Requirements Elicitation for Virtual Reality Products - A Mapping Study

Sai Anirudh Karre
Software Engineering Research Center
IIIT Hyderabad, India
saianirudh.karri@research.iiit.ac.in

Raghav Mittal
Software Engineering Research Center
IIIT Hyderabad, India
raghav.mittal@research.iiit.ac.in

Y. Raghu Reddy
Software Engineering Research Center
IIIT Hyderabad, India
raghu.reddy@iiit.ac.in

ABSTRACT

Software practitioners use various requirement elicitation methods to produce a well-defined product. These methods impact the software product's eventual traits and target a particular audience segment. Virtual Reality(VR) products are no different from this influence. With the notable rise in product offerings across various domains, VR has become an essential technology for the future. Nevertheless, the type of methods practiced for requirement elicitation still has not been thoroughly studied. This paper presents a mapping study on requirement elicitation methods practiced by VR practitioners in academia and industry. We consolidated our observations based on their popularity in the practitioner community. Further, we present our insights on the necessary and sufficient conditions to conduct VR requirement elicitation using the identified methods to benefit the VR practitioner community.

CCS CONCEPTS

• Software and its engineering → Software development techniques; **Requirements analysis**;

KEYWORDS

Software requirements; Requirement elicitation; Virtual Reality; Industrial practices

ACM Reference Format:
Sai Anirudh Karre, Raghav Mittal, and Y. Raghu Reddy. 2023. Requirements Elicitation for Virtual Reality Products - A Mapping Study. In *Proceedings of 16th Innovations in Software Engineering Conference (ISEC '23).* Prayagraj, Uttar Pradesh, India, 11 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 MOTIVATION

Virtual Reality Products have been developed (in part) as instruction and intervention-oriented systems in the past three decades. Space training simulation, training for complicated surgeries, rehabilitation programs, multi-layered data visualization, and construction are a few examples of VR products. With recent advancements in Head-Mounted Devices (HMDs), VR products are being used in various domains. It has become a medium for simplifying complicated tasks, helping stakeholders comprehend complex responsibilities [32]. VR is considered one of the Strategic Technology Trends [18] of this decade. It is meant to guide organizations to focus on using this technology to address digital use cases that are otherwise difficult to comprehend.

Is VR software product development different? - The number of applications built using VR is increasing yearly. However, there isn't any peer-reviewed comprehensive study on the practices and methods followed by the VR developer ecosystem while building VR Products, especially in the enterprise domain. Previous studies have shown that most of the VR Practitioners are from the gaming industry and the Visual Effects industry [1] and primarily rely on Game-Development processes to build VR Products. A recent empirical study on the VR Industry [36] shows significantly low adoption of core Software Engineering practices in real-world VR Product development. One such approach is '*Requirement Engineering*,' - an essential phase of the Software Development process. It was observed that the current VR developers use novice methods for capturing complex requirements for a VR scene. The competitive race for quick product release drives many companies to find new ways to deliver software. This is true for VR software products too.

Does rigorous requirement elicitation matter for VR? - A typical VR Scene revolves around the various attributes like Design flow, Control Flow, Event Flow of the object(s) or asset(s) in the Scene, Acoustics, Physics, Color, Terrain, Response, and reflexes of the participants. The complexity of the VR Scene can be correlated with the increase in length and usage of these attributes. Such attributes have to be considered to elicit the requirements of any given VR Scene. However, a recent empirical study shows that VR Practitioners don't have sufficient tool support. They capture requirements in plain English or use non-sophisticated methods like the Task-Tree method and the Event-Action method with reduced precision [36]. Although capturing requirements in such simple ways isn't inappropriate, it is desirable if clear guidelines, templates and traceability mechanisms can be established to track the changes. Practices that require manually intensive efforts degrade the quality of the VR Scene and eventually increase the delivery cost due to loss of information during the requirements analysis process. These observations motivated us to conduct a literature mapping study to understand the requirement elicitation practices adopted by VR practitioners while developing Virtual Reality Products.

ISEC '23, 25 - 27 February, 2023, Prayagraj, Uttar Pradesh, India

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM.
https://doi.org/10.1145/nnnnnnn.nnnnnnn

The rest of the paper is organized as follows: Our observations on related work is captured in Section 2. The systematic mapping study is covered as part of Section 3. The results from the study and our observations are shown in Section 4. Considering the observations, we provide our insights on bare minimum attributes in Section 5 to conduct requirement elicitation using the identified methods for practitioner adoption. In Section 6, we discuss threats to validity. In Section 7, we provide some conclusions and chart our future research plan.

2 RELATED WORK

Requirement Engineering help define the scope of product features in a piece of software to a large extent. Requirements gathering and analysis are still considered a challenging activity for mainstream software products [56]. Over the years, advancements in requirement engineering have enabled the development of processes wherein systematic elicitation techniques are used rather than ad-hoc requirements gathering methods. While researchers have written about the need to move from "gathering" to eliciting requirements, Jaramillo et al. [31] were the first to conduct an extensive systematic literature review on requirement elicitation methods practised on mainstream software products. The study covered research papers spanning 25 years. In the study, the authors claim that the results remain relevant even now in understanding the state of the art in Requirements Engineering. Their work provided insights into various perspectives of requirements to be considered for mainstream software products. However, the work did not refer to methods specific to VR software products.

Karakostas et al. [42] have articulated various aspects of Requirement Engineering (RE) like Requirement Elicitation, Requirement Analysis, Requirement Specification, Requirement Validation, and Requirement Management. They provided a clear distinction on what Requirement Engineering should focus on any given technology. Vegendla et al. have conducted a Systematic Mapping Study on RE in various Software Ecosystems [69]. They recorded all possible methods practised in the software ecosystem. Pacheco et al. have studied the maturity of RE methods in traditional software products [30]. Both studies help understand the potential usage and maturity of existing techniques on conventional software but not in the VR domain. Sufian et al. conducted a large-scale survey of software requirements prioritization Techniques [67] for mainstream software products. They found various prioritization techniques and tools used as part of the requirements gathering process. One of the objectives of that study was to identify tools & techniques that new researchers in the area can use. However, the work was generic, just like Jaramillo et al.'s [31].

Santos et al. were the first to conduct a systematic literature review on consolidating existing evidence regarding the use of Requirement Engineering for Virtual Reality systems and studied Virtual Reality contributions to the Requirement Engineering process [14]. Their results indicate the deficiency of studies that show the use of the RE process for VR systems because this process must occur according to the technological peculiarities of VR systems [14]. Their conclusions are based on a small dataset. Thus this area of research requires a deep-dive analysis to understand the reality of usage of RE, and specifically the requirements elicitation in VR Systems.

3 MAPPING STUDY

In this section, we discuss the mapping study process including search strategy, search string, databases, exclusion & inclusion criteria, paper selection, and data extraction.

3.1 Research Questions

The Systematic Mapping Study described in this paper uses the guidelines suggested by Petersen et al. [53] in conjunction with PICOC method [4]. PICOC (Population, Intervention, Comparison, Outcome, and Context) can be used to define the scope and context among reviewers who conduct an investigation. The general notions of the PICOC method applied to our research are shown in Table 1. The method also helped construct the research questions for our mapping study. Below are our research questions:

R1: *What are the requirement elicitation methods practiced while building VR Product(s)/app(s)?*
R2: *Is requirement elicitation method usage for VR product(s)/app(s) maturing over time?*
R3: *Are there any requirement elicitation methods for VR used based on field of Interest?*

Research question R1 was formulated to explore the requirement engineering methods adopted as part of various stages of VR product development requirements. Unlike Santos et al. [14], whose observations are focused on a limited dataset, we intended to explore this across various databases. Here *"Requirement Engineering"* constitutes requirement elicitation, Requirement Analysis, Requirement Specification, Requirement Validation, and Requirement Management, as articulated by Karakostas et al. [42]. However, as part of this paper - our search strategy only focuses on ***'Requirements Elicitation'***.

Research question R2, *"maturity"* for a Requirement Elicitation method is meant to signify widely used and accepted method over time by a wide range of VR practitioners. In this study, the scope of the question spans the highly used Requirement Elicitation method(s) across various VR products. Research question R3 considers the adoption of Requirement Elicitation methods in the respective field of interest. Here the *"field of interest"* is interpreted as a class or a domain of products that fall under industry type. It is to understand if the RE methods vary across industry types.

3.2 Search Strategy

An important part of mapping study is the identification of keywords. More often than not, this tends to be an iterative process. The research questions - R1, R2, and R3 are relative and have a shared query set. Thus, a common search string could be constructed for all the research questions. The search strategy was set to identify studies describing at least one requirement engineering elicitation method applied to a VR Software Product or a Prototype.

Search String: We deduced search strings with notions defined as

Table 1: PICOC method applied to our study

Criterion	Description
Population	Virtual Reality related products and applications
Intervention	Requirement Elicitation Methods
Comparison	Comparison between the results captured in various RE Studies
Outcome	Studies where RE methods applied to VR product and apps
Context	Academia, Software Industry and Other published empirical Studies

per the PICOC method [4]. The search string is given below:

C1: "VR" **OR** "Virtual Reality*"

C2: "Requirement Elicitation" **OR** "Software Requirement*" **OR** "Requirement Engineering" **OR** "Requirement Management" **OR** "Requirement process" **OR** "Requirement Evaluation" **OR** "Functional Requirement" **OR** "Non-Functional Requirement"

'*C1*'**AND** '*C2*' is the resultant search string formulated for research questions *R1*, *R2* and *R3*

Given the focus on VR, ***C1*** considers the possible variants of Virtual Reality keyword. Requirement Engineering domain is the core of our study; thus, all likely keywords regarding requirements were considered. Our initial version of the ***C2*** query string contained 'Requirement' as one of the keywords. We had to remove it as it returned too many unrelated papers that were not relevant to our study. We had to narrow it down as per RE process definitions [42]. Given VR technology is relatively recent, we did not consider publication year as a filter limit as part of the search string. Compared to earlier study, this gave us an an open-ended dataset. Multi-level analysis [38], i.e., systematic review and finalization of the search string for trends in the Virtual Reality research area was conducted. We considered only papers that talk about requirement elicitation methods to develop a VR product with significant reasoning about the dimensions of the product.

Search Quality Assessment: We followed Kitchenham et al. [38] principles on formulating and finalizing the search string. We developed a search string first, reviewed it with peer researchers from our research center, and mapping study research group. The peer-review approach [38] helped us revise the search string closer to our research questions. A critical review of the search string by fellow researchers from the VR domain helps identify an efficient search string. The authors of this paper have independently conducted the search activity after finalizing the search string, and the results were independently recorded. This activity helped us address search filtration biases. The String search was conducted against a research paper's attributes like abstract, contents of the paper, title, and keywords. Further filtration was performed on these attributes to avoid unmatched research papers. Our supplement data which has collections of our gathered papers is available here [3].

3.3 Databases and Paper Selection

The study considered published research papers until August 2022. Major electronic research databases - IEEE Xplore, ACM Digital Library, Springer, and Science Direct were used for conducting the search. The dataset includes special edition journals, articles, industry talks, and prototypes, etc. Grey Literature i.e., research that is either unpublished or has been published in the non-commercial form (example - Policy documents, standards, etc.), were omitted. We focused only on active research publications. There were no additional filters placed on these databases. The database included publications of indexed journals, conference proceedings, review papers, workshop proceedings, late-breaking works, industry track papers, and companion proceedings. The search order performed on the databases returned most of the results. The search fields and search string were formulated to ensure that the search process was similar across all the electronic research databases.

Exclusion Criteria - Articles with unnecessary information about requirement engineering, topics related to the description of requirement engineering or industry white papers were excluded. Articles with sparse details about the requirement elicitation method and with no related study setup on VR Products were ignored. Papers that did not mention anything about the requirements of the VR product built as part of their research were also not considered. Books were not included as part of this study.

Inclusion Criteria - Papers that proposed or revised or discussed requirement engineering method(s) and approach(s) were considered as part of our study. A equal match of the search keywords against title, abstract, keywords, or some part of the paper was also considered. The paper consists of the study conducted in Academia or on an Enterprise Product was given primary consideration. All papers were included immaterial of the publication date. Papers published only in English language were considered.

3.4 Data Extraction

We followed the data extraction protocol proposed by Kitchenham et al. [38]. Attributes like Paper UniqueID, Paper Type (Journal/-Conference/Review Article), Author(s), Editor(s), Title of the paper, Pages, keywords, DOI, year of publication, ISBN, Publisher, Extraction date, and Type of DataSource are extracted for each paper. As part of data extraction, the search string rendered ***1771*** research papers across all the databases (*Springer – 111, ACM – 80, IEEE – 1377, ScienceDirect – 203*). After conducting the first-level review, we excluded the content types as mentioned below. Book chapters, conference proceedings, conference articles, early-access-research papers were considered for review. Full-length journal proceedings were included as part of Journals. Newsletters, editorials, press notes, magazine articles were excluded from the study as they didn't contain enough literature for our research. Reports were excluded from the study as they have vague details about the practice of requirement engineering methods. Books were excluded from the study as they are too comprehensive for a mapping study and are likely candidates for literature review rather than mapping study. After the exclusion, the search dataset contained ***638*** research papers from all databases. We applied the exclusion and inclusion criteria over these research papers. We were able to filter them to ***210*** research papers, which hold good for our literature review. Based on further examination, ***60*** research papers were found to have discussed at least one requirement elicitation approach or method with a reasonable explanation. Table 2 provides details of these concluded research papers. All the search strings from various databases and the review data dump is available as part of our mapping study resources [3].

4 DISCUSSION

Based on our literature study, we ensured that each paper reviewed had some aspect of eliciting requirements for the product or prototypes. We excluded papers where there was no clarity or reference to requirement elicitation methods and its implications towards the built product. As part of the study, we came across papers from both academia and Industry. In both cases, the VR practitioners followed various requirement elicitation methods. They attempted to bring out the intent of their research by identifying the requirements for their product(s) or prototype(s). In this section, we discuss our observations in three parts - types of methods identified, trend identified per particular method over the years and methods specific to a type of Industry as the responses to our research questions.

R1: *What are the requirement elicitation methods practiced while building VR Product(s)/app(s)?*

As part of our observations to *R1*, we categorize our observations into four different themes - *Widely used approaches, Focused approaches, Customized approaches, Unique approaches.* These themes are categorized based on our analysis of literature and the nature of usage/implementation of the requirement elicitation methods used to develop a VR product or a prototype. It is to provide clarity on interpreting the technique based on usage.

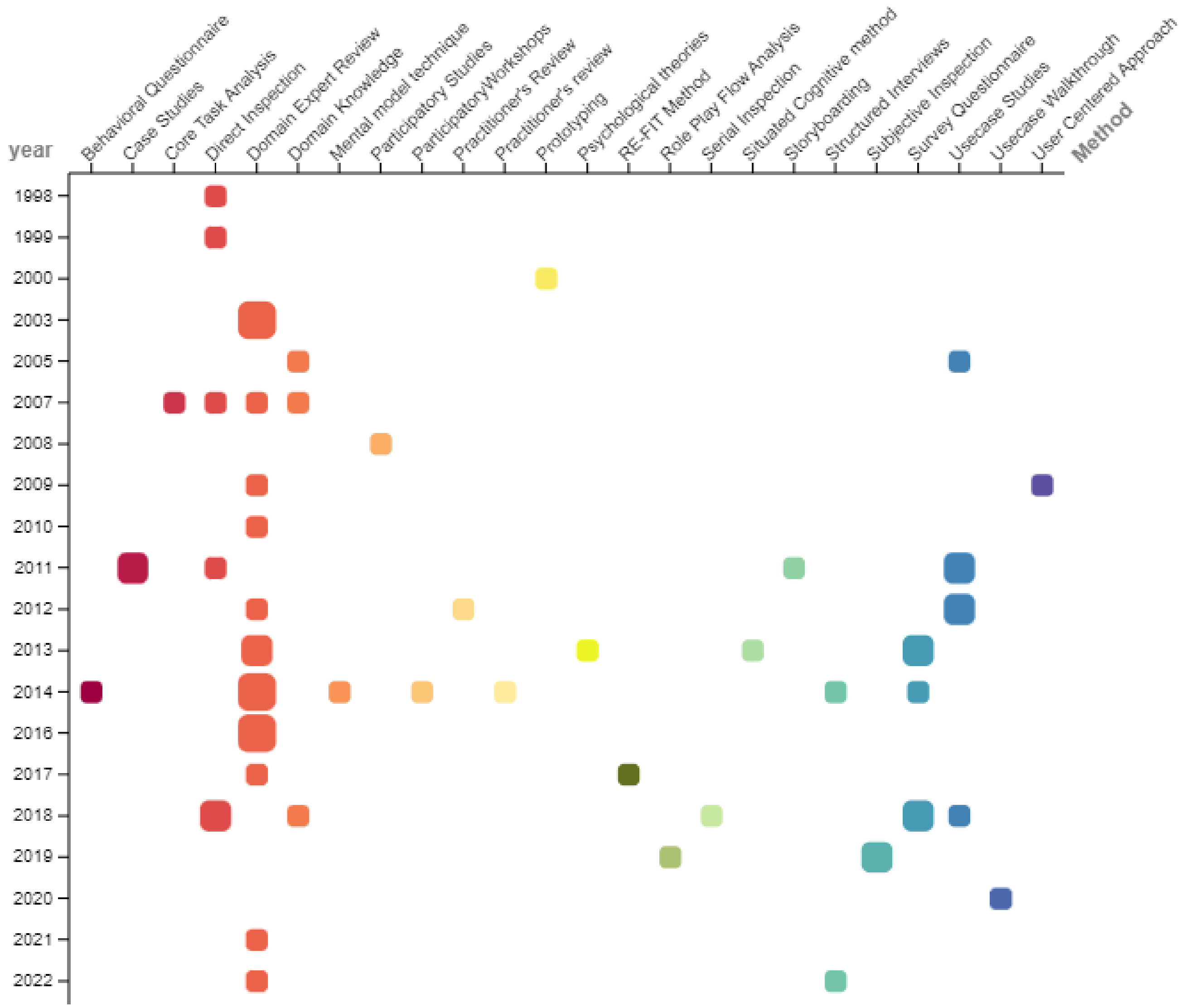
Widely used approaches - In the instances where VR practitioners are not aware of the initial product design or have very limited knowledge about the VR product, *'Direct Inspection'* approach was found to have broad acceptance across all the domains. It is because of its simplicity and provides power to the requirement analyst to figure out the requirements by themselves. At such a stage of product development with no clear way forward, requirements are determined based on the potential interests of the end-users. No other structured approaches are followed by the practitioners to record and formulate the initial requirements in these cases. Few of the use-cases include - building collaborative design apps using VR for better Design [62], building user-centered data visualization in VR [9] for personalized view, simulation-based evaluation of user interfaces in automotive industry [54] for multi-user and multi-task assistance, implementing as second-life virtual world platform for effective human interaction [33] for addressing social phobias, haptics based editor for designing immersive experiences in VR [16] and NASA's simulation-based ground test and protocol analysis tool for spacecrafts [21].

In almost all the domain-specific applications, VR practitioners seek inputs from *'Domain Experts Review'*, more so in health care based VR apps. Simulation-based medical planner for patients with cardiovascular disease [65], Training medical practitioners on conducting minimal invasive abdominal cancer surgery [76], educating surgeons about endoscopic surgery using simulation-based methods [78], training dental practitioners on addressing dental anesthesia [13], implementation of patient-specific cognitive engine for robotic needle insertion during surgeries [68], conducting eye-tracking based evaluation techniques for nursing professional to treat pediatric patients [52], Spinal Cord Injury re-hab [35], Care ecosystem for ADHD patients [66] etc. require domain experts to be a part of the development process. Other prototypes included implementation of JET remote handling operations [58], virtual training systems for Industry workers [49], Game-based education on Safety for Industries [34], facilitating building model adoption in construction industry [22], AR-based application for controlling resources on construction projects [37], developing a visual inspection system for an in-vessel robot in spaceships [72], motion-based games for building physiotherapy applications [51], improving social skills in autistic children [5]. Studies on domain expert reviews required in case of entertainment applications include implementation of virtual Indonesian musical instrument [26] and developing a 3D city model for real-estate market development [59] and VR Tour Guiding [43]. A likert based questionnaire is used to prioritize the need for a feature in a VR based training tool called MediTool [44]. User feedback is captured by providing 2D and 3D based training setup to understand the impact of VR based training on medical surgeons. VR Cycling Scenes are developed to use them as part of an empirical field study on understanding the physical environmental factors related to cycling in older adults [40]. Practitioner's reviews were captured to develop the flow of the cycling scene to ensure that they are relevant to the context of cycling.

'Survey Questionnaire' is another requirement elicitation approach that was preferred by VR practitioners. The use-cases include luxury brand virtual shopping [2] with diverse options for selection as features, building virtual worlds for personalized data and process visualization [25], understanding human emotional responses concerning arousal and valence [20], providing virtual experiences through social VR [24], understanding students' perspectives on mixed reality in higher education [75] are few of the research prototypes that followed survey-based questionnaire approach. The above observed are widely used approaches across the existing literature.

Focused approaches - VR practitioners use existing *'Domain Knowledge'* while formulating requirements. Enhancing UML modeling using VR [7], developing a structured teaching system using virtual platforms [63] and building location-based services for virtual college campus tour [73] are the research works where VR practitioners have relied on existing domain knowledge. In [48], authors discuss a VR based simulator for Training for Railway Wagons maintenance. Domain experts played a key role on providing support towards design and architecture of the simulator. While solving real-world problems, VR practitioners have relied on the *'Practitioner's Studies'* or literature of existing practitioners. They include a therapy system for arm and hand rehabilitation [55], Building a haptic based dental simulator and its related patient examination system [71], examining multi-modal interactions for foot reflexology [12]. Practitioner's Studies widely preferred for use-cases

Figure 1: Yearly Trend of Requirement Elicitation method maturation



where protocols and standards are involved. If a VR product should abide by any standard, it is significant to consider a practitioner's studies. In cases where VR practitioners required a steady understanding of the requirements, they tend to follow the *'Subjective Inspection'* approach. Software Development Process Education [23], Therapy for overcoming Glossophobia or fear of public speaking [28] and building a haptic feedback system for assessing wrist motor functions for patients with upper motor neuron lesions [41] are the cases where this approach practiced.

VR practitioners follow *'User Case Studies'* in cases where VR applications required user-centered observations. VR practitioners built novel solutions for large scale collaborative VR environment simulations [8], multi-user VR environments [29], social interaction using ubiquitous virtual environments [39], developing ontologies for real-time interactive systems [74], developing virtual class service using a predefined SERVQUAL methodology [17], Edge Computing based Human Behaviour Recognition System [64] building intelligent systems for virtual roaming [11] and user-centered design for facial surgery training [45]. All such cases required focused understanding about users and their behavior in a virtual environment.

Customized Approaches - For instances where VR practitioners had to build a common solution for a large scale problem, they formulated customized approaches to address complex requirements. *'Case Studies'* based approach helped VR practitioners to understand the complexities behind the end-user demands, and the captured observations are customized to address the product needs. Virtual Negotiation Training application [10], Designing a game-based interactive stroke rehabilitation system [27] followed case study based approach. Our study observed other minor approaches apart from the above methods. *'Situated Cognitive method'* used to study the social conventions on learning for non-natives and low literates [61]. *'Participatory Workshops'* approach was used to develop serious games for providing and promoting healthy habits in the northeastern Brazilian countryside [15]. For heuristic evaluation of virtual museum *'Structured Interviews'* are conducted from end-users via smartphone [47]. *'Behavioral Questionnaire'* used as an approach to examining the participants to construct requirements for studying therapy for a sense of presence and meta-cognition to VR exposure of Social Phobias and Fear of Flying [50]. *'Role Play Flow Analysis'* approach used while developing a role-play game-based app for a virtual environment. These custom approaches are developed and practiced by VR practitioners to address the important requirement needs of VR products.

Unique Approaches As part of our study, we found that in a few cases, VR practitioners have followed unconventional methods to meet their requirements. While building virtual actors for a collaborative learning environment, practitioners have followed the rapid *'Prototype'* approach to address frequent changes in requirements [19]. It helped them to address dynamic requirements and enhance the prototype in a timely fashion. Another approach called *'Core Task Analysis'* was adopted while developing a mobile augmented reality tool for maintenance work [60]. A method like this can help developers drill down the necessary features based on the tasks defined in the application. VR developers can easily correlate the intent and motive behind a defined task while building the VR product. *'Story boarding'* method followed while building training systems for bridging gaps between end-users and developers in Software Development ecosystem [57]. It provided an end-to-end flow of responsibilities for every task in a VR product. A method like *'Psychological theories'* was adopted for developing a virtual environment for early diagnosis of dementia patients [70]. It follows a steady and thorough multilevel process to capture requirements before finalizing a feature. *'Mental model technique'* is another approach used to construct an image-based spatial presence of virtual experience [46]. Requirements are generated based on the tailored metal model defined per participant. A customized approach called *'RE-FIT method'* was formulated by Bhimani et al. [6] using virtual experience for empowering people with special needs. This approach steadily captures the requirement and correlates with the needs of the end-user. All these methods seem to be unique as the VR practitioners have used these methods on use cases which are uncommon when compared with traditional approaches.

Table 2 provide us details about the requirement elicitation method and its related reference mapped by type of Industry or Domain along with the details of the product/prototype built by the VR practitioners.

***R2:** Is requirement elicitation method usage for VR product(s)/app(s) maturing over time?*

Our observations to *R2* are divided into the following themes - *Traditional Practices, Shift in Approach, and Scope for Automation.* We argue our consolidated findings under these themes for clarity.

Traditional Practices - Fig 1 describes the yearly trend of requirement elicitation methods practiced by VR practitioners. Based on the available data, we observe that the requirement elicitation adoption in VR actively started in the last decade by practicing simple approaches like *'Direct Inspection'*, *'Prototyping'* and *'Use case Studies'*. *'Direct Inspection'* is widely used to date in VR products which are novel in design and idea. To be specific, researchers conducted a direct inspection to determine the value of the product scope for target users and then formulated constraints of the product idea by not implementing any specified techniques to build an early prototype version of VR products. Most early VR products are highly focused on a specified need or activity, which might not make VR practitioners think about novel approaches while capturing requirements. Early VR apps for collaborative design-based VR environments [62] and User-centered data visualization [9] are no longer usable as these VR apps are highly sophisticated and dependent on customized external hardware for generating immersive experience to the end-users. The value of VR simulation gained prominence in the healthcare industry, leading VR practitioners to adopt *'Domain Expert Reviews'* as a new approach to gathering requirements to build simple applications for healthcare practitioners.

Shift in Approach - With the advent of simplified hardware for VR, new VR applications have emerged in the latter parts of the last decade. We see a shift in new requirement elicitation methods while building VR applications. There is a rise in domain-specific applications where VR practitioners have started adopting *'Domain Expert Reviews'* as a means of addressing domain-specific problems. It has significantly become important for VR practitioners to interact with real-world practitioners to gather and correlate their gathered requirements with real-world scenarios. With the rise in addressing complex problems through VR, VR practitioners have built customized approaches to meet the requirement needs of the target audiences of the respective VR application. *'Situated Cognitive method'* and *'RE-FIT Method'* are two good examples where the developers have to establish a new approach to gather data and have finalized their requirements.

Other novel methods include *'Participatory Workshops'*, *'Role Play Flow Analysis'* for multi-user applications, and *'Core Task Analysis'* for task-based applications with complex actions are recommended for VR developers to adopt. Most remarkably, methods like *'Psychological theories'* recorded by domain practitioners and *'Mental model technique'* supports VR developers to develop better User-centered social or personalized VR applications in the future.

Interestingly, neither an automated nor semi-automated approach was observed as part of prevailing practices in the VR development ecosystem. VR practitioners do not seem to be using automated approaches as part of their requirement elicitation process. Most of the current VR applications are facing below challenges regarding requirement gathering.

- It is not easy to document VR-specific requirements as the semantics of VR product development when compared with traditional Software products are different.
- VR practitioners cannot identify or capture inter-related and inter-dependent requirements at the early stages of VR product development.
- None of the practical requirement elicitation methods supports the incremental review and validation of requirements. VR practitioners have to make a fresh start when gathering or updating requirements during the open-ended VR development process.
- It is already observed that VR product development turns out to be too costlier if there are frequent changes to requirements or the design aspects of VR products [36]. VR practitioners are in great need of a process or method that could address such development challenges.

R3: *Are there any requirement elicitation methods for VR used based on field of interest?*

Table 2 provides an abstract categorization of elicitation methods practiced by the Industry grouped by domains. We have classified the identified research works into potential domains like *'Design'* - for product owners and developers, *'Analytics'* for data visualization, *'Education'* - for both social learning and technical education, *'Health care'* that includes VR applications build for physiotherapy, general medicine, surgeries, and rehabilitation; *'Space'* industry for vessel inspection, simulation studies, and training; *'Automotive'* and the *'Construction'* industry for safety regulation and quality control; *'Entertainment'* and *'Social'* Industries for respective business centered applications.

As per our study, we observed that the Healthcare domain seems to be an early adopter of utilizing VR-based applications to address complex problems. These problems involve training activities, simulation-based surgery studies, rehabilitation practices, medication planning, and treatment planning. To handle such strenuous activities through VR, practitioners have adopted the *'Domain Expert Review'* method as the best fit in most cases. In a few cases, they had to rely on *'Practitioner's Reviews'* and respective theories to capture requirements and develop the product. One reason for choosing such a focused approach could be the real-world implications of these products on end-users. In general, almost all the domain-specific tasks are well managed by experts from the respective fields. Thus involving such experts as part of requirement elicitation will yield better results and pave a path for a robust VR product. Other methods like *Case Studies*, *RE-FIT method*, and *Psychological theories* are also employed, which have distinct features and offerings. Distinctively, most health care applications appear to address focused problems involving much effort from requirement analysts.

Products built for the social network domain widely rely on *questionnaire-based* requirement studies. These questionnaires were subjective and objective in structure. They are designed to capture the target-user understanding in detail and help the VR practitioners to prioritize and plan the feature after every release. Entertainment, Design, and other minor domains followed various questionnaire-based requirement elicitation methods. Education is one unique domain that adopted processes like *Core Task Analysis* and *Situated Cognition method* to build VR-based educational products. These methods are structured and iterative in their setup. This aids requirement analysts in conducting requirement studies after every release or enhancement to the existing product. *Core Task Analysis* approach appears to be an ideal method for VR applications requiring frequent requirements changes. It also decreases the cost of analysis as this method has the flexibility to capture the understanding of change in specification.

5 BARE-MINIMUM ATTRIBUTES FOR VR ELICITATION

Considering the elicitation methods in practice by VR practitioners, we illustrate the necessary and sufficient attributes required to conduct requirement elicitation for VR product development. It is desired to have at least a hypothetical idea of the following attributes during elicitation. The detailed specification of these attributes can be further extrapolated during the requirement specification stage. The following are the bare-minimum attributes deduced heuristically using the ***abductive reasoning*** approach for conducting basic requirement elicitation of VR Products.

- **Scene Properties**: Capturing the 3D environment properties is key for any VR product. It is required to understand the dimensions, degree-of-freedom, and boundaries of the play area of a 3D environment from the respective stakeholders. For example, a VR therapy product for overcoming Glossophobia or fear of public speaking [28] can be offered in different variants. The VR practitioners should understand the scope and degree of the scene to deliver potential layouts considering the requirement.
- **Article**s: These are the assets or objects of a 3D environment that play a significant role in the interaction. For example, a VR training product for facial surgery requires specific medical hand-held tools to interact with the persona in the scene. VR practitioners should be able to record and co-relate the intent and usage of these tools for executing a surgery training scene.
- **Action-Responses**: VR practitioners must research the possible actions between the articles and participants in a scene and their potential responses to one another. These action responses between the available articles in a VR scene could be synchronous and asynchronous. This defines the behavior of an article in a given scene. For example, a VR product for early diagnosis of dementia patients [70] requires a careful understanding of the articles and dementia participant traits to address the diagosis. The interactions of such participants could be sensitive and discreet.
- **Acoustics**: audio is a vital attribute of a 3D Environment that defines the authentic aesthetics of a scene. It provides an advantage to the scene while addressing the intent of the scene. For example, a VR Tour guiding product [43] aims to provide the remote aesthetics of a tour. The acoustic effects of a tour, monument, or place will elevate the participant's experience in such a VR scene. VR practitioners should obtain an abstract view of such acoustic effects while working with the stakeholders during the elicitation.

The above-defined bare-minimum set of attributes is inevitable and necessary for the elicitation process for VR products. All other attributes can be considered add-ons and may add more richness to the VR product. The following attributes are sufficient for more transparency of a VR product at an elicitation stage.

- **Control-flow of Scene**: It is significant to register the expected journey of a scene across a timeline from the stakeholders. A constructive control flow of the overall scene will position the scope and limits of a VR product. The observed methods - Storyboarding, Role Play Flow Analysis, and Mental model technique help VR practitioners elicit the control flow of the scene to some extent. For example, a VR product that aims to construct an image-based spatial presence of virtual participant experience [46] requires eliciting the possible journey of a participant for a quality VR scene.
- **Action-flow of Articles**: Synchronous and Asynchronous flow of events in a 3D scene will help VR practitioners define the articles' timeline in a given VR scene. Article action flow is crucial to define the behavior of a scene. For example, VR products that provide massively multi-user interactions [29] require eliciting all possible action events of all the articles in the scene to generate potential response outcomes.
- **Data-flow**: Logging the data in all levels of VR scene execution is optional. However, understanding the data flow is required in the case of VR products that need to judge participants' journeys in the scene. For example, VR products that implement a patient-specific routine for robotic needle insertion during surgeries [68] require eliciting a sequence of events and their respective data points to evaluate the correctness of needle insertion.

In practice, approaches like *Domain Expert Review, Direct Inspection, Survey Questionnaire, and Use case-based Studies* are widely used for their ease of execution. It is easier and faster to conduct elicitation of a VR product using these approaches. However, it requires multiple iterations to reach precise specifications as most of the target products are domain-specific. To avoid multiple iterations, few VR practitioners have ideated customized approaches like the Situated Cognitive method, Participatory Workshops, Structured Interviews, Behavioral questionnaires, and Role Play Flow Analysis. These approaches help VR practitioners to elicit requirements briefly, eventually reaching detailed specifications of a VR product.

Almost all the identified elicitation methods are manual and human-intensive in practice. The elicitation output of experienced VR practitioners is anticipated to be more productive than a naive VR practitioner. Despite the method, the VR practitioner must be more cognizant of the overall VR technology while eliciting the requirements. Thus a human-in-a-loop may create more challenges for VR product development teams. There is an excellent scope of automation from elicitation to specification of VR requirements. None of the identified existing approaches can be scoped for automation. New tools and techniques are to be scoped for future research for better elicitation and specification of requirements to product quality VR products.

6 THREATS TO VALIDITY

As part of our study, We considered research papers only in English. We followed extensive peer review throughout the mapping study. The possibilities of a few primary studies being overlooked are limited. Our mapping study records the observations directly from the identified research papers. The study might impact factors from the outcome of research papers. They include the experience and skill set of the VR practitioner, the relevance of the method to a real-world context, the credibility of the VR product, and the hypothesis on which the VR product was developed. The subjects involved during the development of the respective VR product may differ if a different requirement elicitation method was applied. We have attempted to conduct this study under a systematic mapping search and review protocol. Results may differ if the search strategy and data extraction are renewed with a different protocol. An additional thorough meta-level literature review is required to interpolate observed methods' maturity in relevance and practice.

7 CONCLUSION

We conducted a preliminary investigation regarding requirement elicitation methods in VR prototypes or products through our mapping study. Our primary goal was to understand the current state-of-the-art practices using a requirement elicitation method by VR practitioners. Our insights include domain-specific requirement approaches for targeted users. Various requirement elicitation methods offer different strategies to build a customized VR Product for targeted businesses. Despite such variation in requirement elicitation methods, there is difficulty specifying a suitable technique for a particular domain-specific VR product. At large, we noticed a need for a generalized Requirement Specification tool or a language for better VR requirement elicitation and specification. As part of our future work, we continue to work on requirement specification tools to aid developers in building better Virtual Reality products.

ACKNOWLEDGMENTS

The authors thank our VR Domain experts from Deloitte Digital, Khronos Group, EUROVR and Academia for participating in peer review process.

REFERENCES

[1] Saiqa Aleem, Luiz Fernando Capretz, and Faheem Ahmed. 2016. Game development software engineering process life cycle: a systematic review. *Journal of Software Engineering Research and Development* 4, 1 (09 Nov 2016), 6.

[2] Samar Altarteer, Vassilis Charissis, David Harrison, and Warren Chan. 2013. Interactive Virtual Reality Shopping and the Impact in Luxury Brands. In *Virtual, Augmented and Mixed Reality. Systems and Applications*, Randall Shumaker (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 221–230.

[3] Anonymous. Last Accessed - October 2022. Mapping Study Suppliment data. (Last Accessed - October 2022). https://github.com/vranonymous/requirementsmapping

[4] Jean-François Auger. 2008. *Sociology* 42, 5 (2008), 1032–1034. http://www.jstor.org/stable/42857205

[5] Omaima Bamasak, Roa'a Braik, Hadeel Al-Tayari, Shatha Al-Harbi, Ghadeer Al-Semairi, and Malak Abu-Hnaidi. 2013. Improving Autistic Children's Social Skills Using Virtual Reality. In *Design, User Experience, and Usability. Health, Learning, Playing, Cultural, and Cross-Cultural User Experience*, Aaron Marcus (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 342–351.

[6] Aman Bhimani and Paola Spoletini. 2017. Empowering Requirements Elicitation for Populations with Special Needs by Using Virtual Reality. In *Proceedings of the SouthEast Conference* (Kennesaw, GA, USA) *(ACM SE '17)*. ACM, New York, NY, USA, 268–270. https://doi.org/10.1145/3077286.3078467

[7] Bin Zhang and Ye-sho Chen. 2005. Enhancing UML Conceptual Modeling through the Use of Virtual Reality. In *Proceedings of the 38th Annual Hawaii International Conference on System Sciences*. 11b–11b. https://doi.org/10.1109/HICSS.2005.239

[8] A. Boukerche, D. Duarte, R. Araujo, L. Andrade, and A. Zarrad. 2005. A novel solution for the development of collaborative virtual environment simulations in large scale. In *Ninth IEEE International Symposium on Distributed Simulation and Real-Time Applications*. 86–94. https://doi.org/10.1109/DISTRA.2005.5

[9] D. R. S. Boyd, J. R. Gallop, K. E. V. Palmen, R. T. Platon, and C. D. Seelig. 1999. VIVRE: User-centred visualization. In *High-Performance Computing and Networking*, Peter Sloot, Marian Bubak, Alfons Hoekstra, and Bob Hertzberger (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 807–816.

[10] Joost Broekens, Maaike Harbers, Willem-Paul Brinkman, Catholijn Jonker, Karel Van den Bosch, and John-Jules Meyer. 2011. Validity of a Virtual Negotiation Training. In *Intelligent Virtual Agents*, Hannes Högni Vilhjálmsson, Stefan Kopp, Stacy Marsella, and Kristinn R. Thórisson (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 435–436.

[11] W. Chen. 2018. Design and Analysis of An Intelligent System for Building Virtual Roaming. In *2018 International Conference on Virtual Reality and Intelligent Systems (ICVRIS)*. 26–29. https://doi.org/10.1109/ICVRIS.2018.00015

[12] O. H. Chimeremeze, S. Sulaiman, D. R. A. Rambli, and O. Foong. 2014. Multimodal interactions in traditional foot reflexology. In *2014 International Conference on Computer and Information Sciences (ICCOINS)*. 1–6. https://doi.org/10.1109/ICCOINS.2014.6868428

[13] Cléber G. Corrêa, Fátima de Lourdes dos Santos Nunes, and Romero Tori. 2014. Virtual Reality-Based System for Training in Dental Anesthesia. In *Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality*, Randall Shumaker and Stephanie Lackey (Eds.). Springer International Publishing, Cham, 267–276.

[14] A. C. C. d. Santos, M. E. Delamaro, and F. L. S. Nunes. 2013. The Relationship between Requirements Engineering and Virtual Reality Systems: A Systematic Literature Review. In *2013 XV Symposium on Virtual and Augmented Reality*. 53–62. https://doi.org/10.1109/SVR.2013.52

[15] C. C. da Silva, B. G. M. de Alcantara, J. C. S. Olimpio, C. M. G. de Gusmao, A. G. da Silva Filho, and W. P. dos Santos. 2014. Ilera-Aiye: A virtual world for the development of serious games for health education and promotion in the Northeastern Brazilian countryside. In *2014 IEEE 3nd International Conference on Serious Games and Applications for Health (SeGAH)*. 1–8. https://doi.org/10.1109/SeGAH.2014.7067084

[16] Fabien Danieau, Philippe Guillotel, Olivier Dumas, Thomas Lopez, Bertrand Leroy, and Nicolas Mollet. 2018. HFX Studio: Haptic Editor for Full-body Immersive Experiences. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology* (Tokyo, Japan) *(VRST '18)*. ACM, New York, NY, USA, Article 37, 9 pages. https://doi.org/10.1145/3281505.3281518

[17] Darryl and Y. Bandung. 2012. Designing evaluation system for virtual class service in limited network capacity using SERVQUAL methodology. In *2012 International Conference on Cloud Computing and Social Networking (ICCCSN)*. 1–5. https://doi.org/10.1109/ICCCSN.2012.6215725

[18] Brian Burke David Cearley. October 2018. Top 10 Strategic Technology Trends for 2019. *Gartner Technology Report* (October 2018).

[19] Daphne Economou, William L Mitchell, and Tom Boyle. 2000. Requirements elicitation for virtual actors in collaborative learning environments. *Computers Education* 34, 3 (2000), 225 – 239. https://doi.org/10.1016/S0360-1315(99)00047-0

[20] Sergio Estupiñán, Francisco Rebelo, Paulo Noriega, Carlos Ferreira, and Emília Duarte. 2014. Can Virtual Reality Increase Emotional Responses (Arousal and Valence)? A Pilot Study. In *Design, User Experience, and Usability. User Experience Design for Diverse Interaction Platforms and Environments*, Aaron Marcus (Ed.). Springer International Publishing, Cham, 541–549.

[21] M. L. Gernhardt, K. H. Beaton, S. P. Chappell, O. S. Bekdash, and A. F. J. Abercromby. 2018. Development of a ground test analysis protocol for NASA's NextSTEP phase 2 habitation concepts. In *2018 IEEE Aerospace Conference*. 1–27. https://doi.org/10.1109/AERO.2018.8396513

[22] Ning Gu and Kerry London. 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction* 19, 8 (2010), 988 – 999. https://doi.org/10.1016/j.autcon.2010.09.002 The role of VR and BIM to manage the construction and design processes.

[23] Ulas Gulec, Murat Yilmaz, Veysi Isler, Rory V. O'Connor, and Paul Clarke. 2018. Adopting Virtual Reality As a Medium for Software Development Process Education. In *Proceedings of the 2018 International Conference on Software and System Process* (Gothenburg, Sweden) *(ICSSP '18)*. ACM, New York, NY, USA, 71–75. https://doi.org/10.1145/3202710.3203161

[24] Simon Gunkel, Hans Stokking, Martin Prins, Omar Niamut, Ernestasia Siahaan, and Pablo Cesar. 2018. Experiencing Virtual Reality Together: Social VR Use Case Study. In *Proceedings of the 2018 ACM International Conference on Interactive Experiences for TV and Online Video* (SEOUL, Republic of Korea) *(TVX '18)*. ACM, New York, NY, USA, 233–238. https://doi.org/10.1145/3210825.3213566

[25] Hanwen Guo, Ross Brown, and Rune Rasmussen. 2013. A Theoretical Basis for Using Virtual Worlds as a Personalised Process Visualisation Approach. In *Advanced Information Systems Engineering Workshops*, Xavier Franch and Pnina Soffer (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 229–240.

[26] R. R. Hariadi and I. Kuswardayan. 2016. Design and implementation of Virtual Indonesian Musical Instrument (VIMi) application using Leap Motion Controller. In *2016 International Conference on Information Communication Technology and Systems (ICTS)*. 43–48. https://doi.org/10.1109/ICTS.2016.7910270

[27] Linda Harley, Scott Robertson, Maribeth Gandy, Simeon Harbert, and Douglas Britton. 2011. The Design of an Interactive Stroke Rehabilitation Gaming System. In *Human-Computer Interaction. Users and Applications*, Julie A. Jacko (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 167–173.

[28] D. Herumurti, A. Yuniarti, P. Rimawan, and A. A. Yunanto. 2019. Overcoming Glossophobia Based on Virtual Reality and Heart Rate Sensors. In *2019 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT)*. 139–144. https://doi.org/10.1109/ICIAICT.2019.8784846

[29] L. Itzel, R. Suselbeck, G. Schiele, and C. Becker. 2011. Specifying consistency requirements for massively multi-user virtual environments. In *2011 IEEE International Workshop on Haptic Audio Visual Environments and Games*. 1–2. https://doi.org/10.1109/HAVE.2011.6132543

[30] Garcia Ivan, Carla Pacheco, and Myriam Reyes. 2018. Requirements elicitation techniques: A systematic literature review based on the maturity of the techniques. *IET Software* 12 (04 2018), 365–378. https://doi.org/10.1049/iet-sen.2017.0144

[31] A. Jaramillo Franco. 2015. Requirements elicitation approaches: A systematic review. In *2015 IEEE 9th International Conference on Research Challenges in Information Science (RCIS)*. 520–521. https://doi.org/10.1109/RCIS.2015.7128917

[32] Sankar Jayaram, Hugh I. Connacher, and Kevin W. Lyons. 1997. Virtual assembly using virtual reality techniques. *Computer-Aided Design* 29, 8 (1997), 575–584. https://doi.org/10.1016/S0010-4485(96)00094-2

[33] Ji-yi Xu, Bin Xie, and Jin-lin Zhai. 2011. The implementation method and improvement of media piug-in in SecondLife 3D platform. In *Proceedings of 2011 International Conference on Computer Science and Network Technology*, Vol. 3. 1669–1673. https://doi.org/10.1109/ICCSNT.2011.6182287

[34] G. Jin and S. Nakayama. 2014. Virtual reality game for safety education. In *2014 International Conference on Audio, Language and Image Processing*. 95–100. https://doi.org/10.1109/ICALIP.2014.7009764

[35] Kazi Sinthia Kabir, Ahmad Alsaleem, and Jason Wiese. 2021. The Impact of Spinal Cord Injury on Participation in Human-Centered Research. In *Designing Interactive Systems Conference 2021* (Virtual Event, USA) *(DIS '21)*. Association for Computing Machinery, New York, NY, USA, 1902–1914. https://doi.org/10.1145/3461778.3462122

[36] Sai Anirudh Karre, Neeraj Mathur, and Y. Raghu Reddy. 2019. Is Virtual Reality Product Development different?: An Empirical Study on VR Product Development Practices. In *Proceedings of the 12th Innovations on Software Engineering Conference (formerly known as India Software Engineering Conference), ISEC 2019, Pune, India, February 14-16, 2019*. 3:1–3:11. https://doi.org/10.1145/3299771.3299772

[37] K. Kirchbach and C. Runde. 2012. Augmented Reality for Construction Control. In *2012 16th International Conference on Information Visualisation*. 440–444. https://doi.org/10.1109/IV.2012.76

[38] Barbara Kitchenham, Pearl Brereton, David Budgen, Mark Turner, John Bailey, and Stephen G. Linkman. 2009. Systematic literature reviews in software engineering - A systematic literature review. *Information & Software Technology* 51, 1 (2009), 7–15. https://doi.org/10.1016/j.infsof.2008.09.009

[39] Youngho Lee, Jongmyung Choi, Sehwan Kim, Seunghun Lee, and Say Jang. 2011. Social Augmented Reality for Sensor Visualization in Ubiquitous Virtual Reality. In *Virtual and Mixed Reality - New Trends*, Randall Shumaker (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 69–75.

[40] Mertens Lieze, Van Cauwenberg Jelle, Deforche Benedicte, Van de Weghe Nico, Matthys Mario, and Delfien Van Dyck. 2020. Using virtual reality to investigate physical environmental factors related to cycling in older adults: A comparison between two methodologies. *Journal of Transport Health* 19 (2020), 100921. https://doi.org/10.1016/j.jth.2020.100921

[41] X. Liu, Y. Zhu, H. Huo, P. Wei, L. Wang, A. Sun, C. Hu, X. Yin, Z. Lv, and Y. Fan. 2019. Design of Virtual Guiding Tasks With Haptic Feedback for Assessing the Wrist Motor Function of Patients With Upper Motor Neuron Lesions. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 27, 5 (May 2019), 984–994. https://doi.org/10.1109/TNSRE.2019.2909287

[42] Peri Loucopoulos and V. Karakostas. 1995. *System Requirements Engineering*. 160 pages.

[43] Duy-Nam Ly, Thanh-Thai La, Khanh-Duy Le, Cuong Nguyen, Morten Fjeld, Thanh Ngoc-Dat Tran, and Minh-Triet Tran. 2022. 360TourGuiding: Towards Virtual Reality Training for Tour Guiding. In *Adjunct Publication of the 24th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Vancouver, BC, Canada) *(MobileHCI '22)*. Association for Computing Machinery, New York, NY, USA, Article 15, 6 pages. https://doi.org/10.1145/3528575.3551436

[44] Omar López Chávez, Luis-Felipe Rodríguez, and J. Octavio Gutierrez-Garcia. 2020. A comparative case study of 2D, 3D and immersive-virtual-reality applications for healthcare education. *International Journal of Medical Informatics* 141 (2020), 104226. https://doi.org/10.1016/j.ijmedinf.2020.104226

[45] Christine Mégard, Florian Gosselin, Sylvain Bouchigny, Fabien Ferlay, and Farid Taha. 2009. User-centered Design of a Maxillo-facial Surgery Training Platform. In *Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology* (Kyoto, Japan) *(VRST '09)*. ACM, New York, NY, USA, 265–266. https://doi.org/10.1145/1643928.1643997

[46] N. D. Mohd Muhaiyuddin and D. R. Awang Rambli. 2014. Navigation in image-based Virtual Reality as the factor to elicit spatial presence experience. In *2014 International Symposium on Technology Management and Emerging Technologies*. 349–354. https://doi.org/10.1109/ISTMET.2014.6936532

[47] S. E. Motlagh Tehrani, N. M. M. Zainuddin, and T. Takavar. 2014. Heuristic evaluation for Virtual Museum on smartphone. In *2014 3rd International Conference on User Science and Engineering (i-USEr)*. 227–231. https://doi.org/10.1109/IUSER.2014.7002707

[48] Alexandr Nikitin, Nina Reshetnikova, Ivan Sitnikov, and Olesya Karelova. 2020. VR Training for Railway Wagons Maintenance: architecture and implementation. *Procedia Computer Science* 176 (2020), 622 – 631. https://doi.org/10.1016/j.procs.2020.08.064 Knowledge-Based and Intelligent Information Engineering Systems: Proceedings of the 24th International Conference KES2020.

[49] D. M. Oliveira, S. C. Cao, X. F. Hermida, and F. M. Rodriguez. 2007. Virtual Reality System for Industrial Training. In *2007 IEEE International Symposium on Industrial Electronics*. 1715–1720. https://doi.org/10.1109/ISIE.2007.4374863

[50] Ioannis Paliokas, Athanasios Tsakiris, Athanasios Vidalis, and Dimitrios Tzovaras. 2014. Sense of Presence and Metacognition Enhancement in Virtual Reality Exposure Therapy in the Treatment of Social Phobias and the Fear of Flying. In *Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality*, Randall Shumaker and Stephanie Lackey (Eds.). Springer International Publishing, Cham, 316–328.

[51] Liliana Pasquale, Paola Spoletini, Dario Pometto, Francesco Blasi, and Tiziana Redaelli. 2013. Requirements Engineering Meets Physiotherapy: An Experience with Motion-Based Games. In *Requirements Engineering: Foundation for Software Quality*, Joerg Doerr and Andreas L. Opdahl (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 315–330.

[52] Toni B. Pence, Lauren C. Dukes, Larry F. Hodges, Nancy K. Meehan, and Arlene Johnson. 2014. An Eye Tracking Evaluation of a Virtual Pediatric Patient Training System for Nurses. In *Intelligent Virtual Agents*, Timothy Bickmore, Stacy Marsella, and Candace Sidner (Eds.). Springer International Publishing, Cham, 329–338.

[53] Kai Petersen, Sairam Vakkalanka, and Ludwik Kuzniarz. 2015. Guidelines for conducting systematic mapping studies in software engineering: An update. *Information and Software Technology* 64 (2015), 1 – 18. https://doi.org/10.1016/j.infsof.2015.03.007

[54] Tony Poitschke, Markus Ablaßmeier, Stefan Reifinger, and Gerhard Rigoll. 2007. A Multifunctional VR-Simulator Platform for the Evaluation of Automotive User Interfaces. In *Human-Computer Interaction. HCI Applications and Services*, Julie A. Jacko (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 1120–1129.

[55] P. Pyk, D. Wille, E. Chevrier, Y. Hauser, L. Holper, I. Fatton, R. Greipl, S. Schlegel, L. Ottiger, B. Ruckriem, A. Pescatore, A. Meyer-Heim, D. Kiper, and K. Eng. 2008. A Paediatric Interactive Therapy System for arm and hand rehabilitation. In *2008 Virtual Rehabilitation*. 127–132. https://doi.org/10.1109/ICVR.2008.4625148

[56] P. Rajagopal, R. Lee, T. Ahlswede, Chia-Chu Chiang, and D. Karolak. 2005. A new approach for software requirements elicitation. In *Sixth International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing and First ACIS International Workshop on Self-Assembling Wireless Network*. 32–42. https://doi.org/10.1109/SNPD-SAWN.2005.5

[57] Amy Rankin, Joris Field, Rita Kovordanyi, Magnus Morin, Johan Jenvald, and Henrik Eriksson. 2011. Training Systems Design: Bridging the Gap Between Users and Developers Using Storyboards. In *Proceedings of the 29th Annual European Conference on Cognitive Ergonomics* (Rostock, Germany) *(ECCE '11)*. ACM, New York, NY, USA, 205–212. https://doi.org/10.1145/2074712.2074752

[58] S. Sanders and A.C. Rolfe. 2003. The use of virtual reality for preparation and implementation of JET remote handling operations. *Fusion Engineering and Design* 69, 1 (2003), 157 – 161. https://doi.org/10.1016/S0920-3796(03)00307-7 22nd Symposium on Fusion Technology.

[59] K. Sanjaya, F. Henning, and K. R. Purba. 2017. 3D LIDAR City Model Application and Marketing Plan Development. In *2017 International Conference on Soft Computing, Intelligent System and Information Technology (ICSIIT)*. 238–242. https://doi.org/10.1109/ICSIIT.2017.50

[60] Paula Savioja, Paula Järvinen, Tommi Karhela, Pekka Siltanen, and Charles Woodward. 2007. Developing a Mobile, Service-Based Augmented Reality Tool for Modern Maintenance Work. In *Virtual Reality*, Randall Shumaker (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 554–563.

[61] Dylan Schouten, Nanja Smets, Marianne Driessen, Marieke Hanekamp, Anita H. M. Cremers, and Mark A. Neerincx. 2013. User Requirement Analysis of Social Conventions Learning Applications for Non-Natives and Low-Literates. In *Engineering Psychology and Cognitive Ergonomics. Understanding Human Cognition*, Don Harris (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 354–363.

[62] Hagen Schumann, Silviu Burtescu, and Frank Siering. 1998. Applying Augmented Reality Techniques in the Field of Interactive Collaborative Design. In *3D Structure from Multiple Images of Large-Scale Environments*, Reinhard Koch and Luc Van Gool (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 290–303.

[63] Jinseok Seo and Gerard J. Kim. 2007. Teaching Structured Development of Virtual Reality Systems Using P-VoT. In *Technologies for E-Learning and Digital Entertainment*, Kin-chuen Hui, Zhigeng Pan, Ronald Chi-kit Chung, Charlie C. L. Wang, Xiaogang Jin, Stefan Göbel, and Eric C.-L. Li (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 69–80.

[64] Di Shao, Xiao Liu, Ben Cheng, Owen Wang, and Thuong Hoang. 2020. Edge4Real: A Cost-Effective Edge Computing Based Human Behaviour Recognition System for Human-Centric Software Engineering. In *Proceedings of the 35th IEEE/ACM International Conference on Automated Software Engineering* (Virtual Event, Australia) *(ASE '20)*. Association for Computing Machinery, New York, NY, USA, 1287–1291. https://doi.org/10.1145/3324884.3415297

[65] B. N. Steele, M. T. Draney, J. P. Ku, and C. A. Taylor. 2003. Internet-based system for simulation-based medical planning for cardiovascular disease. *IEEE Transactions on Information Technology in Biomedicine* 7, 2 (June 2003), 123–129. https://doi.org/10.1109/TITB.2003.811880

[66] Evropi Stefanidi, Johannes Schöning, Sebastian S. Feger, Paul Marshall, Yvonne Rogers, and Jasmin Niess. 2022. Designing for Care Ecosystems: A Literature Review of Technologies for Children with ADHD. In *Interaction Design and Children* (Braga, Portugal) *(IDC '22)*. Association for Computing Machinery, New York, NY, USA, 13–25. https://doi.org/10.1145/3501712.3529746

[67] M. Sufian, Z. Khan, S. Rehman, and W. Haider Butt. 2018. A Systematic Literature Review: Software Requirements Prioritization Techniques. In *2018 International Conference on Frontiers of Information Technology (FIT)*. 35–40. https://doi.org/10.1109/FIT.2018.00014

[68] X. Tan, C. Chng, B. Duan, Y. Ho, R. Wen, X. Chen, K. Lim, and C. Chui. 2016. Design and implementation of a patient-specific cognitive engine for robotic needle insertion. In *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. 000560–000565. https://doi.org/10.1109/SMC.2016.7844299

[69] Aparna Vegendla, Anh Nguyen Duc, Shang Gao, and Guttorm Sindre. 2018. A Systematic Mapping Study on Requirements Engineering in Software Ecosystems. *J. Inf. Technol. Res.* 11, 1 (Jan. 2018), 49–69. https://doi.org/10.4018/JITR.2018010104

[70] Syadiah Nor Wan Shamsuddin, Hassan Ugail, Valerie Lesk, and Elizabeth Walters. 2013. Towards Early Diagnosis of Dementia Using a Virtual Environment. In *Transactions on Computational Science XVIII*, Marina L. Gavrilova, C. J. Kenneth Tan, and Arjan Kuijper (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 232–247.

[71] D. Wang, Y. Zhang, J. Hou, Y. Wang, P. Lv, Y. Chen, and H. Zhao. 2012. iDental: A Haptic-Based Dental Simulator and Its Preliminary User Evaluation. *IEEE Transactions on Haptics* 5, 4 (Fourth 2012), 332–343. https://doi.org/10.1109/TOH.2011.59

[72] Hesheng Wang, Lifei Xu, and Weidong Chen. 2016. Design and implementation of visual inspection system handed in tokamak flexible in-vessel robot. *Fusion Engineering and Design* 106 (2016), 21 – 28. https://doi.org/10.1016/j.fusengdes.2016.03.005

[73] T. Widiyaningtyas, D. D. Prasetya, and A. P. Wibawa. 2018. Adaptive Campus Virtual Tour using Location-Based Services. In *2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*. 419–423. https://doi.org/10.1109/EECCIS.2018.8692853

[74] Dennis Wiebusch, Martin Fischbach, Marc Erich Latoschik, and Henrik Tramberend. 2012. Evaluating Scala, Actors, & Ontologies for Intelligent Realtime Interactive Systems. In *Proceedings of the 18th ACM Symposium on Virtual Reality Software and Technology* (Toronto, Ontario, Canada) *(VRST '12)*. ACM, New York, NY, USA, 153–160. https://doi.org/10.1145/2407336.2407365

[75] F. Willicks, V. Stehling, A. Richert, and I. Isenhardt. 2018. The students' perspective on mixed reality in higher education: A status and requirement analysis. In *2018 IEEE Global Engineering Education Conference (EDUCON)*. 656–660. https://doi.org/10.1109/EDUCON.2018.8363293

[76] P. S. Windyga, R. Medina, and G. M. Onik. 2003. Augmented vision for minimally invasive abdominal cancer surgery. In *Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No.03CH37439)*, Vol. 2. 1160–1163 Vol.2. https://doi.org/10.1109/IEMBS.2003.1279455

[77] Yu-Chen Yang. 2019. Role-play in Virtual Reality Game for the Senior. In *Proceedings of the 2019 7th International Conference on Information and Education Technology* (Aizu-Wakamatsu, Japan) *(ICIET 2019)*. ACM, New York, NY, USA, 31–35. https://doi.org/10.1145/3323771.3323812

[78] S. Yu, X. Fan, and Z. Liao. 2009. A Study of the Endoscopic Surgery Simulation Training System Based on 3D Virtual Reality. In *2009 International Conference on Computational Intelligence and Software Engineering*. 1–4. https://doi.org/10.1109/CISE.2009.5364746

Table 2: Requirement Elicitation method mapped with respective reference

Industry	Requirement elicitation Method	About the Product/Prototype	Reference
Analytics	Direct Inspection	Data Visualization	[62]
Automotive	Direct Inspection	Simulator based Automotive UI	[9]
	Domain Expert Review	Train Wagon Maintenance Simulator	[48]
Construction	Domain Expert Review	Building Modelling in Construction Industry	[19]
	Domain Expert Review	AR for Construction Control	[65]
	Domain Expert Review	VR for Safety Training	[76]
	Domain Expert Review	City Model Planner	[58]
Design	Direct Inspection	Collaborative Design Setup	[8]
	Usecase Studies	Collaborative Virtual Environment	[7]
	Domain Knowledge	UML using VR	[49]
	Domain Knowledge	VR Content Authoring	[63]
	Storyboarding	Design and Code Review within Teams	[60]
	Usecase Studies	Intelligent Interactive and User Cognition	[54] [64]
	Mental model technique	VR for Spatial Presence Experience	[55]
	Survey Questionnaire	Arousal and Valence Studies for VR	[45]
	Direct Inspection	Haptic Editor for Immersion Experience	[78]
	Use case Studies	Roaming in VR Scene	[22]
	Subjective Inspection	VR for Haptic Feedback	[57]
Education	Prototyping	Collaborative Learning VR App	[33]
	Domain Expert Review	Industrial Training	[29]
	Core Task Analysis	Maintenance Training VR App	[39]
	Usecase Studies	Virtual Class Services	[10]
	Situated Cognitive method	Learning App for Non Natives and Low Literates	[27]
	Serial Inspection	SE Process Education	[74]
	Survey Questionnaire	MR for Higher Education	[37]
Entertainment	Direct Inspection	Second Life 3D Platform	[17]
	Survey Questionnaire	VR Shopping	[71]
	Survey Questionnaire	Personalized Virtual Worlds	[61]
	Structured Interviews	Virtual Museum and Tour Guiding	[2] [43]
	Domain Expert Review	Teaching Virtual Indonesian Musical Instrument	[51]
HealthCare	Domain Expert Review	Medical Planning for cardiovascular disease	[70]
	Domain Expert Review	Abdominal Cancer Surgery Training	[25]
	Participatory Studies	Arm and Hand Rehabilitation therapy	[5]
	User Centered Approach	Maxillo-Facial Surgery Training	[46]
	Domain Expert Review	Endoscopic Surgery Simulation Training	[12]
	Case Studies	Interactive Stroke Rehabilitation	[34]
	Practitioner's Review	Dental Simulation Studies for Dentists	[15]
	Domain Expert Review	Physiotherapy Motion Games and Spinal Cord	[47] [35]
	Psychological theories	Early Diagnosis of Dementia	[50]
	Practitioner's review	Traditional Foot Reflexology Study	[13]
	Participatory Workshops	Promoting Health Education in Brazil Country Side	[20]
	Domain Expert Review	Dental Anesthesia Training	[52]
	Domain Expert Review	Virtual Pediatric Patient Training System for Nurses	[68]
	Domain Expert Review	Robotic Needle Insertion Training and ADHD	[26] [66]
	Likert Based Survey	Health Care Education	[44]
	Practitioner's Review	Physical impact on Cycling in Older Adults	[40]
	RE-FIT Method	VR for Special Needs	[72]
Social	Use case Studies	Multi-User Virtual environments	[6]
	Use case Studies	Social VR using Sensors System	[59]
	Case Studies	Virtual Negotiation Training	[24]
	Domain Expert Review	Social Skills for Autistic Children	[16]
	Behavioral Questionnaire	Therapy for Social Phobias	[23]
	Survey Questionnaire	Social VR	[11]
	Domain Knowledge	Campus Virtual Tour	[75]
	Role Play Flow Analysis	Role-play in VR Game for Elders	[73]
	Subjective Inspection	VR for Glossophobia	[21]
Space	Domain Expert Review	JET Flight Remote System	[77]
	Domain Expert Review	In-Vessel Visual Inspection System	[28]
	Direct Inspection	Space Simulation Studies	[41]