the solutions were given by Bogan et al., but a sequential flow for the implementation was not suggested within this meth

odology.

3.3.2 Deployment-related Methodologies for XR Technologies

The following chapter is dedicated to the deployment and technology-oriented methodologies for XR. This means that the focus is less on the aspects of business requirements but rather on creating the prerequisites and the time sequence for the deployment.

As mentioned in **chapter 3.1** , various technology-focused deployment approaches exist for concrete use cases, i.e., implementation reports. These have already been analyzed. The following chapter focuses on methodologies that exhibit a certain generality and foresee universal application. Research gaps can be identified based on these approaches, and relevant principles for the research purposes can be derived.

The VR Value Chain (de Regt et al. 2020)

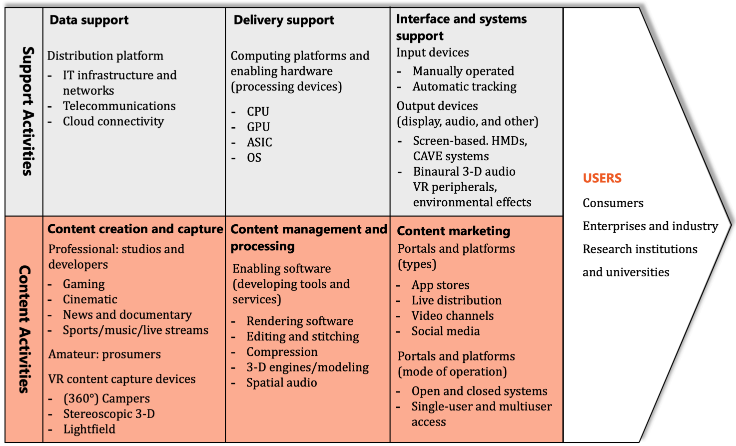

Figure 3.11: The VR Value Chain (de Regt et al. 2020)

The VR Value Chain, presented by de Regt et al., is a framework for academic and managerial purposes. The goal is to enable organizations to create value with VR and to understand the ecosystem surrounding the technology (de Regt et al. 2020).

Figure 3.11 shows the VR Value Chain. De Regt et al. draw on Porter's value chain model. Within this structure, de Regt et al. summarized the activities of organizations that are required to deploy VR technology. The structure of core and support activities was adopted. For the VR implementation, the core activities are transformed into content activities. These consist of content creation by humans and hardware, content management by software, and content marketing via appropriate distribution platforms. Support activities include data support for the network infrastructure, delivery support via the processing units, and interface support via the in- and output units of the XR technology hardware. The VR value chain model addresses users, who can be from private (B2C), commercial (B2B), or academic backgrounds.

For defining strategies, i.e., creating value with VR, de Regt et al. state that in an industrial context, VR will be beneficial for high labor cost segments or segments with a high error severity. The value added is either achieved through product enhancements or process improvement (Porter and Heppelmann 2017).

Regarding the sequential flow for deployment, the methodology suggests five phases (1) Content assessment, (2) Commitment, (3) Allocation of resources, (4) Testing and implementing, (5) Assessment and support. Especially for resources, de Regt et al. concretize in terms of required competencies, such as 3D design, programming skills, software quality assurance (SQA), UX design, and project management.

De Regt et al. provide a holistic framework for organizations to deploy VR technologies in a value-creating manner. The framework is independent of the VR technology configuration and industry, use case scenarios or target users. The approach has a dedicated scope toward the activities performed with resources rather than the resources themselves. It furthermore provides value-creating advice and a sequence to follow for the deployment execution. The technological scope is restricted to VR technologies and again, blurred with value added suggestions from AR technologies. Even though the framework suggests testing and reassessment, the feedback iterations with the user required to achieve a UCD still needs to be improved.

VR Development and Configuration Process (Simões et al. 2020)

Simões et al. introduced a methodology for the XR development and configuration process. Within their study to deploy XR technology into industrial training and maintenance processes, they suggest a framework that is "[...] rather general but flexible enough [... for] different requirements and implementations."(Simões et al. 2020) With the emerging relevance of industrial XR technology, the methodology is dimensioned for the complexity of industrial systems.

The holistic deployment approach considers the relevant XR technology aspects of hardware, software, and content. The seven steps of the suggested process follow a sequential logic to achieve a successful deployment. The initial trigger of the framework is the existence of a potential benefit through XR, which is manifested by defining requirements. Once relevant data for deployment are uncovered, they must be processed accordingly. The setup of an XR environment follows this in terms of interactions and physics. Mainly the focus on users with a proof-of-concept (PoC) session for onboarding target users, and a re-design iteration follows a certain human centricity. After rolling out the solution, Simões et al. highlighted the possible necessity of iterating the entire process to achieve a successful XR technology deployment (Simões et al. 2020). Figure 3.12 depicts the XR development and configuration process.

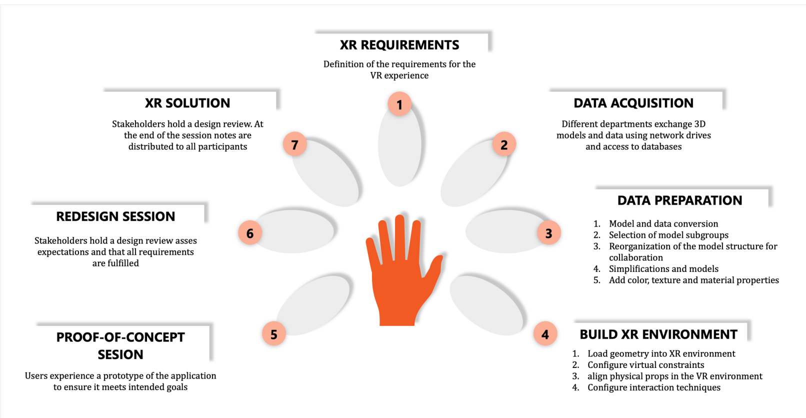

Figure 3.12: VR Development and Configuration Process (Simões et al. 2020)

Overall, Simões et al. provided a generic and universally applicable methodology that is not only viable for industrial XR deployments. The perspective of a benefit-driven deployment initiation, the iterative character, and the strong integration of the end-user within the configuration process positively affect the success probabilities of the deployment project. The framework description contains inconsistent usage of the XR and VR terminology. A clear distinction and definition of both terminologies are missing. While some configuration steps are investigated and described in detail, other steps are missing insights for deployment relevance. E.g., the deployment trigger is a potential benefit, but the source of the potential benefit has not been systematically identified. Furthermore, the XR environment configuration was described at a generic level.

3.3.3 Methodologies from Related Technologies

Regarding methodological research on XR technologies, the following chapter will present and analyze relevant approaches from the research areas of related technologies.

Digital Twins

As mentioned in **chapter 3.2.1**, DT is a technology directly related to XR technologies. DT, in general is a core technology for linking the real (physical) and the virtual world (Tao et al. 2019). A DT consists of a physical element, a digital element, and the connection of these elements (Grieves 2015). Initially used in the aviation industry to map the condition of airplanes, the technology is increasingly used in other industries, especially in the production environment (Glaessgen and Stargel 2012; Negri et al. 2017). A DT generally results from the recording of one's condition and the recording of the condition of the environment by a product or system (Haag and Anderl 2018). The system can be of any size and depict the value chain of an organization or a whole city (Mohammadi and Taylor 2017). Figure 3.13 displays the underlying data model for DTs.

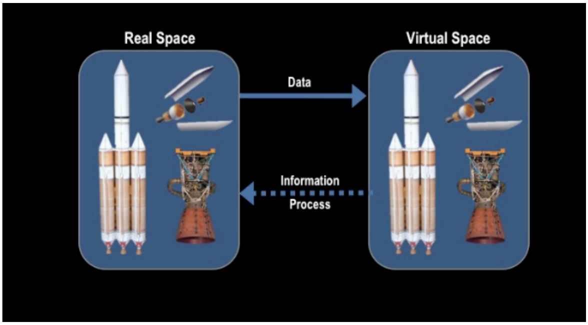

Figure 3.13: Information Mirroring Model (Grieves 2015)

With the real-time mapping of the physical state of a product or system, and the ability to interact and independently collect new data and information, and the technology of the DT is related to XR technologies (Tao et al. 2019).

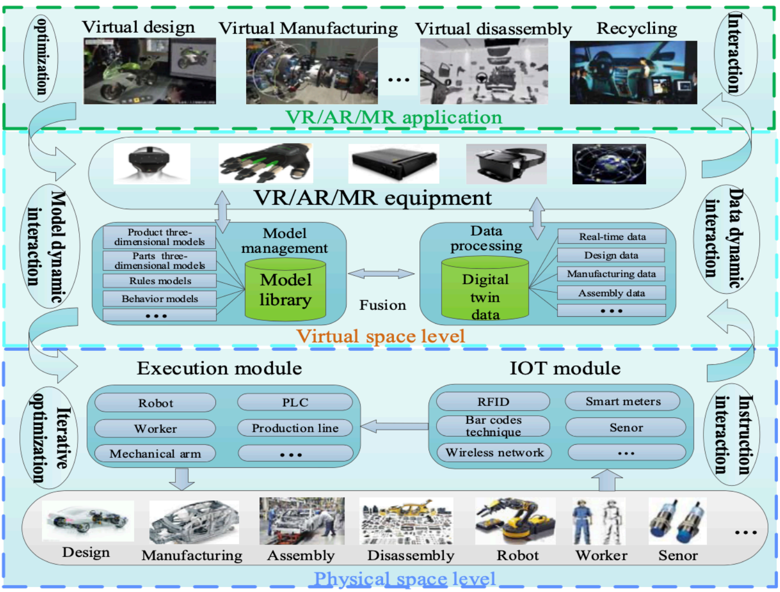

Figure 3.14: Methodology for applying XR technologies in Digital Twins (Tao et al. 2019)

Figure 3.14 shows the framework presented by Ke et al., which illustrates the interaction between XR technologies and DTs in a production environment. The physical level represents the value creation that consists of the value chain, the physical execution, and the Internet-of-Things (IoT) module for acquiring relevant data. Within the virtual layer, Ke et al. suggested merging DT data, 3D assets, and the XR equipment to combine both technologies in the context of value creation. Based on this, users interact at the application level and achieve optimization of the physical layer. Overall, the framework demonstrates the synergies of these technologies and the importance of the digital components as a prerequisite for implementing XR technologies (Ke et al. 2019).

Information Technologies and Information Systems

XR technologies are a subfield of the research area of information systems (IS) and are assigned to the field of information technologies (IT) (Chuah 2018). Basic enablers and highly specialized hardware and software components are fundamental to any XR technology setup. In line with the research objective, relevant concepts from these areas will also be analyzed to transfer important findings. IT is a highly comprehensive field of research, and a complete presentation exceeds the scope of this thesis. However, relevant concepts concerning the technology deployment must be considered.

The connection between IT/IS, and value is persistent and has been extensively studied. As the value creation of a business model consists of various dimensions for value added, they need to be distinguished. It is relevant where IT, IS, and XR Technologies can add value. Cronk and Fitzgerald analyzed the field of value in IS literature and executed a derivation of dedicated dimensions for the value added of IS/IT to organizations (Cronk and Fitzgerald 1999):

- System dependent
- User dependent
- Business dependent

The system-dependent value of IS is performance-related and is reflected in the measures of availability, accuracy, or response times. The user-dependent value from IS for organizations is reflected in the efficient use of an IT system as well as the attitude of individuals towards IS. The business-dependent value of IS for an organization is reflected in the achievement of economic targets and the correlation between IT systems and business success. Overall, the value of IT, IS, and XR technologies in organizations can be multidimensional and should be distinguished for quantification.

In 1994, Venkatraman presented a framework that outlines the relationship between IT and business and provided guidance on deploying IT in a value-adding manner (Venkatraman 1994). Despite its long existence, this framework is still applied for adopting cutting-edge IT technologies, such as blockchain technologies (Malhotra et al. 2022). Figure 3.15 depicts the framework.

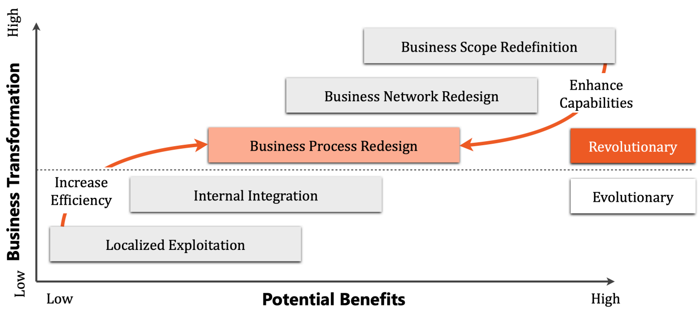

Figure 3.15: IT-enabled Business Transformation (Venkatraman 1994)

This framework highlights the relevance of IT deployment to businesses. While the framework demonstrates how to successfully implement IT from a business perspective, as the business model transforms, the value that can be generated by IT also increases. IT cannot be used as a universal tool for business success. Furthermore, it is shown that the successful business deployment of IT is an organizational task that must be solved from a strategic perspective. Venkatraman's methodology emphasizes the focus that must be placed on the deployment of IT. The fundamentally important role of the addressed business process and its design is persistent, regardless of whether IT deployment aims for productivity gains or capability enhancements. (Venkatraman 1994)

Mobile Technologies

As mentioned in **chapter 2.4.1**, mobile devices are a significant component of XR technologies. Those mobile technologies have also been researched in terms of the impact of their deployment in value creation. Coursaris et al. state how mobile technologies can support mobile users and mobile activities through connectivity, personalization, and localization. The improvements along the value chain are achieved through tracking, data access, and optimized people relations through communications (Coursaris et al. 2006). Like XR technologies, mobile technologies provide new possibilities to shape interaction within the value creation and add value to business models.

Metaverse

Based on the recently created hype from the renaming of the tech player Facebook to meta, the term Metaverse is widely discussed in research and industry (meta 2021). The Metaverse can be understood as a

> “[…] hypothetical synthetic environment linked to the physical world.“ (Lee et al. 2021).

As XR technologies provide the capability to create VEs, i.e., synthetical environments, the correlation between Metaverse and XR Technology deployment is significant and sometimes mistakenly used as synonyms (Xi et al. 2022). The vision of the Metaverse is achieved by the increasing maturity and combination of advanced technologies, thereby creating new opportunities for interaction in the universe. These include the technologies for data transmission (e.g., 5G and cloud), for establishing semantic relationships and synthetic interaction (e.g., AI), for communication, for decentralized data storage and individualization (blockchain), and ultimately for the representation of new worlds through XR technologies (Lee et al. 2021; Tim Krodel 2022).

The combined value added by these technologies is larger than the sum added isolated by each technology. The Metaverse has a high degree of user-centricity because it contains a significant social component. The deployment of XR technologies in the context of value creation will benefit from increasing content availability through this “hype”. New potential use cases for business models will arise and enable innovative value creation concepts and opportunities to address target customers.

3.4 Research Gaps

Based on the analysis of the state-of-the-art in the **chapters 3.1, 3.2, and 3.3** the following section will highlight the identified research gaps and the belonging research questions (RQ) that are to be answered with the development of the methodology in **chapter 4**.

Based on the illustrated structure of XR technologies from **chapter 2.4** of hardware systems, software development, and content creation and the varying application scenarios from **chapter 3.1** , it becomes evident that there are various possible XR technology configurations for value creation. The definition of the setup for the deployment in value creation is a multi-dimensional problem of requirements, e.g., performance, data availability, cost, resources, intended use, and user-centricity.

Meanwhile, the risk increases that the technological depth required in the presented technology fields blurs the focus on the output of added value in a business model. Identifying the sweet spot of hardware setup, software composition, and content is essential for a successful deployment. With the VR value chain model from de Regt et al. (**chapter 3.3**), a first approach was presented that focuses on the required activities to deploy VR technologies (de Regt et al. 2020). Regarding the **research objective I** to enable the handling of the underlying complexity as well as the **main objective** of industry-independent applicability, current research lacks (1) a holistic perspective on XR rather than solely VR and (2) a technology focus rather than an isolated activity focus. Therefore, the first RQ is:

RQ1: How can the comprehensive field of XR technologies be holistically described to enable a successful deployment without affecting it through the underlying complexity?

As presented in **chapter 3.1**, the existing literature investigating the deployment of XR technologies in the context of value creation can be distinguished into two categories, (1) research reviews and (2) implementation reports. Research reviews provide an overview of how a set of XR technology configurations are deployed in a defined field of investigation, i.e., a set of operational processes, business processes, or industries. The research character is of an ex-post view on XR technology distribution, benefits, and obstacles across industries or value creation steps. Implementation reports guide how a specific XR technology configuration was deployed within a use case. They are restricted to both the specific technology configuration as well as the specific scenario of the deployment. Within **chapter 3.2**, a taxonomy was suggested to generalize the value-added from the XR technologies within a value creation across business processes and industries. Regarding the **main objective** of holistic applicability, **research objective II** of deploying XR technologies in a value-adding manner, the existing research lacks a connection to a generic process-based value creation model as well as the differentiation of the value-added. Therefore, the second RQ is:

RQ2: How can a value-adding deployment initiative of an XR technology in value creation be methodologically identified?

Chapter 3.3 discusses different methodological approaches for XR technologies. They are divided into economic-oriented and deployment-oriented approaches. Existing economic approaches show clear value structures but are limited to single XR technology configurations. The monetary assessment is performed quantitatively, mainly on the cost side, while the potentials are barely identified. On the other hand, the implementation-oriented approaches as well as the methodologies from related technologies specify a time sequence but do not have a coherent link to value creation through the deployment. They either focus on a specific technology configuration or lack a dedicated distinction and definition of XR technologies. Regarding the **main objective** of sequential applicability as well as the systematic executability of **research objective III** it becomes evident that the methodologies for XR deployment in the context of value creation lack a generic yet universally applicable approach, depicting both implementation effort and benefits. Therefore, the third RQ is to be defined as:

RQ3: How can a sequential approach be designed for the deployment of XR technologies in the dimensions of technology configuration, value generation, and user orientation?

3.5 Summary of the State-of-the-Art

Chapter 3 shows the state-of-the-art of current research on XR technologies in value creation, illustrates the current research character of this domain, derives the general purposes of deploying XR technologies in value creation, and demonstrates how the deployment of XR technologies can be carried out methodically. Based on these explanations, the research gaps are formulated regarding the research objectives of this thesis by means of research questions to precisely articulate the requirements for the methodology precisely.

Chapter 3.1 shows the current research is characterized by the two research streams, research reviews and implementation reports. While the research reviews have an ex-post character and are conducted from the perspective of generic main processes or industries, implementation reports show clear characteristics in both the technology used and the specific characteristics of the targeted business process. By mapping the research landscape, this chapter contributes to the **main objective** of holism of industries, business processes and in the context of value chains.

Chapter 3.2 derives industry and business process agnostic deployment purposes from existing literature. These are data acquisition, assistance, visualization, optimization, and collaboration. The identified taxonomy contributes to the **main objective** of holism. In addition, **research objective III** is addressed since the generic deployment purposes enable a systematic selection and identification of application scenarios. A contribution is furthermore made to **research objective II** since the abstracted purpose orientation and its integration into the methodology also results in a reduction of complexity.

Chapter 3.3 presents various methodological approaches to the deployment of XR technologies and shows, particularly in view of the current state of research, that no methodology sufficiently addresses generic value creation and provides a holistic view of XR technologies**.** Through the approaches from the general IS methodologies, the relevant steps for the sequential execution as well as the systematic and agile execution for **research objective III** are identified in this chapter.

Chapter 3.4 sums up the research gaps of the investigated fields and uses the formulated research objectives from **chapter 1.2** to derive clear research questions, that specify the requirements for the methodology, that is to be developed within **chapter 4.**

4 Methodology for Deploying XR technologies in Value Creation

This chapter describes the core of this thesis and presents a methodology for deploying XR technologies in value creation. To develop the methodology with respect to the **research objectives** from **chapter 1.2** and to close the identified research gaps by answering the RQs from **chapter 3.4**, the addressable requirements for the methodology are defined in **chapter 4.1. Chapter 4.2** then describes the starting point for the deployment. The XR technology morphology is presented a means for handling the complexity of XR technologies aligning with **research objective I.** A generic value creation reference model is used for the holistic mapping of the value chain as well as the industrial and business process agnostic applicability of the methodology from the **main objective.** In addition, the different origins of deployments as well as the realizable added values are supposed to contribute to **research objective II** since the realization as well as the classification of the added value by the deployment are considered. **Chapter 4.3 to chapter 4.8** describe the execution of the deployment in sequential steps, which are iterative in itself as well as in total, to address the **research objective III** of the systematic, agile execution and the sequential execution from the **main objective**.

4.1 Requirements towards the Methodology

The main objective is that the developed methodology enables the use of XR technologies in the value creation of business models while answering the research questions from **chapter 3.4**. Therefore, the following requirements are to be achieved within the setup of the methodology.

Ex-ante Focus

One of the critical points of discussion regarding the existing state-of-the-art for XR technologies in value creation is the retrospective nature of existing initiatives. Therefore, the methodology is intended to enable deployment regarding the future state of value creation. For this purpose, it is an objective of the elaboration to design the methodology in such a way that (1) the existing state of value creation can be recorded, (2) the adaptions to the value creation through the deployment can be made in a structured way and (3) the impact on the future design of value creation with deployed XR technologies can be defined.

General Applicability

The methodology also aims to demonstrate universal applicability. The design is supposed to be industry agnostic. This means that the methodology can be applied independently of the industrial characteristics. Without claiming completeness, this methodology is not intended to be limited to individual industries. This also applies to designing the methodology independently of processual idiosyncrasies. This also does not mean that every process can be mapped with it, but the creation and application should not be limited to a single main- or subprocess of the underlying value chain. To achieve general applicability, the user-centered orientation of the methodology is defined as the key objective for general applicability. Both the methods to be nominated and the methodology process should focus on the target users of the XR technologies.

Agile Execution

As elaborated in the state-of-the-art, the agile approach has become the common practice for many reasons in the field of IS. Previous approaches to XR deployments lack agility in the implementation attempts. For this reason, the goal is to develop a methodology for agile implementation. For this purpose, in addition to considering the criteria for agile software development, approaches from related technologies are to be considered in the methodology composition and transferred to the context of XR technologies. Furthermore, it should be possible to adapt and enhance the methodology by using modules or methods from related technologies.

Table 4.1 summarizes the requirements that must be addressed within the presented methodology, derived from the initial research objectives as well as the identified research gaps from the state-of-the-art.

Table 4.1: Requirements towards the methodology

No.	Requirement description
1	**Ex-ante focus**
a	Mapping of the current state of value creation
b	Anticipation of future state of value creation
c	Defining the deployment impact
2	**General applicability**
a	Industry agnostic
b	Process agnostic
c	User centricity
3	**Agile execution**
a	Holistic iteration
b	Inherent iteration
c	Extensibility

4.2 Foundations and Structure of the Methodology

The methodology consists of four modules "XR technology morphology", "Value creation reference model", the "deployment stakeholder", and the "deployment sequence". Figure 4.1 shows the overall structure of the methodology.

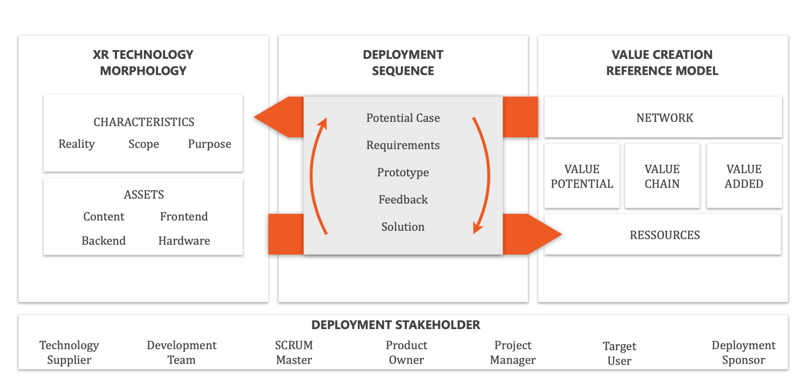

Figure 4.1: Structure of the methodology

While the modules for the morphology of XR technologies and the value creation reference model provide the foundation for the deployment, the deployment sequence is executed with six methodical steps through the deployment stakeholder as the procedure of the deployment flow. The methodological steps are:

1. Identification
2. Analysis
3. Initiation
4. Utilization
5. Implementation
6. Integration

These steps can be iterated individually and as an entire sequence and are the core of the methodology described in **chapters 4.3 to chapter 4.8.**

4.2.1 Morphology of XR Technologies

Looking at the VR value chain from de Regt et al., the required activities for deploying VR to generate value are listed in (de Regt et al. 2020). However, there needs to be a more technological focus and a holistic perspective on XR rather than solely on VR. Module 1, therefore, covers the morphological clustering of XR technologies for their use in a value chain. With a morphological breakdown of the technologies, a modular foundation can be systematically composed and deployed in value creation. **Chapter 3.1** distinguished XR technologies in hardware systems, software development, and content creation. These three technological modules generate XR in different forms with associated characteristics. To enable a holistic deployment, the methodology under XR technologies includes (1) the characteristics of the XR generated from the XR technologies and (2) the technological assets that enable this generation.

Characteristics

Reality: The XR generated for value creation is mapped with the presented distinction between VR, MR, and AR. The required form of XR is derived from the identified potential use case (i.e., potential case) and directly affects the technological assets required.

Scope: The scope of the deployment of the selected XR technology designates whether the application is intended by one firm for end consumers (B2C), by one firm for another firm (B2B), or by one firm for the use by the end consumers of another firm in the value chain (B2B2C). This topic is addressed within the methodology at the technology level because it directly affects the design of the technological setup in terms of technology available to the user, the user experience, and the underlying data infrastructure.

Purpose: As stated in **chapter 3.2**, the use of XR technologies in value creation has different purposes, which are crucial for the morphology of

XR technologies. In combination with the reality to be represented for a defined scope in the value chain, the technology can be used for data acquisition, assistance, visualization, optimization, and collaboration.

Assets

Content: XR technology is generally used to display content to users. Under this heading, the content to be displayed is divided into the categories 2D, 2.5D, and 3D. 2D content in the context of XR technologies includes all content necessary for the user, which conveys information without the third dimension and requires mapping via the UI. 2.5D includes semantic information in addition to the two-dimensional content and is conveyed to the user in an abstracted three-dimensional manner. The 3D content consists of all models, animations, scenes, and properties displayed to the user in the third dimension.

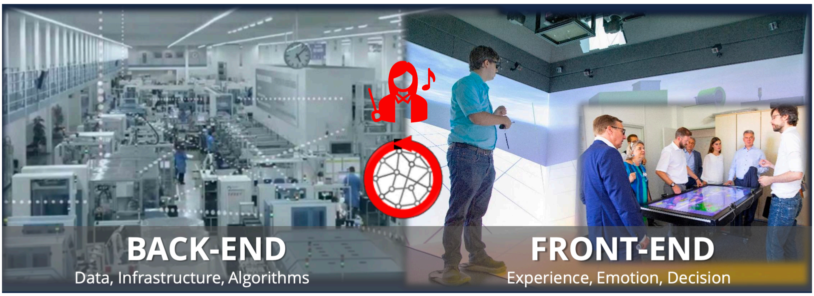

Figure 4.2: Back-end and Front-end of digital technologies (Ovtcharova 2022)

Front-end: To reduce technological complexity in the holistic context of the XR technology deployment, the structure of technological assets for XR software development follows the technology clusters shown in Figure 4.2. This distinguishes what users see and does not see from their perspective when using the XR technology. The Front-end includes everything that the user perceives. This consists of the UI, through which the user navigates in the XR, and the UX, which the user experiences at the meta-level, affecting his emotions and decisions while experiencing the XR. In addition, the Front-end includes the technical environment, through which the user accesses the XR. It is necessary to distinguish for both the user and the execution whether the XR software technology is implemented on the web, as an app, or as a local executable software module.

Back-end: The Back-end contains all software-technological assets that are not directly accessible and experienceable to the users. This includes the required databases, the data programming interfaces (DPIs), and the engine, i.e., the collection of APIs, libraries, SDKs, IDEs, and customized algorithms for operating the XR technologies.

Hardware: As mentioned in **chapter 3.1**, hardware is an essential asset for XR technologies. As explained in the state-of-the-art, it provides the necessary input, output, and processing units for the generation of XR in the context of value creation. This component results from the selected configurations and characteristics of the previous XR technology components and thus forms the basis for the deployment.

4.2.2 Value Creation Reference Model

The value creation reference model for XR technology deployment is to be defined from the previously mentioned approaches to value creation with generic characteristics to not restrict the methodology towards isolated processes yet concrete enough to enable a target-oriented deployment of XR technologies.

Value potential: The origin of every XR technology deployment initiative is the existence of a certain potential in the value creation of a business model. For the methodology, it is assumed that no value creation is entirely efficient and that a potential underlies any value-creating construct. It is assumed that the potential in the value chain has three different origins. The first origin is the existence of a pain point. This means that a process in value creation causes unnecessary additional effort or contains sources of errors. This identified pain point can be addressed by deploying XR technologies. The second case is the existence of a best practice of a competing or non-industry-related organization that uses XR technologies to perform, optimize or avoid a process, that exists within the considered value chain. The third case can be an innovation leap. Thus, a previously unsolvable pain point or a non-transferable best practice can be made possible by the availability of a new technology combination for the XR deployment.

Value chain: The core of the value creation reference model is based on Porter's value chain, in particular the understanding of the processes and the value creation participants (Porter 1985). Figure 4.3 depicts the value chain reference for the deployment of XR technologies.

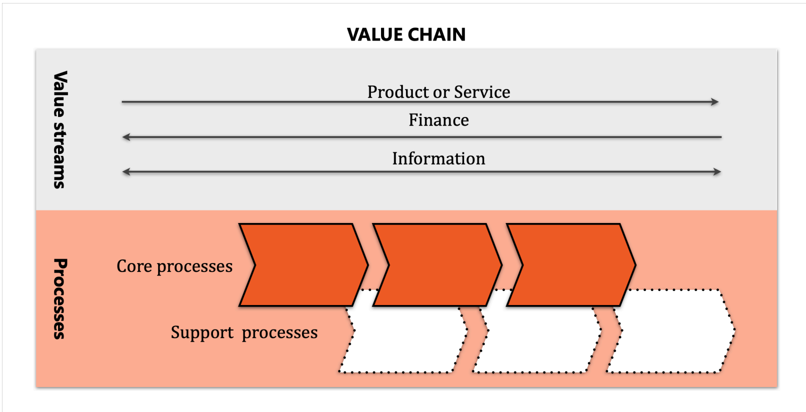

Figure 4.3: Reference value chain for XR technology deployment

With the goal of independent applicability of the methodology to specific processes, the concept of process differentiation into core and support processes is adopted from Porter. This is relevant for the development of the XR technology as the nature of the process is interconnected to the requirements for the XR technology deployment. Since Porter's model is based on activities, an intermediate layer is required for process understanding to link the defined processes to the value creation partners, i.e., the value network (Fiala 2005). Therefore, the value streams in the value chain must also be mapped in addition to the processes. The deployment of the XR technologies can affect and be linked to the material flow (downstream), the financial flow (upstream), and the information flow (up- and downstream). For this reference model, however, the material flow is to be understood as a product or service stream to make the methodology applicable to as many industries and business processes as possible and not only restrict it to a product-based value creation.

Value added: The perspective of the value added of an XR technology deployment is based on the value concept from Bowman and Ambrosini, considering the perceived value in use and realized exchange value (C. Bowman and Ambrosini 2000). The terminology to be considered for this methodology is value in use, value in transfer, and additionally, value in experience as this can be considered suitable for manifesting the economic impact of XR technology deployment in value creation (T. Krodel et al. 2023). Value in use aims to value that is not directly monetizable but still quantifiable, such as an efficiency increase or quality improvements. Value in transfer refers to the direct monetized added value of XR technologies. That is revenue that may be generated by capturing previously non-existent revenue streams of the business model through XR technologies (Osterwalder et al. 2010). Value in experience is to be considered for this methodology particularly against the background of the subjective perceptions of XR technology and the experience provided by those technologies provide. This category covers the added value that arises from a user's emotional experience. The partially non-monetizable value originates from the enthusiasm, loyalty, or any subjective perception of the target user from the value-creating organization.

Network: Analogous to the previously described value chain, the methodology's value creation reference model for XR deployment furthermore adopts Porter's network of value creation partners. According to

Porter, the roles of the value creation partner are the supplier, the business unit, the sales channel, and the customer (Porter 1985). The supplier can play a vital role in the deployment and can either be required to provide necessary data or be more integrated into the business unit's value creation through the purposes of XR technologies. A business unit represents the central point of the methodology. The XR deployment is initiated, executed, and coordinated based on the business unit`s role. A channel can be an integral part of the business unit or an external partner in the value network, and can be integrated or enabled through XR technologies. It is not only considered a sales channel for the underlying concept, as the channel might fulfill other roles in the value creation, e.g., the distribution or application of the core product from the business unit. The persona customer is also to be mapped within the methodology and focused on in the case of a customer-centric XR technology deployment. Using these four roles, it is possible to depict various value creation constellations independent of industry and processes by combining them to depict the value creation of the deployment initiative.

Resources: Following the resource-based view, an organization needs three types of resources to create value: physical resources, human resources, and organizational resources (Barney 1991). These three categories were adopted for the methodology of using XR technologies in value creation. Physical resources in the context of XR technologies include all technologies and existing infrastructure underlying the use of XR technologies integrated in the value creation. Regarding human resources, the know-how in developing and using XR technologies is necessary. Furthermore, human intelligence is considered an essential resource because the added value of XR technologies is directly determined by the adaptability and creativity of the user. Regarding organizational resources, the digital resources of value creation are mainly considered for XR technologies. Here, the necessary software and content assets, as well as the data streams, should be considered.

4.2.3 Deployment Sequence

Based on the presented morphology of the XR technologies as well as the Value Creation Reference Model, a deployment sequence is generated within the methodology in six methodological steps. Based on the identification of a potential case, as explained in **chapter 4.2.2**, the deployment of XR technologies takes place in the following sequence. Figure 4.4 depicts one deployment sequence. This sequence is described statically but can be iterated in each step and the entire execution.

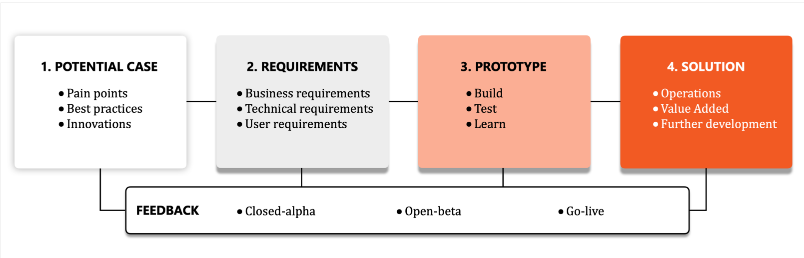

Figure 4.4: Deployment sequence of the methodology

<u>**Potential case:**</u> For the methodology, the new term potential case is introduced as a combination of the existing “potential” in the value creation and the” case” from the use case. Use cases are widely used for IT deployments as soon as there is an existing applicability of a technology. As mentioned before, the source of a potential case can be either a pain point, a best practice, or an innovation.

<u>**Requirements:**</u> Based on the present value creation construct, a set of requirements is derived from the potential case. These requirements are divided into economic, user-oriented, and technical requirements. They can be static and subject to dynamic changes during the deployment sequence. This results in creating and maintaining a backlog of requirements for implementing the technology deployment following agile software development. The transformation of the potential case into

requirements is the essential starting point for a successful XR technology deployment.

Prototype: The prototype of the XR technology deployment primarily fulfills only the necessary requirements and serves to validate the potential case. Initial assumptions are validated using the prototype, and existing requirements are prioritized and supplemented. The prototype is based on a minimum of hardware acquisition and software solution development and aims at a fast and user-centric solution development through build-test-learn iterations.

Feedback: Feedback from the prototype phase is an ongoing part of the deployment sequence and continuously indicates the project's direction. The confirmation of assumptions through feedback can be used to achieve a PoC and a Proof of Value (PoV) to trigger investment in the solution by the business unit. If applicable, feedback can identify the necessary adjustments to the concept and drive them within the build-test-learn cycles. In addition, the feedback can unveil new requirements and trigger a pivot point for the deployment initiative. This results in the definition of new requirements. If the feedback phase does not deliver any constructive content, the deployment initiative must be stopped.

Solution: After the feedback implementation, the XR technology deployment is implemented in the form of a mature XR technology solution, and requirements are integrated according to the prioritization and budget. The solution can then be deployed in an application scenario in a value-generating manner and scaled across the value chain. While scaling, the deployment initiative has achieved a Proof of Value The real-world application of the solution unveils new requirements that either generate a new potential case or result in continuous further development of the existing solution. It should be considered that the development of the XR technology solution is never finished, as the further development, as well as the maintenance of the solution, is an ongoing task throughout the lifecycle.

4.2.4 Deployment Stakeholders

To achieve the deployment sequence, a group of individuals is involved and is responsible for the execution of the XR technology deployment in the value creation. Each stakeholder has different interests and responsibilities throughout the deployment sequence. The background of the deployment stakeholder can vary from members of the value creation organization as well as third-party service providers that enhance the team setup with skills, that might not be available to the organization.

With the requirement for agile executionof the methodology, the roles of an agile team, according to SCRUM, are a fundamental part of the deployment stakeholders. These include the product owner, the SCRUM master, the development team, and the project manager (Mundra et al. 2013). Table 4.2 sums up the interests and responsibilities of each stakeholder.

Table 4.2: Interests and responsibilities of the deployment stakeholder

Stakeholder	• Interests	Responsibilities
Technology supplier	• Adding value to one's organization through providing XR technologies	• Providing the right XR technologies to the development team with suitable framework
Development team	• Receiving technical requirements for the functionalities • Involvement in the context of the deployment initiative	• Delivering the requested functionalities on time with the required quality
SCRUM Master	• Receiving clear user requirements for transferring them to the development team	• Ensuring the delivery of the functionalities by technically coordinating the development team activities
Product Owner	• Close collaboration with the SCRUM Master for ensuring technical execution • Close collaboration with the target user for understanding the user requirements	• Understanding the target user needs • Providing the target user needs to the SCRUM Master • Surveilling the progress of the XR technology solution
Project Manager	• On-time delivery of aligned milestones	• Coordinating the stakeholder communication

	• Avoiding disturbance of the deployment sequence • Acquiring relevant information from all stakeholders for his responsibilities	• Ensuring the delivery of solutions according to quality, costs, and time • Providing an operational framework for the agile project execution • Planning the execution process
Target User	• Receiving an XR technology solution, that is easy to use and adds value to one's needs	• Providing useful feedback to the product owner about the usability through the development process • Adapting to new approaches coming with the XR technology solution • Willingness to learn and utilize the XR technology solution
Deployment Sponsor	• Generating ROI through XR technology deployment	• Providing budget to the project manager throughout the deployment sequence

Depending on the selected XR technology setup, the development team must be composed of Front-end, Back-end, and DevOps developers for the corresponding domain. Additionally, the development team may include UI/UX designers and 3D artists for content creation. Furthermore, the development team includes software testers (i.e., SQA engineers) that ensure the functionality and usability of the developed solution. The project manager connects the SCRUM team with the other stakeholders. Due to the variance and complexity of the XR technologies, the technology provider is seen as another stakeholder for the deployment project since a temporary acquisition of hardware equipment can be economically reasonable, especially for achieving the PoC. The deployment sponsor provides funding for the project. Ultimately, the focus of the entire deployment is the target user, whose acceptance and use of the XR technology reflects the success of the deployment.

Figure 4.5 depicts one detailed deployment sequence with the methodical steps on the presented modules.

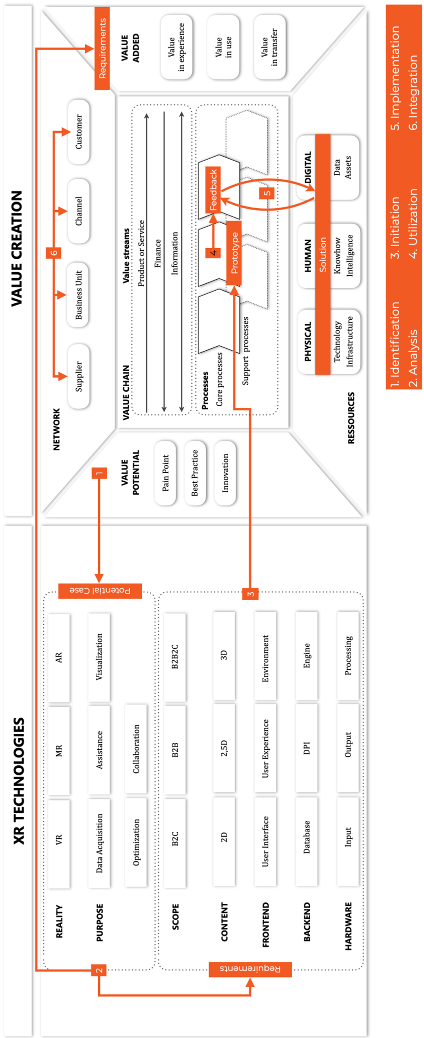

Figure 4.5: Methodology overview

The following chapter describes the methodical steps through the deployment sequence in detail. Each step contains individual economical or technical methods to present a methodological approach for the XR deployment according to the defined requirements.

4.3 Identification

The first step in the methodology is to identify a potential case within the value creation of a business model. According to Brown Feld, one of the most common approaches for identifying, developing and designing new solutions in various fields, including IS, is the design thinking approach (Brown 2008; Dolata and Schwabe 2016). Based on an existing issue, which could be either a problem or an opportunity, this approach provides the framework for developing new value-generating solutions in a creative sequence. This sequence consists of the following steps (Blackburn-Grenon et al. 2021):

1. Understanding the issue
2. Defining the issue
3. Discovering and developing potential solution ideas
4. Testing the solution ideas
5. Implementation

Assuming that the potential case is based on an issue, the proposed methodology suggests three sources of potential cases. First, the value creation can contain a specific pain point, which means that a (sub-)process or the link between (sub-)processes within the value chain contains inefficiencies. The second source is the transfer of a best practice from a different process, organization, or industry to the underlying value creation. Third, a technological breakthrough can be the source of a potential case as it might enable an XR technology deployment within an existing value creation in a way that was impossible before. The following sections explain the methodological approaches to identify and shape the potential cases as the first step towards deploying XR technologies.

4.3.1 Pain Points

A pain point is considered to be an existing inefficiency in the value creation organization. The pain point is known to be the closest participants of the process in the value creation organization. It is known to the person responsible for the value creation process, i.e., the management. Based on this, the deployment stakeholders are aware of the pain point to a certain degree of detail. It is then up to the deployment stakeholders to understand and detail this pain point to identify a potential solution using XR technologies. This solution can be initiated by mapping the root causes of the pain point against the XR technology deployment purposes. Figure 4.6 depicts the development from a paint point to an identified potential case in the form of a potential case.

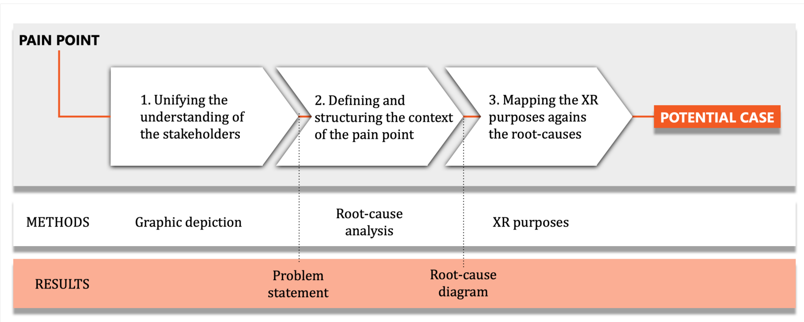

Figure 4.6: From pain point to potential case

Unifying the Pain Point Understanding

To potentially identify a pain point and create a unified understanding, the project manager oversees bringing all relevant participants together, e.g., within the scope of a workshop. To capture the pain point and create a mutual understanding of the pain point, each workshop participant should create a rudimentary graphical depiction of the pain point. By avoiding the verbal description of a problem, the participants must focus on the essential components of the underlying section of the value creation. The various perspectives result in various depictions that can be clustered and utilized among the stakeholders to unify the perspective of the pain point and synthesize the root causes. The result of the gathering session around the pain point should be clearly defined problem statements that can be tackled within the deployment initiative.

Defining and Structuring the Pain Point

The description and detailed understanding of the pain point is then done by structuring the affected (sub-)process, the directly and indirectly, involved participants, and the impact of the pain point on the organization. One common approach to cluster and prioritize the root causes of pain points is the Cause-Effect Diagram, also called the "Ishikawa Fishbone" Diagram (Juran and Godfrey 1999). Originating from the quality management in production systems, this method has been utilized in various fields, such as in the context of supply chains and business processes (Kanti Bose 2012). By organizing the relations of reasons for a dedicated pain point, a structured cluster of potential leverages to solve the pain point is created. Figure 4.7 depicts an exemplary fishbone diagram.

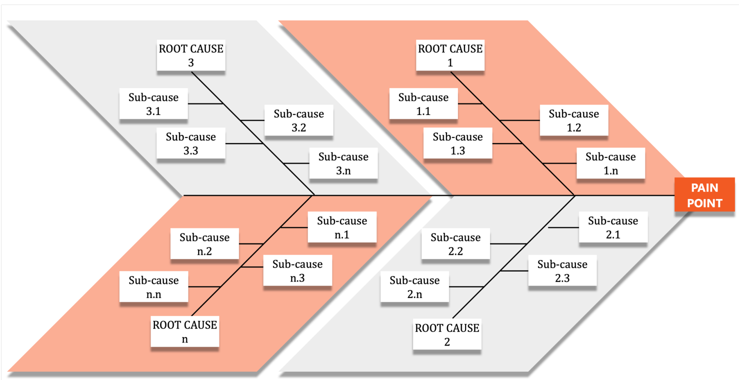

Figure 4.7: Schematic Root-Cause Diagram

With the foundation of the structured analysis of a pain point, the identification of the solution with the help of XR technologies can be triggered. By aligning all stakeholders within this session, the whole deployment initiative is initiated with a shared vision as well as the required ownership of the organization to excel with the deployment initiative.

Mapping a Solution to the Root Causes of the Pain Point

As a result of the pain point investigation, the elements of the root cause diagram that can be resolved by XR technologies should be identified. For this, it is necessary to assess the proposed purposes of XR technologies against the root and sub-causes of the pain points to identify a solution approach for an XR technology deployment. By combining the XR purpose with the root cause of the pain point to a functional solution, the initially identified problem statement can be transferred into a solution statement. This finalizes the identification phase for the pain point-driven deployment initiation. Table 4.3 summarizes a list of possible transformations from the XR purpose over the root cause to a possible solution approach, i.e., potential case.

Table 4.3: Purpose – root cause – solution mapping

With the help of [XR purpose] …	**… the [root cause] should be resolved…**	**…by [possible solution approaches]**
Data acquisition	missing data sets	enabling the collection procedure
	bad data quality	improving the collection procedure
Assistance	manual errors	guiding the process of execution
	slow process execution	providing information to the user automatically
Visualization	lack of dimensioning	showcasing the three dimensions of the user
	lack of accessibility to the physical product	creating a general accessible virtual environment
Optimization	high amount of change requests	providing standardized solutions to the customer virtually
	Missing insights about behavior of system interaction	simulating system components interaction virtually

Collaboration	redundant versions between stakeholders	enabling asynchronous collaboration on one version
	communication gaps	increasing the possibilities of collaboration in shared spaces

As a result, the pain point is transformed into solution statements with a transparent approach to the underlying issue. Based on these statements, an extensive analysis can be performed to enable the execution of the deployment initiative.

4.3.2 Best Practices

The second origin of a potential case lies in best practices. This means that another organization or another section of the value creation masters a (sub-)process with the deployment of XR technologies, thereby leveraging potential. The source of the potential does not result from a problem in a process but rather from a new way to design, handle and perform the (sub-)process. The source can therefore be from the reference initiatives of other organizations, cross-industry knowledge exchange, or the involvement of third parties (Jarrar and Zairi 2000). The responsible organization for the value creation can actively seek these approaches, e.g., through research or benchmarking initiatives. Assuming that the identification of best practices is dynamic and partially characterized by coincidence, the number of possible best practices for a value creation is relatively high. The focus of this methodology is therefore directed towards identifying whether a best practice is suitable for an XR technology deployment, i.e., the transformation of a best practice for the underlying value creation.

The major challenge is to identify whether the best practice and its purpose within the external organization is deployable within the underlying value creation and can therefore be a potential case. To do so, this methodology suggests a qualification process, which the identified best practice must pass, regardless of an internal or external origin. Figure

4.8 depicts the qualification process of a best practice for an XR technology deployment initiative.

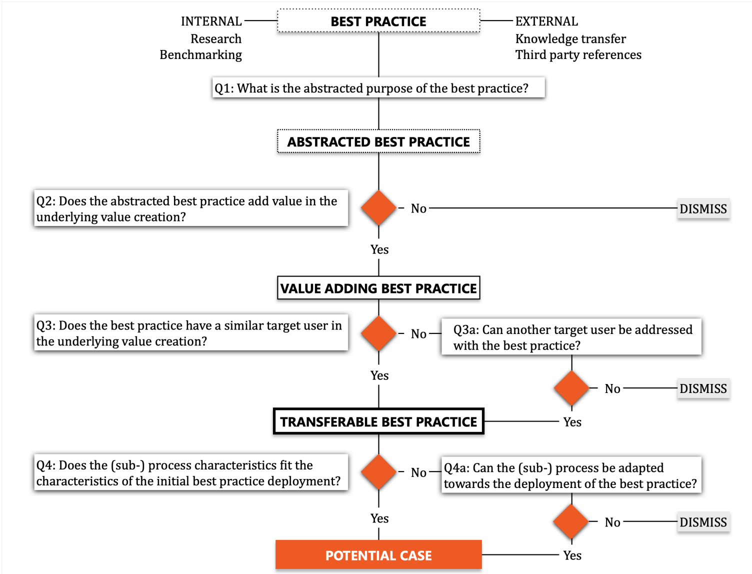

Figure 4.8: Best practice qualification process

Abstracting the Best Practice

To enable the qualification of the best practice for the given value creation, it first needs to be abstracted. This involves determining which XR technology deployment purpose the best practice is pursuing in the external organization. Thus, it must be determined whether the XR technology, in the best practice, enables data acquisition, assistance, visualization, optimization, or collaboration. Based on the abstraction, it can subsequently be determined how the best practice (abstracted) can add value to the value creation process.

Assessing the Potential Value Added of the Best Practice

The second step in qualifying the abstracted best practice is determining whether the existing best practice can be applied as a driving component in the value creation system. For this purpose, the NICE design themes mentioned in **chapter 2.2** are to be applied (Zott and Amit 2010). Thereby, the integration design of the best practice into the own value creation can be shaped. Table 4.4 summarizes the four possibilities for validating the value-adding transfer of the XR technology best practice to the underlying value creation.

Table 4.4: Applying the NICE design themes to XR technology best practices (Zott and Amit 2010)

Novelty	Can the XR technology purpose be deployed to create a new (sub-) process for the value creation?
Lock-In	Can the XR technology purpose be deployed to integrate relevant target users in a way to make it difficult for them to leave the value creation system?
Complementarities	Can the XR technology purpose be deployed to combine (sub-) processes in the value creation to release synergies?
Efficiency	Can the XR technology purpose be deployed to improve the flow of existing (sub-)processes to reduce costs for value creation?

Assessing the Transferability of the Best Practice

After determining the value-added use of the best practice, it is necessary to determine whether the target group of the best practice is comparable to the target group of the underlying value creation. Suppose there is a divergence in the characteristics of the target users. In this case, it must be checked whether another target user in the value creation can be addressed with the XR technology deployment. This primarily involves checking whether there is a knockout criterion for the use, such as a lack of access to the required technology or organizational criteria. A detailed user analysis should not be performed at this point, as this will be done in the Analysis phase (**Chapter 4.4.1**).

Assessing the Deployability of the Best Practice

As for the target user, it must be assessed at this point whether the process characteristics of the respective value creation are comparable to those of best practice. In the case of divergence, it needs to be checked whether the process can be adapted to the present value creation. Likewise, the focus should be on potential knockout criteria rather than a detailed process definition and modeling initiative. This is done in the context of the system analysis in **chapter 4.4.2**.

As a result of the qualification process, a potential case with an XR technology purpose is available. This also includes a potential technology setup, a characterization of the target user, and a concrete positioning of the added value generated by the deployment. This provides the basis for the analysis phase in **chapter 4.4.**

4.3.3 Innovation

Innovation is the third source for identifying a deployment project. According to Schumpeter, an innovation is the implementation of a new combination in a technological and organizational context (Schumpeter 1934). For deploying an innovation, the external or environmental factors of a value creation must be considered in addition to the technological and organizational aspects within the organization (Tornatzky et al. 1990).

Accordingly, innovation-driven deployment is either to establish a process that does not yet exist or to innovate the execution of an existing process. In contrast to the pain point, innovation-driven deployment is not about fixing a single pain point but much more about the organizational establishment of a new approach to value creation. The difference from the best practice-driven deployment project is that the XR technology has never been deployed in an organization similar to the underlying value creation. The XR technology needs to be sufficiently performant for the intended use to add value. Thus, three perspectives of the innovation aspects emerge in the identification phase to trigger the XR deployment.

Technological Perspective

According to the combinatorial technology evolution (CTE) theory, deploying new technologies is always a combination of existing technologies (Arthur 2009). Therefore, the existence of suitable technologies can be an innovation driver for deploying XR technologies in a way that has not been done before. For this reason, it should be examined within this identification phase which technologies the XR technology can be combined to achieve value adding output for the underlying value creation.

On the one hand, this can be done by combining XR technologies with enabling technologies. This means that value-adding technology is added to the XR technology stack to prepare the data input or provide the required hardware performance. The result is fulfilling a deployment purpose that would only be possible with enabling technology. However, the XR technology stack can be extended by exploiting technology. This means that the output of XR technology deployment purpose is processed and utilized. Therefore, exploitation technology contributes to value creation based on the deployment of XR technology. Table 4.5 sums up the role that enabling and exploiting technologies can play within the XR technology stack for value creation.

Table 4.5: Role of enabling and exploiting technologies for an innovation-driven XR technology deployment

XR Purpose	Role of enabling technologies	Role of exploiting technologies
Data acquisition	Acquisition of better data quality (e.g., new sensor technology)	Processing the output data of XR for business insights (e.g., Machine Learning)
Assistance	Provision of non-accessible data to the XR deployment (e.g., IoT)	Acquisition of non-existing data through XR (e.g., Artificial intelligence)
Visualization	Pre-processing of 3D assets (e.g., real-time rendering)	Enriching non-immersive databases (e.g., PDM)

Optimization	Provision of required data and semantics (e.g., digital twin)	Prediction of future actions based on XR technology utilization (e.g., Predictive Maintenance)
Collaboration	Reduction of time delay in interaction (e.g., 5G)	Integration in regular collaboration tools (e.g., Knowledge Management)

Organizational Perspective

From an organizational perspective, the identification phase of innovation-based deployment must examine how the technological enrichment of the XR technology stack can be integrated. This involves considering how the (sub) process can be rearranged, adapted, or replaced to generate added value through the innovative XR technology stack. These processes may need to be extended with manual or semi-automated activities to ensure temporary data availability for the project. As the innovation-based approach is a project that has yet to be done in the form before, the project's outcome for value creation is still being determined. This makes organizational support by the deployment sponsor and the target users even more critical. The project manager must manage expectations accordingly. This can be achieved by reducing the requirements for the technology as part of a PoC, to the extent that the potential added value of the approach can be demonstrated as early as possible. Furthermore, appropriate risk identification, assessment, and mitigation of the deployment initiative must be established from the identification of a potential case of innovation origin.

Environmental Perspective

The environment of value creation is the third aspect of innovation-driven deployment. Knowledge acquisition plays an important role in this context. Since both the value creation organization and comparable institutions have not yet carried out the deployment under consideration. For this reason, the organization might not have the required skills and capacities for execution. For this reason, it is necessary to assess at this point whether there are suitable external partners for the endeavor. Particularly against the background of the innovative approach, it may be appropriate to collaborate with research institutes for the XR deployment project.

4.3.4 Summary of the Identification Phase

The first step of the XR technology deployment is the identification of a suitable potential case, which consists of the assumed "potential" in the value creation and the "case" of a use case. The methodological approach is based on Brown's design-thinking approach, focusing on understanding, defining an issue, and generating potential solutions. The established purpose of XR deployment plays a central role in this step. The potential cases originate from three sources. In the case of an existing pain point, it must be broken down into its root and sub-causes, which can then be addressed by XR. In the case of best practice, it is necessary to abstract the best practice through the XR purpose and qualify it within the context of the underlying value creation according to the user and the targeted process. The potential case through innovation arises from the extension of the XR technology stack by enabling or exploiting technologies and the organizational transformation and acquisition of external knowledge sources.

In all three cases, the identification phase results in a concretized solution approach regarding the deployment of XR technologies in the value creation process. In the analysis phase, the objective is to prepare a solution approach for the actual implementation using concrete requirements.

4.4 Analysis

According to Cronk and Fitzgerald, the value of IS, and therefore also for XR technologies, lies in three dimensions: user, system, and business (Cronk and Fitzgerald 1999). To deploy XR technologies in a value-generating manner, the identified potential case from 4.3 must be analyzed and evaluated in these dimensions to prepare for the initiation of the XR technology deployment.

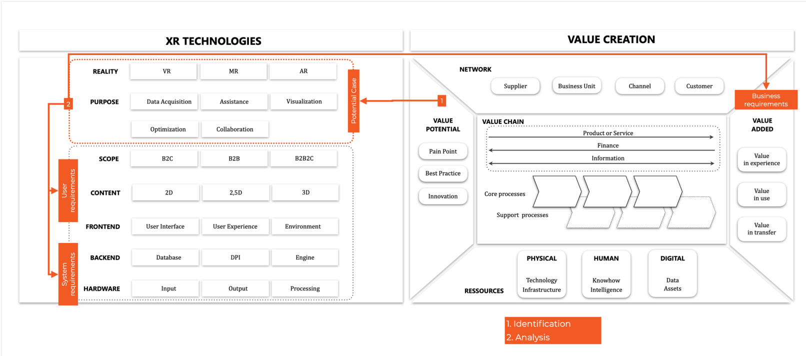

Figure 4.9: Analyzing the potential case to derive requirements

The identified potential case from a pain point, a qualified best practice, or a potential technology combination for innovation contains a desired XR technology functionality in a dedicated area of the value creation. Based on this functionality, the required reality to generate through the XR technology and the XR technology purpose is stated, resulting from the identification phase, as shown in Figure 4.9. The next step is to translate this potential case into an actionable deployment initiative in the form of requirements through a three-layered analysis.

First, the user perspective must be determined to fulfill the requirement of user-centricity. Deployment success stands and falls with the acceptance of the users. To ensure acceptance, the user and its requirements must be involved from the early stages of the deployment initiative (Paetsch et al. 2003). In this context, the individual user's requirements must be captured, as well as their responsibility in the (sub-)process chain to create a desirable solution. The user analysis defines the scope, content, and Front-end morphology required for the deployment.

Subsequentially, it becomes evident which Back-end morphology must be chosen for the XR technology to enable the user in the desired manner. Based on the user-specific requirements, the system analysis can be performed to draw an information architecture and a targeted process design for the XR technology deployment. From this, the technological requirements can be captured, both on the users' and organizations' sides. The feasibility of the solution can then be ensured, and the integration effort can be quantified based on this.

The business-oriented analysis is oriented toward the value creation. It consists of the identification of the value added and the estimation of the costs for the deployment and the operation of the deployed XR technology. The value unleashed through the deployment is to be quantified in the sub-dimensions of the value in use and the value in transfer. Additionally, the value in experience is to be assessed within the business analysis. XR technologies might provide a new form of value that cannot be directly quantified within the existing value understanding.

4.4.1 User Analysis

The first step of the analysis phase addresses the user. Regarding the user-centered execution of the methodology, the user is at the beginning of the transformation of an identified potential case into a solution. By creating the user requirements, the XR technology setup for the deployment scope, the displayed content, and the Front-end of the technology can be defined.

The goal is to lay the foundation for user acceptance during this analysis phase. According to the technology acceptance model (TAM), the two core components for technology acceptance are perceived ease of use and perceived usefulness of the addressed target user (Davis 1989). The first step is to define the different roles within the targeted solution to ensure the perceived ease of use for the target users. For this purpose, the user-centered tool and agile artifact of persona development should be applied to conceptually model the target users through the deployment stakeholders (J. Ma and LeRouge 2007). This enables the deployment stakeholders to develop the necessary user understanding for the solution's design, and the key is shaped towards the target users' convenience. By identifying the different roles, the target users can be distinguished and addressed with features towards their capabilities and needs. Overall, the identified personas provide the foundation for defining the scope of the XR deployment.

Additionally, a core component of an agile and user-centric software development effort, regardless of the field, is user stories (Noel et al. 2018). To ensure the perceived usefulness, the second step is to create the user stories of each persona for the target users to capture the requirements of the solution to be deployed. By doing so, the features of the solution can be captured from the addressed target users and can be prioritized and organized within a product backlog for an agile and iterative deployment of the XR technology (Schwaber 1997; Schön et al. 2017). Based on these user stories, the content to be displayed and the Front-end of the XR technologies can be defined.

Persona Development

Generally, a persona is an imaginary person with the typical characteristics of a dedicated user group to that represents a set of target users (J. Ma and LeRouge 2007). Persona development is performed within a joint session of the deployment stakeholders empathizing with a role and defining both the subjective and objective core characteristics of the role. Putting oneself in the role of a persona to be developed builds an understanding of the overall context of the solution. Figure 4.10 shows an exemplary persona development framework.

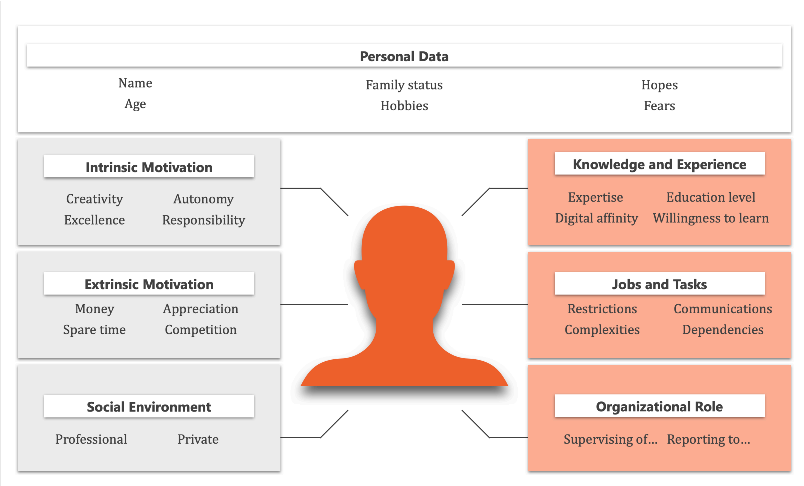

Figure 4.10: Template for persona development (J. Ma and LeRouge 2007)

This exemplary profile suggests structural directions for the development of the personas. Defining the personal data within this framework fulfills the purpose of creating a more tangible person empowering the creativity of the deployment stakeholders developing the persona. The left side of the profile aims to detect more subjective and emotional components of the represented user group, providing the required motivators for developing a desirable solution. The perspective of the personas is a more objective-focused set of information to tailor the solution architecture towards the value-adding requirements of the represented user.

Given the complexity of administrating, authoring, and maintaining an XR technology solution, the personas should be distinguished into the two categories, admin user and end user. While the admin user is coordinating the usage, the content, and the access to the solution, the end user is performing the core functionalities with the intended purpose within the value creation. In doing so, the answer is drafted towards a more autonomous deployment of the XR technology, making the set of users more independent from third parties and the overall solution more convenient for the organization. In addition to the user-centric orientation of the stakeholders, this creates elementary system components for system analysis in the next step.

As a result, the personas can be transferred into the desired scope of the XR technology deployment. The identified characteristics of the involved users can be stated if the technology is deployed in a B2C, a B2B, or a B2B2C context.

User Stories

Their requirements for the solution must be collected, mapped, and orchestrated to provide valuable features to the target users. A common artifact within the agile deployment is the definition of user stories. In general, user stories are a partially structured collection of requirements from the perspective of a user for a software product to be developed. They are created by using the following structure:

"I as [WHO] want/should/need [WHAT] so that I can [WHY]."
(Wautelet et al. 2014)

Thus, the user story consists of a user (i.e., persona) desiring a functionality for a specified reason. This level of communication enables an interdisciplinary understanding between deployment stakeholders. E.g., it also allows a developer to understand the background of the desired functionality.

The initial collection of the user stories is to be executed within a sequence of collaborative sessions to acquire a set of user stories, which can then be stored in the product backlog of the deployment initiative. Each user story must be prioritized by the product owner against a potential value added to the target user and the technical feasibility to enable the deployment initiation with a restricted set of functionalities. Overall, different sets of user stories are aggregated into epics to provide the context of the user stories to the deployment stakeholders and maintain the executability of the user stories (Lucassen et al. 2015). Overall, the product backlog continuously evolves throughout the deployment initiative and is therefore maintained and refined by the product owner based on the users' needs (Sedano et al. 2019).

In the next step, the prioritized user stories are refined into so-called tasks with a stronger technical reference (Liskin et al. 2014; Müter et al. 2019). To ensure a mutual understanding of the user requirements, the tasks must be formulated straightforwardly and drilled down into technical executable sub-tasks for the team. Table 4.6 suggests concrete verbs to maintain clarity for the developers within the product backlog.

Table 4.6: Action verbs for task creation from user stories (Müter et al. 2019)

Verbs	**For defining**	**Example in the context of XR**
Create	New feature	Create new asset with interactions
Update	Enhancement	New interaction method with existing scene
Merge	Combination	Add part of one interaction to another interaction
Delete	Removing	Eliminate asset from scene
Validate	Entry checks	Create a validation check to retrieve right data
Control	Manage functionality	Establish an error message to avoid issues during usage
Investigate	Identify	Potential impact of a new feature on the system

The formulation of the tasks of user stories is to be performed within a joint effort of the SCRUM master and the product owner, covering both the technical domain knowledge of the SCRUM master and the developers as well as the detailed user understanding of the product owner.

As a result of the user stories, it is now possible to formulate which content is shown to the end user. It is important to differentiate which two-dimensional content is presented, e.g., in the form of the required information. In addition, the three-dimensional component in the form of assets and models must be derived from the user stories. While doing so, it is to be decided which LoD is required to provide a value-adding solution and a convenient user experience. To further reduce complexity, the user stories must also be used to evaluate which three-dimensional content can be presented to the user in an abstract form. Thus, the 2.5-dimensional content provision can save development effort and the computing power required to provide the user experience.

Furthermore, user stories allow us to choose how the information, experience, and interactions are accessible to the user. This defines UI requirements. The linking of user stories results in the basic framework for the user experience, which is designed accordingly during initiation. Additionally, the XR solution environment can be derived from user stories. This clarifies whether the solution is a mobile application or whether a stationary solution meets the user's requirements. As a result, the Front-end component of XR technology is defined.

4.4.2 System Analysis

The system analysis aims to identify the interaction of the value creation system with the solution to be developed based on the identified personas and user stories. The first step is to divide the relevant user stories into functionalities and transfer these functionalities into an information architecture. Thus, the entire interaction between the admin user, the end user, and the corresponding information flow in the value creation is drafted. The requirements of the user stories are to be mapped against suitable Back-end modules of the XR technology. In addition, the information architecture and its integration into the value creation process may require interfaces for the data flow from and into the solution. Based on this, the defined purpose, and the user stories, a Back-end technology stack can be created that includes the databases, the DPIs, and XR software modules for the engine of the solution.

In the second step, the underlying value creation process will be drafted with the information architecture. The deployment of the solution can either shorten the existing core process, replace existing sub-processes, and therefore require an additional support process for operation. The should-state of the (sub-)process with the deployed XR technology will be drafted within this step. This unveils which hardware components are required for deploying the solution into the value creation.

Information Architecture

An Information architecture is a framework of information categories between users and systems (Brancheau et al. 1989). For the deployment of XR technologies as a prototype/solution, the objective is to obtain an overview of how the business-oriented functionalities of the user stories relate to each other, the organizational structure, and other applications. The overall objective is to create a bigger picture of the system to derivate the proper engine setup for the targeted solution.

The development of the information architecture is inspired by existing methods of BPM, such as event-driven process chains, data flow diagrams, and the BPMN (**chapter 2.2.2**). Regardless, the described approach tries to follow the principles of agile modeling (Ambler 2001). The simplicity is intended to avoid overengineering of the requirements and the resulting complexity and to empower the development team (Paetsch et al. 2003). The outcome of the modeled information architecture is the systems requirements for deploying the XR technology based on an abstracted data flow. The information architecture of the solution provides an initial hierarchy and interconnection of the user stories. The user stories are broken down into the four components shown in Table 4.7.

Table 4.7: Components of the information architecture

Component	Description	Example
Screen/Scene	A screen or scene is static perspective of the user while using the solution. The term screen depicts a two-dimensional interface for the user. The term scene depicts a static impression of a 3D experience of the user.	**Screen:** log-in app screen of a MAR solution. **Scene:** Three-dimensional view on a scenery within an HMD VR solution.
Interaction	An activity of the user that brings him to the next scene/screen.	Hand gesture or touch action

Dataflow	Connecting lines between the interactions and screen/scene.	Transition of user data to the next screen/scene
DPIs	Interfaces in the architecture where data is passed into or out of the system to enhance or retrieve data from existing data sources.	**Output**: Connection of the collected data to the ERP system. **Input**: Depiction of three-dimensional data from the PDM system

Figure 4.11 depicts an example of an information architecture by showing two personas of an admin user and an end user. Data from the admin user is actively extracted and pushed toward external systems through the DPIs, e.g., Enterprise Resource Planning (ERP) systems. The end-user can retrieve data automatically connected through the DPI in the end-user interface. An exemplary user story is indicated within the abstracted architecture to show the connection between the user stories and the information architecture.

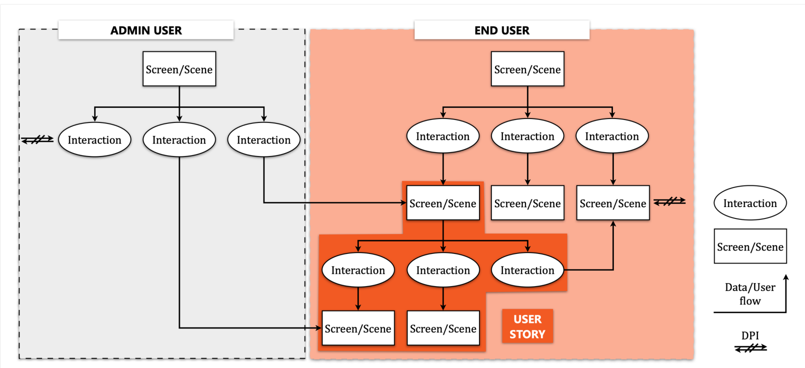

Figure 4.11: Abstracted information architecture

The information architecture is created in the form of a mind map. It is essential for the creation of the information architecture to anticipate the target user's behavior and to model it based on the manual process to be enriched. Thus, the application can be integrated into the existing value creation model. Based on the holistic depiction of the interaction, the existing data sources that are required can be identified. Furthermore, the overall technological requirements towards the Back-end of the XR technology stack become evident. While the information architecture illustrates the DPIs and the databases to be created and integrated, the overall architecture requirements provide the possibility to nominate a suitable engine to operate the XR technology. Especially the interactions within the information architecture and the exposure of possible DPIs enable a decision on the most appropriate engine setup for the targeted solution.

Process Design

Based on the information architecture, the second step of the system analysis is to design the process of value creation and integrate XR technology into the existing flow. The target of the process design is to identify the required hardware setup of the input, output, and processing units to deploy XR technology within the value creation processes. Thus, it must be identified how user activities are affected by XR technology. Furthermore, it must be determined which additional activities are integrated into value creation to carry out the process with XR technology. In the initial use phase, workarounds may have to be established to avoid the time-consuming and costly automated integration of XR technology into the existing system landscape. Therefore, for the goal of PoC, it is advisable to make a limited set of data available. On the other hand, this results in manual effort for value-creation participants.

To execute the process design for XR technology deployment, the CAP framework is combined with the process visualization theory (Phalp 1998; Overby 2008). In this sequence, the four core properties of process virtualization are examined within the analysis phase of the CAP framework and explored accordingly. The steps are to be executed within the methodology:

1. Capture
   Identify and depict the value chain's core processes that are

affected by the user stories and the resulting XR deployment. While doing so, it is furthermore to define which sub-processes and support processes belong to the core processes.

2. Analyze
   The process virtualization theory is applied to the captured core processes and the belonging sub- and support processes to design them according to the XR technology deployment. The following characteristics must be investigated and defined (Overby 2008). Table 4.8 summarizes the analysis focus on drafting a virtual value creation process with XR technology.

Table 4.8: The virtualization theory for XR technology deployments (Overby 2008)

Focus point	Generic description	XR example
Sensory	Mapping of the physical components from sub- and support processes.	Creation of the static virtual scene and dynamic connections between the virtual and physical scene.
Relationship	Defining the relations and interfaces between the affected sub- and support processes.	Defining of data input and output fields for 2D or 3D data transfer.
Synchronization	Establishing the required time reference between the sub-processes and support processes.	Establishing of a temporary storage or cache of the 3D content.
Identification	Installing control mechanisms in the flow of the overall process.	Tracking of user behavior and establishing of rules.

3. Present
   Subsequently, the overall process, core, sub-process, and support process must be illustrated in a target state with the XR technology applied. This picture summarizes the analysis result and provides an orientation for the initiation phase. It is important to note that this picture is an initial representation that can change during the progression of the deployment. It must be continuously checked whether the initial assumptions made in capturing the process are still valid and whether the XR technology changes

the behavior of the user in such a way that further adaptation is necessary for the process or the solution.

With the executed process design as a basis, the acquired results can be used to define the hardware setup for the XR technology deployment. The output unit requirements depend on how the real scene is to be represented by the virtual scene. Accordingly, the setup is to be selected depending on whether, for example, full immersion is necessary or if the virtual scene is to be projected into reality. The input unit requirements result from how the mapped virtual scene is influenced by the real scene and the interaction that takes place in it. Therefore, sensors and tracking systems must be selected. The setup of the processing unit must be aligned with how the synchronization via temporary storage units and computing power must be ensured, and automated control mechanisms must be installed.

4.4.3 Business Analysis

The business analysis proposes conducting a cost-benefit analysis of the XR technology deployment. The initial analysis results do not impose any requirements on the technological setup. Yet, the results of the analysis are to be seen as an economic requirement for the business performance of the solution. These requirements are omnipresent throughout the deployment process and must be continuously verified regarding their viability. Especially for the deployment sponsor, adherence to the identified business requirements is important to ensure the value-adding deployment of XR technologies.

For the added value, a distinction must be made between qualitative added values that cannot be directly monetized and added values that can be now quantified. For the cost analysis, a difference must be made between initial implementation costs and ongoing operating costs. On the cost side, the opportunity costs must be considered. For the technical implementation, resources must be reallocated from the existing value creation and applied to the realization. For example, an employee who is also a target user must be planned and included on the cost side for requirements collection, feedback acquisition, and temporary efficiency losses due to the conversion of the process with XR technologies.

4.4.3.1 Value Added

The added value from the deployment is defined based on the NICE framework and the value generation according to the generated use value and realized exchange value explained in **chapter 2.2** (C. Bowman and Ambrosini 2000; Amit and Zott 2001; Zott and Amit 2010). The terminology is adopted from the categories suggested to define the economic impact of XR technology deployments in value creation (T. Krodel et al. 2023). As XR technologies are highly experienced-driven and provide value while being used, the categories in this framework are defined as the value in experience and the value in use. Furthermore, the deployment of XR technologies creates a transferable value in the form of new services. Therefore, the third value added category in this methodology is the value in transfer.

Value in Experience

The value in experience is derived from the lock-in of the NICE framework (Zott and Amit 2010). This methodology suggests that an XR technology offers a new way for users to participate in a value creation. Thus, using XR technology, an experience is created for a target user who is motivated to interact with the ecosystem of value creation in a way that the user would not do without the XR experience. Therefore, XR technology deployment enables users to participate and contribute to the value creation through its use. Furthermore, the experience creates a lock-in for the user and makes it increasingly difficult to switch to another ecosystem that is not part of the underlying value creation. E.g., this indirectly avoids the occurrence of churn costs.

In concrete terms, this means that the experience of the XR technology use triggers the intrinsic motivation of the user to act in a way that they would not do without the experience. This includes, for example, a user consciously trying to avoid errors in a process flow. On the other hand, a potential customer may become aware of the value creation construct and the offered product or service through the experience in the first place.

With the three-dimensionality and the subjectivity of user perception, XR technology deployment is experience-driven. Consequently, the potential value in experience through XR technology is higher than that of comparable two-dimensional approaches (e.g., mobile applications). Even though the value in experience cannot be monetized directly, it is the foundation for value added through the value in use or the value in transfer.

Value in Use

Value in use results from applying the XR technology in a process of the value creation. As shown in **chapter 3**, XR technology can increase a process's efficiency because using technology simplifies the execution of the process steps. It is assumed that for the realization of the value in use, the user is part of a partner in the value creation network, e.g., the business unit. Several process steps can be combined using XR technologies, and synergies can thus be leveraged. Overall, the added value comes from an increase in productivity.

The productivity generated by XR technologies in a (sub-)process directly or indirectly reflected in the value-added. For example, XR technologies can improve a process by either simplifying or combining complex activities or reducing errors, thus reducing costs. This means that a lower use of resources or less effort for rework results from XR deployment. On the other hand, XR technology can optimize and accelerate a process in the execution itself that the output quantity or the quality of the value creation is increased. In both cases, a monetarization metric can determine and quantify the added value. While the value in use is directly noticeable in the value creation, it can only be monetized indirectly as no transaction is executed. The value in use is to be continuously tracked by comparing the as-is state or the state of value creation without the XR technology with the state with its use. Table 4.9 shows possible combinations and describes to what extent the value in use is created through cost savings or profit increases.

Table 4.9: Possible metrics for calculating the potential value in use of XR technologies

Value in use category	**Leverage**	**Monetarization metrics**	**Example**
Cost savings	Scrap reduction	Number of avoided errors	AR solution guides the user through the steps and avoids human mistakes
	Time reduction	Reduced working hours	VR solution reduces the loading time of 3D models through an integrated user experience
		Reduced process steps	MR solution combines process A and B by capturing the relevant data from both automatically
	Reduced process complexity	Time and error reduction	XR solution is designed in a straightforward journey and eases a tendinous existing process with multiple systems
	Standardization	Reduced product variations	The provision of pre-defined options to the user in an immersive way avoids customization requests
Profit increase	Output efficiency	Increased output volume	With the VR solution for visualizing products enables the salesperson to address more potential customers
	Improved quality	Increased sales price	The XR solution enables a more precise production process and therefore improves the value of output
	Up-selling	Increased sales volume	With the presentation of the product in the XR solution, the product is more desirable and gets sold more often
	Cross-selling	Increased sales volume (related products)	The presentation of related products to potential customers increases the sales of another product than intended by the customer

Based on the user stories, the expected value in use is to be stated as assumptions that can be validated throughout the deployment sequence:

"With the deployment of the XR technology, we assume to create [LEVERAGE] by reducing/increasing the amount of X [MONETIZATION METRIC] for the value of Y."

The assumptions for the added value in use can address multiple leverages. These assumptions are then to be tracked and validated within the business re-assessment (**chapter 4.7.2**).

Value in Transfer

The third value-adding category of XR technologies is value in transfer. Unlike the value in use, this is concluded by a transaction between two entities. This means that in this value-adding category, the user is part of a different organizational unit than the unit providing the XR technology.

According to the value creation theory of Bowman and Ambrosini, an organization creates usable value and realizes monetary value through a transfer (C. Bowman and Ambrosini 2000). In the context of XR technologies, the user can access a new form of a service provided via the XR technology in the value creation. This can be either a standalone service as a new offering or an add-on service to existing products or services.

The added value created by XR technologies for transfer can be seen as an extension of the existing value creation spectrum of services. To quantify the value in transfer, according to Osterwalder, the seven possible revenue streams are therefore to be used to recognize, define, and transfer the possible added values (Osterwalder et al. 2010). The revenue stream of the asset sale is excluded since XR technologies, in the complexity of their morphology, cannot be realized as an independent overall product by a one-time sale of the construct. Table 4.10

summarizes the possible six revenue streams from the transferable added value of XR technologies.

Table 4.10: The generation of value in transfer with XR technologies, based on (Osterwalder et al. 2010)

Revenue Stream	**Description**	**Exemplary realization through XR Technologies**
Usage fee	Fee for the use of an offer charged by the time of use	The developed XR solution can be used on-site on the provider for a dedicated fee per time unit.
Subscription fee	Periodically accruing fee for the agreed term of use of an offering	The user agrees to a monthly payment to access advanced XR features in an existing application.
Leasing fee	Granting of the exclusive right to use an offer for a physical product over a defined time	The XR technology stack of hard- and software is provided to a user for a dedicated time.
Licensing fee	Granting rights to use an asset for a fee	The developed XR software technology stack is provided to another possible organization.
Brokerage fee	Share of the fee for arranging transfers of value from a third party	The XR solution contains an area where products or services from other providers are purchasable; each purchase is rewarded with a share of the revenue.
Advertising fee	Fee for advertising a third-party offer on a platform	The XR solution contains an area where products or services from other providers are displayed.

The usage fee, the brokerage fee, and the advertising fee are irregular added values that depend on the number and frequency of users of the XR technology. The subscription fee, leasing, and licensing generate recurring revenue streams for the value in transfer over the planned duration in each case. Overall, the transferable added value of XR technology can be realized and quantified based on these possible revenue streams.

4.4.3.2 Cost Estimation

XR technology deployment incurs costs for the organization of the value creation. Various cost items must be considered, during the deployment sequence. These are divided into three categories: initial costs, operation costs, and scaling costs.

Initial Costs

For the initial deployment of XR technology, the implementation requires a budget for setting a prototype in the initiation phase. Table 4.11 shows the cost items incurred for the initial setup.

Table 4.11: Initial cost positions for XR technology deployment

Cost type	Cost cause	Required resources	Cost metrics
Conceptual costs	• Research & analysis • Potential case identification • Concept definition • Communication & Documentation • Project management	• Project manager • Strategists • External experts	• Internal time required (Billing rate per time) • External fees (Cost per time / cost per concept)
Design costs	• UI design • UX design • 3D Asset creation	• UX designer • 3D artist	• External fees • (Cost per time / cost per concept / cost per asset)
Development costs	• Front-end development • Back-end development • Server operations • Technical project management	• SCRUM master • Domain developers	• External fees • (Cost per time / cost per user story / cost per sprint)
Opportunity costs	• Requirement delivery • Feedback provision • Testing	• Product owner	• Internal time required (Billing rate per time)
Hardware acquisition costs	• Hardware rental • Sandbox access fees • Testing devices	• XR devices • Hardware setup	• Cost per time unit • Cost per device
Software license acquisition	• IDE, SDK, Library access • Sandbox access Purchase of test equipment	• XR engine components	• Costs per license

For the initial cost, parts of the required Deployment Stakeholders and required resources might be outside the organization. For this reason, costs are incurred for the acquisition of external resources. The concept of the XR technology deployment can require both internal and external capacities for an identification and analysis of the potential case. It can be assumed that external resources will be needed for the design and development effort. In this case, costs can be incurred based on time and material (input-oriented) or deliverables (output-oriented).

Furthermore, the required time of the identified product owner or target user is to be applied in the initiation phase. The time required for the development of requirements or testing must be evaluated using an internal billing rate for the actual value creation activity. Additionally, there are possible costs for the required hardware and software licenses. Hardware should not be purchased for the initiation phase but should be made available to potential technology pools, rentals, and sandbox organizations to reduce costs in this phase. However, acquiring a small number of devices required for the development team might be needed for the immediate testing of development deliveries.

Operation Costs

Once the initiation of the XR deployment is complete, the solution or prototype must be made accessible to the target user group. For this purpose, the developed solution must be transferred from the development environment to a productive or staging environment. This incurs high operation and maintenance costs. Table 4.12 shows the cost items for the XR technology deployment and the XR technology operation.

Table 4.12: Operations cost positions for XR technology deployment

Cost type	Cost cause	Required resources	Cost metrics
Ramp-up	• Server setup • Transition-out (optional)	• Back-end technologies • Domain developers	External fees (Cost per time / cost per concept / cost per asset)
Hosting	• Server operation • Cyber security	• Back-end technologies • Domain developers	• Server costs • Insurance costs • Operational service fees
Maintenance	• Version updates • Bug fixing • Improvements	• Domain developers • Back-end technologies	• External fees (Cost per time / cost per concept / cost per asset) • Internal resource acquisition (cost per resource)

During the operation, a ramp-up must be performed after initiation. This involves setting up the server instances and bringing the XR solution into an environment that is accessible to the target user. Hosting incurs costs for operating the hardware landscape, particularly for server instances. For product maintenance, it may be the case that organizations build their resources to save costs and generate know-how in the long run.

Scaling Costs

As soon as the solution delivers the desired added value during operation, the PoV is achieved, and the XR solution can be further developed and scaled accordingly. This is to be done in the integration phase (**chapter 4.8**). Regarding costs, the positions in Table 4.13 are relevant for scaling.

Table 4.13: Scaling cost positions for XR technology deployment

Cost type	Cost cause	Required resources	Cost metrics
Further development	• New feature identification • Feature execution • Feature optimization • Development for new platforms	• Project manager • Strategists • Development team • Product owner • Scrum master	• Internal time required (Billing rate per time) • External fees (Cost per time / cost per concept)
Resource acquisition	• Physical • Digital • Human	• UX designer • 3D artist • Domain developer • Data • Software components	• Cost per resource
Training	• Workshops • Training material (e.g., videos, tutorials, descriptions)	• Product owner • Target users	• Internal time required (Billing rate per time)
Business development	• Marketing activities • Scouting for new target user groups	• Project manger • Dedicated sales manager	• Internal time required (Billing rate per time)
User service	• Support • Feedback collection	• Support manager	• Internal time required (Billing rate per time)

The costs for scaling are versatile. Depending on the scale, further development can be economically viable. Depending on the long-term nature and added value, as well as the relevance of the intellectual property, the organization must build up the relevant resources for the independent operation of the XR technology as part of the scaling process. This includes domain developers, XR technology hardware setup, etc. Furthermore, it may be necessary for scaling to teach end users how to apply the XR technology, especially for achieving value in use. In addition, it may be useful to build an independent team for business development for the XR technology if the objective is value in transfer. If the XR technology is to be scaled in a B2C context, it will be necessary to establish user or customer support. These cost centers must be identified and evaluated accordingly as soon as the XR technology is scaled in the value creation.

Budget Allocation

To bear these costs, the organization must provide a dedicated budget. The deployment sponsor is responsible for allocating this budget as he fulfills the role of the budget responsible within the value creation (e.g., top management). The budget must be defined value-based rather than cost-based. This means it is estimated based on the identified potential case and the analyzed added value from the first part of the business analysis. The required budget is consumed by the costs incurred during the deployment sequence. The budget will be monitored continuously during the deployment sequence and released iteratively according to the agile approach. Figure 4.12 shows the qualitative progression of the initial, operational, and scaling cost categories over time.

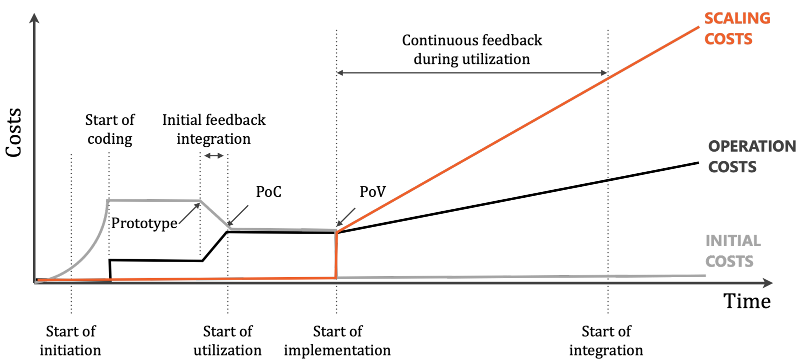

Figure 4.12: Qualitative progression of cost categories within the XR deployment

The initial costs start with the need for conceptual effort and increase through the design of the potential solution. The maximum initial cost occurs with the technical programming execution. Likewise, the costs for the operation of the development environment increase. With the completion of the prototype, these operational costs increase because the prototype must be accessible to the alpha testers. The initiation costs decrease as the development effort is reduced to implement the initial feedback, rather than creating developing new functionalities. A dedicated amount of initiation costs will still be required to add the feedback from the beta test to achieve the PoV. Operational costs increase with the number of users until the critical quantity for the PoC is reached. With the PoV, a critical number of users must prove with the PoC that the added value can be generated. Subsequentially, the scaling of the solution through further development begins. During the iteration of utilization and implementation, feedback is continuously implemented as part of the development, resulting in increased effort. As the functionality and reach of the XR technology increases, so does the cost of operations.

Overall, it is advisable to perform an effort estimate of the required number of user stories to be executed before the initiation to release of the required parts of the budget. The first version of the deployment should deliver a prototype and thus achieve a PoC. Then, based on the user feedback, the evaluation should define how the next budget will be allocated to achieve the PoV. Due to the iterative budget release, the deployment stakeholders are encouraged to prioritize the user stories in a value-generating way. Nevertheless, an available budget contingent is necessary to enable the high-quality implementation of the XR technology deployment.

4.4.4 Summary of the Analysis Phase

The potential case defines the purpose of XR technology in XR morphology and which form of XR, that is, VR, AR, or MR, is to be generated. The analysis of the identified potential case aims to prepare for the initial execution and to ensure economic viability. Three phases of analysis were performed.

The analysis starts with a user-centered approach and focuses on potential users. Through the development of the personas involved, the scope of the application becomes apparent, and the context in which the application is to be operated by which roles can be determined. With the help of user stories, the desired functionalities were captured in a semi-structured manner. These are transferred into technically realizable tasks using predefined wording. Based on this, the content to be shown and the requirements for the Front-end can be specified.

The system analysis begins with the linkage of the decomposition of the user stories into functionalities, consisting of screens or scenes and interactions. These are transferred into an information architecture, showing which databases are required, which data interfaces the solution needs, and which functionalities the engine must fulfill in the back end. Based on the information architecture, a target process is then designed, which specifies through virtualization requirements which physical hardware is necessary to use the XR technology in the identified process.

Business analysis is secondary to operational initiation; however, economic viability must be ensured. Therefore, a preliminary cost-benefit analysis of XR technologies with continuous monitoring was performed. The qualitative Value in Experience, quantifiable value in use, and monetizable value in transfer are to be estimated. In comparison, the costs of initiation, operation, and scaling must be estimated. Furthermore, it is important to plan an iterative budget release in the business analysis based on the potential value to be added within the value creation and to create awareness of the economic milestones of PoC and PoV.

The result of this phase is the users' requirements against the solution's scope as well as the content and Front-end of the XR technology. These are documented as personas and user stories. The system analysis defines the technical requirements of the Back-end in an information architecture. The process design resulting from the information architecture provides a hardware setup in the form of a targeted process flow. The economic requirements are stated as the value to be added in experience, in use, and in transfer, as well as the potential costs.

4.5 Initiation

For the initiation, the required technical and organizational setup is established to enable both the development team and the deployment stakeholders with the general conditions to execute the deployment. Within the design phase, the requirements from the analysis phase must be transferred into a visual prototype. The target user can assess this prototype and agree on it as a deliverable with the product owner. Based on the confirmed visual prototype and the technical and organizational conditions, the execution in the form of technological development can be performed.

4.5.1 Setup

To initiate the deployment of the XR technology, the project manager oversees the creation of an appropriate setup for the development team. This means creating general organizational conditions for the development team by providing access to the required information and an appropriate environment for executing the requirements. Furthermore, the setup requires the provision of technical resources to the development team within the restricted budget to create a prototype for achieving the PoC.

General Conditions

First, to provide the development team is to be provided with the required general conditions, the project manager establishes a communication setup with the deployment stakeholder. This communication setup consists of (Schwaber 1997):

- The regular exchange between the development team (e.g., SCRUM dailies)
- Status updates between the project manager, the product owner, and the SCRUM master (e.g., Jour Fixes)
- Frequent progress reporting to the deployment sponsor
- Announcements and updates to the target user
- Documentation and task management (e.g., SCRUM board)

By doing so, the project manager can track the execution progress, identify potential impediments, and manage the business expectations by an apparent target formulation. Furthermore, extensive documentation of performed tasks, achievements, and potential risks during the deployment process provides a legal security layer and problem-resolving base in case of difficulties during the deployment flow.

Second, it is advisable to establish a hybrid setup for the deployment from the processual organization in the form of a sandbox environment (Ribiere and Tuggle 2010). This means establishing the XR deployment as a stand-alone approach within the targeted process while the existing process remains unaffected by the initiation. Subsequently, the initiation of the prototype requires manual effort to simulate the real environment by creating manual data availability. Furthermore, this might require additional effort to execute the prototype with the target user as the target user has to build additional capacities for testing and providing feedback. However, this ensures the maturing of the solution without risking downtime costs, which might be a potential showstopper for the overall XR deployment.

Technology Acquisition

To initiate the XR deployment, it is required to provide the development team and later the targeted with XR technology that is yet to be available to the organization. While purchasing XR technology is expensive and carries economic risks before the PoV is achieved, temporary access to the XR technology can be granted through technology renting platforms and sandbox labs within the initiation phase. This enables the achievement of the PoC and or the PoV without significant hardware investments.

If the XR solution is supposed to be operated on COTS devices (e.g., mobile phones, PCs, and Laptops), the project manager must ensure that the existing hardware for value creation fulfills the system requirements for the targeted XR solution and if the target user has access to the required type of device. Furthermore, it ensuresthat the target user and the development team are willing to utilize their devices in case they are outside the value creation (e.g., privately owned mobile phones).

For mobile XR technology hardware (e.g., HMD XR), the project manager can reduce the initiation costs for hardware by renting the required hardware stack. Platforms such as grover provide access to various XR hardware technologies for a fixed period (grover 2022). If the PoC cannot be achieved, these technologies can be returned to the platform. Furthermore, the avoidance of major investments improves budget availability. Consequently, the budget can be utilized for development and testing capacities. This improves the quality of the overall XR technology and increases the likeliness of a successful PoC and PoV.

For stationary XR technology (e.g., VR CAVE), the installation and operation costs are high. The initiation costs can vary from 80.000 EUR (2-sided) up to 750.000 EUR (6-sided) just for installation and cause operation costs of up to 3.000 EUR (sky real 2022). Unless the assessed value from the business analysis is not assumed to be significantly higher at a certain confidence level, creating a setup for the initiation with lower costs is required. The next evolution of the innovation sandbox is regional technology sandbox labs, temporarily providing access to sophisticated XR technology for companies (IMI 2021). Next to the access to relevant XR hardware technology, participation within this kind of framework enables the acquisition of know-how and experiences for the deployment initiative from other participants.

4.5.2 Design

As described in **chapter 2.4.3.1**, the process of a user-centered design follows four steps:

1. User context analysis
2. Derivation of user requirements
3. Development of alternative approaches
4. Iterative adaptation of the approaches

Both the user's context and the user requirements emerge from the user and system analysis. Based on this, the development of alternative design approaches can now occur as the first step of the initiation phase.

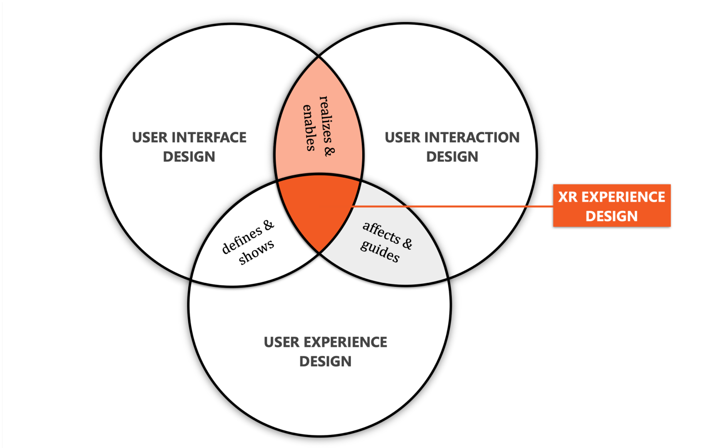

Figure 4.13: The components of XR experience design

The theoretical foundations distinguish between UI, UX, and user interaction design. For the methodology, an integrated design approach is proposed as these three components are interdependent in the context of the XR experience. Figure 4.13 shows these dependencies. As the XR experience is dependent on three-dimensionality, the designed XR experience requires the creation of 3D assets.

XR Experience Design

As discussed in **chapter 2.4.3.1.**, the usability heuristics, according to Molich and Nielsen, are the basis for a user-centered and user-friendly development of a human-machine interaction (Molich and Nielsen 1990). For the XR technology deployment and the design of the XR experience, these principles must be transferred, considering the user's subjective perception. Table 4.14 shows the transfer of the principles to the XR context.

Table 4.14: Usability heuristics transferred to XR experience design (Molich and Nielsen 1990; Nielsen 1994; Stanney et al. 2021)

Usability heuristics	**General description**	**XR-related description**
Dialogue simplicity	Avoid irrelevant information	Separate virtual content and text dialogue information
Language of user	Use of familiar words and grammar for target user	Provide short and helpful guidance through scenes without interfering the 3D experience
Minimized memory load	Avoid necessity to remember advice for longer time	Unique and unequivocal interactions; continuous access to hints on interaction mechanisms
Consistency	Unified schemes, layouts and structure of actions and interfaces	Unified schemes and meanings of haptic, visual, and audio output
Feedback	Information about background system activity	Inform user in case of longer loading times for 3D assets or scenes
Exit points	Ability to leave scene at any time at a visible spot	Ability to leave scene at any time at a visible spot without significant loss of progress
Shortcuts	Integrate advanced features for experienced users to increase usage speed	Enable skipping of guidance or information that the user already knows; Hiding of irrelevant information; adaptability of interactions and interface
Error prevention	Design to avoid unwanted actions	Confirmation of critical actions that change the scene or data status
Constructive error notification	Provide precise messages with guidance to recovery	Provide precise messages with guidance to recovery
Error recovery	Enable un-do of unwanted or incorrect actions	Enable un-do of unwanted or incorrect actions

To involve the target user at an early stage and test alternative design proposals for workflows, the user stories, the information architecture, and the usability guidelines will be drafted into a 2D clickable prototype by the UI/UX designer. Existing graphic software solutions, such as Adobe XD and Figma, provide the possibility to prepare the solution and simulate two-dimensional flows by linking the screens and scenes (Adobe 2022; Figma 2022). With the help of the clickable prototype, design alternatives can be tested, for example, through A/B testing (Young

2014). Furthermore, with the help of the collected feedback from the simulated interaction, relevant findings for the interaction design can be made.

The 2D clickable prototype is then enhanced with a three-dimensional interaction design. The methodology suggests an XR interactions catalog for drafting the interaction within the XR experience. This catalog is based on the introduced interaction alternatives from **chapter 2.4.3.1**. De Clerk et al. suggest for a VR scene three categories of interaction design (de Clerk et al. 2019):

- Speech
- Gesture
- Touch

All of these can be applied to AR and MR and therefore be integrated into the design of the XR experience. However, the catalog is restricted to one specific use case scenario. Thus, the catalog for this methodology is to be enhanced, especially by the options of interacting with the XR solution through dedicated analog input devices, i.e., controllers or mouse and keyboard. The fourth category to enhance the catalog with remote interaction devices is to be defined as “Remote”. Depending on the potential case and the interaction flow, these categories have advantages and disadvantages. Table 4.15 summarizes the four provided interaction design categories with possible pros and cons for the user and the setup.

Table 4.15: Interaction design categories for XR experience design

Interaction category	Description	Pros	Cons
Speech	The user navigates through the XR experience by providing spoken commands	• Hands-free interaction • Partially intuitive to learn	• Restricted commands and interaction options • Additional processing units and software required

Gesture	The user navigates through the XR experience with predefined hand gestures that are captured by the tracking system	• Hands-free interaction • Immersive experience through merger of real and virtual interaction	• Restricted commands and interaction options • Gesture library needs to be learned and accessible through experience
Touch	The user interacts with the scene or the 3D assets on a dedicated touch interface	• Intuitive to learn and apply • Easy applicable to MAR	• Additional device required • Additional scene representation required
Remote	The user is provided with physical input devices to operate within the XR experience	• Common familiarity of keyboard and mouse interaction	• Additional device required • Reduced immersion

The interaction possibilities should be streamlined toward the user stories and validated against the usability requirements. Furthermore, the target user should be asked to provide feedback on their preferences in combination with the clickable prototype. Nevertheless, the business requirements should be kept in mind to avoid an extensive increase in the introduced cost categories in **chapter 4.4.3.2**.

By implementing the feedback to the clickable prototype and shaping the interaction model towards the user preferences, the development team should agree on a design freeze for the initial version with the product owner. This ensures that the development team can execute the defined requirements for the prototype without changing the requests. Additionally, the effort-intense process of 3D asset creation and interaction can be initialized with certain planning security based on the defined visual appearance of the solution.

3D Asset Creation

Creating 3D assets is a crucial point in the design phase of the deployment. As soon as there are no appropriate 3D assets available (in terms of format and size) within the information stream of the value creation, they must be created. This requires both creative and technical know-how from the 3D artist. The assets must be prepared according to the user stories and the Front-end environment. A critical limitation is the creation of assets that can be used in the desired environment. For this, the 3D artist must make a tradeoff between the visual quality (i.e., LoD), the model complexity (i.e., polygon count), and the file size. The major tasks of the 3D artist in creating 3D assets are:

- Creation of model and model components
- Conversion of model file format
- Merging and separation of models
- Texturing
- Shading
- Coloring
- Creation of dynamic behavior (i.e., animations)
- Rigging (i.e., defining scaling and cropping axis within the model)

In terms of restricted model availability and model storage capacities in the XR solution (e.g., MAR solution), the rigging enables the display of model variants based on one 3D asset. Overall, the 3D assets for an XR deployment in value creation can be generated in three ways.

From scratch: If there is no existing data set to be displayed within the XR experience, the 3D artist creates the different scene views and the objects to be displayed within these scenes from scratch. To do so, the 3D artist needs visual requirements from the product owner, which can be provided as reference objects and pictures. Furthermore, the 3D artist needs the technical requirements to provide the 3D assets in the correct format with the right technical characteristics. By providing the context of the targeted environment and the hardware setup, the 3D artist can create the appropriate 3D assets for the deployment initiation with 3D modeling software (**see chapter 2.4.3.2**).

From existing assets: The second way is to create 3D assets from the existing 3D data, that can be displayed within the XR solution. This means that the 3D artist must change the format and the technical characteristics of an existing database to be displayed within the XR solution. This first requires the product owner or the project manager to provide the 3D artist with the database. They might require collecting the database within the value creation and therefore need capacities from the target user to extract relevant data. After that, the 3D artist converts the models in the data base using a 3D modeling software or a conversion program (e.g., from a CAD format to a displayable, more lightweight design). After converting the format to the desired target format, the 3D artist might require reducing the polygon count of the model and repairing potentially corrupted geometry from the conversion. Furthermore, the 3D artist then adds missing metadata to the model for the visual appearance (e.g., texturing, shading, and coloring).

From external sources: The third possibility for creating 3D assets to initiate the XR technology deployment is the acquisition of existing assets. Various virtual marketplaces and communities exist in which 3D assets are available for purchase. These assets can be acquired in various data formats and LoD, ready for deployment in the XR experience. In this case, a 3D artist might not be required, as the project manager or the product owner can collect the data for the development team independently. Especially for background scenes and secondary 3D assets in the scene, this can be a proper enhancement to increase the initiation speed of the deployment, as the creation of these models is time consuming. It should be noted that these models do not violate any copyrights and can be deployed within a commercial context.

Overall, the 3D asset creation in the initiation phase of the deployment must be prioritized in terms of functionality rather than visual appearance to achieve the status of the PoC. Furthermore, the focus should be on providing a limited set of 3D assets for the initiation rather than integrating existing data sources with high-effort workflow implementations.

4.5.3 Development

The development phase includes the technological coding realization of the prototype. According to SCRUM, the agile software development methodology is the core component of this deployment sequence. Figure 4.14 depicts the structure of the SCRUM methodology.

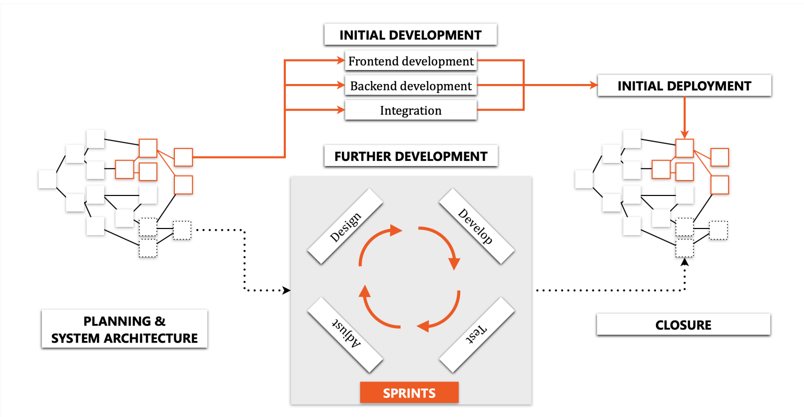

Figure 4.14: Agile SCRUM methodology for the initial XR development; adapted from (Schwaber 1997)

It follows a sprint-based implementation approach and is considered an iterative cycle of development work with flexible deliveries over a fixed period (Schwaber 1997). Within the analysis phase of the user stories and the information architecture (system architecture in Figure 4.14), the initial planning for the XR deployment was performed. The design prototype, the interaction design, and the 3D assets were generated within the design initiation phase and provided to the development team and are ready for execution. For the implementation of the prototype, i.e., the initiation of the development, the XR deployment methodology suggests a deviation from the purely sprint-based approach for the delivery of the PoC. Due to the technical complexity of XR hard and software, it is necessary to implement a fixed scope of deliverables for the initial setup of the programming solution and to keep the time component flexible. Based on a defined functional scope, the development team can then leverage synergies within the XR Front-end and Back-end development, the hardware configuration, and the 3D asset integration. After the initial development of the prototype, the methodology suggests moving to a fully agile SCRUM model as part of the implementation, focused on functionalities rather than the technologies (**chapter 2.4.2**). Based on an agreed functional freeze and design freeze, the prototype's development phases are separated into Front-end development, Back-end development, and integration. After the finalization, the initial deployment of the prototype to the target user must be performed to finalize the initiation phase.

Front-end

First, the Front-end must be developed. Therefore, the development team, in the person of the Front-end developer, sets up the required environment. For mobile solutions, the Front-end developer creates a setup in the respective domain (iOS or Android). In case the XR deployment is planned for a dedicated XR device, the Front-end developer sets up the Front-end within the UI building component of an IDE (if available) or in the native Front-end environment that can then be connected to the regarding APIs, SDKs, and libraries.

After the setup is finalized, the operative task of transferring the 2D clickable prototype into Front-end code is executed in detail. In case the clickable design prototype is drafted in a graphic software compatible with the respective Front-end environment, code snippets with information about layout, spacings, UI elements, colors, and fonts can be directly added to the Front-end code. 2D assets such as pictures can be extracted from the 2D design prototype.

The prototype without functionalities is then transferred to a Front-end prototype. Within the Front-end development, it is to be considered which calculation and progressing tasks (e.g., rendering, model calls, temporary data storage) of the overall XR technology stack are to be performed from the Front-end layer to improve the XR experience in terms of loading times and latencies. In case functionalities are performed in the Front-end, they are also to be developed in this phase. The Front-end is then transferred into an operatable mask for the user which needs to be integrated into the Back-end development.

Back-end

From the Back-end perspective, the Back-end developer creates a system setup of databases and a server infrastructure to create the required system architecture. This system architecture fulfills the task of running the XR application and storing, changing, and providing 3D assets. To create value in use, it may be necessary to add a tracking engine in the system architecture to extract user behavior data and transfer it into value-adding insights. The DPIs are exposed and integrated as part of the system setup in this step.

The setup of the XR engine provides functional development. The Back-end developer compiles required SDKs, IDEs, libraries, and APIs to perform the required functionalities within the XR solution and links them through Back-end coding. In the respective environments, it is possible to acquire pre-coded functionality modules to be integrated into the Back-end technology stack. This may reduce the effort required to create a full-fletch functionality from scratch.

Additionally, the Back-end development consists of the logical execution of the interaction design by linking the Front-end prototype with the system setup and the execution of interaction functionalities. Calculation- intense renderings and processing for the Front-end scenes can be performed in dedicated Back-end components of the system setup. Intelligent distribution of this task within the XR experience is to be defined, so models can be rendered while the user is performing a different activity.

Technical Integration

As part of the integration, the Front-end and the Back-end code are then connected by both parties. Within the developers' technical testing, the functionality of the defined features must be ensured. Iterations and adaptions on both sides are planned within this phase, as the initial connection requires a build-test-learn iteration.

After the Front-end and Back-end, the developer performs the technical integration, and the prototype is delivered to the SQA engineer to perform various testing scenarios. Next to the testing of the visual correctness between the Front-end prototype and the design prototype, the SQA ensures functional correctness. To do so, available unit tests must be performed. The steps of these unit tests should be defined together with the product owner to ensure realistic testing of the delivered prototype before non-technical deployment stakeholders are involved.

Initial Deployment

After the approval of the SQA engineer, the prototype is ready to be tested by the deployment stakeholders. The delivery of the prototype must be done within an appropriate testing environment. This environment depends on the selected environment. While mobile applications can be transmitted via TestFlight (iOS) or distributed as an .APK file (Android Package Kit), other prototypes must be installed and set up in a dedicated XR hardware configuration (Apple Inc. 2022a). For this initial deployment, it may be necessary to provide technical assistance from the development team to the testers.

4.5.4 Summary of the Initiation Phase

The initiation phase is based on user, system, and business requirements. As a first step, the project manager must create the framework conditions for initiating the XR deployment, i.e., he must create a sandbox environment for the targeted process, establish a communication landscape and ensure the required hardware availability.

From the user stories and the information architecture, a 2D clickable prototype is then designed in the design phase. An interaction design is created using suitable voice commands, gestures, touch interactions, or remote commands. Additionally, the necessary 3D assets are created in the required LoD, and format based on references and requirements or on existing models.

The development follows an adapted SCRUM methodology, as it follows the execution of an agreed and defined design and functionality scope for the implementation of the prototype. In the steps of Front-end coding, Back-end coding, integration, and initial deployment, the specified requirements are then transferred into an initially deployable prototype for the utilization phase.

4.6 Utilization

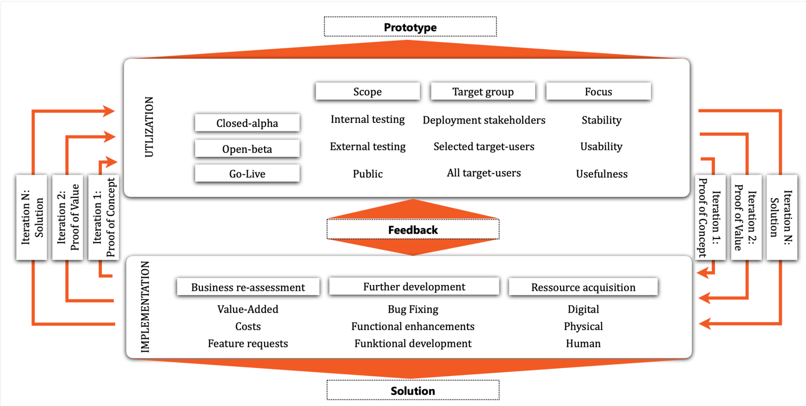

Figure 4.15: Iteration loops of utilization and implementation

The initiation phase provides a prototype for utilization across the identified target audience. The utilization phase aims to create feedback for the iterative development of this prototype into an XR technology solution. Feedback must be implemented in terms of cost-effectiveness, functional advancement, and resource acquisition. Thus, the utilization and implementation phases iterate through the collection and implementation of feedback. Depending on the maturity of the prototype or solution, feedback must be collected with a varying focus and target audience, as shown in Figure 4.15.

Through iteration loops between the utilization and implementation, the prototype matures incrementally. The first maturity level to achieve is the PoC of the initiated potential case. This means, that the setup of Front-end, Back-end, and hardware of the XR technologies interact in a way that provides the required functionalities in a defined and limited scenario. Regarding the special technical requirements of the XR technology composition and the underlying complexity, the PoC is technology driven. Once the technical feasibility is proven, the next maturity step can be targeted.

The PoV is the result of the second iteration. In this scope, the XR technology has proven that the functionalities from the XR technology composition can deliver the analyzed value added. This means that the XR technology fulfills the requirements of each of the nominated value adding categories. This does not mean that the PoV already provides all assumed value added at full scale, but the targeted benefit can be generated. E.g., with the PoV, the assumed operational time is reduced, although it is not reduced to the total amount indicated.

The third maturity level of the iteration is the status of the XR technology as a solution. This means that the XR technology has reached a level of functional and technological maturity at which it can be used to generate value in the value creation. The number of iterations from the application by the tester and the implementation of the feedback depends on the technological setup and functional scope. In addition, the XR technology development in the state of an XR solution is never finished. Due to the continuous use by the target users and their changing requirements for the solution, new starting points for improving, changing, or extending the solution are continuously created for the solution.

4.6.1 Closed-Alpha Testing

The first iteration of the prototype aims to deliver the PoC. Accordingly, it should be proven that the initial execution of the collected requirements works from a conceptual and technological perspective. This means that XR hardware and software composition has fundamental stability. Since the functionalities were implemented in a reduced manner due to budget restrictions and the usability may be limited, it can be assumed that the prototype cannot be used directly by the target user and not in the targeted process of the real environment. In this phase, testing must therefore be carried out in a closed environment with a technologically experienced user group and to the exclusion of the actual end user. Therefore, the phase should be called closed (closed environment and target group) alpha (first application). To avoid unnecessary effort for the development team, the PoC should be tested in the technological environment of the development team. Although this might cause instabilities for the tester, the avoidance of creating a full-fletch pipeline before the PoV is achieved is more important. The feedback collected during this phase can be used to fine-tune XR hardware and software and the developed content to make it usable for the target user. Therefore, the product owner is in charge of performing initial testing and to provide first feedback to be integrated before the target user gets to test it. Furthermore, the product owner is responsible for getting familiar with the usage and handling of the prototype to provide a useful demonstration to the target users to initiate their utilization.

Closed alpha testing identifies bugs, functional errors, incorrect implementations, presentation flaws, and conceptual inconsistencies. The product owner is responsible for tracking the user stories' initial implementation and focusing on the technical functionality. These points are distinguished in bugs, adaptations, extensions, and new functionalities. Figure 4.16 depicts the simplified flow of the closed alpha testing. While the product owner can perform the closed alpha testing, he is the representative to identify and nominate further potential alpha testing participants to collect more feedback. The product owner is then responsible for aggregating the feedback and preparing it for the development team.

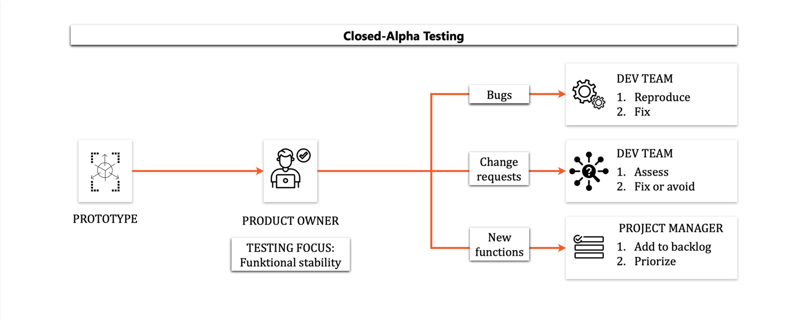

Figure 4.16: Flow and focus of the closed-alpha testing

Bugs should be documented in a structured manner for the development team so that the SQA engineer, or the developer can track the identified misbehavior of the prototype. The documentation of the bugs is to be written in a guideline for the development team to reproduce the issue. For this purpose, the product owner must document the following points:

- Description of the scenario
- Steps to reproduce
- Description of the misbehavior
- Description of the expected behavior

In the case of conceptual flaws, change requests are to be documented by the product owner as enhancements or function adjustments. For this purpose, the product owner must document the following points for the development team:

- Description of the scenario
- Description of the initially developed flow
- Description of the desired flow
- If necessary, designs for visual adjustments

Change requests must not have a large-scale impact on the system infrastructure and cause ripple effects in the system. For example, the adaptation of an interaction model may work in one scene. However, due to the architecture of the XR technology, it may cause a failure in another scenario. Therefore, change requests must always be evaluated by the entire development team and controlled by the SCRUM master with a technological background. Furthermore, it is necessary to assess whether the change request is necessary to execute in terms of functional completeness for the initial scope. By assessing whether the existing functionalities provide a workaround for the required change, the necessity can be evaluated. If possible, the change request can be postponed, thereby avoiding additional effort for achieving the PoC.

Even if the focus in the closed alpha phase is predominantly on ensuring the initiated functionalities, the need for new functionalities not included in the existing product backlog may already arise in this testing phase. The product owner must record these new functionalities in the product backlog in the form of user stories. The product owner then reviews them with the project manager and prioritizes them in the backlog. The development of new features within the implementation of the alpha feedback should be avoided to reduce budget spending and accelerate the speed of achieving the PoC.

4.6.2 Open-Beta Testing

After the initial improvement by implementing the closed alpha feedback, the first iteration results in a stable version with the minimum usability requirement. Thus, the prototype was raised to the status of a technological PoC. This PoC is then to be tested with a selected group of the actual target users. Therefore, the PoC must be set up in a staging environment to be accessed by the target users. This ensures independent testing without being affected by development activities. The focus here is on how the target user handles the PoC and what obstacles exist in using the PoC in a real value creation scenario. Figure 4.17 depicts the sequence of the open beta test.

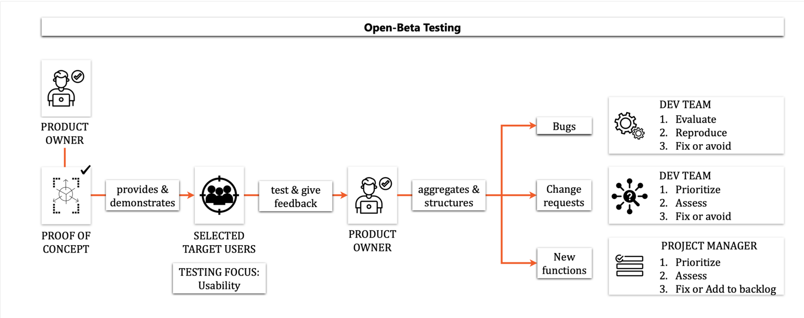

Figure 4.17: Flow and focus of the open-beta testing

Before the beta test can start, the selected target users must be introduced to the use of the PoC and familiarized with its handling through training and demonstration. Therefore, the product owner must provide the target users with a demonstration of the major functionalities to ensure the onboarding process. The PoC still has a reduced function set and may not contain user assistance within the XR experience. It is furthermore to assume that the target users are less familiar with the handling of the XR PoC as their skillset is focused on value creation-related core processes. The demonstration reduces the hurdles of initially using the PoC. It might be required to ensure the capacity of the target user for the testing as they are integrated into the existing value creation mechanisms. This is to be ensured between the project manager and the value creation responsible, i.e., management or deployment sponsor.

The target users are furthermore to be briefed by the product owner on how to test the PoC within their user scenarios. It is then required to let the target users utilize the PoC unsupervised over a dedicated period and to collect feedback afterward. As mentioned before, the target user might lack XR technology-related skills. Therefore, the provided feedback might come up in a structure that cannot be utilized by the development team or due to handling errors. To avoid the tedious processes of training the target users with the right way of providing feedback, the product owner should collect the unstructured input from the target user and then process the feedback for the development team.

Like in alpha testing, the feedback is structured into bugs, change requests, and new functionalities. Other than in the beta testing, the feedback must be assessed differently to filter out the relevant issues to be implemented for achieving a PoV. The bugs identified by the beta testers are, therefore, to be rated at different severity levels. It could be the case that an identified bug is not to be fixed immediately as the next priority if its impact is marginal and, for example, a potential enhancement has a more positive impact on the usability and the value added. Table 4.16 sums up bug severity levels and provides examples for each.

Table 4.16: Bug severity levels

Severity Level	Description	XR example
1	Fundamental malfunctions that make the use of the entire XR technology system impossible.	Loading of an 3D model into the scene crashes the application.
2	Malfunctions that make the use of a XR technology subsystem not possible or significantly restricts it.	When performing an interaction in a certain sequence the user cannot change the 3D model anymore without a restart.
3	Minor malfunctions that have a minor impact on usability and graphical experience.	Error of the interface design or longer loading times to perform an interaction within a scene

The product owner must filter the identified bugs from the beta feedback and assess their severity with the development team. After that, the product owner and the development need to estimate the effort to fix these bugs. Based on those two dimensions, they can decide which bug to prioritize and fix.

The beta feedback will provide a significant amount of change requests and ideas for further functionalities development from the target users, as they will have a different perspective on utilizing the PoC. These are to be structured, analyzed, and evaluated. It is to be assessed by the product owner which of the functional adaptions, enhancements, or new functionalities are required to provide the user with the required usability for adding value within the utilization. Based on an effort estimation by the development team regarding the system architecture impacts and ripple effects, the product owner can decide which features and bugs are to be fixed, adapted, enhanced, and added to the PoC. It might be required to align the content of the beta feedback with the project manager. The project manager must align with the deployment sponsor to increase the development budget if the target users require a high-effort functionality that creates significant additional capacity requirements. However, the budget for beta feedback should be higher within the initiation phase, as the real target user feedback provides the required direction for creating a value adding XR solution.

4.6.3 Go-Live

Implementing beta feedback resulting from the first real users creates in a PoV. The PoC was extended by the functions that the user needed to generate added value in the value creation. This solution demonstrates both technical stability and usability for the user. Thus, the PoV is ready to be released to the target group. This will be done during the go-live. The PoV is then operated in the production environment with a dedicated infrastructure accessible to all potential target users. While closed alpha and open beta testing is part of the initial deployment, the Go-Live is a repetitive action within the deployment. This is required for the initial publication of the PoV as well as for each new release of the XR solution.

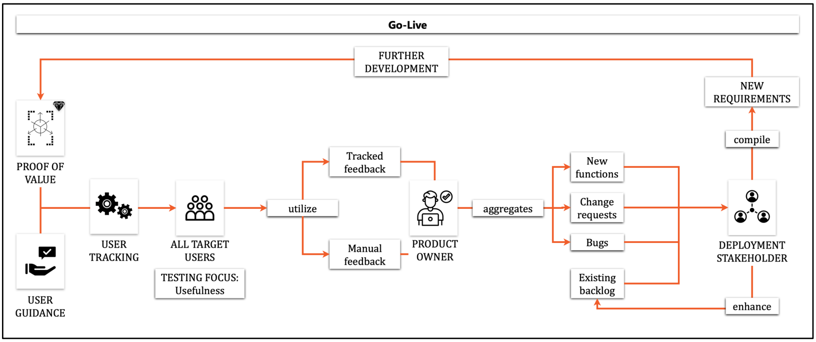

Figure 4.18: Flow and focus of the acquisition of feedback after go-live

Since the scope of users has now been increased to the full scope of potential target users and the timing of user onboarding has shifted, the person of the product owner can no longer handle the introduction to the XR technology solution. Of course, the usability of the PoV should be as easy as possible and, ideally, self-explanatory. However, the complexity of the processes to be mapped by the XR solution can limit this process. Before go-live, the PoV must therefore be extended with necessary explanations for the user regarding the application. For example, for interaction models, instructions for using the PoV can be shown during the initial application as part of onboarding. Furthermore, tutorials can be shown to the user in interactive sequences to introduce them to the usability step by step. Other possibilities include the provision of explanatory videos and static instructions.

To ensure functional stability even in larger scopes of operation in the production environment, the PoV of the XR technology must be equipped with automated monitoring and surveillance systems for going live. This allows the identification of potential bugs in the system landscape during the utilization. The XR technology stack can be enhanced with automatic reporting systems for tracking functional crashes as well as in-app surveys to ensure technical functionality in production utilization. E.g., this can be implemented as an SDK within the XR engine of the Back-end. It may be accurate to establish separate feedback tracking systems for XR technology solutions with respective platforms. However, it must be considered that this means additional work that cannot be used for further functional development.

Various options are available for testing usability and deriving requirements for improving usability in live operation. For example, user behavior can be tracked automatically and systematically by dedicated solutions if they are available in the corresponding environment. This allows for the identification of drop-off points and usability obstacles. Furthermore, opinions and wishes can be obtained from the user by providing a dedicated feedback form. In addition, user feedback can be actively scouted and evaluated on the corresponding platforms on which the XR Solution is operated. If there is a general lack of user acceptance, feedback points for improvement can be collected via user surveys or by inviting and observing test groups using the XR solution. Finally, continuous dialogues with the target user will provide valuable insights about features, their functionalities, and further requirements to be added to the PoV or the solution.

Eventually, the collected feedback from the various sources must be aggregated, filtered, structured, and processed by the product owner again to collect executable user stories and new requirements. Participants from the deployment stakeholder, including the product owner, SCRUM master, project manager, and deployment sponsor, compile the feedback, as well as the requirements from the existing product backlog to a reasonable set of new requirements to be added to the PoV. These can be executed, and various releases of new versions to an XR solution can iteratively improve the solution. Requirements not selected for a new release are stored in the existing backlog and might be executed within the next iteration of the further development within the implementation phase.

4.6.4 Summary of the Utilization Phase

The utilization phase follows the initial deployment of the prototype and iterates with the implementation phase. The prototype is used for the first time outside the development team for closed-alpha testing. The goal is to achieve a stable level through targeted feedback from expert testers who are not part of the target user. The implementation of this feedback yields the PoC.

The PoC is then tested in the open-beta phase with a limited number of target users under realistic conditions. Due to incomplete usability, it is necessary to familiarize the target users with the solution and then allow them to test it independently. The feedback is collected and processed by the product owner and then implemented in the PoC. This results in the PoV.

It is then transferred to the production environment and released to the entire audience of target users. For this purpose, the PoV must initially be extended with user guidance. In the go-live phase, the usefulness of the PoV is continuously tested under real conditions. User feedback is to be collected via automated tracking technologies as well as via manual queries of the target users. The feedback collected here is aggregated by the product owner and maintained in the product backlog. This forms the foundation for the further development of the PoV into an XR solution during the implementation phase.

4.7 Implementation

The utilization and implementation phases alternate iteratively, as shown in Figure 4.15. Accordingly, after collecting the feedback through the utilization, it is necessary to implement this feedback in the existing XR solution. Primary, this means that the XR solution is further developed technologically in terms of its functionality. With increasing functionality and usability, it must also be verified whether the XR solution delivers the expected added value from the analysis phase (**chapter 4.4.3**). A business reassessment reviews initial assumptions and identifies further possible value added. The re-assessment of the budget allows conclusions about the economic viability and enables potential investment decisions for the acquisition of resources for enhancing the value creation with XR technology. It is additionally necessary to plan to acquire which physical, human, and digital resources are to be invested in for the deployment of the developed XR solution in the value creation.

4.7.1 Further Development

The initial development of the prototype included a fixed set of functionalities and requirements. In the first step, this was separated into the technological fields of Front-end development, Back-end development, and integration. Even if this restricts the agility during the initiation, the underlying complexity of the XR technology development requires consistency for the first setup. Furthermore, synergies can be exploited to reduce the effort for initiation. The initiation phase finishes with the PoV. This means the feedback from the open-beta test has been implemented and deployed, and the PoV delivers a certain added value. For the further development, it is necessary to switch to a fully agile approach in this phase. The further development is executed in sprints, a defined period for the development team to deliver a set of features. Figure 4.19 depicts the setup for the agile further development.

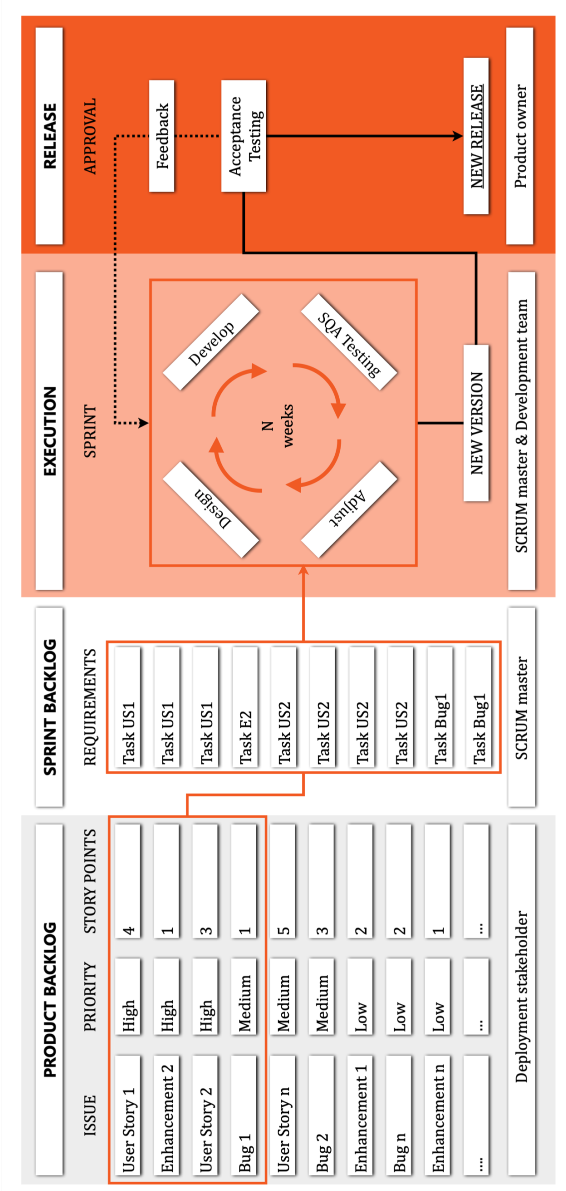

Figure 4.19: Agile setup for the further development of the XR solution

The foundation of the further development is the maintained product backlog. This backlog consists of the initially identified user stories that were not executed yet within the development of the prototype. Furthermore, it contains the collected feedback points of the testing iterations that have not been implemented for achieving the PoV. The issues within the backlog are user stories, enhancements, or bugs. These issues are prioritized by the deployment stakeholders together. By doing so, the business perspective of the product owner and the project manager, as well as the technological perspective of the SCRUM master and the development team, is reflected in the product backlog. It may be that the deployment sponsor requires a certain functionality for the value added to the business model. Otherwise, it can be a priority to execute a functional adaption or a code refactoring from the technical perspective to ensure the scalability and stability of the XR solution.

Next to the priority, the issues must be assessed regarding the effort. A common practice within the effort estimation in the agile software development is the use of story points (Coelho and Basu 2012). Story points are a unit of measurement for the effort required to implement a user story (ISO 2009). The assumption in story points is relative to each other, relating the effort of developing each issue from the product backlog (Coelho and Basu 2012). This is performed by the SCRUM master supported by the development team. The relative scale makes it difficult to estimate an initial effort based on, for example, labor time. With the existing PoV, an increasingly valid estimate of effort can be provided as the XR solution matures. Due to the variance in the complexity of different XR technology implementations, this variant is particularly suitable for the underlying context. Story points can be assigned accordingly, e.g., for the additional effort of possible 3D asset creation for a sprint. In the context of further development, an initial story point contingent must therefore be allocated for each sprint. This contingent is to be checked continuously after the release of a new version in a retrospective and adjusted if necessary.

For initiating a sprint, the deployment stakeholders nominate the relevant issues from the product backlog until the defined contingent of story points is allocated. The nominated enhancements, bugs, and user stories are then transferred into technically executable tasks for the development team by the SCRUM master. All tasks are collected in the sprint backlog and define the sprint's scope. It can be furthermore considered to combine sprints for the XR technology deployment in case the next release requires a significant feature upgrade. Thereby synergies in the XR development can be leveraged, and the effort can be reduced compared to an iterative execution of a major feature.

The execution of the sprint itself is an iterative flow over a fixed period, usually between one and four weeks, depending on the underlying development environment. The sprint is executed through the performance of designing the XR experience, developing features, ensuring functionalities through SQA testing, and adjusting the new functionalities according to the SQA feedback. Within frequent communication routines between the development team, the SCRUM master, and the product owner, the quality and time of the delivery are tracked. While the SCRUM methodology suggests daily interaction, the frequency of interaction between the roles mentioned above is to be adapted to the complexity of the XR deployment environment. As the execution of a particular feature might require more time, a daily communication routine can affect the efficiency of the SCRUM team in the context of an XR technology deployment.

After the sprint is fulfilled, the new version is deployed to the product owner. The sprint delivery is variable and adjusted throughout the execution within the communication routine (Schwaber 1997). This is particularly relevant for the XR deployment, as complications can arise during implementation due to the complexity of the development environment. Thus, the disproportionate effort can be avoided by a consensual adaptation of the scope. Even if the initial scope is not fulfilled in the agreed form, a satisfactory deliverable can still be rolled out by jointly adapting the scope. The product owner performs a final acceptance testing of the sprint deliverable and confirms the new version of the XR solution. To ensure the consistency of the XR solution, the development team documents the relevant implementations after the acceptance. If the new functionalities significantly impact the usability, it should be considered to perform optional user testing, as in the open beta test. If not, the latest version can be prepared for going live by shifting the new version to the production environment.

4.7.2 Business Re-Assessment

The economic motivation of the XR technology deployment in the value creation is the identified value added in the business analysis (**chapter 4.4.3**). After the deployment of the prototype and the achievement of the PoC, implementing the feedback from the open-beta testing with real users ensures the value added through the deployment, i.e., the PoV. However, the full expected value added is not achieved within this state. Therefore, the business re-assessment aims to identify the quantity of the value added against the costs. By quantifying the value and the costs, the deployment stakeholders can decide if and how the XR technology deployment should be continued. To do so, the value added must be re-assessed and the cost consumption of the previous activities and future costs must be estimated.

Tracking of the Value Added

To assess the impact of the XR technology deployment on the value creation, the value categories value in experience, value in use, and value in transfer are to be evaluated. The deployment of the XR solution affects the value creation in different locations and can therefore be tracked by assessing and quantifying reliable indicators along the value creation. Table 4.17 sums up the relevant factors.

Table 4.17: Re-assessment scheme for quantifying the value added

Value Added	Impact location	Impact tracking	Impact indicators
Value in experience	Across the value chain	Assessing indirect impact of the deployment on the value creation	• Awareness • Traffic • Usage time • User count • Partnerships
Value in use	In the targeted process	Quantifying the leverage and monetization metrics	• Productivity increase • Cost reduction
Value in transfer	In the finance stream	Tracking and summing of new revenue streams	• Recurring revenue

Quantifying the value added from the value in experience created by the XR deployment is not directly possible. The value in experience will be indirectly reflected in the value creation and can only be measured by correlations between the XR solution usage and the core business results. To provide a founded decision-making on future steps, the value in experience should be measured with indirect indicators of the value creation. The impact can become visible anywhere in the value creation, even though it is unrelated to the addressed core business. These are mainly the awareness generated for the value creation organization, reflected in the traffic on the XR solution, the usage time and user count, and potential partners acquired through the deployment initiative. E.g., a deployment initiative for optimizing the production workflow of a business unit creates awareness within the industry and attracts talents for recruiting. By comparing these indicators with the core business results, the correlation between the deployment and the value added within the value creation can be estimated. Nevertheless, these impacts will be reflected in a long-term perspective.

For re-assessing the value in use, the initial assumptions from the business analysis need to be verified. The leverages and metrics of the value in use are listed in Table 4.9. As the deployed XR solution will directly affect the targeted process, the impact is located within this process and can be measured there. The value added can be quantified by measuring the leverage amount of the value in use. With the monetization metrics, the value added of the deployment initiative in the value creation can be monetized by multiplying it with the value of the regarding leverage, e.g., price increase, cost per scrap part, cost per working hour, etc.

The value in transfer is created directly through monetization. It can be tracked within the XR solution from the additional revenue streams and summed up as an overall value. This monetary value will be reflected in the finance stream of the value chain. While re-assessing the value in transfer, it should be verified if the XR solution provides opportunities for additional revenue streams than assumed in the initial business analysis. Furthermore, it is to be verified how the potential of the different revenue streams can be considered for the next development iterations and how this potential can be increased with functional enhancements or adaptions.

Tracking of the Costs

Monitoring the XR deployment costs is primarily focused on anticipating future costs of operating and scaling the XR solution. Of course, verifying that the initiation costs budgeted originally have been met is necessary.

Due to the complexity of the XR technology environment and the dynamics of the user feedback from the iterations of the deployment, there are continuous new demands on the development team and, thus an increasing need for a budget. In addition, technological limitations can result in significant additional effort for marginal improvements to the functionalities, especially when transitioning the PoC to a PoV. The connection of the XR solution to existing solutions, which was previously avoided by manually creating the sandbox requirements, can also mean a significant effort for the further development of the XR solution due to the adaptation of existing systems that may be necessary. Table 4.18 summarizes the major cost drivers to identify and verify in the context of the business re-assessment.

Table 4.18: Critical cost drivers for implementing XR solutions

Cost drivers	Critical factors
Operation Costs	Scaling the XR solution to a higher number of users requires exponentially more server capacity for distributing storage-intense 3D assets.
Development Costs	Improving a functionality in terms of usability and usefulness requires exponential amount of development capacities for minor improvements due to technical limits.
Hardware Costs	Providing the availability of the XR technology hardware stack for all target users requires significant investments
Integration Costs	Creating a seamless interaction between the existing system landscape and the XR solution requires adaptions in the systems as well as in existing processes.
Support Costs	Scaling the user count will increase the number of required trainings and explanations as well as additional resources to resolve occurring issues during the usage.

The critical cost drivers are identified according to the XR solution. Depending on the availability of a concept change or a concept extension to bypass these critical drivers, the functional spectrum of the XR solution must be adapted, and the product backlog must be prioritized. On the other hand, the critical cost driver can be bypassed through targeted investments in the context of resource acquisition and established as a component of value creation (**chapter 4.7.3**).

Evaluation of the Business-Re-Assessment

Based on the tracking of value added and costs, a business re-assessment can be performed. The deployment stakeholders, especially the deployment sponsor, can then decide on the scope for the subsequent iterations. Figure 4.20 depicts the scheme of re-assessing the business aspect of the XR technology deployment.

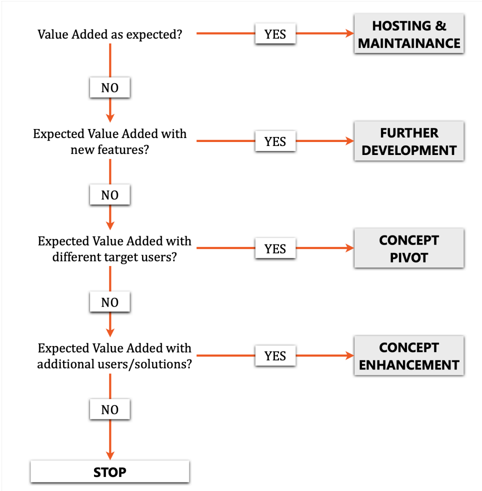

Figure 4.20: Evaluation scheme for the business re-assessment

If the initial assumptions are fulfilled, the deployment iterations of the further development and feedback acquisition from the go-live utilization continue. The task is to host and maintain the XR solution and plan further functionalities for further value added. It can also be the case that the initially assumed value added is not provided by the XR solution. If this is the case, the deployment stakeholders have three options.

The first option is a concept extension. It might be the case that the XR solution itself provides the right features for the intended purpose. Still, the overall situation of the value creation lacks the required assets for achieving the expected value added. In this case, it might make sense to develop a supplemental digital solution to create the assets for the initial XR deployment. E.g., a touchpoint for generating required data or the required access to the data generated with the XR solution can be established to create the intended value added.

Second, the deployment stakeholder can scout for a concept pivot. This means that the XR solution is to be applied in a different context than initially expected, or the XR solution requires significant changes to the existing function set. The developed XR solution might provide a higher value added if a different target user applies the functions with changes in the XR experience design towards the new target user, the XR solution can be adapted to deliver the expected value added.

Third, the deployment can be stopped. This option should be chosen if the application of the XR solution does not provide the required functionalities for the value added or the assumed costs of operating the XR solution at full scale extends the assumed value added.

4.7.3 Resource Acquisition

After further development and reassessment of the XR technology deployment business case, the corresponding resources must be established. The XR solution becomes an integrated part of the value creation. The resources to be built up are structured into physical, human, and digital resources.

4.7.3.1 Physical Resources

Technology

Implementing the XR solution requires the acquisition of physical technology. One focus is on the XR hardware technology required to operate the XR solution. For the target user in the value chain, it is a basic requirement to be equipped with the appropriate equipment to generate added value through the XR solution. Initially rented XR hardware or devices provided in small quantities must be purchased in the implementation step and added to the technology pool of the value creation. If the target user is not a direct member of the value creation but is addressed in a B2B or B2B2C relationship with the XR solution, it may make sense to provide t devices to the external user. This is then regarded as an investment that amortizes through the promotion of the usage rate and the resulting value added.

Infrastructure

The second focus of the XR solution implementation through physical assets is enhancing the existing infrastructure of the value creation. Here, it must be considered how the existing equipment of the addressed process can be adapted or expanded to enable the use of the XR solution. This can involve additional sensors in the existing infrastructure of the process to complement the input unit of the XR technology stack and improve the user experience. It should also be considered whether the acquisition or expansion of the in-house server landscape of the value creation makes sense to counteract exponentially increasing operation costs.

4.7.3.2 Human Resources

Knowhow

Human resources are likewise required to implement the XR solution in the value creation process. On the one hand, this includes the know-how for the operation and further development of the XR solution. For the initiation and delivery of the PoV, it may have made sense for the value creation organization to work through external service providers as a development team. To operate the XR solution in the long term with a positive impact on value creation, an in-house development team should be established. This can reduce the costs of operating and scaling the XR solution. However, this poses a significant challenge. Suitable software engineers with the necessary skillset for 3D development are rare and therefore have a high income. In addition, existing developers often have a computer game development background, reducing their motivation to work in the context of value creation.

A dedicated development unit can be established offshore if there is no availability for suitable XR software engineers in the existing recruiting market of the value creation organization. This way, availability bottlenecks, and high wage costs can be avoided. However, outsourcing the development workforce creates challenges in the remote coordination of the development process, intercultural understanding, and the risk of uncontrolled loss of intellectual property.

Intelligence

From a human resources perspective, implementing the XR solution also requires a certain level of intelligence among the users and stakeholders involved. On the one hand, this means improving the handling of the XR solution and the skills in its use through training. By setting incentives for usage, employees should be intrinsically motivated to work with the XR solution and solve problems on a self-initiative basis. In addition, employees should be incentivized to develop a sense of opportunities to work with and add value through the XR solution with new approaches and business ideas.

On the other hand, the digital intelligence of the value creation organization must be promoted by prioritizing the digital affinity of potential employees in the application process. In addition, a fundamental mindset must be established in the organization that reinforces solution-oriented thinking and enables employees to develop, test, and implement new technologies and approaches.

4.7.3.3 Digital Resources

Data

Implementing the XR solution in the value creation requires the acquisition of digital resources. To do so, the existing data and related databases of the value creation are to be connected by integrating the XR solution into the information stream of the value chain. As the initial development was performed in the scope of a sandbox approach with simplified, one-directional DPIs, the operation of the XR solution requires manual effort. These conditions must be transformed by connecting the XR solution to the existing system landscape to achieve a significant value added. This reduces manual effort. As mentioned before, a one-time effort can arise as the existing system landscape might become subject to changes for establishing a connection between the XR solution and the data infrastructure.

Assets

The second category of digital resources to consider is digital asset acquisition. This involves incorporating the assets created externally for the initiation phase into the existing digital resource landscape. For example, developed software modules and licenses for XR software may have to be purchased to scale the solution. In addition, it may be necessary to create new digital software assets to enable the operation of the XR solution in the desired context if the previously used assets do not have the desired range of functions for the aimed deployment.

The value adding deployment of the XR solution requires an automated exchange of relevant 3D assets for transferring to, displaying in, and manipulating with the XR solution. Especially converting the format of 3D assets and continuously enabling data consistency throughout the value creation is a challenge to master from the resource perspective to enable a value adding deployment.

Overall, the XR solution developed throughout the iteration of the utilization and the implementation is established as a core asset across all three resource categories and becomes a component of the value creation.

4.7.4 Summary of the Implementation Phase

The scope of the implementation is the actual execution of the XR deployment into the value creation. After iterations of initial development and feedback acquisition through the utilization, the XR technology has achieved the status of a PoV. This means the ideated concept adds value to the value creation. To accomplish the complete value potential, the PoV must be implemented in the value creation to achieve the status of an XR solution. The implementation of the XR solution consists of three dimensions.

First, the PoV must be further developed from a technological perspective. Other than the initial development, the further development of the implementation phase is executed strictly agile. This means that the product backlog is maintained and prioritized. The collected issues of the product backlog are transformed into executable tasks of a sprint backlog and then developed in sprints. A major difference to the traditional agile setup is the communication within a sprint, suggesting less frequent communication to foster efficiency within the XR development context. The deliverable of the further development sprint is finally approved by the product owner and released into the go-live loop of the utilization phase.

Second, the implementation phase suggests performing a business re-assessment while developing the PoV to an XR solution. The business re-assessment is executed in three steps by (1) tracking the value added, (2) tracking the costs, and (3) evaluating the results. For the value added, the value categories are tracked differently. The value in experience is not monetizable and should be quantified by relevant indicators, such as traffic and user count. The impact of the value in experience can be tracked long-term through correlations between the overall business results and the indicators. The value in use is quantified by measuring the performance of the addressed process through the XR technology and then monetized with value leverages. The value in transfer is tracked by summing up the newly generated revenue streams through the XR solution.

Third, the XR technology is implemented in the value creation by acquiring dedicated resources. For establishing the XR solution in the value creation, physical, human, and digital resources must be acquired. The physical resources address the equipping of the targeted process with technology and infrastructure. Human resources for implementing the XR solution are to be established in terms of know-how, meaning the hard skills of developing and operating the XR solution. In terms of intelligence, digital affinity, and solution competence in working with technologies are to be incentivized. From a digital resource perspective, the implementation of the XR solution is executed by establishing automated data interfaces and acquiring software assets for running the XR solution on a large scale.

The implementation phase delivers a value adding XR solution within the value creation with a certain technical maturity. This XR solution is now to be integrated along the value creation.

4.8 Integration

The implementation phase delivers a fully functional XR solution for adding value within the value creation. The integration of the solution now aims to establish this technically mature XR solution across the value creation. In the context of this methodology, this is understood to increase the usage of the XR solution. This usage can be reinforced in two directions. Figure 4.21 depicts the integration logic into the value creation.

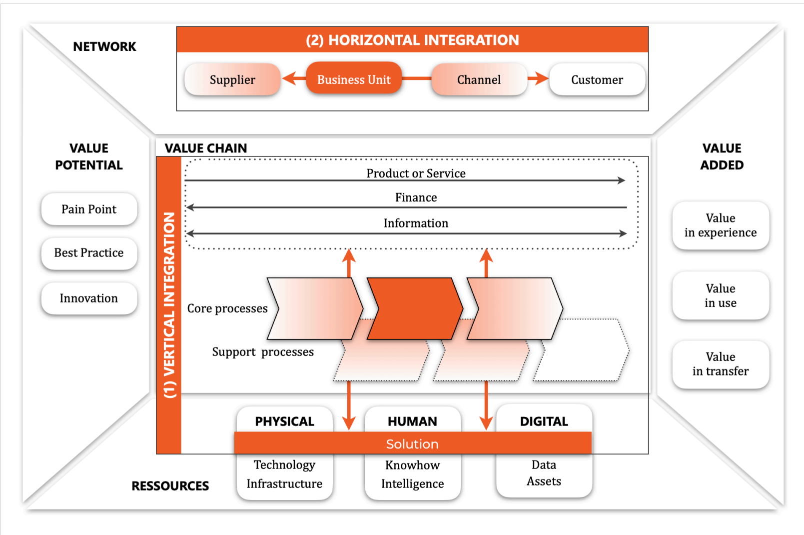

Figure 4.21: Integration directions of the XR solution into the value creation

The directions are to be understood in the depicted value creation reference model. The vertical integration provides a deeper integration of the XR solution into the existing core process. The horizontal integration offers a broader application of the developed XR solution across the value creation network (intra-organizational) and beyond (inter-organizational).

4.8.1 Vertical Integration

Vertical integration aims for stronger integration of the XR solution into the affected core process of the value creation. It can be assumed that the XR solution refers to a part of a core or support process. For vertical integration, the XR solution must be functionally anchored in the existing process by adapting the existing value creation structure by creating user acceptance of the target user and by a consistent integration into the system landscape of the value creation.

Functional integration

The functional integration focuses less on the XR solution's functional development than on the implementation phase's further development. It is more addressed towards the functional design of the surrounding sub-processes of the addresses process from the XR solution. With the adaption of the core process's organizational flow, the utilization of the XR solution is improved. This functional customization for XR solution integration can be done with three leverages.

First, the input for the XR solution from the previous sub- or core process can be optimized. By adding working steps to the upstream subprocess, necessary data and information can be prepared at an earlier stage to improve the usage of the XR solution. For example, by converting a data format in a previous process, the XR solution can be used more quickly in the addressed process of the XR solution.

Second, the flow of the sub-process can be adapted for its execution with the XR solution. By arranging required activities and the responsibilities for executing those activities, the XR solution usage can be enforced or improved. E.g., the execution part of a sub-process can be enhanced with a supporting workforce to perform the XR solution purpose centrally and thereby ease the other workforces from a time-consuming process step. By doing so, both synergies and execution performance can be improved through adapting the value creation sub-process towards the XR solution.

Third, the output can be optimized by adapting the downstream process steps for the XR solution deployment results. By adjusting the subsequent process part, the added value of the delivered contribution of the XR solution is increased. This can be achieved by changing systems or formats in use within the subsequential processes. In addition, by specifying predefined standards through the XR solution, standards can be established along the subsequent value chain, enabling improved productivity throughout the value chain.

Additionally, the functional integration of the XR solution into the core process can require more functionalities of the XR solution for optimizing the process. Furthermore, additional complementary XR solutions or non-immersive digital solutions can be necessary to optimize the XR technology deployment. Both cases trigger the initiation of a new deployment initiative. Overall, the vertical integration by functionality aims to establish the XR solution within the product or service stream of the value stream to create physical improvements in the value creation for the XR technology deployment.

Increased acceptance

For the vertical integration of the XR solution in the value creation, the user acceptance must be increased. Implementing the solution based on the user stories and the personas is the foundation for acceptance. This must then be increased through vertical integration, both qualitatively and quantitatively.

The qualitative increase in user acceptance is achieved by supporting the user in applying the XR solution. The hesitation of the target users to adopt a new approach should not be underestimated when integrating the XR solution into the value creation. With the help of training and roadshows, the added value of the XR solution must be continuously demonstrated to the user to strengthen his motivation to use it. Likewise, the added value depends on the qualitative application of the user. Accordingly, the improved handling of the solution also reinforces the created added value. In addition, continuous interaction between the product owner and the user should be encouraged to obtain feedback on the application of the XR solution. In addition to increasing the quality of the functionalities, this can also increase the motivation to use the XR solution.

From a quantitative perspective, the user acceptance of the XR solution can be vertically integrated with the creation of range. With the development of the XR solution for a dedicated hardware constellation, access to potential target users is limited. The availability of this constellation may be restricted, and the purchase of a suitable device might not be an option for the target user. It can be further anchored in value creation by adapting the XR solution for other platforms and end devices with better availability. This option may trigger either a further development in the implementation phase or a new analysis phase if the XR experience must be changed significantly.

Systems integration

Figure 4.22 depicts the automation pyramid. This model is defined by the International Society of Automation (ISA) and called ISA 95. During the implementation phase, DPIs and automated data connections between the XR solution and the existing systems were established as a part of the digital resource creation.

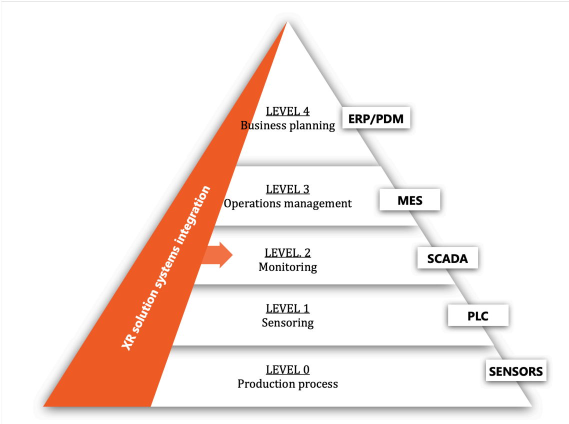

Figure 4.22: Vertical integration of the XR solution into the systems landscape of a value creation; adapted from (ANSI/ISA. 2005; Åkerman 2018)

The data linkage has so far only been established system-wise. In the context of vertical integration, this automatically linked data must be aligned consistently throughout the different system layers. The sensor data from the XR solution can be integrated with the processual sensor data and be matched with the program logic controller (PLC) of the sensoring layer. The supervisory control and data acquisition (SCADA) layer can furthermore receive data from or provide data to the XR solution. The manufacturing execution system layer (MES) is specifically for manufacturing-related value creation processes and represents a relevant data layer within the value creation to be integrated with the XR solution. Last, the interconnection of relevant data from the XR solution can be aggregated on a strategic level and then be established for the ERP or PDM systems. Ultimately, the vertical system integration is to be executed across all layers for consistency and the XR technology's value-adding deployment.

4.8.2 Horizontal Integration

In addition to the in-depth integration of the XR solution in the value creation process, the second option for increasing usage is scaling through horizontal integration. The focus is on deploying the XR solution for multiple parties and enabling it to be used by various entities. The intra-organizational integration aims at enabling other participants in the network of the underlying value creation with the XR solution. In addition, the resulting XR solution can also be made available beyond the present value creation organization to potential outside entities through inter-organizational integration.

Intra-organizational integration

Horizontal integration within the value creation organization is achieved by deploying the XR solution to other entities in the network. Depending on the scope of the XR solution, whether deployed in the B2B, B2B2C, or B2C context, it should be evaluated whether additional parties can be addressed with the XR solution in the context of a different scope. It is scaling to new platforms and devices in the integration phase to reach new target users.

It may be the case that the existing XR solution delivers a comparable value added for other value creation participants. Should a potential case arise with a partner of the network, an extension or duplication of the concept should be considered according to the methodology. A business analysis should then be conducted to assess how the XR solution can be monetized with the other partner. The deployment could be offered as a Software-as-a-Service model (SaaS). This results in several advantages. Through the SaaS deployment, the existing XR solution can realize additional revenue streams and thus achieve a higher value in transfer for the owner. In addition, a more vital linkage of the value creation partners results. The data infrastructure between the partners can be integrated. In addition, the additionally generated data from the usage enables improved analyses and thus knowledge generation. Finally, the other value creation partner benefits from the existing resources of the owner of the XR solution and is not obliged to build them up itself.

Alternatively, horizontal integration between the value creation partners can be achieved by deploying complementary XR solutions or non-immersive solutions. Analogous to the complementary deployment of touchpoints in vertical integration, the provision of an additional solution generates relevant data for the deployment of the XR solution. Thus, for example, a touchpoint for the end customer can generate relevant customer data, providing an integrated approach to value creation in the XR solution in the value creation process itself.

Inter-organizational integration

Cross-organizational, horizontal integration results from exploiting the XR solution outside the underlying value creation organization. This means that the XR solution is deployed to other value creation organizations. Those organizations may be active in the same industry or outside the industry. In the context of digital service delivery, it is appropriate to provide the XR solution to competing companies if the impact on the core business is lower than the additionally generated value in transfer.

A possibility of realization for inter-organizational integration is industry-specific technology-sharing platforms. Here, participants can access technological assets from other providers and use them for their core business. An individual agreement between the technology provider and the technology buyer creates an advantageous situation for both parties. The provider can generate further value-in-transfer with its technology assets, i.e., XR solution. The customer saves development effort by taking over existing assets and can significantly reduce the required time for deployment. Finally, this fosters stronger networking of value adding organizations, which can leverage synergy effects.

4.8.3 Summary of the Integration Phase

The integration of the XR solution in the value chain takes place in a vertical and horizontal orientation. Vertical integration has a focus on the increased application in the core process around the addressed process of the XR solution. This is to be done by functional adaptations around the addressed process, the reinforcement of user acceptance, and the consistent integration in the information systems of the business unit.

Horizontal integration can occur both within the value creation network and outside the organization. Additional value can be added by customizing the XR solution and making it available as SaaS to partners. Complementary solutions at partners for the XR solution can increase the value in use. In the context of inter-organizational integration, the developed assets of the XR solution can be exploited via technology exchange platforms for additional value in transfer.

4.9 Summary of the Methodology

The potential case is identified with the help of the identified XR technology purposes. In the case of the existence of a pain point, it is decomposed by an analysis and addressed using abstract XR purposes. In the case of a best practice from another organization, a direct abstraction takes place using the XR purposes and a check for potential added value via a qualification process. In the case of innovation, it is checked whether the XR purpose delivers a potential case by linking it to another technology under the organizational framework conditions in the given environment. This enables the industry-agnostic and business-process agnostic identification of potential deployment initiatives focusing on a purpose-oriented value-adding deployment approach according to **research objective II and III**.

The potential case is prepared for the initial implementation through the requirements analysis from the user, system, and business perspective. Through the development of personas and user stories, the technology acceptance is ensured, and the agile implementation is prepared, which contributes to systematic **research objective III.** Transferring the user stories into an information architecture forms the software requirements. These provide information about the required process design based on the VIP framework. Hardware requirements for the XR technology are derived from this. The business analysis provides for the determination of the qualitative value in experience, the value in use, and the quantitative value in transfer. The initiation, operation, and scaling costs must also be estimated here and budgeted according to the pattern presented to address the value-adding deployment character according to **research objective II**.

In the initiation phase, the design must be carried out after the general conditions have been created in a sandbox environment and the necessary technology has been made available to the development team. The XR experience design is carried out in the user interface, user experience, and interaction design fields. In this phase, the 3D assets are to be created from scratch, from existing 3D assets, or through acquiring third-party suppliers. The initial development is based on a defined range of functions and, unlike the strictly agile approach, is divided into the Front-end, Back-end, and integration to reduce the XR-related complexity of the development. The prototype developed from this is then transferred to an iteration loop consisting of utilization and implementation. Overall, the initiation phase provides the required asset of technological guidance for handling the complexity of XR technology deployment of **research objective I.**

Utilization is performed with different scopes depending on the maturity of the XR solution. The prototype is stabilized in a closed-alpha phase, transferred to a PoC through the implementation of the initial feedback, and prepared for the use of the target users. The open beta phase is done with the PoC and a restricted group of target users. The feedback collected during this phase will be implemented through further development to ensure that added value is generated during use. This results in a PoV. The go-live of the PoV addresses the entire target user group, and the continuous use provides feedback on the usefulness. The PoV is gradually transformed into an XR solution in an indefinite number of iterations. Overall, the utilization phase delivers contribution to the **main objective** of a sequential deployment character.

In addition to further development, the implementation phase also includes continuous business re-assessment and the establishment of resources for the operation of the XR solution in the value chain. Once the XR solution has been achieved, it is then integrated, either vertically in terms of process depth or horizontally into the value network. An integration outside the present value creation can also be realized as a new business opportunity. This results in the continuous consideration of value-added through the methodology offering agility in the application according to **research objective I and III.**

Figure 4.23 shows the summary of the deployment sequence. Based on the XR technology morphology, the value creation reference model, and the involved deployment stakeholders, this sequence develops the XR solution to integrate into a value creation from an identified potential case showing the holistic applicability of the **main research objective**. With the help of the XR technology morphology the complexity of the technology domain can be maintained while enabling sufficient technological details to steer the deployment execution according to **research objective I.** Yet, the overall architecture depicted in Figure 4.23 provides a systematic and sequential execution according to **research objective III**.

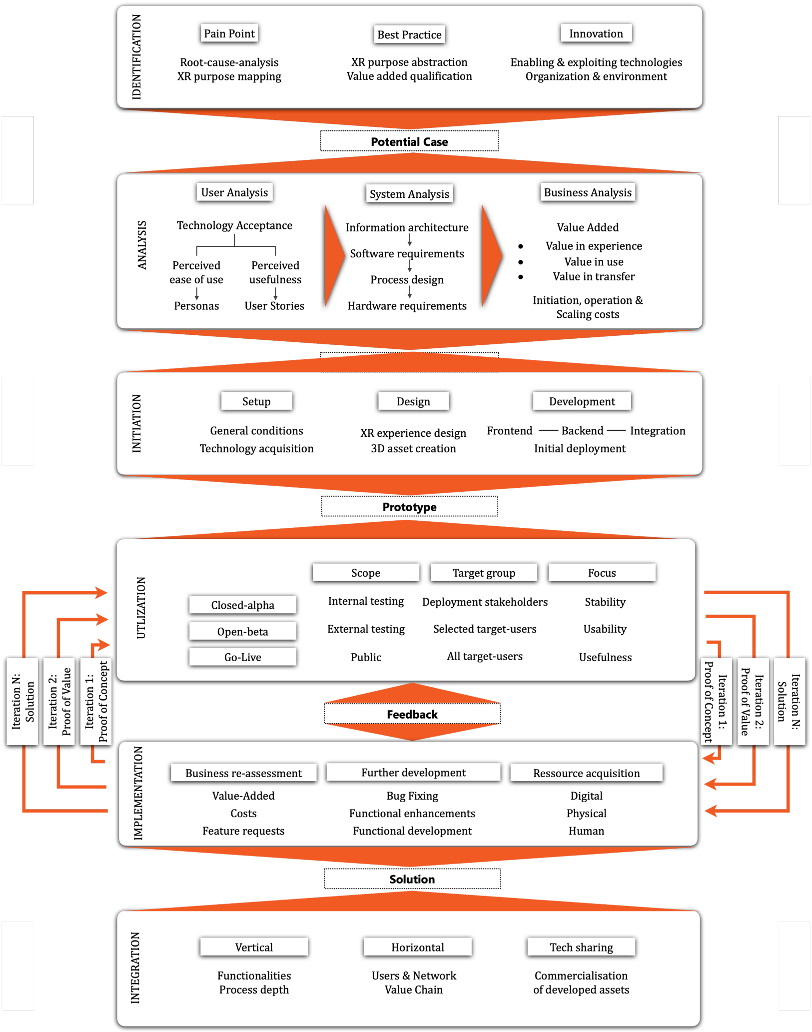

Figure 4.23: Summary of the methodology deployment sequence

5 Validation

Based on the methodology presented in **chapter 4**, **chapter 5** validates the methodology with two industrial XR technology deployments. Each of the presented potential cases is based on different value creation architectures, different origins of the potential case and XR technology characteristics. After an initial description of the respective value creation architecture, the description of the sequential steps with their characteristics follows.

Potential case 1 comprises an automotive use case. Productivity is to be increased by implementing a desktop VR-based 3D configurator for planning semi-finished vehicles. The complex planning process and the strong demand for customer individualization represent a pain point in the value creation that is to be addressed by deploying the desktop VR solution for respective target users.

Potential case 2 comprises a construction site use case. The transfer of the best practice of an AR-based measurement to the facade industry is aimed at here. With the help of AR technology from a COTS device, the sales channel of the processor is to be empowered by the business unit of the manufacturer of facade material. The data collected using AR will enable (1) faster execution of the core process of the offer creation and (2) better planning of product design and production processes through business intelligence.

As mentioned in **chapter 1.2**, the methodology follows the subsequential **research objective** to be practically applicable. Through the validation, the execution steps of the methodology are to be demonstrated under real economic conditions and provide tangibility through industrial examples for execution and potential challenges.

5.1 Potential Case 1: Planning of semi-finished products in the special vehicle industry with Desktop VR

The first potential case is the deployment of a 3D configurator based on desktop VR technology. The configuration includes planning a vehicle line of a manufacturer. To reduce the deployment's complexity, the manufacturer's vehicle variance is reduced to one vehicle line for the execution. In addition to the high number of units, this vehicle line represents the core business. The complexity of the variance in the model line justifies the deployment as value potentials can be leveraged, and a system can be created to be rolled out across other vehicle lines of the product range.

In this scenario, the business unit is the vehicle manufacturer and the central point of the underlying value creation. The core process of the deployment project is ordering a new vehicle from a customer, i.e., a fire department. Thus, each customer communicates their individual requirements while processing their order. A planning process is then initiated based on these requirements, which in the end then triggers an order release and the start of the customer-specific vehicle production. This requires iterative communication between the responsible equipment planner and the customer. The iterative communication and repeated change requests cause inefficiencies in the entire value creation. Therefore, the sub-process of equipment planning within the core process of order management must be captured and executed with the desktop VR 3D configurator.

5.1.1 Initial Architecture of the Value Creation

Network

The central business unit of the underlying value creation is the manufacturer. The business unit coordinates the acquisition of the required products, components, and materials for constructing, manufacturing, delivering, and maintaining the demanded vehicles. Therefore, various suppliers exist, such as raw material suppliers, equipment suppliers, production machine providers, and Truck OEMs (Original Equipment Manufacturer). The underlying target of depicting the equipment planning process in a VR environment, primarily the equipment manufacturer and the Truck OEMs, is relevant, as these parties maintain relevant data and 3D assets required for operating the 3D configurator. The channel of the value creation is partially integrated into the business unit as a dedicated sales department for the fire trucks and partially excluded in third-party dealerships for special firetruck equipment. The customer role within the value creation network is any organization requiring firetrucks and financial sponsors (e.g., governmental institutions or companies). The customer types are to be distinguished in industrial organizations (e.g., companies), professional fire departments, voluntary fire brigades, and others. Each has significant characteristics in ordering fire trucks, such as professional purchasing departments (e.g., companies) or large-scale order volume (e.g., government).

Value Chain

The product or service stream in the fire truck delivery is directed downstream. Sourced components for each truck are assembled and pushed toward the customer. A shell vehicle is created from the initial plan of a fire truck, which is then equipped with the required equipment in a joint session between the planner, manufacturer, and customer. After delivering the truck, service performance for maintaining the functionalities is executed. The information stream of the value chain is bidirectional. In the downstream direction of the vehicle production, the information stream contains information about the equipment plan. The upstream part consists of the customer-specific requirements for the order and the upcoming change requests during the order and execution process. From the financial perspective, the value chain follows an upstream direction, with the customer paying for the delivered truck and the business unit paying for the ordered components.

The core processes of the business unit of the value creation are R&D, purchasing, sales, order management, production, product management, and after sales. In terms of the underlying scope, the regarded core process is order management, consisting of the order received by the sales process, the equipment planning, and the transfer of the planning to the manufacturing process. The equipment planning, especially the support process of the communication between the customer and equipment planner, is the primary source of change requests and customer approval and is to be focused on for the 3D configurator.

Resources

The existing physical resources are the technology and infrastructure for producing the firetrucks, such as construction sites, office buildings, machines, logistics network, etc. For the deployment, especially the physical technology equipment in terms of IT (e.g., laptops and computers) and their performance is to be considered, as the 3D configurator requires dedicated hardware. The core human resource for the underlying subprocess of equipment planning is the specific know-how about equipment planning and the positioning of tools. This consists of country-specific requirements for mandatory equipment to tactical equipment configuration setups for different firefighting scenarios in different areas. The digital resources of the underlying value creation, especially of the business unit, are the existing 3D CAD models of the firetrucks and the equipment models. Additionally, several software tools are utilized for managing all data around products, variants, process execution, and sales, which are relevant for the deployment and later the integration of the 3D configurator as a solution in the value creation.

Value added

The business unit is considered a leading provider with an extensive history in the firetruck industry. A certain value in experience exists in terms of quality and technological sophistication. The value in use lies in the usability of the firefighting vehicles with a focus on ergonomics, reliability, customer individuality, and operational, tactical design. The value in transfer results from selling firetrucks and the belonging services.

Value Potential

The considered value potential for the present value creation lies in the pain point of inefficient equipment planning. Due to the existing system requirements, the repetitive planning process requires high capacities of skilled labor of engineers. In addition, the ordering process allows a high degree of variance in planning due to the high degree of coordination required. As a result, the customer has too many opportunities to place individual wishes along the order management process. Even though this is considered a central part of the added value in use, the underlying scenario presents potential to address this maximized individuality, resulting from a lack of understanding and imagining the potential configuration variants.

5.1.2 Identification

The understanding of the existence of the pain point of value creation is present in the business unit and results from inefficient equipment planning. A root-cause analysis is performed to identify the 3D configurator potential case. Figure 5.1 shows the result of this analysis.

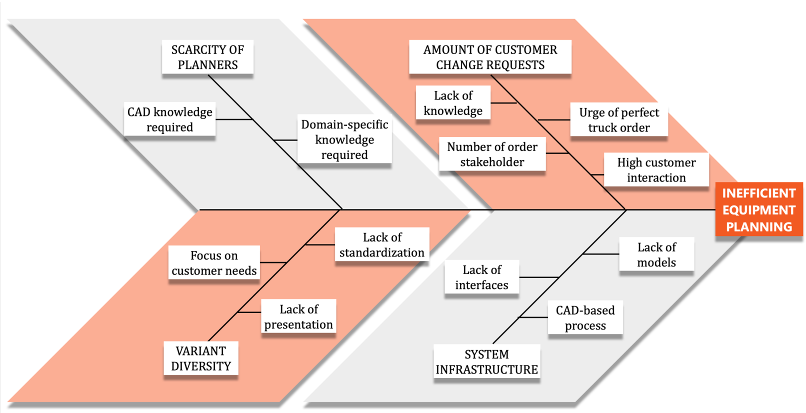

Figure 5.1: Root-Cause-Analysis of Potential Case 1

The pain point of inefficient equipment planning is separated into four root-causes. The high customer interaction between planner and customer gives room for change requests. The limited availability of planners results from the need for special know-how in equipment planning and the CAD domain. The variety of variants results from the strong customer focus, and the CAD-based configuration slows down the planning process. As a solution approach in the form of a potential case, a 3D configurator based on desktop VR technology is nominated to optimize the process by:

- Streamlining the customer interaction process with specified and visualized equipment possibilities.
- Capturing the specific knowledge of the equipment planner in a UX and making it accessible to other users through a simplified interaction.
- Pre-defining configuration options to initiate the standardization of variants in the value chain.
- Taking the process out of the CAD environment to make it easier and more connectable within the value creation and the customer.

The identified potential case for suggested XR technology morphology from the methodology is depicted in Figure 5.2.

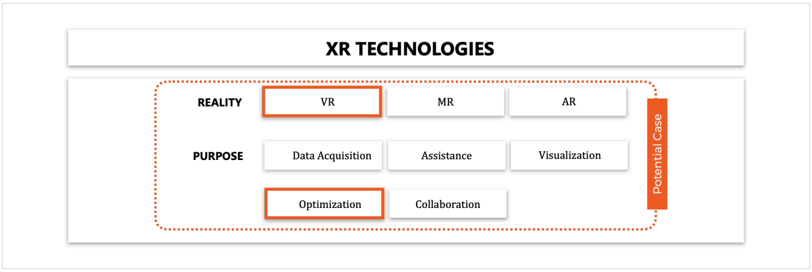

Figure 5.2: Identified XR technology potential case 1

5.1.3 Analysis

User Analysis

The involved users around the 3D configurator for the load planning are the equipment planner as well as the representative of the fire department, i.e., the firefighter. While the role of the equipment planner is interpreted as admin due to his expertise, the firefighter is to be distinguished as various target users. As mentioned at the beginning, the purchasing behavior of fire departments differs depending on their size and origin.

The user analysis showed that a relevant share of sales comes from the customers of the volunteer fire department. They are also the cause of various change requests in the process, as there is an increased need for changes due to their low order frequency. In addition, this customer group predominantly orders similar vehicles of the product lines with standardization potential. Other customer groups required less support from expert buyers (companies or professional customer groups) or buy special models of the product line. Thus, the target customer of the voluntary fire departments is to be addressed for the present potential case.

The user analysis also showed that the transformation of the entire equipment planning process is highly complex and must be performed iteratively. For implementing the required expertise into the 3D configurator solution, the process must be transferred step by step. For this reason, the 3D configurator must be developed for the scope of the PoC and the PoV and for a first solution approach for the internal application purpose by the admin user, i.e., the equipment planner. In addition, a visualization interface will be provided to the end user to enable them the tracking of their configuration in 3D. Subsequently, the visualization interface will be gradually extended by functions so that the end user can eventually plan his own vehicle. However, this target is taken out of scope for the first iteration of the solution. Table 5.1 sums up the initially collected user stories for the equipment planner as the admin user and the firefighter as the future end user.

Table 5.1: Abstract from the Initial Product Backlog with User Stories (US) for admin and end user of potential case 1

I as an equipment planner want to… (admin user)	
US1a	Create a new project
US2a	Select a truck based on vehicle characteristics
US3a	Load existing projects to plan new projects from it
US4a	Select fixed equipment with the configuration codes
US5a	Select fixed carrier systems with configuration codes
US6a	Adjust the shelf layout of the locker rooms
US7a	Load equipment from a library into the scene
US8a	Upload my own equipment required for specific configurations
US9a	Change orientation and place equipment in the truck
US10a	Change the vehicle characteristics
US11a	Load equipment and codes from an excel sheet
US12a	Delete equipment from the configuration
US13a	Create a PDF report for the customer
US14a	Create a PDF report for the production
US15a	Save a configuration with a unique code to be retrievable for the customer
US16a	….
I as a firefighter want to … (target user)	
US1b	View my truck configuration in 3D
US2b	Add comments to the 3D model for the equipment planner

US3b	Select from predefined configuration options
US4b	See best fitting options for my operation area
US5b	Track the status of my truck and equipment in the 3D model
US6b	See possible truck options
US7b	…

The defined scope leads to a stronger focus on the admin user. The configuration process can be transferred iteratively to the equipment planning configurator, and the knowledge can be transferred subsequentially. With the target user in mind and to leverage initial benefits from the enablement of efficient communication, the first version of the solution should also consist of a truck viewer with a commenting functionality for the target user (US1b and US2b).

System Analysis

Based on these user stories, an information architecture can now be developed. As mentioned above, the solution for the first version will focus on optimizing the configuration internally at the equipment planner and integrating the end customer through a visualization tool. Figure 5.3 shows the initial information architecture for the 3D configurator of the equipment planner.

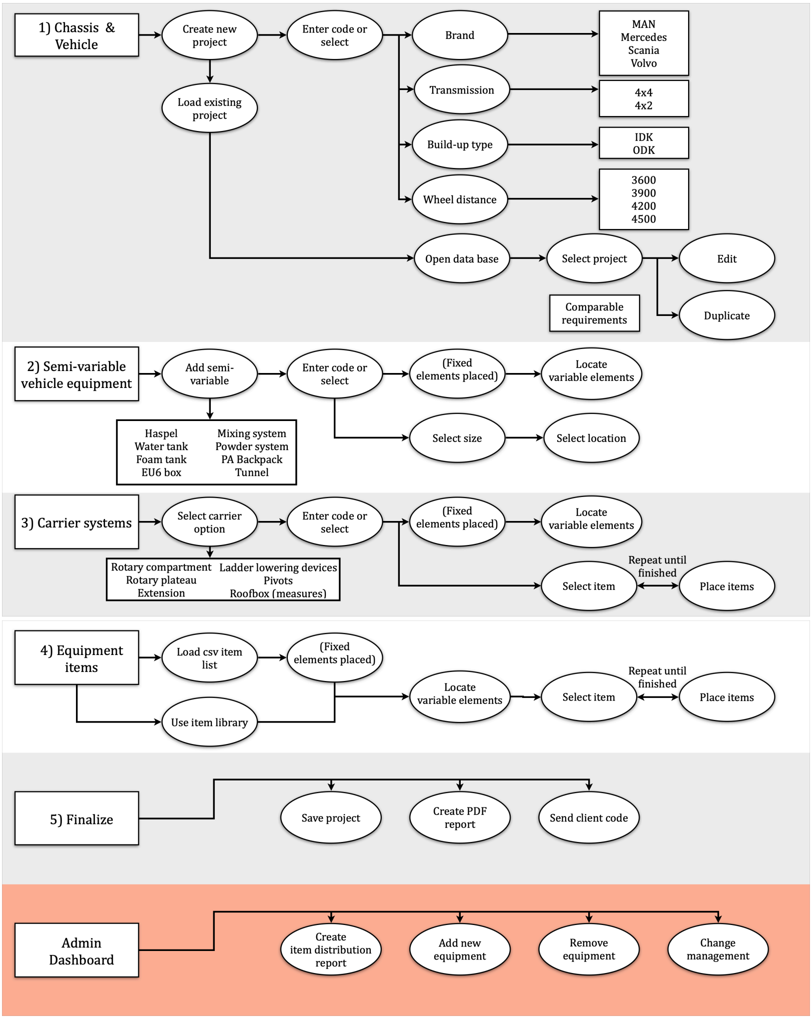

Figure 5.3: Information architecture for the admin user of potential case 1

Customer access is provided via the so-called truck viewer. The truck viewer is a replication of the system with limited functionality and is executed via a web-based solution. Each configuration is given a unique code and calls the stored configuration via the web interface for viewing. In addition, the information architecture receives a simplified DPI for exporting planning results as one PDF each for the customer and the manufacturing process. The planning process is driven by a dynamically established model library, which allows the admin user to import own models and thus scale the configurator during usage. For this purpose, the loading planner receives, in addition to the tool, a workflow to independently create suitable 3D models from CAD files.

For the overall scope, the best suitable development environment to set up the depicted information architecture is the IDE UNITY3D. With the availability of the WebGL library, the desired information architecture between the equipment planner and firefighter can be established. Additionally, the availability of dedicated plugins enables the integration of DPIs and interfaces.

With the existing equipment planning process being the reference, there is no requirement to perform a process design. With the target of transforming the configuration process into a desktop VR environment, no additional hardware is required for the first scope of the solution. This requirement can change in the future if the scaling of the configuration visualization is to be performed toward an immersive experience.

Business Analysis

Table 5.2 lists the cost and benefit analysis results of the 3D configurator for the scope of deploying it with a focus on the equipment planner.

Table 5.2: Cost-benefit analysis of potential case 1

Value Added		Costs	
Value in experience	• Uniqueness of the business unit • Technological leadership • Additional experiences for special customers (not directly applicable)	Initial costs	• Costs for 3D modeling • Costs for UI/UX design • Costs for initial development • Opportunity costs for required capacities through equipment planner (knowledge provision, model provision, testing, feedback) • Acquisition of software licenses • Acquisition of assets for the development of interfaces • Server setup costs
Value in use	• Cost reduction for the planning process through less time required • Increased output through reduced planning bottleneck and increased lead times • Reduced variances through establishing of standards in configurations	Operation costs	• Costs for hosting the model library • Costs for hosting the web-based viewer solution • Creation of further 3D assets
Value in transfer	• Advertising or brokerage fee for suppliers' equipment in the 3D configurator (not directly applicable) • Additional lifecycle services (not directly applicable)	Scaling costs	• Costs for further functionalities (not defined yet)

First, the potential value added by the 3D configurator is to be estimated in the value categories of the methodology. The value in experience results from underlying the technological leadership of the business unit with the deployment of the 3D configurator. No competitor has a comparable 3D experience for exploring configurations. The further potential value in experience can result from providing special experiences for the large-scale customer, providing the created configuration in VR, e.g., decision making. The value in use results from immediate reduced costs for planning through avoided planning capacities. Additionally, removing the bottleneck in planning will lead in the future to faster lead times, and establishing standards through the configurator enables a smoother execution of the entire value chain. The potential value in transfer is not immediately applicable due to the scope of deploying the 3D configurator for the equipment planner. From the long-term perspective, with the end user in scope, potential value added arises for advertising fees or brokerage fees by providing suppliers a platform for presenting the product within the context of the 3D configurator. Furthermore, additional services or subscriptions for the customer can be sold via the future solution.

In terms of costs, the major part is required for initiation costs. As there is no model compatibility of CAD for the targeted environment, creating an initial configuration spectrum requires significant manual effort and, therefore, a budget for the initiation. Furthermore, the initial design and development involve budget as well as the capacities of the admin user. The costs for hosting are expected to be rather low, as the targeted audience size is restricted, and the only hosting cost driver to be considered is the model transfer through the library. The scaling costs are not estimable yet as the further development of the solution can be targeted in various directions.

5.1.4 Initiation

Setup

The initiation is done by creating the appropriate setup for the initial scope definition. The intended major user for the first version is the equipment planner, and the end-user firefighter is addressed through a web-viewing interface in the initial stage. A product owner is nominated on the business unit side to enable the implementation representing the admin user and target user. In addition, for the implementation of the special know-how of the equipment planner into the tool, its capacities are to be released by the business unit. This includes providing the required initial model database to perform initial planning tasks and test the functionalities. The technology mainly requires a laptop or PC with a moderately powerful GPU to run the solution. As per initial screening the available machines to the equipment planners are rather performant. Due to the availability, the solution can be designed for the given prerequisites. However, there may be a need for new machines if the existing hardware of some equipment planners is selectively outdated.

XR Experience Design

The UI of the 3D configurator is based on the existing CAD system, and the UX design captures the existing process flow in the CAD system to increase admin user acceptance. The selection of the basic vehicle is made by selecting vehicle properties affecting to the available planning space in the truck. These properties are chassis manufacturer, transmission, wheelbase, and team room. The user is guided through the configuration process in the steps "Aufbauten" (build-ups), "Halterungssysteme" (carrier systems), and "Ausrüstungsteile" (equipment). As shown in the information architecture of Figure 5.3, each of the steps is repeatable. Depending on the step, the user loads equipment and components from the equipment library or retrieves predefined codes via text input. It is assumed that the equipment planner has access to the specific codes due to his experience and due to the order from the customer. In addition, there are optional visualizations and camera interactions on the left side of the user interface, such as ergonomic mode or intersection mode, to identify hidden storage room. Shortcuts to the individual equipment rooms and navigation keys for part movement complement and simplify the interaction with the tool. Figure 5.4 depicts the UI of the 3D configurator.

Figure 5.4: UI and UX design of potential case 1

In terms of usability, the interaction design is based on both familiar computer game interactions and familiar equipment planner interactions. All interactions are therefore based on the mouse and keyboard. The rotation of the camera, i.e., users' point of view, around the vehicle is controlled by the keys W-A-S-D. The so-called pen mode allows the user to move the camera lateral via Shift+ drag & drop or via the keyboard through Q and E. In addition, there are commands to rotate the equipment by pressing the space bar and the corresponding rotation direction. The rotation arrow keys are placed in the UI to give the overlap of these buttons an alternative according to the UCD. Table 5.3 lists the interactions of the 3D configurator.

Table 5.3: Interactions of potential case 1

Interaction	**Interaction design**
Load equipment	Load list or download item in library
Place active equipment	Click on position
Activate equipment	Double click item
Deactivate equipment	Right click
Put equipment in scene	I & Drag & Drop
Move equipment left/right	Arrow keys left/right
Move equipment front/back	Arrow keys up/down
Move equipment up/down	Shift & Arrow keys up/down
Rotate equipment by 90°	Space & W-A-S-D-Q-E or UI buttons
Rotate equipment by 5°	Space & Arrow keys left/right/up/down
Remove equipment	Activate item & delete key
Place item in collision	Move item into object & click Y key
Open rotating shelf in specific angle	Space & Click on handlebar, enter value
Rotate camera	W-A-S-D key
Move camera	Shift & Drag & Drop or Q-E
Zoom camera	Mouse wheel
Reset camera	C key

The equipment placement consists, in general, of 6 DOF. It is positioned on the desired surface via drag & drop from the right-sided library. After initial placement, these equipment items can be precisely positioned via the arrow keys. Parts can be duplicated via copy & paste commands. Important for the execution of the loading planning is a default activation of collisions, i.e., parts cannot be moved through walls or other equipment. By pressing the Y key, this restriction is bypassed, and parts can be placed in a collision. This requirement results from potential cuts in surfaces for optimized equipment storage and provides the equipment planner with more flexibility.

3D Asset Creation

A minimum set of available 3D models is required for initiation. For this purpose, the existing CAD models must be converted into FBX models and then prepared to reduce the polygon count and, thus, the weight of the models for the configuration. Depending on the model's size and the geometry's complexity, this conversion must be done manually. To limit the enormous variance and depth of components and to limit the number of models to be prepared manually, they must be clustered.

The vehicle models serve as the foundation of each configuration. These are highly complex due to the available construction data and must be prepared manually. In addition, the availability of these models is limited since the data sovereignty of the vehicles lies with the truck OEM. To master this complexity, the truck models must be differentiated and abstracted. Changing components of the truck can be rigged. This way, a truck model that has been prepared once can represent several vehicle bases. Figure 5.5 shows the subdivision of the truck models as well as the provided rigs.

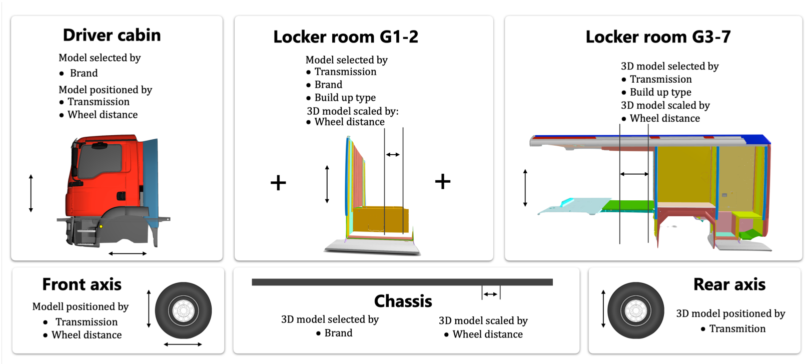

Figure 5.5: Clustering and rigging of vehicle models of potential case 1

For example, models in the truck with predefined positions and dynamic information are fixed-placed equipment options. These are accessed via the equipment codes of the order management. With the setting of a global origin across all model categories, this information can be stored consistently. Some options are fixed, and other parts can only be moved or rotated in the direction of one axis.

Freely placeable models must be prepared accordingly and provided with a naming convention and relevant metadata for future integration with other systems (e.g., product number) and created in an initial, scalable library.

Development

The Front-end development of the UI and UX design is conducted in the environment of a local software build for windows systems. In addition, a web viewer for common Internet browsers is set up, with which the end user can see and comment on his configuration. Customized functionalities are to be developed for the interaction model. Especially the movement of the equipment, the selected collision, and the placement of the parts on reference surfaces require the development of custom scripts. The precision required to derive a construction plan from the configuration requires that the models' colliders are mapped point based. This results in innumerable combinations and thus as a bug source, which are to be limited by continuous SQA. The listed user stories from Table 5.1 are implemented in the Front-end. Figure 5.6 shows an example of the functional breakdown of US6a into realizable tasks.

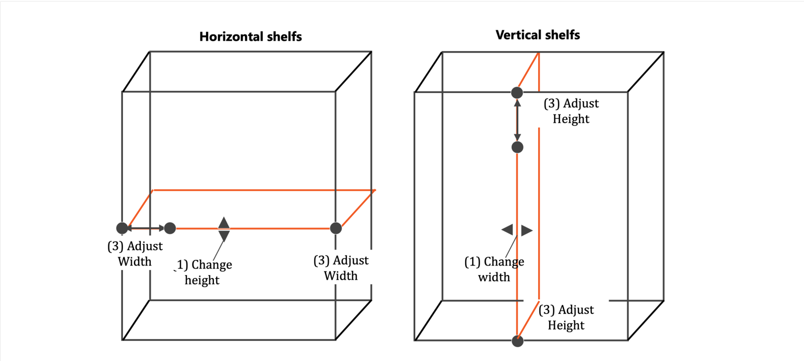

Figure 5.6: Functional depiction of US6a – Adjusting the layout of the locker room

The database in the Back-end is to be built according to the described model logic from 3D asset creation. The created rigs of the vehicle variants and the models with the meta information are stored in a local database in the software build to enable the modification and to call these combinations via codes and properties. This prepares the subsequent integration of the 3D configurator into the existing system landscape in a later stage. Furthermore, the setup of a variable equipment library with up- and download functions for synchronization and scaling of the library during usage is necessary. The challenge is to store a DPI in the local software build that verifies the current version of the library and updates it with missing models. In addition, a central storage location for the configurations is needed that provides access for both the local software and the web viewer.

The engine for operating the configurator is based on the UNITY3D IDE. This is extended with the WebGL API to enable a web-based visualization of the vehicle created by the equipment planner. In addition, the engine will be extended with corresponding DPIs. Besides the model exchange and the central storage and management of the configurations, the engine must be extended by a DPI for the output of the configurations as a PDF file. For this purpose, the positions of the equipment towards the centralized origin and selected configurations are provided in JSON format. A web-based renderer complements them to output an illustrated PDF for both the equipment planner and the customer. These functionalities are required to enable the value adding potential and integrate the configurator without immediately replacing the previous equipment planning process.

5.1.5 Utilization

Closed-Alpha

The implementation of the 3D configurator was iterative. After the Front-end was implemented, the first usable version was a prototype with a limited model and range of functions. The prototype should show the vehicle linking and scaling according to the described logic, the loading of fixed options, and the free placement of equipment according to the interaction model. The interfaces for the model library, the PDF export, and the connected web viewer were avoided initially.

The product owner performed a closed alpha testing. In the prototype phase, the interaction model and the logic of the collision already showed a high number of corner cases and ripple effects, i.e., undesirable effects of the functions on each other. The usability and stability of the configuration process were thus not given. For this reason, a conceptual extension to a strict separation according to interaction classes had to be optimized at an early stage.

Open-Beta

After ensuring stability, the prototype was functionally extended to a PoC. In addition to extending the model spectrum for the first scope of the solution, the dynamic equipment library was added. In addition, a web viewer was implemented for the customer, which should provide access to the configurations.

The PoC was tested in an open beta testing with a limited number of equipment planners. In addition to identifying further functional improvements, numerous change requests and wishes for new functions were received. These had to be transferred to the product backlog. The testing of the web viewer showed that the web environment could not fulfill the amount of data and the rendering requirements for mapping a configuration. For this reason, a pivot was made to a local viewer build, which is to be operated by the end-user locally on his computer.

Go-Live

After implementing the necessary beta feedback, especially creating a local truck viewer, the DPIs for exporting the data from the configurator were implemented for the go-live. This allowed the data for value creation to be extracted system by system and passed on manually. Thus, the PoC delivers the first added value through the usability of the configuration. The PoV was thus achieved and could be transferred to the production environment.

In the practical application, it became apparent that the desired functionalities were available but that the PoV had to be scaled up through further development to be considered a complete solution and to replace the existing load planning system. The focus is on functional requirements. Once the functionality has been improved, the solution must then be supplemented with additional model series to deliver the desired added value.

5.1.6 Implementation

Further Development

With the PoV available in the live environment, implementing the 3D configurator into the value creation can proceed in accordance with the methodology. First, an agile sprint model must be used for further development. For this purpose, the product backlog, including the further development requests from beta testing, must be evaluated, and prioritized. The existing feedback results in two sprints for the functional further development of the 3D configurator. Figure 5.7 shows the composition of the nominated functionalities for the first sprint of further development, transformed into a sprint backlog.

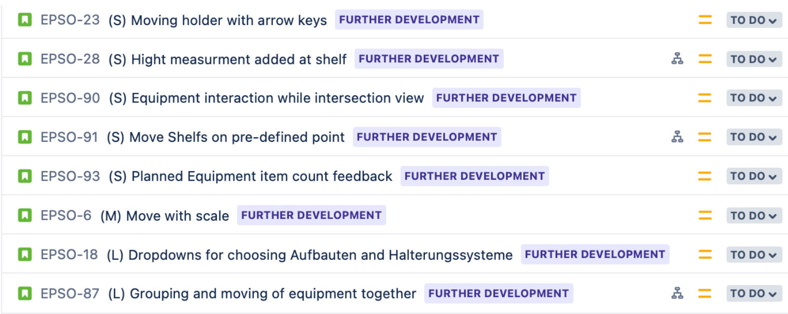

Figure 5.7: Sprint backlog for the first further development sprint of potential case 1

As shown in the sprint backlog, the tickets are estimated with an adapted method of the story points. Based on the development, it could be determined that there are functionalities of the size S, M, and L. A sprint with a development duration of three weeks can be executed with two to three S tickets, two M tickets, and two L tickets. Two M tickets can substitute for one L ticket; one M ticket can be substituted for two S tickets. This can be used to define the scope and executed once the business re-assessment justifies the release of a further development budget.

Business Re-Assessment

Due to the limited scope of the internal use of the configurator for the first version of the solution, there is no Value in Experience and no Value in Transfer. The use of the PoV shows that for internal usability and usefulness, further functionalities are still needed to release the assumed value in use. The reason for this is the extensive requirements of the loading planner for the execution of its work steps.

From a cost perspective, this results in further development costs as the most critical cost driver (Table 4.18). Operation and support will not be significant due to the small number of users, and hardware will only require selective upgrades. In the long term, however, there will be additional costs in connecting the current standalone solution to the system landscape of the business unit. Especially the interface between CAD and the 3D configurator needs to be established either by the development of an automated interface or by a manual workforce.

For this reason, according to the business re-assessment scheme from Figure 4.20, the assumed value added is not yet available. The corresponding further development of the functionalities according to the prioritization suggests that the added value will be present after the implementation of the further development sprints. In addition, it is to be evaluated according to the scheme whether a conceptual pivot releases new added value. For example, it appears that the previously delivered visualization of the vehicle can also be used as sales support. In addition to the further development of the equipment planner, the tool can also be used for up-selling in the sales process. The potential value added is overall promising. Further development of the configurator is therefore recommended.

Resource Acquisition

For the existing deployment stage, two possible investments must be considered regarding resources. As already mentioned, operation and scaling require an interface between CAD and the 3D configurator, which can be operated either by a human resource with unique know-how or by developing a digital asset in the system landscape.

From a hardware perspective, it should be considered whether the loading planners should be equipped with appropriately performing equipment to improve the user experience during use and to increase productivity.

5.1.7 Integration

With the status of the 3D configurator as a PoV being implemented, the integration is not to be performed yet. However, the deployment sequence has shown several connection points to be established for integrating the configurator along the value creation.

Vertical integration

As already mentioned, the functional depth of the 3D configurator requires the implementation of further features. For vertical integration, further vehicle lines are to be integrated into the configurator to cover the depth of the entire equipment planning process of the business unit. These vehicle lines might require an adaption in the UX for the configuration process and storing vehicle models with dedicated meta information. An automated validation rule system could be established to enhance the quality of the configuration process for the subsequent downstream processes in the value creation. Also, the creation of a seamless data transfer from the equipment planning process to the production process integrates the 3D configurator in the value creation.

Furthermore, vertical integration requires adjusting previous processes in the upstream direction of the value chain. By establishing requirements for the R&D processes to create CAD models ready for the conversion of the 3D configurator, an automated integration becomes possible.

Horizontal integration

The first horizontal integration achievement goes along with the initial deployment goal. The standardization of vehicle variants along the value creation, driven by the deployment of the 3D configurator, is the achievement with the most promising value adding potential. This can only be achieved by combining customer touchpoints for a guided configuration process. This guidance can be established so that the customer's experience in configuring their own vehicle outweighs the urge for maximal individualization.

To increase the value in experience, the creation of VR experience for dedicated clients is to be evaluated. With the database and the infrastructure being established and the 3D models being available in a VR-accessible environment, the VR experience can be established with low effort. The only additional requirements appear towards the interaction design, as this is not directly transferable into an immersive VR experience.

In the long term, vertical integration can be achieved by creating a digital vehicle twin based on the existing equipment configuration, reaching from the equipment supplier and truck OEM over the business unit to a lifecycle touchpoint for the customer.

5.2 Potential Case 2: Sales process enhancement for processors in the construction industry with mobile AR

The second potential case for applying the presented methodology relates to deploying a MAR-based application for offer creation in the construction industry. The app is developed with necessary AR and non-AR functionalities to simplify and accelerate the data collection process. For this purpose, the COTS device iPad PRO is used to collect measurements on the construction site via the installed LiDAR sensor. This data is then processed in a UX to create an offer for a renovation project. In addition to increased productivity, the deployment of the MAR app enables holistic data collection about sales activities, which can be used along the value chain.

The application addresses the processor of construction material and is provided by the material manufacturer, i.e., the business unit. The addressed core process by the deployment is the offer creation of the channel processor. This requires various sub-processes consisting of customer data entry, capturing of construction site details, measurement, visualization, and the compilation of the offer. The lack of available data and the duration of the repeated data collection process on the construction site delays the offer process and exposes potential drop-off points to the customer. The tool is intended to empower the processor and simplify his day-to-day business.

5.2.1 Initial Architecture of the Value Creation

Network

The network of the value creation is centered around the business unit. This business unit produces facade renovation material. For this purpose, the business unit procures the necessary material from raw material suppliers and processes it into ready-to-use renovation material. The channel for the distribution of the product is the network of certified processors. They purchase the material from the business unit and use it to renovate their customers' buildings. These can be, e.g., architects, owners, or investors.

Value Chain

The downstream material flow reaches from the raw material to processed renovation material to the application on buildings. The information flow between the channel and business unit is maintained through dedicated systems and service spots by exchanging required and available renovation material in amount and variance. The financial flow is directed upstream for purchases of renovation materials by the channel or raw materials by the business unit.

Resources

The major resources of the value creation are next to the existing production locations and logistic networks, the network of human specialists applying the renovation material on facades. The business unit trains its channel members to enhance their skill set and to provide a high level of quality for their products. From a digital perspective, the business unit operates relevant SAP systems for maintaining material availability and Salesforce systems for handling sales data towards the channel. Furthermore, the processors maintain their own ERP systems, depending on the size of their respective companies.

Value Added

Within the value creation, various value is added throughout the value chain. The processors are generating value in transfer for receiving payments for their renovation material application service. The business unit is generating value in transfer with the sales of their renovation material. For the customer, value in use is generated through the application of the renovation material on their building, improving the visual appearance and longevity of the building while avoiding a costly renewal of the facade. Within the value creation, value in experience is lacking as the business follows classical and rational product economy characteristics.

Value potential

While the execution of the renovation material application follows a manual process, the creation of offers for the customer by the processor contains potential value in use. The lack of available data required for creating a quote and the hesitance of the customer while contracting a renovation project can release value potential when overcome. Additionally, the material flow in the product or service stream can be smoothened when predicting needs for renovation material amount and colors, reducing inventory through prediction, and releasing value in use for the business unit.

5.2.2 Identification

In this case, the potential case is based on a best practice. The business unit receives information from an external source on how measurements can be taken with the ARKit using an iPad PRO and the integrated LiDAR sensor. Thus, the best practice qualification scheme must be used to evaluate whether this results in a potential case, according to Figure 4.8.

The collection of measurements fulfills the XR Purpose of data collection. As the fast collection of required data in the form of measurements can be valuable for the channel of the business unit, it must be examined how this value adding best practice can be made available to the channel. Extending the sub-process of data collection by providing an iPad PRO then creates a potential case for the business unit. This potential case can be assessed with the NICE design themes to assess the value adding potential and to initiate the analysis of the deployment sequence. The assessment is shown in Table 5.4.

Table 5.4: Applying the NICE design themes to potential case 2 (Zott and Amit 2010)

Novelty	Can the XR technology purpose be deployed to create a new (sub-) process for the value creation?
→ Yes, the iPad can be integrated to establish a new workflow for acquiring relevant offer data.	
Lock-In	Can the XR technology purpose be deployed to integrate relevant target users in a way to make it difficult for them to leave the value creation system?
→ Yes, by providing a tool for acquiring data the channel is already connected to the product of the business unit	
Complementarities	Can the XR technology purpose be deployed to combine (sub-) processes in the value creation to release synergies?
→ Yes, by integrating further features required for preparing offers and projects, the data can be kept centrally.	
Efficiency	Can the XR technology purpose be deployed to improve the flow of existing (sub-)processes to reduce costs for value creation?
→ Yes, by accelerating the offer creation and creating the project execution can be optimized. The enabled digital prediction provides further efficiency potential.	

Subsequently, the potential case results in the deployment of an MAR application for acquiring relevant measurement data in a B2B scope.

5.2.3 Analysis

User Analysis

As the COTS device is generally accessible, the potential end users of the potential case are any user downstream in the value chain. The potential target users are to be analyzed to identify the most promising target user. To do so, the potential users are distinguished in the personas mentioned above processor, architect, facility manager, and investor/owner. Considering that the measurement of the building requires a certain level of know-how on how the renovation material will be applied to it, the initial target user should be the processor for deploying the first version of the solution. Based on the created touchpoint, other user groups around can be addressed with new functionalities later. The contact person will take the role of the admin user towards the processor, i.e., the sales representative of the business unit. With the capturing of the measurement data through the MAR, other features for creating the offer from those data are defined with the required user stories. Table 5.5 sums up the major user stories for the processor as the end user.

Table 5.5: Abstract from the initial product backlog with user stories for admin and end user of potential case 2

I as a sales representative want to... (admin user)	
US1a	See the usage of the app by region, time, and processor
US2a	See the demand for amount and colors of renovation material
US3a	Extract the data of the usage for integration into existing systems
US4a	...
I as a processor want to ... (end user)	
US1b	Measure, combine and adjust different facades with the app
US2b	Maintain a list of all running projects
US3b	Create visual prototypes for convincing my customers
US4b	Create a valid offer for potential customers through the app
US5b	Add individual price components in the offer creation
US6b	Export the offer and send it through the iPad
US7b	Create and maintain customer contacts
US8b	Have access to knowhow and tutorials about processing the renovation material
US9b	Have my own profile with relevant data about my achievements
US10b	Collect relevant information of a project within the app
US11b	...

Potential case 2 focuses on the end-user processor. For the first version of the solution, the admin user takes on a monitoring role of the activities, with its user stories not required to initiate the solution. The listed user stories can then be transformed into an information architecture of the MAR app for the processor, as shown in Figure 5.8.

System Analysis

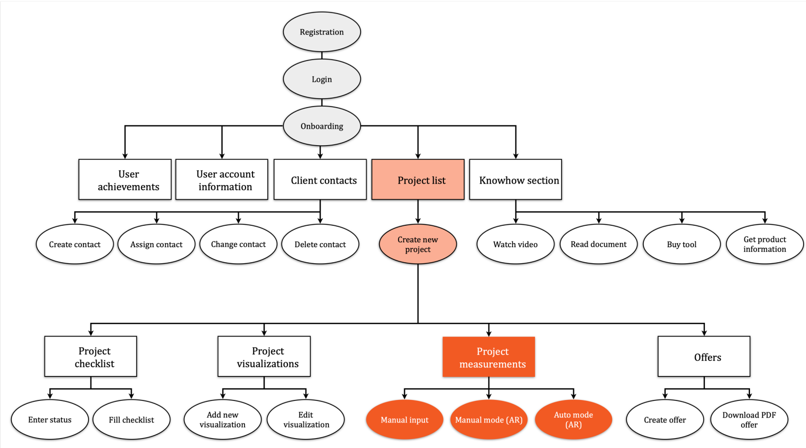

Figure 5.8: Information architecture for the end user of potential case 2

The information architecture follows the user flow and includes relevant steps of a B2B application. The app is accessed via an account created as part of a one-time onboarding process, coordinated manually by the admin user. The information architecture is centrally focused on the projects but offers access to desired functionalities in different categories. Regarding the data structure, the projects require an assignment to a customer. In addition to general project information, prototype visualization can be achieved through photos of the building objects. The focus of the project is the measurement function. Three different options are available to record measurement components and combine them centrally in the measurement. Based on the project information, the visualization, and the measurement, the processor can create a quotation specifying his individual values. In the offer section, the SAP system of the business unit is connected to store current prices and inventories in the offer. Overall, the information architecture is monitored via a tracking system to track activities on a holistic level and make them available to the admin user in a business intelligence (BI) center.

After the potential case is based on a best practice, the existing process is affected by the deployment. Thus, the end user's process must be drafted accordingly with the MAR app. The hardware requirements result from the necessity of an iPad PRO for the operation of the app. To design the process with the XR technology, it must be captured, analyzed, and presented with the XR-based extension according to the methodology. Figure 5.9 shows the result of the process design.

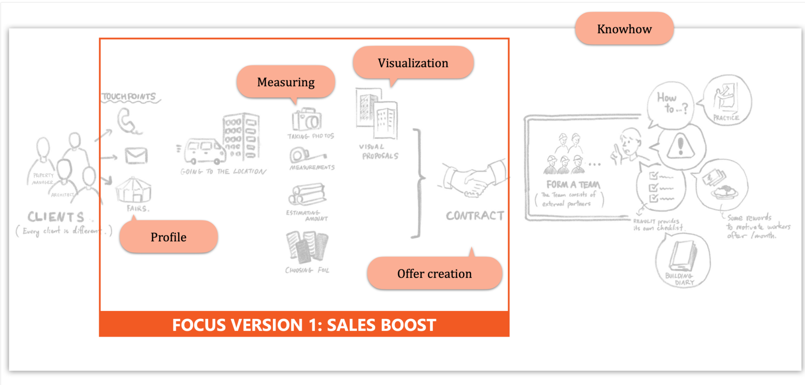

Figure 5.9: Graphic recording of the process design for potential case 2

The capturing of the process is executed with a design research approach by graphic recording the overall offering process together with a processor. By illustrating the flow, abstractions are made intuitively, and the process can be mapped. The As the XR technology deployed is AR, a virtualization of the process is not required as suggested in the methodology. The presentation of the process enables the allocation of the defined functionalities from the user stories and the information architecture to the captured process to ensure the benefit of each feature within the enhanced offer creation process through the MAR app.

Business Analysis

Table 5.6: Cost-benefit analysis of potential case 2

Value Added		Costs	
Value in experience	• Strengthened relation between business unit and processor	Initial costs	• Conceptual costs • Costs for UI/UX design • Costs for mobile app development • Costs for acquiring iPad hardware for the product owner and selected testers
Value in use	• Increased sales volume through faster offer creation for the business unit • Increased efficiency in the value chain through prediction for the business unit • Increased efficiency in the offer creation for the channel	Operation costs	• Costs for hosting the application
Value in transfer	• Subscription fee for premium functionalities (not directly applicable)	Scaling costs	• Costs for further development of functionalities • Costs for training and demonstration • Costs for scaling the app to other platforms • Costs for developing integration touchpoints

Table 5.6 summarizes the initial cost and benefit analysis of potential case 2. On the value adding side, the app adds value in experience as the processor is provided with a lock-in experience by the business unit. Thereby, the processor is stronger connected to the ecosystem and the products provided by the business unit. The major focus of the deployment of the MAR is on achieving an upselling of the products from the business unit. Second, the acquired data from the processor's utilization helps to optimize inventory along the value chain in the long term. After establishing the MAR solution, a potential value in transfer could be achieved by providing certain advanced features in the app as part of a pro edition with a subscription model for the processor.

From the cost perspective, this deployment does not require 3D modeling, as the AR feature is utilized to capture real data. For initiation, the major costs result from the development effort. Additionally, hardware must be acquired as iPads for the product owner and selected processors for open beta testing. The operation costs are low as storing and hosting data does not require high capacities as in a 3D model-based deployment. With the scope of a specialized B2B solution, the number of users is restricted, and thus the traffic is limited. For scaling the solution, the budget will be required to equip the processors with the required hardware and know-how through training to utilize the MAR app.

5.2.4 Initiation

Setup

After collecting the potential case requirements, the prototype's initial development can be executed. With the business unit coordinating among the deployment stakeholders, the product owner and the deployment sponsor provide relevant capacities and the budget for the development. The communication setup between the product owner and the development team is established via a project manager and a project management tool. Furthermore, the product owner, the development team, and respective testers must be equipped with an iPad for performing the required tests of the utilization phase.

XR Experience Design

As the solution aims for a MAR application, the XR experience design is mainly drafted towards a 2D mobile experience. The UI and UX design follow the traditional UCD design principles with the utmost simplicity in utilization. The flow of the information is to be aligned with the designed process flow of the processor to enable the execution for the major purpose of offer creation. The AR feature within the 2D experience requires a specific setup to ensure the required functionality and stability.

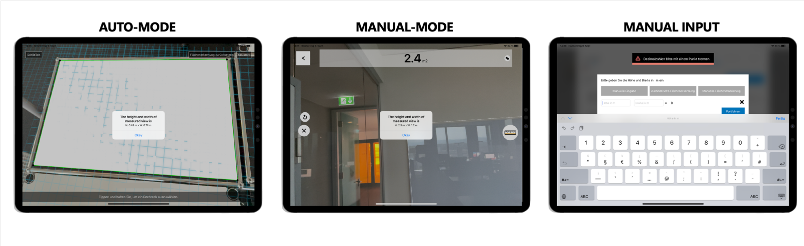

Figure 5.10: AR-specific experience design of the AR feature in potential case 2

Figure 5.10 depicts the AR-specific experience design with three different measurement modes. Through the AR-based measurement from the ARKit, the user should be able to measure components of a facade and combine them into a total building measurement by specifying the number of components. Therefore, there are three options for measuring the components. The auto mode uses image recognition and the LiDAR sensor to detect rectangular areas on the facade and to measure them based on the distance to the building. If the recognition is not possible, the user can mark rectangles on the facade via the manual mode and measure them by setting four markers on the facade. As a third option, manual input is possible without the AR feature so that already existing measurements can be recorded, and the app can be used with devices that are not compatible with the measurement feature of the ARKit.

Development

The initial development is done separately for the prototype in steps Front-end, Back-end, and integration. The Front-end environment is the iPad OS, i.e., the mobile environment for the end user. Figure 5.11 represents the targeted technical infrastructure of the Front-end and Back-end of the MAR application. This infrastructure is already set up in the initial development phase to enable proper scalability. For the initial scope, the functional focus is set on the measurement feature.

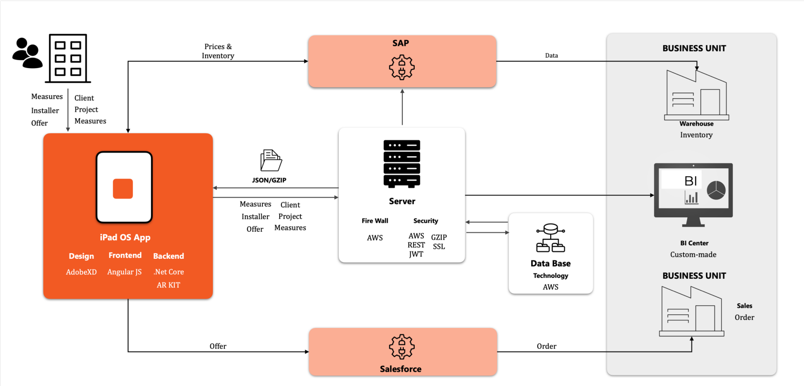

Figure 5.11: Technical architecture of the prototype for potential case 2

The agreed design proposal from Adobe XD is set up as the Front-end code in the iPad OS environment. The development of the measurement functionality and the required flow of the information architecture takes place in the Back-end. For the implementation of the AR functionality, an engine is set up based on the ARKit to collect the measurement according to the design requirements with the available modules. The captured data is then processed via a central server for processing and storage in a secured database. The processing server is then connected via DPIs to connect the MAR app with the SAP system for inventory and, in a later stage, with Salesforce for the sales activities of the business unit.

5.2.5 Utilization

Closed-Alpha

After the iPad prototype is deployed via TestFlight, the product owner can perform closed alpha testing. The test focuses on the application's stability when measuring the building elements and the usability of the collected data for the preparation of the offer.

The application shows the different modes of measuring work. However, the auto mode with automatic detection of surfaces is sensitive to fluctuating light conditions and soiling on the facade. The manual mode allows the user to collect data over a certain range up to and including first building levels. In addition, the time required for data collection is similar to the auto mode. The stability is given here for it. The manual data entry is considered a helpful addition. For the stability of the MAR app, the auto mode should therefore be removed from the function set of the prototype.

Open-Beta

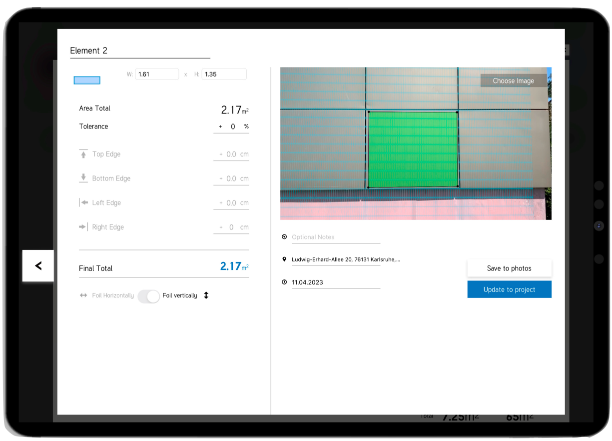

Figure 5.12: UI for post-processing the AR-based acquired data of potential case 2

With the auto mode removed, the prototype is stable and suitable for use with a limited group of real test users. Additional functions for processing the collected data are added to the stabilized prototype. Figure 5.12 shows the functionality of fitting the collected data through manual mode. Since the facade elements may have edges that cannot be captured, post-processing of the captured measurement requires the ability to add area. With the UI, the user can add additional dimensions to all four sides of the captured rectangle. In addition, there is the possibility of adding dimensional tolerances for offcuts or similar. To enable the calculation of the total foil requirement, the user is required to specify the foil direction. This provides him with an optimized calculation.

The open beta testing of the MAR app with the end user showed that the functionalities address the processor's needs. A certain amount of explanation is required for using the app so that the correct handling can be conveyed, and the MAR app can be used in a value-adding manner. Additional requirements also became evident during the beta testing under real conditions. On the one hand, the solely online architecture of the application has limited usability. Due to insufficient network coverage, the app could not be used on some construction sites.

On the other hand, real-world usage revealed that the image-based visualization function is more important than initially assumed. The visualization for the customer is a powerful leverage to shorten the decision-making time and to release the assumed value in use. These two requirements must be met to transform the PoC into a PoV and deploy it to the production environment.

Go-Live

After the implementation of the offline functionality and the improved visualization function, the PoV was achieved. For preparing the go-live, the BI dashboard for the admin user was developed to enable the tracking of the usage in the production environment. After that, the MAR app was launched. The app was thus made available in the AppStore and could be downloaded by any iPad owner. At first, only registered processors from the channel of the business unit received accounts for the access.

The usage after go-live showed that despite the given functionalities in terms of usability and ease of use, the distribution among the processors stagnated. Through targeted user surveys, it was possible to determine that the end user does not have the required time in the drafted process to familiarize themself and utilize the MAR app. This affects the initially designed process and must be re-assessed. In addition, the number of potential end users is strongly limited. Thus, opportunities arise to provide the app to additional user groups. This must be evaluated during implementation and realized accordingly through targeted further development.

5.2.6 Implementation

Further Development

The initial scope of the solution was functionally fulfilled. The lack of adoption of the MAR app in the processor's offer process results from the process design with the MAR app and a limited audience for it. Nevertheless, there is further development potential in the app for improving individual functionalities and optimizing app operation through an admin console for the assignment of user rights and content placement. Due to the lack of usage, this does not require an agile approach, as these functions have a limited impact on the end user. Instead, a conceptual pivot should be considered part of a business re-assessment.

Business Re-Assessment

The lack of adoption of the app in the end user's process means that the expected value in use is not realized. For this reason, the business re-assessment scheme must be applied. The functional fulfillment is given. For this reason, it is questionable whether additional or further developed functionalities can solve the process design issue. Addressing other target groups means a significant effort in adapting the app since the design is focused on the processor. Thus, it is necessary to evaluate whether an additional user in the scenario unlocks the desired added value.

Adding a user to handle data collection for the processor with the MAR app would solve the time bottleneck and directly empower the processor with applicable offerings. The additional user must be familiar with the app and the context of the facade renovation and, accordingly, must be provided by the business unit. Thus, it is worth considering whether, based on the MAR app, the offer creation process should be integrated from the channel to the business unit. The value in use through the targeted upselling of the business unit's products must justify the effort of the app development and operation and the user provisioning.

Resource Acquisition

The conceptual pivot involves a user and the MAR app to provide the processor not with the app but with a generated offer. For this, the business unit must first and foremost build up human resources in the organization. The user must become familiar with the app and build up know-how. Physical resources are needed in the form of hardware devices in the number of additional users. Digitally, all the necessary assets and data are available to implement the MAR app in the value chain with a user and the iPad.

5.2.7 Integration

Vertical Integration

The result of the go-live phase shows that the use of the app for its intended purpose needs to grow. The following approach to value adding deployment is to leverage the in-itself functional app to perform horizontal process integration in the value chain. Nevertheless, vertical integration measures can be considered. First, incentivizing the processor to integrate the app into its overall process can be attempted. Additional added value can be offered to the processor through training, demonstrations, and monetary compensation to drive the adoption. Secondly, the concept can be replicated for other product lines of the business unit. The functionality of the offer creation can be transferred to other product lines running parallel to the value chain. It should be verified in advance whether the processors of the other product lines have the same time bottleneck. If this is not the case, the app can be vertically integrated by transferring it.

Horizontal Integration

Horizontal integration through process adoption is the chosen direction to make the deployment successful. In addition, there are opportunities to establish an ecosystem around the MAR app along the value creation and to address other entities in the network. By adapting the functionalities or rolling out complementary solutions, the target groups architect, investor, or facility manager, can be addressed. For example, the business unit can establish touchpoints for lead generation among the processors' customer groups and place these leads in the MAR app to incentivize usage.

Technology Sharing

The XR deployment has evolved into a solution that uses AR-based data acquisition in the form of measurements. The intelligent processing then creates facade measurements. This functionality itself can be relevant for other participants in the construction industry. Thus, any building materials supplier for facades can benefit from the approach. The business unit's unique characteristic of producing material for renovating smooth surfaces means it is not competing with many other suppliers. For this reason, it should be considered whether the concept and the technology stack can be made available to other building material suppliers by, e.g., licensing.

5.3 Summary of the Validation

The validation of the presented methodology includes two potential cases. Both follow the methodology proposed but differ in the XR technological morphology, the origin of the potential case, and the deployment in the value creation network.

A business unit performs the first deployment for its own sub-process in the value chain. The XR technology is based on a desktop VR approach. The second deployment is a MAR application by the business unit for its channel's core process. While the Desktop VR application emerged from a pain point, the MAR application originated from the transfer of a best practice. In addition to the difference in identification, this impacts the process design in the analysis phase. The Desktop VR solution directly transfers an existing virtual process from the CAD environment. Hereby, the functionalities are defined from the existing process. In the case of the best practice, the process of the channel is extended by the XR deployment and needs to be designed accordingly.

The effort to deploy the desktop VR application is significantly higher than the deployment of the MAR app. This is due to two reasons. First, the complexity of the target process demands more extensive requirements for the solution. For this reason, the transfer process must be migrated to the Desktop VR environment in several steps. Thus, the admin user is focused on the initial stage to ensure that the implementation is technically accurate. Secondly, creating 3D assets is necessary for the Desktop VR deployment. This requires the effort of a 3D artist. Due to the low immersion of the MAR application, this is not required.

Both approaches run into challenges during the deployment. The desktop VR solution requires a significant feature set to replace the existing process, higher than initially assumed. This requires an increased effort for further development. The MAR solution does have the required range of functionality. However, the targeted process requires significant redesign for deployment.

To successfully deploy, these challenges need to be addressed appropriately. The desktop VR application primarily requires a budget for further functional development and, thus, the vertical integration. In a second step, additional added value can be generated through horizontal integration using the resulting concept along the value chain. The successful deployment of the MAR solution requires the channel's support in the targeted process. Here, the targeted added value can be released through horizontal integration in the first step and the acquisition of human resources. In addition, the concept can be transferred vertically to other product lines or generate new value in transfer via technology sharing.

Overall and in accordance with the **research objective of practical applicability**, both potential cases demonstrate the methodology to be applicable across industries. What can be observed from the validation regarding the research objective of subsequential viability, both deployed potential cases demonstrate their value potential in the integration phase. Thus, it should be implicated at the early stage and in the first deployment phases, that the realized value for a viable impact on the value creation can be achieved on the long run. Each deployment for XR technologies might therefore require a longer time perspective in terms of value realization and investment, as the initial value potential to be realized might be smaller than the initial investment required for establishing the solution.

6 Conclusion and Outlook

This chapter summarizes the major findings of this thesis and evaluates the achievement of the research objectives established in **chapter 1.2**. Furthermore, it is to be assessed if the identified research gaps in **chapter 3.4** were addressed accordingly. Based on this evaluation, the outlook describes further research directions from the underlying research initiative.

6.1 Conclusion

The motivation of the thesis and the research need resulted from the discrepancy between the increasing diffusion of XR technologies, their economic potential, the opposing scientific maturity level, and the slow adoption of XR technologies. This discrepancy of technological and economic potential was supposed to be resolved by identifying, analyzing, and ensuring technological usefulness (Davis 1989). The usefulness was defined for this work as economic value added for a company. A technology provides added value in the context of a business model, especially in value creation. This led to the research goals of developing a methodology for a holistic deployment that makes the complexity of XR technologies manageable, the potential added value anticipatable and realizable, and the deployment systematically executable.

For this purpose, the theoretical foundations were presented in **chapter 2**. First, the term value creation was clarified. Within the framework of a business model, value is created in the overall construct of a value chain. The value created can be either usable value for an organization in the value chain or transferable value between organizations in the value chain. Any value generation in a value chain is based on processes and resources. Second, XR and XR technologies were distinguished. XR is an umbrella term for the experiences of VR, AR, and MR. These experiences differ in terms of immersion, interaction, and intelligence, i.e., the capability of the experience to react to a user`s behavior. Regardless of the characteristics in these dimensions, all forms of experiences are generated by XR technologies, particularly hardware systems, software development methods, and content creation methods.

Based on this understanding, **chapter 3** analyzed the current research character of XR technologies in combination with value creation. This resulted in two major research streams: implementation reports and research reviews. Implementation reports have specific requirements for the XR technology and business processes and thus have limited transferability to other application scenarios. Research reviews are ex-post oriented and, therefore, also constraint transferrable to new deployment scenarios. A taxonomy was developed to identify the common deployment purposes of XR technologies in value creation to enable generic applicability. The deployment purposes of data acquisition, assistance, visualization, optimization, and collaboration were identified by analyzing the technologies' tasks, independent from given business processes or industry characteristics.

Additionally, **chapter 3** analyzed existing methodologies to deploy XR technologies in value creation. The methodologies identified were either business-oriented, focusing on the monetary impact of cost and profit, or deployment-oriented, focusing on implementing XR technologies in a given context. Additionally, with XR technologies being part of IS, methodologies with a more generic technological scope from related technologies were analyzed. However, none of the analyzed methodologies provided a sufficient approach regarding the research objectives fulfilling both the technological comprehensiveness and integrity and the value-oriented deployment execution.

Chapter 4 transferred the identified research gaps and objectives into methodology requirements. Next to the general applicability and agile execution, the methodology is supposed to focus on the future state of the targeted value creation. The XR technologies described in **chapter 2.4** and the deployment purposes described in **chapter 3.2** were aggregated in a morphology of XR technologies depicting the complex field with a sufficient technological focus and a structure to manage the complexity. Additionally, the value creation reference model was defined to represent any value creation for the XR technology deployment. The reference model comprises an existing value potential in the value creation. This is referred to as a potential case, i.e., a use case for applying XR technologies with a potential value added. This potential case exists for a value chain composed of value streams and processes. The value chain is operated by a network of value creation partners and uses physical, human, and digital resources to generate value. The result of the deployment is a value-added, which in addition to value in use and value in transfer, can also be value in the experience. The XR technology deployment itself goes through a sequence of development stages. In the process, the identified potential case evolves into requirements, which are transformed into a prototype. This prototype is iteratively developed into a PoC and a PoV through collected feedback and reaches the state of an XR technology solution through economic viability.

The methodology of **chapter 4** consists of six steps to execute the deployment, while each step can be iterated based on the execution process. The identification phase utilizes the XR technology deployment purposes to deliver a potential case from a pain point analysis, a best practice, or a technological innovation. The potential case is then transferred into requirements through an analysis phase by capturing user, system, and business requirements with respective methods. In the initiation phase, a prototype is developed through initial setup, design, and development efforts. Within the iterative utilization phase, the prototype is deployed in the targeted value creation process in dedicated testing phases with varying scopes and technological affinity of target users. Each testing phase delivers feedback to mature the prototype to an XR technology solution. After achieving the solution status, the XR technology is implemented in the business process with further development efforts, as well as with the acquisition of required resources for the operation of the XR solution. After the implementation, the XR solution is integrated into the whole value creation either vertically, i.e., adaptions towards the business process design, or horizontally, i.e., through providing the XR solution across the value creation network.

Chapter 5 presents the application of the methodology under real economic conditions. Two application scenarios from two different industries with different forms of XR are used to demonstrate the universal applicability. Potential case 1 is deployed in an engineering context and demonstrates the use of XR to visualize complex planning processes and improve communication between engineering and customers. Potential case 2 presents how the planning process in the proposal phase of a construction project can be leveraged by the AR capability of a COTS device for data acquisition. Both potential cases were transferred into an XR solution and possess several scaling potentials depending on the planned integration direction in the value creation.

6.2 Outlook

To conclude this thesis and provide further research directions, it must be emphasized how the established methodology achieved the research objectives defined in **chapter 1.2** and to what extent the research gaps from **chapter 3.4** were addressed. Table 6.1 presents the context of the research objectives, the research questions, and the content from the contributing chapters.

Table 6.1: Contribution to research objectives and research gaps

Research objectives	Contributions of the chapters
Main objective: Holistic methodology	• Chapter 2.1: Value, Value Creation, Value Chains • Chapter 2.3: XR terminology • Chapter 4.2: Generic value creation reference model • Chapter 4.2: Deployment sequence

RQ1: How can the comprehensive field of XR technologies be holistically described to enable a successful deployment without affecting it through the underlying complexity?	
Research objective 1: Management of technological complexity	• Chapter 2.4: XR technology characteristics of hardware systems, software development, and content creation • Chapter 3.2: Taxonomy for XR technology deployment purposes • Chapter 4.2: XR technology morphology with purpose and business context integration
RQ2: How can a value-adding deployment initiative of an XR technology in value creation be methodologically identified?	
Research objective 2: Determination of potential value added	• Chapter 2.1: Value in use and Value in transfer • Chapter 4.2: Value in Experience • Chapter 4.3: Identification of potential case through pain points, best practices, or innovation • Chapter 4.4: Business analysis • Chapter 4.7.2: Business re-assessment • Chapter 4.8: Integration
RQ 3: How can a sequential approach be designed for the deployment of XR technologies in the dimensions of technology configuration, value generation, and user orientation?	
Research objective 3: Systematic execution	• Chapter 3.3: Methodologies for XR technology deployment • Chapter 4.2: Deployment sequence • Chapter 4.3: Deployment stakeholder integration • Chapter 4.3 - 4.8: Methodological steps • Chapter 4.6: User-oriented testing phases • Chapter 4.7.1: Agile software further development
Practical applicability	• Chapter 5: Real economic application scenarios

The overall goal of developing a universal methodology was pursued by establishing the context of XR technologies to the value creation of generic business models. It was demonstrated that XR technologies in different forms have the same deployment purposes in different industries. For a systematic extension of this solution-oriented approach, it would be useful to analyze the context between the forms of XR and the deployment purposes. In this context, not only the different XR experiences should be analyzed, but also the different levels of the dimensions of immersion, interactivity, and intelligence of the XR setup should be classified. The extent to which the deployment purposes can be fulfilled is then to be connected to the different criteria of XR experiences. For example, an XR technology deployment for purely capturing environmental data may only require a low level of immersion.

The goal of making technological complexity manageable was addressed by differentiating XR technologies by hardware systems, software development, and content creation. The structured representation of the technologies was established according to the characteristics of the XR experience as well as the required assets for operation. This enables a coordinated acquisition, definition, and implementation of the deployment. However, the underlying complexity of XR technologies also creates synergy potential between the XR technologies and the experiences to be generated. Therefore, the deployment of multi-technology platforms in the context of business models should be investigated for an economical deployment to address a broader spectrum of users. In addition, it should be investigated how simplification can be achieved through standardization and, if necessary, automation of the development and operation of XR technologies.

The goal of adding value through the deployment was addressed by defining and investigating on the three value categories: value in use, value in transfer, and value in experience. In addition, the costs incurred by the development, operation, and scaling of the XR technologies are considered throughout the deployment steps. In the next step, a quantification of the costs as well as the added values should be empirically examined. With well-founded calculation and prediction models of the economic viability in the value categories with the consideration of long-term effects, deployment stakeholders can be convinced easier. In addition, the present focus of the methodology on economic added value could be expanded to include the classification and quantification of other added values, for example, regarding social and sustainable aspects.

The deployment steps presented a systematic procedure for the execution of the deployment of XR technologies, which also fulfills the requirements of user-centricity and agility. In return to the focus on deployment in an existing business model, it could also be investigated according to which design principles business models can be developed to favor the use of XR technologies. In addition to value creation, the value proposition should be addressed. This could be used to define added value for customers based on XR technologies, which would encourage technological deployment through emerging market needs and potentials.

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