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HUOSTON RODRIGUES BATISTA

TOWARDS A DESIGN METHODOLOGY FOR SPECIALIZED IMMERSIVE TRAINING UTILIZING VIRTUAL REALITY, SERIOUS GAMES, BIOFEEDBACK, AND UX DESIGN

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Thesis presented to the postgraduate program in Informatics and Knowledge Management of the Universidade Nove de Julho - UNINOVE as a partial requisite to obtain the title of Ph.D. in Informatics and Knowledge Management.

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Co-supervisor: Prof. Dr. Ulrich Norbisrath

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São Paulo, 28 de junho de 2021.

I dedicate this work to Silvia Denise, my wife, my greatest friend and motivator, someone for whom I have deep admiration, love, affection and respect, who always saw in me more potential and value than I was ever able to see.

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To paraphrase Oscar Wilde in *Di Profundis,* "men have gone to heaven for smaller things than that".

“On résiste à l'invasion des armées;

on ne résiste pas à l'invasion des idées”.

HUGO, VICTOR, *"Histoire d'un crime"*, 1877

RESUMO

As forças policiais desempenham um papel significativo devido à natureza inerente de suas atividades, uma vez que estes profissionais estão frequentemente expostos a uma variedade de situações de estresse agudo e risco de vida. Tais situações demandam, além de decisões rápidas, julgamentos corretos por parte destes profissionais, o que justifica o treinamento constante de aspectos técnicos, operacionais e psicológicos. Entretanto, o treinamento policial é caro, envolve riscos, tem pouca flexibilidade de cenários e, em muitos casos, além de insuficiente, é também ineficiente. Esta tese teve como objetivo propor e validar um método para orientar o desenvolvimento de simuladores de Realidade Virtual que combinem Biofeedback e Serious Games aplicados ao treinamento especializado de profissionais de segurança e agentes da lei e que considere a Experiência do Usuário como o fator predominante. Este método teve origem na prática e validação do desenvolvimento de um protótipo de simulador de Realidade Virtual, cujo único objetivo foi gerar conhecimento para suportar a proposição do referido método. Tanto o método proposto quanto o protótipo que balizou sua proposição basearam-se na metodologia Design Science Research. Este método foi submetido a três ciclos de avaliação, sendo dois com especialistas e um terceiro que consistiu em uma avaliação mais ampla por meio de uma survey com 141 profissionais e acadêmicos de onze países de diversas áreas de especialização que esta pesquisa tangencia, tais como Desenvolvimento de Software, Experiência do Usuário, Educação, Jogos e Indústria 4.0. Após analisar as respostas da survey, foi possível identificar diferentes níveis de relevância das 31 atividades de cada um dos 7 ciclos, determinados pelo número de atividades definidas como muito relevantes ou extremamente relevantes pelos respondentes. Isso permitiu gerar uma quarta e última versão que levou em consideração diferentes reflexões a partir da validação realizada por profissionais e acadêmicos. A versão final do método é composta por Fase/Ciclo 1 - Definition of the general objectives of the simulator phase (4 atividades), Fase/Ciclo 2 - Research cycle (3 atividades), Fase/Ciclo 3 - Planning cycle (5 atividades), Fase/Ciclo 4 - Design cycle (8 atividades), Fase/Ciclo 5 - Development cycle (VR) (5 atividades), Fase/Ciclo 6 - Development cycle (Biofeedback) (3 atividades), e, por fim, Fase/Ciclo 7 - Demonstration and evaluation cycle (3 atividades). Identificou-se que as atividades relacionadas à Experiência do Usuário tiveram, em geral, excelentes avaliações dos respondentes consultados, enquanto as atividades relacionadas a Jogos Sérios e Biofeedback não foram consideradas como tendo o mesmo nível de relevância que as atividades relacionadas à Experiência do Usuário. No entanto, nenhuma das atividades teve classificação de relevância tão baixa que sugerisse sua exclusão do método. Assim, a versão final do método validado teve indicação de todas as trinta e uma atividades distribuídas em cada uma de suas sete etapas, devidamente rotuladas como ‘mandatórias’, ‘recomendadas’ ou ‘opcionais’. Conclui-se que o método é suficientemente abrangente, robusto e flexível para cobrir diferentes especificidades de vários contextos de desenvolvimento de soluções de Realidade Virtual aplicadas ao treinamento de profissionais em situações estressantes.

Palavras-chave: Virtual reality simulator. Virtual reality development method. Serious games. Biofeedback. Trainning. User experience.

ABSTRACT

Police forces play a significant role due to the inherent nature of their activities, since these professionals are often exposed to a variety of acute stressful and life-threatening situations. Such situations demand, besides quick decisions, correct judgments by these professionals, which justifies constant training in technical, operational, and psychological aspects. However, police training is expensive, involves risks, has little flexibility of scenarios, and in many cases, besides being insufficient, it is also inefficient. This thesis aimed to propose and validate a method to guide the development of Virtual Reality simulators that combine Biofeedback and Serious Games applied to the specialized training of security professionals and law enforcement agents and that considers the User Experience as the predominant factor. This method originated in the practice and validation of the development of a Virtual Reality simulator prototype, whose sole purpose was to generate knowledge to support the proposition of the referred method. Both the proposed method and the prototype were based on the Design Science Research methodology. This method was submitted to three cycles of evaluation, two with specialists and a third that consisted of a wider evaluation through a survey with 141 professionals and academics from eleven countries from several areas of expertise that this research tangents, such as Software Development, User Experience, Education, Games, and Industry 4.0. After analyzing the survey responses, it was possible to identify different levels of relevance of the 31 activities in each of the 7 cycles, determined by the number of activities defined as very relevant or extremely relevant by the respondents. This made possible to generate a fourth and final version that took into consideration different reflections from the validation performed by professionals and academics. The final version of the method is composed of Phase/Cycle 1 - Definition of the general objectives of the simulator phase (4 activities), Phase/Cycle 2 - Research cycle (3 activities), Phase/Cycle 3 - Planning cycle (5 activities), Phase/Cycle 4 - Design cycle (8 activities), Phase/Cycle 5 - Development cycle (VR) (5 activities), Phase/Cycle 6 - Development cycle (Biofeedback) (3 activities), and, finally, Phase/Cycle 7 - Demonstration and evaluation cycle (3 activities). It was identified that the activities related to User Experience had, in general, excellent ratings from the consulted respondents, while the activities related to Serious Games and Biofeedback were not considered to have the same level of relevance as the activities related to User Experience. However, none of the activities had such low relevance ratings as to suggest their exclusion from the method. Accordingly, the final version of the validated method indicated all thirty-one activities distributed in each of its seven stages, duly labeled as 'mandatory', 'recommended', or 'optional'. It is concluded that the method is sufficiently comprehensive, robust and flexible to cover different specificities of various contexts for the development of Virtual Reality solutions applied to the training of professionals in stressful situations.

Keywords: Virtual reality simulator. Virtual reality development method. Serious games. Biofeedback. Trainning. User experience.

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LIST OF ABBREVIATIONS AND ACRONYMS

DSR	Design Science Research
DIR	Design Inclusive Research
VR	Virtual Reality
IOT	Internet of Things
SG	Serious Games
SLR	Systematic Literature Review
CLR	Computational Literature Review
SCO	Scopus
WOC	Web of Science
IT	Information Technology
IS	Information Systems
HMD	Head Mounted Device
OSCE	Organization for Security and Co-operation in Europe
UE4	Unreal Engine 4
ADSRM	Agile Design Science Research Methodology
HCD	Human-centered design
MVP	Minimum Viable Product
ASD	Agile Software Development
UX/UI	User Experience and Interface Design
PBR	Physically Based Rendering
PBS	Physically Based Shading
LOD	Level of detail
FACS	Facial Action Coding System

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1 INTRODUCTION

1.1 Contextualization

Fast and accurate decision making in potentially threatening situations is vital for professionals whose practice is surrounded by stressful routines, such as security officers, military and police officers, firemen and street guards. Moreover, these professionals are invested with a significant amount of power and responsibility inherent to their position in cases that potentially involve arrest, use of force and search and seizure, since their decisions have serious immediate consequences of their actions.

These professionals make many decisions every day. Some of these decisions are relatively routinely and easier to make, as there are a number of protocols, rules, standards and procedures available to guide the actions of security agents, such as police officers, for example. However, legislation, policies of law enforcement agencies, and standard operating procedures only cover a portion of police officers' decisions. In stressful or threatening situations, people tend to react impulsively and have no cognitive control (SARASON et al., 1979; ROBERT J. HOCKEY, 1997; GUTSHALL et al., 2017).

Stress can be defined as the body's non-specific response to any demand for change, which in turn can cause a "fight or flight" response, a complex reaction of neurological and endocrinological systems (PORCELLI; DELGADO, 2017; SELYE, 1936). It is precisely for this reason that police officers need to train control over their responses to threats as much as possible.

However, police training is very expensive, complex and time consuming, and only a small variety of real-life scenarios can be included during police training (BERTRAM; MOSKALIUK; CRESS, 2015). One of the reasons for the limitation of scenarios replicated in police training is due to the issue of potential risk to officers (ACHIM, 2019), which in turn could be mitigated in a controlled environment.

In this sense, environments provided by Virtual Reality are useful in simulations of complex training scenarios, especially if training in real situations is not possible (MOSKALIUK; BERTRAM; CRESS, 2013b, 2013a). The ability to simulate stressful or potentially dangerous experiences in the safe and controlled environment of Virtual Reality

(VR) enables the creation of Serious Games with a high level of immersion (BERTRAM; MOSKALIUK; CRESS, 2015).

Serious Games are defined as games that do not have entertainment, fun or amusement as their main goal (MILDNER; `FLOYD' MUELLER, 2016; RALF DÖRNER, 2016; ARGASIŃSKI; WĘGRZYN, 2019). Serious Games have a range of applications that cover areas such as trade, environment and ecological behavior, cartography, machine learning, software development, innovation, health, politics, education, tourism, finance, energy, mobility, accessibility, fashion, usability, risk management and marketing (BAPTISTA; OLIVEIRA, 2019).

In particular, these types of games have great potential to provide interactive opportunities that support learning. Wouters et al. (2013) conducted a meta-analysis of 39 studies on Serious Games. They found that the Serious Games have a positive impact on the achievements of students who participated in their experiments. According to the results of this meta-analysis, Serious Games were effective in acquiring knowledge, especially when the game was integrated to instructional methods and clearly defined objectives.

One way to provide a higher level of involvement is to unite the characteristics of Serious Games implemented in an interactive and immersive environment, something that can be obtained through the use of Virtual Reality. Thus, safe training environments based on Virtual Reality would allow the user to make mistakes without serious consequences, making it possible to gather experiences that help avoid bad decisions in the future (CONWAY; JAMES; GLADYSHEV, 2015; CAI; VAN JOOLINGEN; WALKER, 2019).

In this context, Virtual Reality is applicable since it presents itself as a paradigm that considers the human as the center of the whole system. As it is a technology in development and expansion, several definitions of Virtual Reality (VR) and other terms that permeate the universe of VR can be found in literature, such as simulation and virtual environments (CANT et al., 2019; KARDONG-EDGREN et al., 2019). Although there are numerous definitions, there is some consensus that describes Virtual Reality as an environment, as a form of interaction and as a form of immersion (CISNEROS et al., 2019).

In general, in a Virtual Reality system some sort of head-mounted device is used (like some kind of glasses) that isolates the user from the external environment, making it possible to experience virtual vision and even other sensations provided by immersion in virtual environments (GADIA et al., 2018; JENSEN; KONRADSEN, 2018).

Simulations and virtual environments enabled by Virtual Reality have several significant advantages over other training approaches, such as the quality of the experience, learning through practice, customization of the learning experience that can be designed to meet specific needs with flexibility and immediacy impossible in real life and the possibility of allowing past events to be re-experienced or reused in new scenarios (BERTRAM; MOSKALIUK; CRESS, 2015; BENEDEK; VESZELSZKI, 2017; BAILENSON, 2018; TEIXEIRA et al., 2018; CISNEROS et al., 2019).

Therefore, combining the immersive potential of Virtual Reality and Serious Games can result in a unique and promising approach. The Virtual Reality Serious Games can simulate real life experiences that offer a high level of interactivity and realism, allowing training professionals to actively build knowledge (LIU et al., 2017; SILVA et al., 2017; WU et al., 2018). In this sense, recent studies provide significant evidence that the Virtual Reality Serious Games can lead to a higher level of immersion, which can result in greater engagement and motivation (SHEWAGA et al., 2017; CASERMAN et al., 2018).

Another positive aspect that can result from the combination of Serious Games and Virtual Reality refers to experiential learning, as it involves experiences and processing these experiences so that those who are subject to the training acquire significant knowledge, skills and insights (KOLB, 2015; JANTJIES; MOODLEY; MAART, 2018).

However, considering the physiological responses to emotions as the object of study in simulations whose objective is to measure the response of the trainee in stressful situations and their effects on decision making, it is necessary to create ways of measuring the performance and stress levels experienced during the simulation. Especially if we consider that the link between emotions and body states is reflected in various aspects ranging from behavior to speech, as well as being denoted by their intensity in the body (NUMMENMAA et al., 2014).

Emotions are usually complex and difficult to measure. There are no methods or metrics determined to calculate emotions numerically, although different studies have been conducted towards this goal. However, several physiological measurements have been shown to be related to emotional reactions, and there is also a consensus in the literature that behavioral factors, including facial expressions and body movements, may reveal evidence of more or less emotions (LU et al., 2018; ROZANSKA et al., 2018; TANG; WINOTO, 2018).

In this regard, the use of sensors to capture data such as heart rate, sweating, oxygen level and temperature can help to identify patterns of behavior and responses related to stress levels of an individual. Such data would be useful to evaluate the performance of police officers during training in immersive Virtual Reality environments that simulate typical day-to-day situations (KOLDIJK; NEERINCX; KRAAIJ, 2018; QI et al., 2018; CAPOBIANCO et al., 2019; KALE, 2019). This type of measurement and evaluation that consists in showing users the physiological changes in their bodies directly linked to specific mental activities is known with Biofeedback (SEAWARD, 2018). This technique has been employed on a large scale in areas such as health and therapy with positive results in health problems such as chronic stress, headaches, pain and anxiety (BADAWI; EL SADDIK, 2020).

The technique refers to the process of monitoring and/or control of physiological events in humans, usually through electronic equipment, such as sensors, with feedback in the form of visual, auditory and/or tactile signals, in order to stimulate the cerebral cortex, and this being able to remodulate its excitatory and inhibitory neural connections, learning to self-regulate physiological functions (CHEN, 2014; BADAWI; EL SADDIK, 2020; SUN et al., 2020).

The use of external sensors in combination with forms of capture and evaluation of data from these sensors is closely related to the concept of ubiquitous or pervasive computing (WEISER, 1993; SATYANARAYANAN, 2001), a concept that in turn gives rise to the Internet of Things. The Internet of Things (IoT) is a concept and model that includes a variety of objects that can interact with each other through unique wireless connections, cable and addressing schemes, and that can work with other objects to create new services and applications to achieve common goals (ATZORI; IERA; MORABITO, 2010; RAY, 2018). In its simplest form, the Internet of Things can be considered a network of physical elements enabled by:

- Sensors: to collect information;
- Identifiers: to identify the data source (e.g. sensors, devices);
- Software: to analyze data;
- Internet connectivity: to communicate and notify.

The Internet of Things, in turn, has given rise to a number of other technologies and made it possible to popularize wearable devices such as smart watches, which ultimately make use of various concepts that laid the foundations for the Internet of Things (SIIRTOLA, 2019). The popularization of intelligent devices such as smartphones, smart watches and, at the same time, expanded access to connectivity are paving the way for what is being called Smart biofeedback (DA-YIN LIAO, 2020).

Given the context presented, capturing data from vital signs and using them to improve the experience of those who are subjected to the simulation of events in an immersive simulator in which stress is a common component, can be a beneficial way to improve the experience of the trainee in various situations often impossible to simulate in the real world.

Furthermore, the use of data collected from the performance of the users of a simulator can be a way to improve the evaluation of the performance of trainees (BERNHARDT et al., 2019; KOS et al., 2019), often performed by specialized and more experienced professionals, which can cause distortions of judgment, even if involuntary (KAHNEMAN; LOVALLO; SIBONY, 2011; CORNISH; JONES, 2013; LAI; HOFFMAN; NOSEK, 2013).

Another important aspect to consider is the fact that the data generated by the user experience can be extremely useful to evaluate and improve the simulator itself, in a cycle of continuous improvement and development (ALISMAIL; ZHANG; CHATTERJEE, 2017; JANSE VAN RENSBURG; GOEDE, 2020).

Virtual Reality has the potential to provide experiences and deliver results that cannot be achieved by other media. However, Virtual Reality interaction is not just an interface for the user to achieve their goals. It is also about users working intuitively, something that can be defined as a pleasurable experience and devoid of frustrations.

Considering the nature of Virtual Reality as a medium to provide user experiences, such experiences must be designed and planned in such a way that these users can efficiently achieve their goals. It is important to emphasize that the user is the center of the Virtual Reality experience, which requires even more effort from the developers (STONE, 2016), which can be done using principles of Human-Centered Design (NORMAN, 2005a; OVIATT, 2006; CHAMMAS; QUARESMA; MONT'ALVÃO, 2015).

Human-centered interaction design focuses on the human side of user-machine communication, i.e. the interface from the user's point of view (MAO et al., 2005; CHAMMAS; QUARESMA; MONT'ALVÃO, 2015). Ideal Virtual Reality Experiences are those in which not only the goals and needs are achieved efficiently, but also in an engaging and enjoyable manner (CHECA; BUSTILLO, 2020; MARTINEZ; MENÉNDEZ-MENÉNDEZ; BUSTILLO, 2020). Therefore, adopting human-centered design concepts concentrating efforts on promoting a better User Experience is an essential part of designing quality VR interactions (ORTEGA et al., 2016).

Consequently, the method that will be suggested as the final result of this thesis intends to consider the user as the center of the experience, and as such, proposes the User Experience as an integral part of the method.

1.2 Research Gap

In the context of this thesis, the research gap lies in the crossing of Virtual Reality and Biofeedback technologies with Serious Games methods and strategies as essential pillars for the development of simulators applied to the training of security professionals and law enforcement agents.

In order to highlight the research gap to which this thesis will be dedicated, it is essential to have a previous literature review. There are several different ways to perform a literature review and different types of reviews, such as narrative or integrative reviews, systematic reviews, meta-analyses and integrative reviews (SNYDER, 2019). In the specific context of this thesis, the search for previous works was divided into two parts.

The first part is based on a traditional method of literature review widely used in academic works and has as a source of data academic works published in academic databases. The second part focuses on the search for patents, and has a particular focus on patents of development methods or processes.

To achieve this objective, two different methods of literature review were adopted: Systematic Literature Review (KITCHENHAM et al., 2009), applied to the search for academic papers and Computational Literature Review (MORTENSON; VIDGEN, 2016), applied in the search for patents. The main reason for choosing two different methods at different times is due to the need to constantly update the state of the art of each of the pillars addressed in this study (NEPOMUCENO; SOARES, 2019), process that is facilitated when conducted through the CLR, supported by algorithms and in a semi-automatic way, unlike the SLR, a process that by its nature is conducted manually.

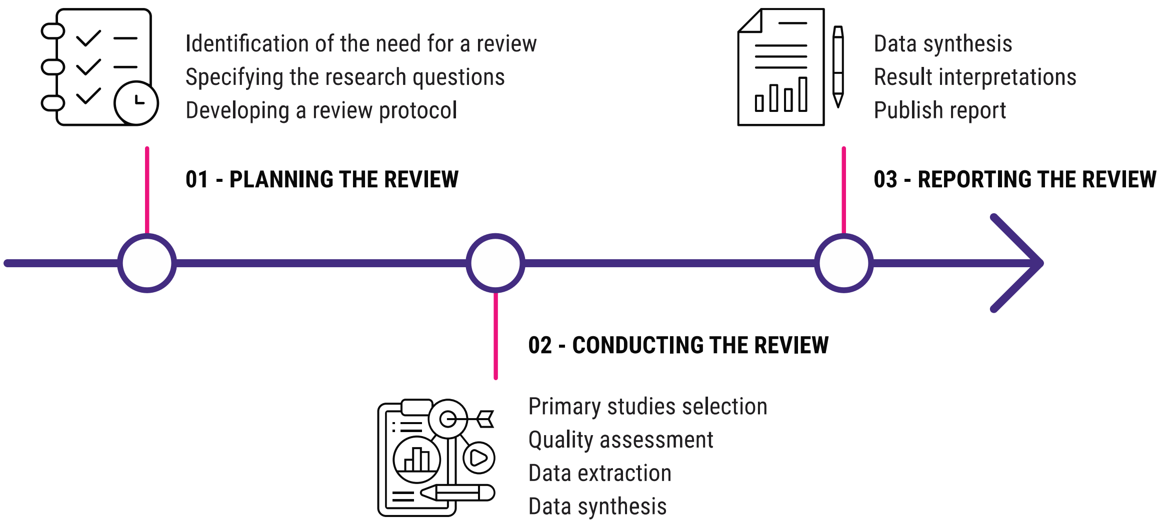
Both methods, described in detail in the following, use exactly the same search parameters, although the types of data and their structures are substantially different.

1.2.1 The search for academic works

During this first stage (the search for academic papers), a method known as Systematic Literature Review (SLR) was used (KITCHENHAM et al., 2009). Any systematic review should follow a well-established protocol or review plan, where the criteria are clearly stated before the review is performed. Kitchenham et al. (KITCHENHAM; DYBA; JORGENSEN, 2004) developed the concept of *evidence-based software engineering*, something common to several areas, such as the particular case of health, which for years has applied specific literature review methods, such as Preferred Reporting Items for Systematic Reviews and Meta-Analyses - PRISMA (MOHER et al., 2009).

According to Kitchenham et al. (2009), the Systematic Literature Review method is divided into three phases: Planning the review, Conducting the review and Reporting the review. Each phase is composed of a series of activities. An overview of the revision protocol adopted in this part of the thesis as well as the activities that each step comprises is presented in Figure 1.

Figure 1 - Phases and activities of Systematic Literature Review

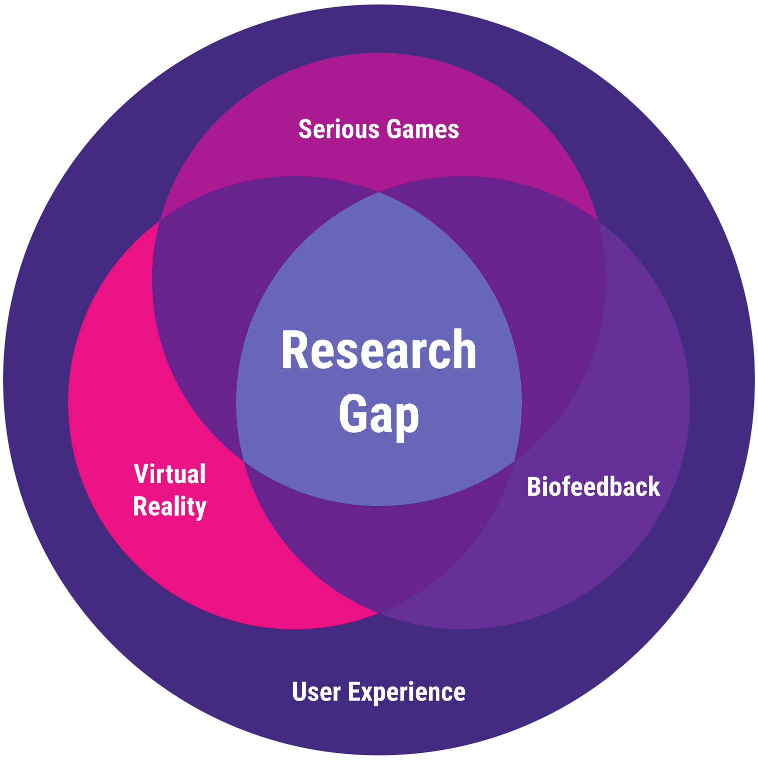


Source: Adapted from Kitchenham et al. (2009).

As mentioned in the previous topic, the pillars on which this proposed method will be based comprise a unique combination of technologies and methods or processes, which makes it unprecedented for the purposes and context for which it is proposed.

More specifically, the Virtual Reality and Biofeedback technologies, combined for the creation of simulators for training security professionals and law enforcement agents whose contents consist of Serious Games and developed with focus on the User Experience. Figure 2 presents a diagram of how these pillars are combined in order to highlight the research gap.

Figure 2 - The pillars addressed in this thesis and the research gap



Source: Elaborated by the author.

As recommended by the Systematic Literature Review method (KITCHENHAM et al., 2009), defined the objective of the review, which in this case is to highlight the research gap, the next activity is to define the research question to be answered as a result of the review. In order to highlight the gap in research and considering the technological and theoretical pillars that ground this thesis, the question that will guide this SRL is:

SRL research question: What are the main models, methods, structures, frameworks architectures, roadmaps or processes used in the construction or development of Virtual Reality simulators that combines Biofeedback and Serious Games for specialized training and that considers the User Experience as a factor?

Once the research question is defined, the next activity that closes the first phase is to define a research protocol. In the specific case of this thesis, this activity was carried out separating the research into four parts, following the recommendation of Snyder (2019), according to the themes considered in this thesis:

1. Terms related to the expression "virtual reality simulators", such as “vr simulator” and “vr simulation[1]”;
2. Terms related to “biofeedback”, such as “iot”, "sensors" and "vitals";
3. Terms related to the construction process, such as "model", "method", "framework", "proces", "rodamap" and "guide";
4. Term “serious game”.
5. Terms “user experience” or “ux”.

Before proceeding with the process of building the research protocol, that besides the definition of the search terms also involves the definition of inclusion and exclusion criteria, it is necessary to define which databases will be considered during the search. For the purposes of this research and considering the substantial differences between databases, it was decided to perform these searches in Scopus (SCO) and Web of Science (WOC) databases, since both have different coverage, but similar rigor in relation to the journals indexed by both databases (FALAGAS et al., 2008; THELWALL, 2018).

It is precisely for this reason that Google Scholar was not chosen, which offers the most extensive coverage, but at the expense of quality, which directly impacts on search rigour and quality (MORTENSON; VIDGEN, 2016).

[1] Database searches can be performed with precise terms and the use of quotation marks, or by applying rules that reduce terms to their root. This practice is known as stemming. In the specific case of this search, the term "simulator" can be reduced to "simul*", which would return results such as "simulator", "simulation" or "simulators", among other variations based on the same root. A detailed discussion of how the technique works can be found in (SINGH; GUPTA, 2017).

Both databases have similar search engines and operate based on the search of different fields and using techniques such as wildcard characters, here represented by the symbol "*", which serves to replace variations in terms and inflections. Wildcards are a search technique that can be used to maximize search results in databases. In addition, boolean operators such as AND, OR and NOT were also applied. These operators connect search terms in order to narrow or broaden a result set. An example of the search string initially used in the Scopus database is presented in Table 1. An overview of the combinations of search terms in each of the databases will be presented in the following Table 2.

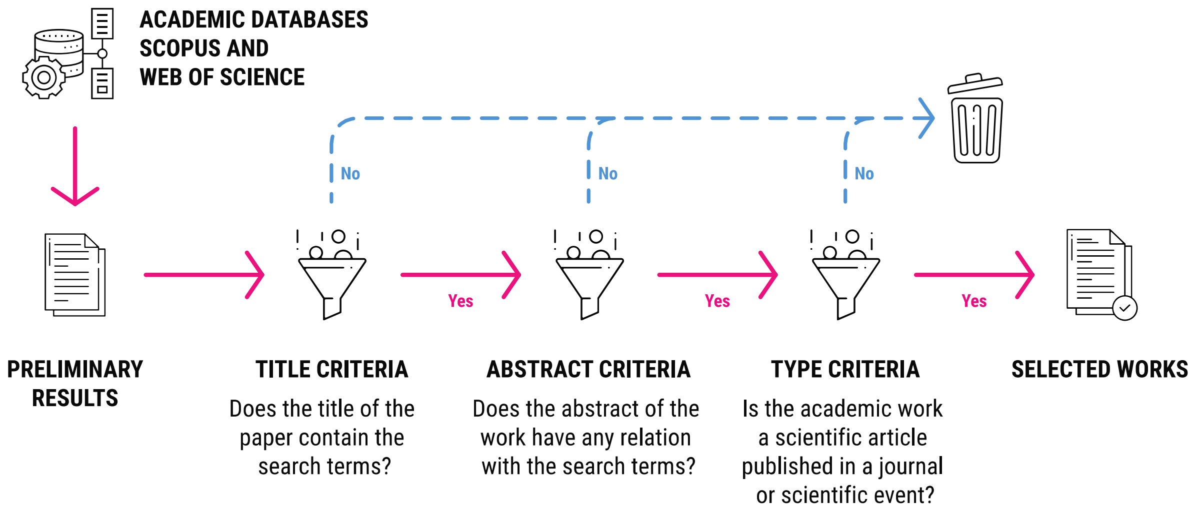
Table 1 - Example of a search string initially used in Scopus database

```
("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR
sensors OR vitals AND design* OR develop* OR framework OR workflow OR
roadmap OR guide* OR construct* OR model*)
```

Source: Elaborated by the author.

Once the search terms and databases to be used have been defined, the inclusion and exclusion criteria are defined, which was done, in the context of this work, in a similar way to the method known as *Preferred Reporting Items for Systematic Reviews and Meta-Analyses - PRISMA* (MOHER et al., 2009), which suggests, among other things, a flowchart of inclusion and exclusion of articles based on clear rules, presented in Figure 3 with the criteria used in this review.

Figure 3 - The inclusion and exclusion criteria used in the search for academic papers



Source: Elaborated by the author.

As a way to delimit the search for articles and ensure the reproducibility and the rigor of the selection process of academic papers (VOM BROCKE et al., 2009; SNYDER, 2019), some additional criteria have been defined. This action refers to the first and second activities of the second phase of the Systematic Literature Review according to the model of Kitchenham et al. (2009).

In the context of this thesis, only academic papers published in peer-reviewed journals were chosen, which excludes white papers, theses and dissertations from the selection. Only papers published in English and whose title and abstract contained the terms used in the search were considered, no matter, therefore, the country of origin. As for the date of publication, all papers published were considered at first, since the nature of the combination of technologies addressed in this thesis makes the possibility of finding older papers very small. The searches for articles were made between September 2019 and December 2020. Table 2 presents the result of the searches made in the Scopus and Web of Science databases.

Table 2 - Results of search done in the chosen academic bases

N.	Database	Search string used	Results	Filter
01	SCO	("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals)	1.256	None
02	SCO	TITLE-ABS-KEY ("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals)	123	Title, abstract and keywords
03	SCO	TITLE-ABS ("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals)	109	Title and abstract

N.	Database	Search string used	Results	Filter
04	SCO	TITLE ("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals)	3	Title
05	SCO	("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals AND design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	1.235	None
06	SCO	TITLE-ABS-KEY ("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals AND design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	100	Title, abstract and keywords
07	SCO	TITLE-ABS ("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals AND design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	87	Title and abstract
08	SCO	TITLE ("virtual reality simulat*" OR "vr simulat*" AND biofeedback OR iot OR sensors OR vitals AND design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	0	Title
09	WOC	ALL=("virtual reality simulat*" OR "vr simulat*") AND ALL=(biofeedback OR iot OR sensors OR vitals)	66	None
10	WOC	TS=("virtual reality simulat*" OR "vr simulat*") AND TS=(biofeedback OR iot OR sensors OR vitals)	59	Title, abstract and keywords
11	WOC	TI=("virtual reality simulat*" OR "vr simulat*") AND TI=(biofeedback OR iot OR sensors OR vitals)	1	Title
12	WOC	ALL=("virtual reality simulat*" OR "vr simulat*") AND ALL=(biofeedback OR iot OR sensors OR vitals) AND ALL=(design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	60	None
13	WOC	TS=("virtual reality simulat*" OR "vr simulat*") AND TS=(biofeedback OR iot OR sensors OR vitals) AND TS=(design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	49	Title, abstract and keywords
14	WOC	TI=("virtual reality simulat*" OR "vr simulat*") AND TI=(biofeedback OR iot OR sensors OR vitals) AND TI=(design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	0	Title

Source: Elaborated by the author.

Given the specificity of the subject and the low probability of intersection of all search terms, it was chosen to start the search for papers that intersect “Virtual Reality Simulators” and “Biofeedback” technologies, focusing on construction methods and processes. As indicated in Table 2 the searching without any filter returned a significant amount of results in both databases, as seen in searches 01, 05, 09 and 12. In the case of the Scopus database, the number of results was significantly higher than the results in the Web of Science database, which can be explained by the size of the database and the number of indexed journals (THELWALL, 2018). From the moment that more specific fields are used and the quantity of search terms related to the purposes of this thesis increases, the quantity of results tends to decrease, as shown in searches 04, 08, 11 and 14.

Finally, it is important to note that the terms "Serious Games" and "User Experience" were used, but due to the specificity of the application proposed in this thesis, no results were returned. Even so, it is clear that there is a gap in the literature as it has not been possible to find academic papers with characteristics similar to those proposed by this research on any of the scientific databases adopted, as highlighted in research results 08 and 14.

In the next phase the exclusion criteria would be used per type of paper and per year of publication, but the research did not reach that phase because no papers were selected in the previous phase.

1.2.2 The search for patents

The second part of the literature review focuses on patents. This is due to the fact that this research is located on the edge of some application areas, and proposes something not only new, but still little explored. The nature of this research is consistent with the description given by Chen et al., (2020), which states that new technologies are, quite often, recombinations of previous technologies and, in many cases, use the knowledge of the past known as a key ingredient.

According to the World Intellectual Property Organization (WIPO) a patent is an exclusive right conceded by the State for an invention, which can be a product or a process (WIPO, 2020). This product or process generally provides a new way of doing something, or offers a new technical solution to a problem. In return, inventors agree to disclose to the public all technical information about the invention in a patent application. Patents, therefore, have the potential to not only reflect new knowledge, but can also serve as the initial seed from which recombination can later create more knowledge and technologies (CHEN; KIM; MICELI, 2020).

However, the task of searching for patents is not simple, and this is due to a series of characteristics of this type of data. The first is that it is not possible to obtain a "world patent" or a universal "international patent". Patents are territorial rights (WIPO, 2020), which implies searches in different organizations and databases. The second factor refers to the exponential increase in patent registration in recent years, led by Asia, which was responsible for more than two thirds of all patent applications, trademarks and industrial design in 2018, followed by the United States.

Therefore, as a way to accomplish the task of searching for patents and aware of the limitations imposed by the nature of the data, a method was employed in this research to make the search process not only more agile, but also judicious. This method is known as

Computational Literature Review (MORTENSON; VIDGEN, 2016; KUNC; MORTENSON; VIDGEN, 2018; LEE; SHIN, 2019), and is based on the use of algorithms and computational methods to perform the task of literature review in large sets of texts, which makes it ideal for the search of documents such as patents or academic papers.

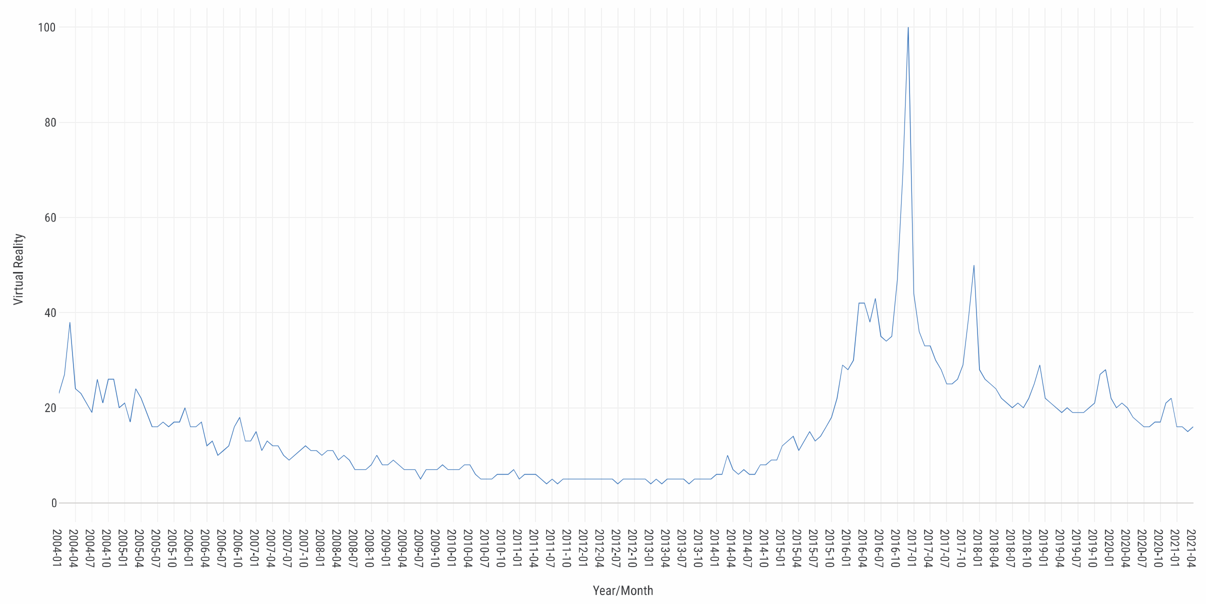
Computational approaches to literature analysis can provide greater validity, thus offering a more objective approach to identify relevance and connection between articles in literature reviews. Another factor for the application of this method refers to a possible decrease of human bias in the choice of articles that will be part of the review, something that could happen in other manual review methods (KUNC; MORTENSON; VIDGEN, 2018). Using a literature review method supported by computer algorithms can be a way to provide agility in literature review and, at the same time, decrease human bias when dealing with the task, whose nature is undoubtedly repetitive (MORTENSON; VIDGEN, 2016).

Until recently, most people found it difficult to find patents. Many patent offices, like the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO), provide free access. These databases, however, are difficult to search. Only simple search phrases are permitted, and many patents are written in complex legal jargon. In addition, some patents are registered in a non-textual format, such as images or gene sequences. In order to perform a proper search, it is necessary to understand how the patents are written and organized, in addition to determining a strict search criterion. The main consequence of this decision is to fatally exclude patents that would be important for the research, but that do not meet the requirements.

Considering this limitation, it was defined that the research for patents conducted in this research would be based on the database Lens.org (LENS.ORG, 2020). The reason for the choice is due to the fact that this database comprises more than 127 million patent registrations from more than 95 different jurisdictions and is completely open and freely accessible. In addition, the base has features that facilitate the search for patent filters, such as advanced Boolean functions, structured search, biological search, classification search, filtering and classification options.

However, there is a difference in the search for a patent that should be clarified, and it refers to how old the patent is. Considering that the maximum duration of some types of patents is twenty years (HORWITZ; HORWITZ; HERSHMAN, 2018), and that some of the technologies addressed in this research have only recently become widely developed, there is no point in extending the research time by patents registered decades ago. Therefore, the search for patents published in the last twenty years has been defined as an additional parameter. As a way to demonstrate the popularity of the term Virtual Reality, we used Google Trends[2] which is a Google site that analyzes the popularity of the top search queries in Google Search in various regions of the world and multiple languages. The site uses graphs to compare the search volume of different queries over time and demonstrate its longitudinal evolution. Figure 4 shows the volume of searches for the term "Virtual Reality" worldwide between January 2004 and May 2021.

Figure 4 - Searches for the term "Virtual Reality" worldwide between 2004 and 2021



Source: Elaborated by the author.

It can be seen from the analysis of the graph that the popularity of the term had a jump between the years 2015 and 2017, which coincides with the launch of a number of Virtual Reality devices that helped popularize the technology and make it accessible to a huge majority of people.

Finally, the last rule defined for the analysis of collected patents refers to the availability of the full text of the patent. The full text comprises the set of claims (even independent and dependent claims), the description, the abstract, and the title (NIEMANN; MOEHRLE; FRISCHKORN, 2017). It is possible to understand the content and application of a patent just by looking at its abstract, or even infer something about it just by reading the title. However, it

[2] https://trends.google.com/

is important to note that there are several patents with exactly the same title and with different sizes of abstract, which do not follow a minimal structure and are sometimes vague. Without access to the full text of the claim it is very difficult to assess the limits or scope of a patent, which makes its adoption impossible for the purposes of this research. Therefore, the availability of the full text of the patent was adopted as the final criterion to select the patents that should be considered.

Regarding the conduction of searches and aiming at research reproducibility, the parameters approached are exactly the same used in the search for academic papers, as previously explained. This includes the key search terms and the Boolean operations applied in the two databases chosen for the collection of academic papers.

However, there is a specific feature of the Lens.org platform that refers to a practice known as stemming, automatically applied in searches performed by the platform. In linguistic morphology and information retrieval, the term stemming refers to the process of reducing the flexed words to the trunk, base or root shape - usually a written word form (SINGH; GUPTA, 2017). However, for the purposes of this research, it was chosen not to use stemming, since the intention is to focus on specific terms and be more precise and accurate[3]. Moreover, the use of stemming proved to be a bad choice in the first searches for bringing results that had absolutely nothing to do with what was intended to search. Regarding the type of document, no distinction was made between Patent Application and Granted Patent.

The search for patents was done between November and December 2020. Table 3 shows the results of searches made in the Lens.org database and details the results found based on the parameters previously explained in item 1.2.1.

Table 3 - Results of the searches for patents made at Lens.org

N.	Search string used	Results	Filter
01	(virtual reality) AND simulat*	71.693	None
02	(title:(virtual reality) OR abstract:(virtual reality) OR claims:(virtual reality)) AND (title:(simulat*) OR abstract:(simulat*) OR claims:(simulat*))	2.910	Title, abstract or claims
03	(title:(virtual reality) AND abstract:(virtual reality)) AND (title:(simulat*) OR abstract:(simulat*))	557	Title and abstract
04	(virtual reality AND simulat*) AND title:(biofeedback OR iot OR sensors OR vitals) AND title:(design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)	10	Title and abstract

[3] There is a more detailed explanation on how the Lens.org platform deals with stemming and the consequences of its adoption in https://support.lens.org/help-resources/basic-help/search-syntax/.

N.	Search string used	Results	Filter
08	(title:(virtual reality) OR abstract:(virtual reality)) AND (title:(simulat*) OR (abstract:(simulat*)) AND (title:(biofeedback OR iot OR sensors OR vitals)) OR (abstract:(biofeedback OR iot OR sensors OR vitals)) AND (title:(biofeedback OR iot OR sensors OR vitals)) OR (abstract:(biofeedback OR iot OR sensors OR vitals)) AND (title:(design* OR develop* OR framework OR workflow OR roadmap OR guide* OR construct* OR model*)))	8	Title and abstract

Source: Elaborated by the author.

As a way to understand the universe of possible patents related to the main construction the first search was made without any filter and using the expressions "virtual reality" and "simulat*", which in this case applies a wildcard character that allows to recover variations of the term. This first search returned 71,693 patents. Since there are no restrictions from where the terms should appear in the texts of the patents, it should be considered that many of the results are of no interest to this research because they return works in all and any application involving virtual reality and simulators. In a preliminary analysis, it was found that some of the returned results used both expressions, but referred to designs or methods that had little to do with the scope of this research.

The second research was carried out with the same terms, but in different positions, such as title, abstract and claim, and returned 2,910 results, a number still very large and without refinement. As previously explained, patent titles do not necessarily reflect their content in an accurate manner. Therefore, it is necessary to apply different combinations of fields, such as title and abstract, which is done using boolean operators, as was done with the research by academic papers.

The third search was based on criteria similar to the second, but removing from the search the field of claims, which generated a total of 557 results. The exclusion of claims from searches is due to the fact that if there is any mention of the area of application or main technology (in this case Virtual Reality) in the title or abstract, it will necessarily appear in the claim (HORWITZ; HORWITZ; HERSHMAN, 2018). This would not be true if it was just a generic term, but in this case, it makes sense. However, it should be noted that up to this point only patents resulting from the relationship between the terms "virtual reality" and "simulat*" were sought, combining simultaneously title and abstract, without therefore including the other terms of interest for this research.

The fourth search was a little more restrictive on certain terms and more flexible on others, and now includes more search terms. In this case, the first part of the search ("virtual reality" and "simulat*") was done freely (without specifying the field where the search should be done), which means that the term will be searched in all the fields available in the database. The expressions related to "biofeedback" and to "methods", "processes", and other terms were restricted only to the title, since this also relates to the nature of the patent, which in this case could be a method or process, as previously explained. This search returned only 10 results of patents registered in the last twenty years, which after analysis and reading of summary and description of the text of the patent, allowed discarding all the results.

Finally, the fifth and last search adopted an approach similar to the fourth, but restricting terms in different positions (fields) in a search more structured in terms of rules, and validated by the system itself[4], resulting in 8 patents. After reading the results, all were discarded for not containing the combination of technologies and application proposed by this search, which reinforces once again its need for execution. It is important to mention that the search terms related to "Serious Games" and "User Experience" were not applied in the patent search. Both terms relate to processes or methods rather than technologies per se. Although it is possible to register processes or methods, a search for both terms in any database will always return a technology or platform that enables, applies, or enhances the use of both. As an example, a search on the Lens.org platform with the term "Serious Games" in the patent title and no time limit returned only 29 records (the search was conducted in December 2020). Almost all the results had something in common: platforms or technologies that use or enable the use of Serious Games. None of them remotely close to the one proposed by this thesis.

At the end of the search for patents and aware that there may be, as previously mentioned, combinations or recombinations of technologies similar to those approached in this research, it is convenient to make explicit that there is, until the moment that the researcher closes this paragraph, no explicit knowledge of a specific combination of technologies with the purpose or application suggested by this work. It is equally important to recognize that the choice of the search database, no matter how logical, does not completely solve a limitation inherent to the type of data being searched. When it comes to patent data, there are limitations that may affect the result of any search. Some of these limitations are inherent to the data provided by the Patent Offices, while others result from the processing of this data by the platform.

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[4] The website has a tool dedicated to the validation of search strings. This makes it possible to search more assertively and according to the internal structures of the site's patent database. There is a detailed documentation about the search in the system, which can be accessed in https://support.lens.org/help-resources/basic-help/how-patent-search-works/.

Therefore, this research is not alienated from the consequences of ignoring, for example, patents without full text. However, for methodological reasons, such as scientific accuracy and reproducibility (POPPER, 2002), it was decided to consider only the complete documents, which should be reflected in work based on this type of data. Even so, the analysis of the results obtained in the searches, even considering all the limitations, further highlights the uniqueness of this work, as well as denotes its importance as a way to advance the existing knowledge in an area that is still assisting its first steps, but whose potential is undeniable.

1.3 Research Problem

As discussed in the previous topic, it is evident that there is a research gap to be explored, since there are no academic papers or even patents with the specific characteristics or application proposed by this thesis. Therefore, the research question that this thesis proposes to answer is:

Thesis' research question: *How to design a method to develop Virtual Reality simulators in combination with Biofeedback and using Serious Games applied to the specialized training of security professionals and law enforcement agents considering the User Experience as the predominant factor?*

1.4 Objectives

The general objective of this thesis is:

Propose and validate the design of a method to guide the development of Virtual Reality simulators that combine Biofeedback and Serious Games applied to the specialized training of security professionals and law enforcement agents that consider the User Experience as the predominant factor.

In addition to the main objective of this thesis, the following specific objectives are presented:

I. Develop a Virtual Reality simulator prototype and validate its construction phases as a proof of concept.

II. Design a method for developing Virtual Reality simulators based on the knowledge acquired from building the prototype that combines Biofeedback, Serious Games and is applicable to the training of security professionals and law enforcement agents.

III. Validate the proposed method with Virtual Reality industry professionals and academic researchers.

1.5 Justification of the Research

The police is one of the most significant institutions of the state, because of the practical results it seeks to achieve (BRAGA, 2003), directly related to the control of conflicts that affect the social order and impact people's lives. In this sense, the main objective of police work is to contribute to the creation of an environment in which people feel safe and can have their rights secured. Therefore, when law enforcement agents commit operational mistakes or deviations of conduct, such mistakes directly reflect in the perception of the efficiency of the organization as a whole by society, which ultimately judges police action and performance (DADDS; SCHEIDE, 2000).

Among the countless problems and disastrous consequences of police misconduct is the high number of deaths caused by law enforcement agents during the course of their activities. A report published by the *Small Arms Survey*, an independent research project located at the Graduate Institute of International and Development Studies in Geneva, Switzerland, states that each year between 2007 and 2012, an estimated 19.000 people were killed during 'legal interventions,' that is, during police encounters all over the world (CARAPIC; DE MARTINO, 2015).

An effective way to decrease the amount of incidents, operational errors and other recurring problems in the performance of police officers is to invest in constant training (HAYES, 2002). There is evidence that investment in police training and education contributes to form better law enforcement agents (CORDNER; SHAIN, 2011; MAZEROLLE; TERRILL, 2018), In addition to improving aspects such as the empathy of police officers (COMPTON et al., 2011; OXBURGH; OST, 2011; LILA; GRACIA; GARCIA, 2013; BAKER-ECK; BULL;

WALSH, 2020), a factor that contributes significantly to police performance and approach in various situations.

However, police training is very expensive, complex, time consuming and not very flexible, since only a small variety of real-life scenarios and situations can be included during police training (CORDNER; SHAIN, 2011; BERTRAM; MOSKALIUK; CRESS, 2015). In addition, the costs associated with police action and the maintenance of the public security structure increase every year (MALM et al., 2005). Besides the high training costs and budget limitations, there are a number of other variables that make police training even more complex. Werth and Werth (2011) cite staff commitment, and student and staff resistance to learning as components that directly interfere with the use of police training.

Finally, there is the problem of human bias in the evaluation and performance of professionals in training. Usually the police field training is conducted under the supervision of a dedicated training professional or a more experienced police officer, who evaluates and judges the performance of the trainee (CORDNER; SHAIN, 2011; MCGINLEY et al., 2019). The figure of the evaluator or supervisor is indispensable for the evaluation process of the officer in training, since the learning process contains non-tangible elements and can be improved by the process of tacit knowledge transfer (POLANYI, 1966). However, his or her evaluation of the officer's performance in training can be affected by a series of personal judgments of which not even he or she is aware. This behavior is known as implicit bias.

Unconscious (or implicit) bias is the visions and opinions about which we are not conscious (CORNISH; JONES, 2013). This type of bias is automatically activated and often operate outside the consciousness of the one who practices them (LAI; HOFFMAN; NOSEK, 2013) and directly affect our daily behavior, our preferences and our decision making (KAHNEMAN; LOVALLO; SIBONY, 2011).

One way to make police training more accessible, flexible, exciting, and at the same time, support the evaluation of supervisors during police training is by using a combination of some technologies and practices. More specifically, this thesis proposes the combination of Virtual Reality and Internet Things to create simulators applied to police training, whose content is composed of Serious Games and considering the user experience as the predominant factor. The development of complex simulators for police training applications with some technology that can help the evaluation and performance of the policeman who uses the simulator still does not have a guide, model or even method that can be applied specifically for this purpose.

Several studies show that Virtual Reality has been applied with great success to the specialized training of security professionals and law enforcement agents due, above all, to its ability to bring real and immersive feedback, besides being able to provide several different scenarios, some impossible in the real world (NETTO, 2015; CASERMAN et al., 2018; DE ARMAS; TORI; NETTO, 2020). However, a common gap in the applications of this type of technology to the safety area reveals the same weakness: the lack of efficient ways to assess the trainee during the use of the simulators (DE ARMAS; TORI; NETTO, 2020).

As a way to contribute to this gap, this thesis proposes the use of sensors to capture biofeedback data in order to improve the evaluation of trainees by the use of real data, diminishing the cognitive bias during the evaluation process. More specifically, data related to the stress of the trainees during the use of the simulator. Stress is an intense, natural and universal reaction that guides both cognitive and physical processes (BANDODKAR; GHAFFARI; ROGERS, 2020a), and can be measured by the use of sensors that capture data such as sweating and heartbeat (CAN; ARNRICH; ERSOY, 2019; ZAMKAH et al., 2020). For this purpose, the use of sensors that capture biofeedback data can serve as an indication to evaluate the response of these trainees to various visual stimuli and even obtain indications of how this trainee responds to each of the situations experienced.

However, even with the use of Virtual Reality as an innovative approach to training through the simulation of realistic environments and experiences, it is not always possible to engage trainees (KAVANAGH et al., 2017). One way to address this problem is through the use of serious games. Serious games are games whose primary objective is not entertainment or fun, and whose main application is related to learning (MILDNER; `FLOYD’ MUELLER, 2016; RALF DÖRNER, 2016; ARGASIŃSKI; WĘGRZYN, 2019). They involve the learner proposing challenges and through several design elements, such as reward systems, difficulty adaptation, narratives, among others. The combination of Virtual Reality technology and techniques and practices common to Serious Games has proven to be a productive approach to improve the engagement of simulator users and therefore worth exploring, even if there are caveats regarding certain elements and practices (CAI; VAN JOOLINGEN; WALKER, 2019; CHECA; BUSTILLO, 2020).

This research, therefore, proposes to present, as a final result, a method for developing simulators. For this purpose, this research will have as fundamental pillars the Virtual Reality technology, the use of Biofeedback and the application of Serious Game mechanics aiming to cover the exposed gaps and limitations.

1.6 Originality of the theme

The literature dealing with the application of simulators for security and defense activities is significant, even in such a specific application area. In addition, there are a variety of companies exploring this industry and producing simulators for specialized training of security professionals and law enforcement.

The article by de Armas et al. (2020), dedicated to mapping the application of simulators for training programs in the areas of security and defense, points out a series of problems in the training of law enforcement officers and security professionals, all of them previously raised by this thesis, such as the high cost of training and, consequently, the short exposure time to training in some cases. However, the article goes further, by trying to map the scenario of simulators and point out their main weaknesses, which makes it interesting as a way to reinforce what this thesis has already detected as problems: what is common to all simulators analyzed by the article is the complete absence of information about the educational methods used in training with simulation and the lack of automatic evaluations of users.

Another detail that this particular article ignores is the fact that some of the commercial simulators cited by it cost thousands of dollars, which would make its adoption by police departments in some countries impossible, especially in states and cities with lower budgets. Still, the simulators cost less than investing in real specialized training, which may include expenses such as shooting booth rentals, round trips (transportation, food, among others), and weapons rentals, to name just a few.

Although the topic is interesting and the simulators have proven their importance and effectiveness, this thesis focuses on a specific question: how are Virtual Reality simulators applied to the training of police and security professionals?

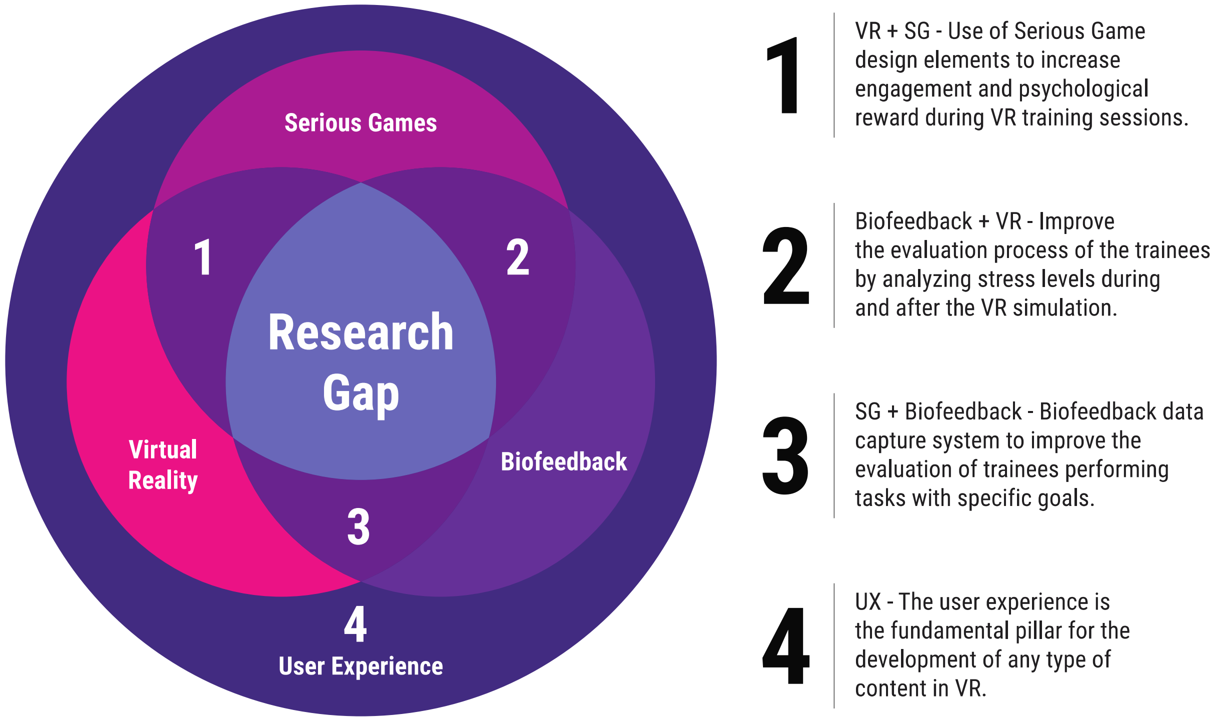
To try to answer this question a series of steps have been taken. At first and to try to verify the validity of the questioning, some informal conversations with developers from different countries and researchers in the field were conducted. During these conversations one thing became clear: none of the interlocutors cited a single method, process or specific reference from the Virtual Reality area, but all of them cited practices common to Software Engineering and some claimed to use paradigms, methods and techniques of software development, in addition to expertise acquired in other areas, such as application development for mobile devices and games.

Since this is a Ph.D. thesis, the next step was to consult the academic literature to try to confirm or refute the assumption that there is no specific method for developing Virtual Reality simulators for the application to which this thesis is concerned. However, after an extensive search that lasted months for academic publications dedicated to Virtual Reality simulator development methods or guides applied to the specialized training of security professionals and law enforcement agents, it was not possible to find any work dealing with the subject. At least no single work with the scope and characteristics similar to those suggested by this thesis.

Another front of efforts to search for solutions that fit the scope and objective of this thesis was done in patent databases. However, after an extensive search it was not possible to find any patent registration with the characteristics described in this work. This is due to the fact that the technologies addressed in this thesis and, more specifically, the interaction between them, represents in itself an unprecedented application.

The research gap addressed in this thesis goes beyond just proposing a method for the development of virtual reality simulators. This work aims to contribute theoretically and practically, in an inter and multidisciplinary way, to expand the knowledge about the development of complex Virtual Reality simulators applied to the specialized training of security professionals and law enforcement officers. Figure 5 highlights the theoretical pillars and the possible interactions between these pillars in the way proposed in this thesis.

Figure 5 - The theoretical pillars of this thesis and their possible interactions



Source: Elaborated by the author.

This will be done, in the context of this research, through the use of a research paradigm called Design Science Research, a relatively new approach to research (JANSE VAN RENSBURG; GOEDE, 2020) with the aim of constructing a new reality (i.e. solving problems) instead of explaining an existing reality, or helping to make sense of it (IIVARI; VENABLE, 2009).

1.7 Structure of this thesis

This thesis is divided into seven chapters which, in turn, are divided into smaller sections with their respective subsections. The chapters, sections and subsections present the development of the study in order to document it and report the results as evidence for the fulfillment of the specific and secondary objectives and the answer to the research question. This section briefly explains this organization.

The present chapter, **Chapter 1**, presents a contextualization, an overview of the problem addressed by the thesis and other general aspects. More specifically, this chapter also presents the research gap, the general and specific objectives, the justification for conducting this research, as well as the originality of the theme and the theoretical and operational definitions adopted in this research.

Chapter 2 brings the theoretical background in the areas of Virtual Reality, Serious Games, Biofeedback and User Experience, also called theoretical pillars.

Chapter 3 of this thesis presents in detail the methodological choices that guide the development of this research. This chapter begins with the methodological characterization and explains, in a detailed way, the Design Science Research paradigm, as well as its scientific basis. This chapter also presents the artifacts generated by this research and provides further details on how the generated artifacts have been demonstrated and evaluated.

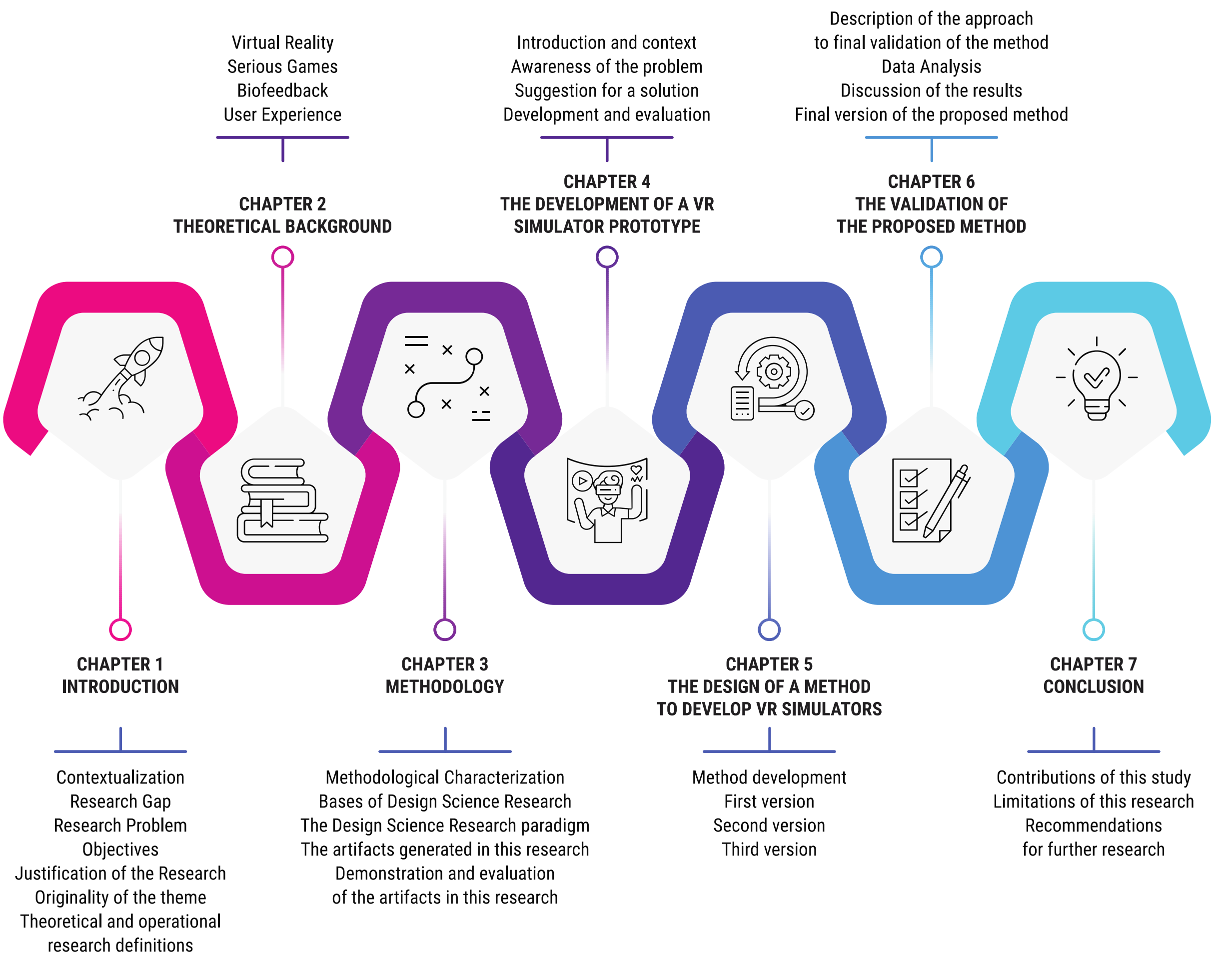
Chapter 4 is entirely dedicated to the development of the first artifact deriving from this research, a Virtual Reality simulator prototype, as well as detailing the process of developing and validating this prototype. The knowledge generated from the development and validation of this prototype provided subsidies for the formulation of the second artifact obtained in this research: a method to guide the development of Virtual Reality simulators applied to the training of security professionals and law enforcement officers. The development of this method is detailed in **Chapter 5**.

Chapter 6 consists of the validation process of the proposed method, whose development is reported in Chapter 5, and offers a detailed analysis of the answers, as well as of the respondents by means of graphs, tables, and descriptions, offering subsidies about the level of acceptance of each of the stages and cycles of the method.

Finally, **Chapter 7** is dedicated to the conclusions and analyzes the possible contributions of this study to academia, and to professionals. This chapter closes with a reflection on the limitations of this research, and offers a number of recommendations for further research.

As a way to illustrate in a general way the organization of this thesis, Figure 6 presents a scheme that contains all the chapters and highlights the content of each of its sections.

Figure 6 - General structure of this thesis with indications of the generated artifacts



Source: Elaborated by the author.

2 THEORETICAL BACKGROUND

This chapter presents the theoretical background in the areas of Virtual Reality, Serious Games, Biofeedback and User Experience, upon which this thesis is based. Each section of the chapter covers one of the theoretical pillars of the thesis and each subdivision covers a more specific aspect.

2.1 Virtual Reality

Virtual Reality (VR) is a technology that allows the immersion of a user in a multi-sensorial representation of a real or fictional computer generated virtual environment (BENEDEK; VESZELSZKI, 2017; CISNEROS *et al.*, 2019; KARDONG-EDGREN *et al.*, 2019). The immersion provided by this technology promotes a user experience which, in turn, is supported by an interactive graphic interface enhanced by non-visual modalities such as auditory, haptic and olfactory to allow the user to feel the presence of a real physical environment (SHAFER; CARBONARA; KORPI, 2017; TAO *et al.*, 2019).

VR is part of a series of technologies commonly described as “immersive” that comprise different levels of user immersion (MILGRAM; KISHINO, 1994). These technologies (such as Augmented Reality or Mixed Reality, among others) are classified according to the degree of “virtuality”, which allows them to define how much the real world is complemented by digital elements. In general, VR technology has the highest degree of virtuality, i.e., the de facto immersion of the user in the context presented.

This, in turn, means that the VR is able to provide experiences with the highest level of immersion compared to other technologies. In Figure 7 the seminal concept created by Paul Milgram and Fumio Kishino (1994), is exposed, in which elements such as the real environment and the virtual environment are presented, as well as the augmented reality, closer to the real environment, and the virtualized reality, closer to the virtual environment.

Figure 7 - Different immersive technologies according to the immersion level

Source: Adapted from Milgram and Kishino (1994).

Sherman and Craig (2003) define the virtual as the being in essence or effect, but not in fact; and reality as the state or quality of being real. Although it may cause confusion of understanding, the authors define Virtual Reality as, in its essence, a term that contradicts itself. What is most fascinating about this definition is that, even though it may seem contradictory, such concept describes the technology in an almost paradoxical way, which allows us to understand its greatest potential: to recreate, represent, transpose and make the user immerse in synthetic, artificial and interactive worlds.

One of the best definitions of the potential of Virtual Reality technology comes from one of its founders, Ivan Sutherland, who developed one of the first VR systems in the world back in the 1960s. The author states that the ideal experience would naturally be an environment within which the computer could control the existence of the matter, in which a chair could be convincing enough to sit in it, or even where handcuffs would be able to confine in fact and a projectile displayed in such an environment would be fatal in the user's perception (SUTHERLAND, 1965).

Sutherland's (1965) definition evokes the threshold between the real and the imaginary, and even after decades of technological advance such a vision is still very current. However, the quantity and variety of applications of Virtual Reality technology and its potential have been widely explored in recent years. In parallel, the technology is becoming increasingly accessible to a large audience. This fact further increases the possibility of further exploration of its immersive capacity, which for some represents a huge leap towards new ways of consuming content (MOLLET; ARNALDI, 2006; BUCHER, 2018).

Virtual Reality technology is generally classified in relation to the different levels of immersion made possible in virtual environments. Immersion is an objective and characteristic description of technology, which allows people to experience and explore virtual spaces in a way similar to real life experience (MCMAHAN, 2003; SLATER *et al.*, 2009; KIM; JEON; KIM, 2017). In this sense, immersion reflects the extent to which computers allow the involvement of users to better represent reality, involving their panoramic view. Furthermore, it is an exquisite technology in terms of resolution, richness, information about the content and disconnection caused in the user in relation to the other physical realities present in the environment (SLATER, 2018).

In Virtual Reality, the perception of presence is a subjective illusion, since users experience a sensation of leaving their current physical location and transporting themselves to the virtual environment to which they are exposed. Thus, users act as if they were really in the virtual environment, perceiving individuals or virtual objects as being real (SLATER *et al.*, 2009; SLATER; SANCHEZ-VIVES, 2016; SLATER, 2018). As a result, the sensation of the user's presence is influenced by several factors, including technological elements, such as the resolution of displays, up to physical obstacles and awareness of devices or equipment (WEECH; KENNY; BARNETT-COWAN, 2019); and also internal factors, such as personality traits or propensity to immersion of each user (BAÑOS *et al.*, 2004; WEIBEL; WISSMATH; MAST, 2010) and, finally, social factors, such as interactions with virtual characters.

In addition, strong emotions such as stress are correlated to a high sense of presence (DIEMER *et al.*, 2015). However, one of the elements that most interferes with a true immersion and the feeling of the user being elsewhere is the awareness of the participants of the simulated environment that is presented to them (SLATER; SANCHEZ-VIVES, 2016; WEECH; KENNY; BARNETT-COWAN, 2019). Finally, one of the factors that can prevent a better experience in immersive environments is known as motion sickness, which refers to the sensation of dizziness, which can be experienced by many people who are introduced to certain Virtual Reality experiences (SAREDAKIS *et al.*, 2020).

The fact is that Virtual Reality technology has a lot of potential for the educational area, which is evident in the quantity and variety of publications dedicated to its applications and effects in this field of research (MIKROPOULOS; NATSIS, 2011; NETTO, 2015; KAVANAGH *et al.*, 2017; PAPANIKOLAOU *et al.*, 2019). Computer-based virtual learning and training environments have existed for decades, but with the advent of immersive technologies, the potential is promising, especially as a way to offer infinite possibilities for exploration through immersion (ZIEGLER *et al.*, 2020). With the aim of improving learning outcomes, VR is able to offer a real replica of environments, which allows participants to evolve within such environments, as well as interact with them while using a head mounted device (HMD) (GADIA *et al.*, 2018; JENSEN; KONRADSEN, 2018).

The Virtual Reality industry has developed a lot in recent years. The technological leap combined with the significant reduction in the cost of VR devices has contributed greatly to its evolution, making the VR available to both common consumers and companies and, eventually, has also allowed increased interest in this technology (FUCHS *et al.*, 2017; GADIA *et al.*, 2018; JENSEN; KONRADSEN, 2018; DE ARMAS; TORI; NETTO, 2020). Simultaneously, over time, the VR hardware market has also developed and currently has a wide variety of different types of devices. As a result, VR is gradually starting to be applied in more and more areas such as entertainment, education, medicine, training, industry, tourism, historical heritage preservation, security and military training (LAWSON; SALANITRI; WATERFIELD, 2015; NETTO, 2015; HOANG *et al.*, 2019; MAKRANSKY; TERKILDSEN; MAYER, 2019; PALLAVICINI; PEPE; MINISSI, 2019; PAPANIKOLAOU *et al.*, 2019; TAO *et al.*, 2019).

Considering the objectives established in this research, it is convenient to focus on the application of Virtual Reality technology for the construction of simulators, besides emphasizing its main characteristics, which will be done as follows.

2.1.1 Virtual Reality Simulators

This topic aims to bring together different visions and offer a definition proposal on the concept of simulation in Virtual Reality. To do so, it is intended to use an approach known as "affordances" and proposed by Gibson (GIBSON, 1986). According to this approach, it is possible to define a technology focusing on its possibilities, instead of its technical characteristics. The advantage of this approach is that it is possible to define a technology by avoiding focusing on merely technical aspects and easily lagging behind, since the nature of any technology is its overcoming (ARTHUR, 2011).

It is possible to approach the Virtual Reality simulation concept in many different ways. One of the most famous in literature is the definition given by the French philosopher Jean Baudrillard in his work *'Simulacres et Simulation'*, which uses the concept of "simulation" to define the emulation of something that seems real, is admitted as real, but it is not necessarily real. This definition gives rise to the concept of "hyperreality" which, according to the author, provides individuals fleeing from the "desert of the real" the ecstasy of hyper-reality and technological experience (BAUDRILLARD, 1994). Although it is a totally philosophical definition, it helps to understand one of the most remarkable possibilities of Virtual Reality technology: make it possible to imitate real-world operations and processes, while at the same time provoking the feeling of "real".

The definition of Virtual Reality proposed by Burdea and Coiffet (2003) presents three main characteristics that corroborate Baudrillard's vision. This is because the authors affirm that Virtual Reality is a mixture of interaction, immersion and imagination. The interactivity of a simulation is defined as the degree to which the simulation acts in a similar way to the real world operational environment when reacting to the actions or inputs of the user (HAMSTRA *et al.*, 2014). Previous research on simulation-based learning suggests that if the similarity between simulation and the real world operating environment captures the critical elements or properties of the skills/tasks to be taught, other aspects (such as physical and sensory similarities) of simulation could tolerate lower levels of realism or deviations from the real world without compromising the effectiveness of training or learning (ALEXANDER *et al.*, 2005). There is even empirical evidence to suggest that an undue emphasis on physical similarity may divert attention away to irrelevant aspects of simulation, thereby undermining the primary objective of learning (NORMAN; DORE; GRIERSON, 2012).

Immersion can be defined as the quality of a simulation that provides mental absorption in a given experience and/or a perceptual presence within an artificial simulated space (MCMAHAN, 2003; SHERMAN; CRAIG, 2003; WITMER; JEROME; SINGER, 2005). Immersion can be classified in two types: diegetic immersion, which occurs when someone becomes absorbed by the experience; and situated immersion, which occurs when someone not only acts, but also experiences the illusion of existing within the simulation through the lived character (MCMAHAN, 2003; ALEXANDER *et al.*, 2005). The diegetic immersion means an experience of flow or cognitive involvement, while the situated immersion denotes presence, that is, psychological sense of being in the simulated place, be it a virtual, physical or computer mediated environment (LEE, 2004; WITMER; JEROME; SINGER, 2005; SLATER; SANCHEZ-VIVES, 2016).

The imagination provided by multiple representations in an immersive world refers to spatial representation and concrete visualization, either in a potentially invisible phenomenon or in a physically inaccessible object, which comes from a unique functionality of Virtual Reality and which promotes the construction of knowledge (MIKROPOULOS; NATSIS, 2011). Instead of using symbols, the environment represented by Virtual Reality supports the spatial representation of an invisible concept (for example, a cell, or the surface of Mars), as well as an impossible event (for example, a historical occasion passed hundreds of years ago) (KARDONG-EDGREN *et al.*, 2019). The extensibility of virtual reality also allows the user to perform actions and interventions in this world (HEDBERG; BRUDVIK, 2008) through simulations of complex scenarios that cannot be experienced in daily life, thus promoting the expansion and realization of imagination or vision. The incorporation of users through their 'avatars' (BLASCOVICH; BAILENSON, 2011), the interactions performed in various ways and the three-dimensional representations in a simulated environment supported by VR promote a greater sense of presence to the user (DALGARNO; LEE, 2010; BOWER; LEE; DALGARNO, 2017).

Considering the elements exposed up to this point, it is possible to have a vision of the main affordances of Virtual Reality technology and, therefore, its potential for simulations:

1. Possibility of replicating real world operations;
2. Interaction with the environment, objects and situations;
3. Immersion provoked by the presence or perception of presence in an experience, which seem "real" and are admitted as such; and
4. Imagination, which allows extrapolating interaction and, in turn, provides experiences that are not possible in the real world;

By observing the list of possible affordances of Virtual Reality technology, the potential of technology to promote learning becomes evident. Considering that this is exactly the focus of this research, it is convenient to add a vision about what is simulation-based learning. To this end, we adopted Sitzmann's vision, which stated that learning simulations refer to instructions given in an artificial environment and that immerse the trainees in a decision-making exercise in order to learn the consequences of their decisions (SITZMANN, 2011). The author did not talk specifically about Virtual Reality, but his definition is, surprisingly, coherent with the affordances of technology, besides focusing on the result: learning.

Thus, it is possible to broaden the definition of the author by appropriating, at the same time, the other contributions cited and to outline a definition of simulators in Virtual Reality: Virtual Reality simulation refers to the replication of real-world situations and procedures in a digitally constructed virtual environment that allows some level of interaction, provides immersion and allows trainees to learn the consequences of their decisions.

Some authors affirm that the difference between games and simulations is denoted by the fact that games are endowed with a series of intrinsic characteristics such as conflicts, rules and predetermined goals, while simulations are dynamic tools, representing reality, claiming fidelity, accuracy and validity (SAUVÉ *et al.*, 2007). However, it is perfectly possible to combine certain elements of both (games and simulators), since the areas of games and simulation are essentially, and above all, a field of interdisciplinary study, and which includes journals, organizations, specialists and an academic production established over the last decades.

Simulation and games cover a range of methods, knowledge, practices and theories such as simulation, games, serious games, computer simulation, modeling, agent based Virtual Reality, virtual worlds, experimental learning, game theory, role-play, case studies and many others (CROOKALL, 2010). A proof that the area of gaming and simulation is, in its nature, established as a research area is the existence of periodicals such as "Simulation & Gaming (S&G)", an interdisciplinary periodical of theory, practice and research dedicated to the exploration and development of simulation methodologies, in addition to games used in education, training, consulting and research, with over 40 years of existence and in continuous development.

The games are widely used in different areas of human activity, and this is reflected both in the diversity and richness of the types of games, and in the spectrum of possibilities of applications and users. In the specific case of this research, it is intended to suggest that the simulation be built in the form of Serious Game, taking advantage not only of its characteristics, but also (and above all), its possibilities of engagement in order to improve the learning experience of the user. Therefore, it is convenient to present the theoretical reference related to Serious Games pertinent to the objectives of this research, which will be done in the following topic.

2.2 Serious Games

The Serious Games are becoming a widely used solution for education and training in a wide range of corporate sectors (LARSON, 2020). However, their definition or adoption is not exactly new. The term “serious game” is originally credited to Clark Abt, who published his work in the 1980s as the starting point for the adoption of the concept (ABT, 1987).

Graham (1996) suggests that video games can deal with serious subjects, such as art and culture, and there are countless examples of this in extremely popular titles today. As an example, we can highlight the series Assassins Creed, by the company Ubisoft, on which several authors have focused to describe their contributions to cultural and historical aspects (SEIF EL-NASR *et al.*, 2008; BALELA; MUNDY, 2015).

However, there are clear distinctions between Serious Games and conventional games, electronic or not. In addition, it is worth noting that the literature addresses a multitude of terms and expressions related to the universe of games, reflecting both the number of actors involved and the diversity of their approaches and applications.

Serious Games are defined as games that have no entertainment or fun as their main goal (MILDNER; `FLOYD' MUELLER, 2016; RALF DÖRNER, 2016; ARGASIŃSKI; WĘGRZYN, 2019). According to Alvarez and Djaouti (2011), what distinguishes a serious game from a strictly playful video game is the addition of the serious dimension to the game scenario. Although Serious Games use characteristic elements of playful games, they are not aimed at entertainment or mere fun. The most important delineating characteristics of Serious Games are related to the psychological rewards and engagement resulting from the adoption process of such mechanics and their applications in the learning process (MICHAEL, 2006; WOUTERS *et al.*, 2013; ARGASIŃSKI; WĘGRZYN, 2019).

The literature on this subject presents a wide range of applications of the Serious Games, as well as their positive results in areas such as business, environment and ecological behavior, cartography, machine learning, software development, innovation, health, politics, education, tourism, finance, energy, mobility, accessibility, fashion, usability, risk management and marketing (BAPTISTA; OLIVEIRA, 2019).

In general, what all these applications have in common is the use of game mechanics as a way to reward and stimulate users, which corroborates the concept formulated by Loh et al. (2015), for whom Serious Game is defined as a game in which the main objective is not its diversification but the optimization of its learning process with the use of visual content. Sauvé *et al.* (2010a), identified six essential criteria to characterize Serious Game:

1. The player;
2. The conflict;
3. The rules;
4. The purpose of the game;

5. The artificial nature; and
6. The educational character.

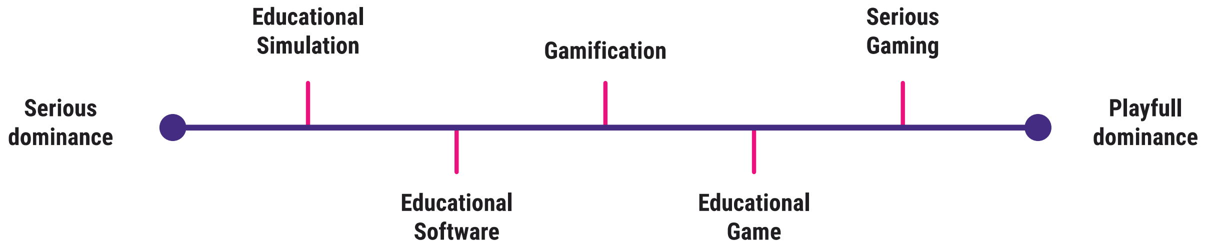
One way to distinguish Serious Games is to consider their most remarkable characteristics. Abdellatif *et al.* (2018) points out 18 different distinguishing characteristics that can be used to evaluate various aspects of Serious Games:

1. Game design;
2. User satisfaction;
3. Usability;
4. Utility;
5. Comprehensibility;
6. Motivation;
7. Performance;
8. Gameplay;
9. Pedagogical aspects
10. Learning outcomes;
11. Engagement
12. User Experience
13. Effectiveness;
14. Social impact;
15. Cognitive behavior;
16. Pleasure;
17. Acceptance; and
18. User Interface.

Other authors also propose classifications not only using specific characteristics, but also through the segment and application of serious games (DJAOUTI; ALVAREZ; JESSEL, 2011). The fact is that the line separating the definitions of Serious Games, simulation, games with educational characteristics and many other categories is absolutely tenuous. Schmoll

(2017) presents an example of the different modalities of the possible playful-educational use of videogames during learning situations. In Figure 8 is presented a universe that goes from the most serious dimension (left) to the most fun dimension (right), thus representing all the variety of this theme.

Figure 8 - Games in a learning context



Source: Adapted from Schmoll (2017).

There are many studies dedicated to different ways of classifying Serious Games and distinguishing them from other types of games, but such classifications and taxonomies are often based on intrinsic characteristics and specific applications, which prevents further generalization or adoption of unique terms and definitions. For the purposes of this research, it is intended to adopt a definition based on the views defended by several authors previously mentioned. Based on it, this thesis essentially adopts two main characteristics: Serious Games are games that have no entertainment or fun as their main objective and, moreover, Serious Games have a focus on the user's learning process.

Serious Games cover many different perspectives as well as different domains, ranging from communication to simulation, in addition to different applications, all with some objective focused on learning. However, despite all these differences, different authors exposed in this section seem to agree on the basic components adopted in Serious Games, which are: there is a 'serious' dimension combined with a 'game' dimension. Thus, both concepts (and their intersection) lead to an important point that is directly related to the main objective of this thesis: the simulation provided by games for training purposes. More specifically, simulation through Virtual Reality in combination with Serious Games for specialized training of professionals.

Given that simulators are a fundamental part of the content of this research, it is pertinent to explain, besides their definition, their relationship with Serious Games and the universe to which this research is intrinsically linked, that is, simulation as a form of learning environment that uses Serious Games as mechanics, being carried out through Virtual Reality.

2.2.1 Serious Games in Virtual Reality

Besides defining Serious Games, Sauvé *et al.* (2010a, 2010b) also state that the artificiality of the game is an essential element to distinguish Serious Games and simulators. The authors establish that simulations are more or less detailed representations of reality (SAUVÉ; RENAUD; KAUFMAN, 2010a, 2010b). Certain authors, such as Lavigne (2012) defend a similar idea, stating that simulation games are not Serious Games, since simulation is a representation of reality. This definition is also in line with the idea defended by Roger Caillois, who categorically asserts that a game must be unreal (CAILLOIS, 2001).

However, this separation between Serious Games and simulations is contrary to the position of several authors of the subject, especially in more recent publications that relate technologies such as Virtual Reality to Serious Games (CROOKALL, 2010; RALF DÖRNER, 2016; CAI; VAN JOOLINGEN; WALKER, 2019; LARSON, 2020). There are authors who even claim that simulations provide realistic levels of emotion and physiological reactivity that occur under real-world force use circumstances (SAUS *et al.*, 2006; LARSON, 2020).

Burdea and Coiffet (2003) describe the nature of Virtual Reality in a triad defined by Interaction, Immersion and Imagination. This description highlights the three characteristics by which Virtual Reality is often addressed in literature (DICKEY, 2005; HEW; CHEUNG, 2010; MIKROPOULOS; NATSIS, 2011; KAVANAGH et al., 2017). These characteristics helped to facilitate experimental and contextualized learning, while increasing the motivation and engagement of individuals submitted to educational content through technology (DALGARNO; LEE, 2010).

One of the most beneficial uses of Serious Games for training, especially if combined with technologies such as Virtual Reality, is the ability to simulate tasks that could otherwise be very dangerous for inexperienced people (MOSKALIUK; BERTRAM; CRESS, 2013b, 2013a; BERTRAM; MOSKALIUK; CRESS, 2015). Thus, games applied to professional training are also an economical solution for reducing the budget and increasing the demand and complexity of training, especially for their ability to represent various scenarios with different levels of complexity (DE ARMAS; TORI; NETTO, 2020).

The fusion of approaches based on Serious Games and Virtual Reality environments, which allow the improvement of learning and training methodologies, has a promising future (ORDAZ *et al.*, 2015; WILLIAMS-BELL *et al.*, 2015; FENG *et al.*, 2018; CHECA; BUSTILLO, 2020). A positive factor for this scenario is the wide availability on the market of affordable software and hardware tools for the development of training solutions (GADIA *et al.*, 2018; JENSEN; KONRADSEN, 2018).

The combination between Serious Games and Virtual Reality can be propitious for the development of simulators with unique characteristics. The fusion of game based approaches and their application in immersive and interactive environments can provide rich learning experience and improve methodologies that favor the training of professionals. Serious Virtual Reality Games will be able to change the way an individual performs their learning and training tasks (CHECA; BUSTILLO, 2020). Thus, instead of passive observers, users become involved in these learning environments as active participants, allowing the development of learning paradigms based on the exploration of simulated environments.

Although there is an abundance of studies on the application and results of adopting the combination of Serious Games and Virtual Reality for training and education, and most of the work is produced without even referring to immersive solutions, it should be noted that these works also fail to include performance evaluations for end users (CHECA; BUSTILLO, 2020; DE ARMAS; TORI; NETTO, 2020).

As a way of contributing to improving evaluation processes and reducing human bias, this research proposes the use of vital data, also known as biofeedback, captured through sensors during training sessions. The use of sensors can be an interesting way of evaluating the level of stress to which the trainee is being subjected during training, which in turn can be understood as an indication of how well this user handles certain situations to which he is subjected during the simulation. Therefore, the next topic addresses biofeedback as a way to enable the capture of vital data during training supported by Virtual Reality in the form of Serious Games applied to professional training.

2.3 Biofeedback

The word "biofeedback" was coined in the late 1960s to describe procedures, developed since the 1940s, for training that alter brain activity, blood pressure, muscle tension, heart rate, and other body functions that would not be controlled voluntarily (DA-YIN LIAO, 2020). Biofeedback studies have their origins in different fields of investigation. On the one hand, studies on instrumental or operant conditioning of autonomic responses - those based on the operant paradigm - maintain that the individual will modify his behavior on the basis of rewards and punishment (AKPAN, 2020).

Biofeedback operates on the notion that individuals have the innate and potential ability to influence the automatic functioning of their body through commitment and will, and, according to Da-Yin Liao (2020), allows individuals to (1) monitor physiological details such as muscle tension, blood pressure, heartbeat, and brainwave signals, (2) become aware of their physiological reactions, and (3) learn to adjust these physiological reactions according to their will.

The operation of the nervous system causes changes in the body of acoustic (for example, the sounds of the heart, lungs, cardiorespiratory pathologies, and the digestive system, among others), chemical, and electrical origin that can be investigated from the anatomical, physiological, and biophysical points of view (BROWN, 1977; SUN et al., 2020; ZAMKAH et al., 2020). Most of these changes provide diagnostics about the state of the individual and are not necessarily consciously accessed. There is some knowledge about these changes, but it is still not fully understood what they mean due to the almost unlimited number of existing physiological mechanisms. In recent decades, however, significant advancement has been observed in the understanding of how the nervous system functions and its implication in physical variabilities (BOUCSEIN, 2012; KANIUSAS, 2012, 2019).

The series of changes that occur in the body generates a plethora of measurable and discriminable signals that, according to the literature, are called biological signals, physiological signals, or simply, biosignals. However, the term biosignal is not used exclusively in the human realm, but rather generically to refer to a wide range of continuous phenomena related to biological organisms. More specifically, biosignals provide information about the biological and physiological structures of living organisms and the dynamics of these structures (SCHMIDT, 2016). In the human case, biosignals detail vital physiological phenomena that are relevant not only to the understanding or awareness of the human functional state and its diagnosis, but also to subsequent therapy, follow-up treatment, and the evaluation of its effectiveness (KANIUSAS, 2012).

Because biosignals exist in an enormous quantity and their nature is very complex, dealing with them is very difficult. The difficulties encountered to identify them, the appropriate nomenclature to describe them, as well as the documentation, reproducibility and comparative analysis between two or more biosignals, are pointed out as fundamental problems for their study and systematization (KANIUSAS, 2019). However, according to Schmidt (2016), there are six types of biosignals that have importance for the field of Human-Computer Interaction, as presented in Table 4.

Table 4 - Six types of biosignals important to the field of Human-Computer Interaction

Biosignal Type	Biosignal Origin
Electrical	Originated in the nerves and muscles.
Electrical Conductance	Arising from the variation in the electrical conductivity of the skin, particularly from the variation between electrodermal resistance and electrodermal potential.
Galvanic Skin Response	Arising from combined values of resistance in the skin.
Bioimpedance	Resulting from the resistance measured when a small alternating current is applied to the skin tissue.
Acoustic	Produced by sounds created by changes in the body, such as blood flow, heart function, ventilation in the lungs, digestion, and movement that can be detected with microphones.
Optical	Observed when there is a change in the optical properties of an organism or body part, such as the oxygen saturation of the blood based on reflection, or the pulse rate caused by a change in skin color.

Source: Adapted from Schmidt (2016, p. 76).

These biosignals have one characteristic in common: they can be captured or converted into a time series of electrical signals that can be analyzed according to their known relationship with physical or psychological states, such as fatigue, anxiety, and stress (SCHMIDT, 2016). This capability makes biosignals extremely relevant for the context of this research.

As for bioelectric signals, these usually originate from neural or muscular activity and have different amplitudes and frequencies (from microvolt to millivolt). The verification that the human body has electrical signals has its origin in the work with dead frogs developed by Luigi Galvani, in the period from 1786 to 1791, in which he demonstrates, through the connection between muscle activity and electricity, that the latter is the vital force of life. In 1794, Alexander von Humboldt and Giovanni Aldini confirmed Galvani's discovery (SCHMIDT, 2016; SHIOZAWA et al., 2019).

Eugenijus Kaniusas (2012) points out that the almost unlimited variety of biosignals in the human body makes it virtually impossible to classify them. However, the author proposes a way to classify them based on three types: regarding their existence, dynamic nature, and origin. Regarding the existence of biosigns, they can be permanent or induced. The first type exists naturally in the human body, without any artificial stimulus, or excitation from outside the body, and are available in a continuum.

The second category, the induced biosignals, are provoked, excited or induced artificially, and exist for a period approximating the duration of the excitation. That is, as soon as the artificial impact is terminated, the induced biosignal decays with a certain time constant determined by the body's properties.

As for their dynamic nature, we have static ("quasi") biosignals and dynamic biosignals. Static (quasi) biosignals carry information in a fairly regular state, and the phenomena involved in their occurrence signal relatively slow changes over time. Dynamic biosignals, on the other hand, produce significant changes over time and have dynamic processes that convey physiological information of interest.

Finally, regarding the origin of the biosignal, the classification proposed by Kaniusas and presented in Table 5, displays some of the most significant biosignals.

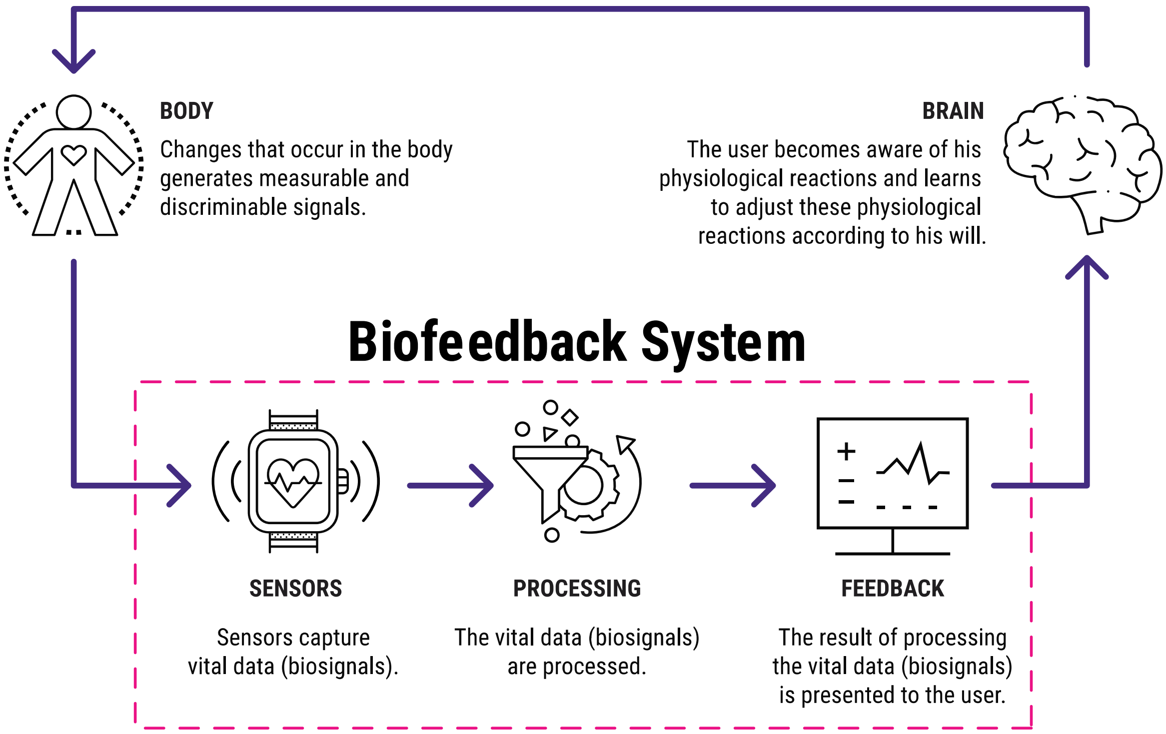
Table 5 - Kaniusas' classification of biosignals according to their origin

Biosignal Type	Biosignal Origin
Electrical	Generated by the activity of neurons or activation of muscles.
Magnetic	Produced by magnetic fields induced by currents during electrical excitation, as, for example, the magnetic fields formed during cardiac electrical excitation.
Mechanical	Fruit of body deformations or local vibrations of the skin revealing physiological data, such as a respiratory cycle that causes changes in abdominal circumference.
Optical	Caused by the absorption and dispersion of light.
Acoustics	Caused by body sounds, such as heart sounds corresponding to consecutive heart valve closures, as well as snoring, breathing, and swallowing sounds.
Chemical	Arising from the chemical composition and its temporal changes in the body's solids, liquids and gases - example: the typical course of cortisol, known as the stress hormone, which, over a 24-hour period, registers a peak during the morning and whose function is to prepare the body for waking up.
Thermal	Linked to the heterogeneous mechanisms of heat loss and absorption in the body.

Source: Adapted from Kaniusas (2012, p. 15–19).

According to Kaniusas (2012, 2019), the process from the generation of a biosignal to its recording can be modeled as a circuit, which is the technical basis of the operation of a biofeedback system. Biofeedback is defined as a technique (WEST; CHUDLER, 2009), a methodology (POP-JORDANOVA; LOLESKA, 2020) but also as a system that detects, measures, and evaluates body activities, such as electrodermal, motor, brain, respiratory, and cardiac, among others. In its most elementary form, a biofeedback system has a scheme similar to the one shown in Figure 9. The schematic presents a loop between the body and the brain, joined by a biological sensory module that collects physiological information, a processing module that manipulates the acquired signal, and a feedback module that relays the extracted information to the user.

Figure 9 - A biofeedback system in its most elementary form



Source: Adapted from Kaniusas (2012) and Schmidt (2016).

Technically, the system provides negative feedback that allows variables to be corrected when they deviate from their normal range of variation. The level of a controlled variable is defined as its target, and it is monitored by sensors or receivers that transmit the information to an element that compares the signal coming from the sensor with the target. Any deviations, over or under the limits of this target, produce an error signal. The existence of this error signal results in the activation of effectors that oppose the deviation from the target, thus guiding the correction of the signal (BASMAJIAN, 1979; POP-JORDANOVA; LOLESKA, 2020).

The biofeedback system allows people to take responsibility for their cognitive, emotional, and behavioral changes, which makes it ideal for applications and activities where stress load is a constant variable. Sensory data are first obtained, processed, and then returned to the human nervous system sensor in a clear, direct, and immediate manner in a feedback scheme. This technique is capable of causing long-term effects by stimulating brain neuroplasticity[5] through conditioning (POP-JORDANOVA; LOLESKA, 2020).

Biofeedback was originally developed for the medical field dedicated to clinical diagnosis and patient rehabilitation (SCHMIDT, 2016). In the medical field, applications of the technique for the treatment of migraine, tension headache, hypertension, cardiac arrhythmias, Raynaud's disease, paralysis, spinal damage and other motor disorders, for the relief of the consequences of strokes, aneurysms, traumatic brain damage, multiple sclerosis, epilepsy, hypoglycemia and diabetes, epilepsy, premenstrual syndrome, chronic pain, urinary incontinence, among numerous other applications (BADAWI; EL SADDIK, 2020; POP-JORDANOVA; LOLESKA, 2020). In the field of psychology, it is used to treat phobias, depression, anxiety, insomnia, and stress, among some clinical situations (BROWN, 1977; GIANNAKAKIS et al., 2019; SUN et al., 2020). There are also applications in scenarios where there is usually a stress load during the performance of activities (APOSTOLIDIS; PAPANTONIOU; TSIATSOS, 2021).

In biofeedback, conditioning is made possible with the use of analog or digital instruments. The simplest training can be performed using scales, mirrors, and sphygmomanometers, but more refined functions can also be trained using digital instruments that perform biosignal collection, such as Electroencephalograms and Electromyograms (GLOMBIEWSKI; BERNARDY; HÄUSER, 2013). Currently, biofeedback systems employ a wide range of sensors and digital devices to measure physiological functions and parameters. Some of these digital devices, such as smart watches, have become increasingly affordable and are equipped with sensors capable of performing vital sign measurements with high accuracy (BADAWI; EL SADDIK, 2020; DA-YIN LIAO, 2020; UMAIR et al., 2021).

While biofeedback exercises can occur in clinical and hospital settings, a variety of new systems have made it possible to perform such exercises in non-clinical environments. The goal of these systems is to achieve biofeedback ubiquity (AL OSMAN; DONG; EL SADDIK, 2016). In addition to location ubiquity, ubiquitous biofeedback-based systems also aim to achieve time ubiquity by enabling continuous monitoring of physiological data. In other words, biological monitoring activities are not session (or time) constrained. Users go about their day while the system is operating in the background (DA-YIN LIAO, 2020).

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[5] Neuroplasticity can be described as the brain's capacity to adjust, reshape, and reorganize to better respond to new situations. While the idea of neuroplasticity is very recent, it is one of the most important developments in neuroscience. More information about the concept can be found in the paper by Demarin, Morović, and Béné (2014).

However, the leap between non-ubiquitous monitoring devices and portable devices owes its advancement to other technologies and paradigms, and has happened over the course of the last two decades as a direct consequence of digital hyperconnectivity, a remarkable and undeniable fact of the current historical moment (FREDETTE *et al.*, 2012; BRUBAKER, 2020). This is the term used to define the time we live in, when so many of us spend most or even all day connected to the internet. One of the many consequences of this technological transformation demanded by modern society was the emergence of the concepts like the Internet of Things (IoT), which surfaced almost forty years after the introduction of the Internet.

The term “Internet of Things” was originally created by Kevin Ashton as a contextual reference to supply chain management around 1999 (ASHTON, 2009). The term was further redefined by several researchers to include applications such as transportation, mining, health, public services, security, education and several other domains. The historical moment that marks the emergence of IoT is generally defined around 2008 and 2009. At this time, the world population began to be eclipsed by networked devices. Over time, the number of interconnected “things” that included human beings and other devices (gadgets) experienced an exponential escalation, beyond any prediction manifested previously. This eventually culminated in the original concept of the Internet of Things, which is also defined as the use of the Internet as a link between the various services and objects, beyond human beings (SINGH; TRIPATHI; JARA, 2014).

However, connectivity is only part of the equation. It is necessary that the connected object has some kind of processing power and is capable of performing tasks autonomously. This concept, in turn, has the name of pervasive computing, a term that refers to the tendency to incorporate computational capacity (usually in the form of microprocessors) into everyday objects to make them communicate effectively and perform useful tasks (KRUMM, 2018). The main objective of this concept is to minimize the end user's need to interact with computers as computers. Pervasive computing devices are network connected and constantly available.

Both concepts, in turn, have enabled the advancement of technologies such as sensors used today in wearable devices such as smart watches. Smartwatches today have a number of sensors, are wirelessly connected to heterogeneous networks, and have substantial processing capacity (POONGODI et al., 2020). These devices, in turn, provide unique opportunities for users to monitor their data and physiological responses, and are currently not only popular, but also accessible and have been deployed in several areas (RAAD, 2021).

Considering the objective of this thesis already exposed in the Introduction chapter, it is convenient to explore the theoretical reference related to the capture of vital signals by means of sensors. In the context of this research work, this technology will be suggested and adopted as a way to support and improve the evaluation of trainees during the use of simulators for specialized training. Therefore, it is convenient to explain how the Biofeedback technology can be fundamental as a way to support the capture of vital signs, more specifically signs of physical or emotional stress, which can serve as clues to evaluate the performance during the training sessions.

2.3.1 Sensors to measure physiological responses

In the era of electronic health systems, the inclusion of the Internet of Things brought a change in health paradigms by promoting the availability and accessibility of data with great ease (BHATT; DEY; ASHOUR, 2017). IoT's applications in health have helped people keep track of their medical histories, as well as remind them of appointments, perform calorie counting checks, blood pressure variations and exercise checks (SEEMA ANSARI *et al.*, 2020).

When regular medical equipment are connected to the Internet, they can collect crucial new data, provide further insight into symptoms and trends, permit remote care, and overall give patients more control over their lives and medical treatments. Wearable devices are one of the most adopted IoT systems for personal use. According to Gartner projections, competition from the lower cost smartwatches market will reduce average sales prices by 4.5% in 2021, thus resulting in a 27% increase in device sales volume over 2019 (GARTNER, 2019).

The rapid expansion of wearable IoT devices, such as smartwatches, can be explained for a number of reasons. First, these devices are in their majority very affordable and easy to use. Things like fitness bracelets, smart watches, or training shoes are basically things that people have been wearing for years. The idea of making these ordinary objects more connected and accessible makes the possibilities for using the data generated by these devices even more propitious. One of these possibilities is to use the data generated by such devices to measure physiological responses, detecting, for example, individual stress levels when participating in training.

Stressful situations can generate excitement and anxiety (SELYE, 1936). Stress is an intense, natural and universal reaction that impacts cognitive and physical processes, with consequences that can be beneficial in the short term, such as improved performance (BANDODKAR; GHAFFARI; ROGERS, 2020b). However, long-term stress can cause debilitating results such as cancer, coronary heart disease, accidental injury, lung disease, liver disease and suicide (YAO et al., 2019).

There are several ways to measure a person's stress levels. The literature cites methods ranging from measuring biological responses (L. RACHAKONDA *et al.*, 2018) to psychological assessment instruments (COHEN; KAMARCK; MERMELSTEIN, 1994; KRAGH *et al.*, 2019).

Some of these methods are invasive and require specific equipment, although they demonstrate high accuracy, such as the measurement of cortisol concentration in blood (KRAEMER *et al.*, 2005; HERANE VIVES *et al.*, 2015). Emerging methods that depend on chemical analysis of hair and saliva offer non-invasive alternatives, but have the disadvantage of requiring manual collection and measurement (HERANE VIVES *et al.*, 2015), which could imply in delay in response or treatment of the problem.

Recent research has adopted intelligent devices, such as sensors, to detect levels of certain biochemical markers, including cortisol, present in sweat in a non-invasive way and in real time, as is the case of research conducted by Torrente-Rodríguez *et al.* (2020). The research presents the development and application of a flexible wireless device based on graphene, capable of measuring the cortisol levels in sweat in a non-invasive way, in real time and with remarkable accuracy.

Today, wearable devices are popular and many consumers use them, in particular, to record their physical activity and sleep. Wearable monitoring devices such as smart watches are used to monitor personal health, fitness, health behaviors and well-being in daily life. The data recorded by these wearable devices is an example of real-world data that can provide practical observations and insights into stress levels, as even the simplest devices have multiple sensors to capture vital data (SIIRTOLA, 2019).

This vital data, when combined, can provide solid evidence for assessing stress levels through physiological responses, which makes them convenient for applications such as professional training and education. In recent years technology has begun to infiltrate educational processes, providing the emergence of an era known as Education 4.0 (HALILI, 2019; KESER; SEMERCI, 2019), a learning approach that aligns with the fourth emerging industrial revolution. Among the various technologies listed as part of this new approach, the

Internet of Things gains prominence, along with technologies such as Artificial Intelligence, Virtual Reality, Augmented Reality, robotics, among others (CIOLACU *et al.*, 2019).

In the scope of this research, the Internet of Things, and more specifically the use of sensors to detect stress levels, will be considered as a proposal to improve the performance evaluation of professionals in training. This technology, in turn, will have its application proposed in combination with other technologies, such as Virtual Reality and practices such as Serious Games, thus seeking to achieve the objective proposed in this thesis and exposed in the Introduction chapter.

2.4 User Experience

A remarkable feature of Virtual Reality (VR) experiences is the possibility of suspending disbelief enough to make the user feel as if they have stepped into a whole new world. Being able to interact with that world makes it even more compelling. Therefore, interaction can promote or break the illusion. Interactivity, in turn, is directly linked to one of the factors that most influences the success of an VR application: the User Experience (UX) (HASSENZAHL; TRACTINSKY, 2006; THÜRING; MAHLKE, 2007; PREECE; SHARP; ROGERS, 2015).

The worldwide standard on human-system interaction ergonomics, ISO 9241-210:2019 (ISO, 2019), defines user experience as a person's perceptions and responses as a result of using, or anticipating using, a product, system, or service. According to the standard, user experience includes all emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors, and achievement that occur before, during, and after use. The ISO standard also lists three factors that influence user experience: the system, the user, and the context of use. In part 3, dedicated to "terms and definitions", the standard ISO 9241-210:2019 indicates that usability addresses aspects of user experience when it states that usability criteria can be used to evaluate aspects of user experience. That is, according to the standard, the concept of usability precedes the concept of user experience. The standard, however, does not clarify the relationship between user experience and usability, but both are treated in an overlapping manner, since usability includes pragmatic aspects (performing a task) and user experience focuses on users' feelings arising from both pragmatic and hedonic aspects of interacting with the system.

Therefore, before conceptualizing what User Experience is, it is important to define the concept of "Usability", since usability is a determining factor in any user experience (NIELSEN, 1994; KRUG, 2013; PALLAVICINI; PEPE; MINISSI, 2019). Usability is best translated as “ease of use”. The amount to which a product, system, or service can be utilized by specific users in a given application context to achieve specified goals in an effective, efficient, and fulfilling manner is referred to as usability (NIELSEN, 1994). Good usability is usually not even explicitly perceived, while bad usability is evident. Usability is important for all products with an interface between humans and technology or between humans and machines. Whether it is software, websites, mobile devices, medical equipment, or complex control systems for running machines, they all benefit from good usability.

User Experience expands the term usability to include aesthetic and emotional factors, such as an attractive and desirable design, trust-building aspects or fun during use (joy of use) (THÜRING; MAHLKE, 2007). This holistic approach encompasses the entire user experience that is performed when using a product[6]. Users should not only reach their goal quickly and smoothly, but - depending on the application area - also experience positive feelings such as fun or joy during use.

According to Hassenzahl and Tractinsky (2006), the User Experience is a consequence of the internal state of the human being (mood, expectations and needs, for example). The characteristics of the designed object (complexity, usability and functionality, for example) and the context or environment where the person-product interaction occurs, enable various opportunities for user experience. Our daily lives are surrounded by products, which allow more than their mere functionality. The user experience perspective understands the current needs of people, who are no longer looking for functional products, but rather, for products that have positive, experiential, and emotional aspects.

For Thüring and Mahlke (2007), the user experience is acquired during the interaction of the person with the product, and usually this interaction aims to solve a particular task, situated in a certain context, and that takes a certain time to be accomplished. This experience also considers the user's particular attributes, such as their knowledge or skills, and the characteristics of the object itself, such as its functionality and interface, which determine its

[6] From now on the term 'product' will be used to encompass both tangible and non-tangible concepts or objects. This is due to the fact that technology comprises products (like a VR glasses, for example) and promotes experiences (like a VR simulation, for example), which in turn provoke reactions. These products are not always something tangible. Therefore, in this context there is no distinction between what is tangible or not, since both assume that there is interaction between the user and this 'object', be it tangible or not.

main particularities, and that can also interfere in the user experience in their interaction with the object.

Considering the nature of Virtual Reality as a medium to provide user experiences (JERALD, 2016), such experiences must be designed and planned in such a way that these users can efficiently achieve their goals. It is important to emphasize that the user is the center of the Virtual Reality experience, which requires even more effort from the developers (STONE, 2016), which therefore requires applying design principles common to the field of User-Centered Design (NORMAN, 2005a; OVIATT, 2006; CHAMMAS; QUARESMA; MONT'ALVÃO, 2015).

User-Centered interaction design focuses on the human side of user-machine communication, i.e. the interface from the user's point of view (MAO et al., 2005; CHAMMAS; QUARESMA; MONT'ALVÃO, 2015). Ideal Virtual Reality Experiences are those in which not only the goals and needs are achieved efficiently, but also in an engaging and enjoyable manner (CHECA; BUSTILLO, 2020; MARTINEZ; MENÉNDEZ-MENÉNDEZ; BUSTILLO, 2020). Therefore, adopting human-centered design concepts concentrating efforts on promoting a better User Experience is an essential part of designing quality VR interactions (ORTEGA et al., 2016). But it is important to note that the concept of User Experience is not restricted to the field of Human-Computer Interaction, or limited to digital artifacts. Furthermore, its nature is subjective, as it is about the individual's perception and thinking regarding the use of a specific product, system or service. It is also dynamic, and can be constantly modified over time due to changing circumstances and innovations (HASSENZAHL, 2010).

A more holistic view on User Experience is offered by Norman in his influential work *"Emotional Design: Why We Love (or Hate) Everyday Things"* (2005b). The author defends the idea that a product or experience reaches the human being on three cognitive and emotional levels: the visceral, the behavioral, and the reflexive. The visceral level corresponds to the most immediate level of processing, when a person reacts to the visual aspect or other sensory levels (e.g., auditory and tactile aspects) even before interacting. On the behavioral level, the emotions that products or experiences provoke are related to automatic human behavior, which we are not aware of.

Emotions are evoked through the relation USE vs. EFFECTIVENESS. It is directly related to the ease and pleasure of using a product, of performing a task from start to finish with ease and without interruptions. The reflective level involves conscious considerations and reflections on previous experiences. Although this level does not have direct access to the visceral level, it can affect the behavioral level, because if the user has had a bad experience in the past, he probably does not want to use a similar product or experience again, and if he does, he interacts with a bad view and anticipating negative emotional responses. Put simply, UX embraces the philosophy of understanding people and giving them things that they can understand and which provide value and joy.

Designing user experiences for Virtual Reality environments involves the use of specific processes and artifacts that are not necessarily the same as those existing and consolidated for traditional web, desktop or mobile applications (MÜTTERLEIN; HESS, 2017; KIM; RHIU; YUN, 2020; SAGNIER et al., 2020). Even traditional game components do not always work perfectly when transposed directly to Virtual Reality (CHECA; BUSTILLO, 2020). Therefore, it is essential to address the subject of User Experience in the context of Virtual Reality and its particularities, which will be done in the following topic.

2.4.1 User Experience in Virtual Reality

Virtual Reality has the potential to provide experiences and deliver results that cannot be achieved by other media (JERALD, 2016; BAILENSON, 2018). However, Virtual Reality interaction is not just an interface for the user to achieve their goals. It is also about users working intuitively, something that can be defined as a pleasurable experience and devoid of frustrations.

Usability is, therefore, a crucial factor for the success of the user experience in Virtual Reality. Accordingly, it is worth mentioning Jakob Nielsen (NIELSEN, 1994) and his ten usability heuristics for digital interface design, which are:

1. Visibility of system status;
2. Matching between the system and the real world;
3. User control and freedom;
4. Consistency and standards;
5. Error prevention;
6. Recognition instead of recall;
7. Flexibility and efficiency of use;
8. Minimalistic design;

9. Helping users recognize, diagnose, and recover from potential errors; and
10. Help and documentation.

Usability heuristics provide guidelines that professionals can use to create better experiences. The goal of these heuristics is to help to create interactions that can be refined until they are so intuitive that users need no further instructions on how to use them. However, it is important to emphasize that not every type of heuristic works in the same way to evaluate every type of system (SUTCLIFFE; KAUR, 2000). It can be argued that conventional usability evaluation methods, such as the heuristic evaluation proposed by Nielsen (1994) could be applied to Virtual Reality systems. However, Nielsen's heuristics, for example, do not address issues such as object location and manipulation, or navigation in immersive environments.

Considering that Virtual Reality is a technology that demands interactions, and such interactions can establish the success or failure of an experience, it is important to mention the specificities of interaction in immersive environments. For this purpose, one can refer to Jason Jerald's work entitled *'The VR Book: Human-Centered Design for Virtual Reality'* (2016) where the author raises some key terms for interaction in immersive environments:

1. Intuitiveness - How simple it is for a user to understand how something works. Does it work as they expect?
2. Events - Define what actions are possible and how something can be interacted with by a user.
3. Signifiers - Any perceptible indicator (a signal) that communicates to a user the proper purpose, structure, operation, and behavior of an object.
4. Constraints - Limitations on actions and behaviors imposed intentionally or unintentionally on a design. Such constraints include logical, semantic, and cultural limitations to guide actions and facilitate interpretation.
5. Feedback - Communicates to the user the results of an action or the status of a task, helps understand the state of the thing being interacted with, and helps drive future actions.

Most of these terms were popularized by Don Norman in his book *'Design of Everyday Things'* (2002), but it is also possible to find similarities with several of the heuristics advocated by Jakob Nielsen, which reinforces the idea that interaction is a pervasive concept and is not strictly tied to a specific media. All authors show a constant concern with the protagonism of the user and his possibilities of interaction, regardless of the media or type of interface. The protagonism of the user in relation to any kind of interaction is something so important that there are even technical standards that aim to regulate and assist the creation of better user experiences. This is precisely the case with ISO 9241-210 (ISO, 2019), which defines six principles for user-centered design development:

1. The design is based upon an explicit understanding of users, tasks and environments;
2. Users are involved throughout design and development;
3. The design is driven and refined by user-centered evaluation;
4. The process is iterative;
5. The design addresses the whole user experience; and
6. The design team includes multidisciplinary skills and perspectives.

There are two descriptive elements to consider when thinking about VR: presence and immersion. Psychological involvement is a central aspect of VR. When this occurs, the motor and perceptual systems communicate with the virtual world in a way close to what they do in the real world (BAILENSON, 2018), effect, which in turn is known as presence. Immersion is a term used to describe the support or even stimulation of the feeling of presence in a virtual world - thus immersive technology (MÜTTERLEIN; HESS, 2017; SLATER, 2018).

Both concepts of presence and immersion, combined with the concern with protagonism, but above all, with user comfort and satisfaction, justify the User Experience as a central theme when it comes to Virtual Reality. This is also explained by issues that go beyond comfort. Since this is an immersive media, in which the user is transported to a new world, there is a good chance that this user completely loses the reference to reality and the notion of his own body.

This phenomenon, by the way, refers to proprioception, a term used to name the ability to recognize the spatial location of the body, its position and orientation, the force exerted by the muscles, and the position of each body part in relation to others, without using vision (TUTHILL; AZIM, 2018). For example, proprioception allows a person to close their eyes and touch their nose with their index finger. Besides the risk of losing awareness of their own bodies, another possible problem commonly experienced by certain users is virtual reality sickness. Virtual reality sickness happens when being exposed to a virtual environment creates symptoms that are similar to motion sickness symptoms (LAVIOLA, 2000). The most common symptoms are headache, stomach sickness, nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation, apathy, postural instability and general discomfort (LAVIOLA, 2000; SHAFER; CARBONARA; KORPI, 2017; WEECH; KENNY; BARNETT-COWAN, 2019; SAREDAKIS et al., 2020).

Having exposed all these concepts, approaches, definitions and possible effects, it is clear the role of User Experience and how it should be addressed when it comes to immersive experiences and technologies, as is the particular case of Virtual Reality. It seems obvious to put the user at the center of all kinds of product development, but in many cases, this is not what happens (KIM; RHIU; YUN, 2020). Considering the user experience as an integral part of Virtual Reality, prototyping becomes essential to create experiences that consider the user as a determining factor (NEWMAN et al., 2015; BÖHMER et al., 2017; AHMED; DEMIREL, 2020). In this aspect, adopting a methodology to be followed, even if in a flexible way, can contribute to reduce user frustration and even make the development process faster, more efficient, and less based on trial and error. This is precisely the ambition of this research work.

3 METHODOLOGY

The objective of this chapter is to provide an overview of the research project and the research methodology employed in this thesis. According to Benbasat and Weber (1996), research methods shape the language we use to describe the world, and the language we use is able to shape how we think about the world being described. In other words, the methodology selected and applied to a study affects its results and inferences in a decisive way.

Therefore, the course of a study must include the careful selection of a suitable research method to direct scientific research. Consequently, the motivation behind the choice of a methodology requires equally careful evaluation. In this context, the research project of a study is a strategy to gather and examine data that will allow the researcher to answer the research questions proposed by the study (MCMILLAN; SCHUMACHER, 1993; FLICK; KARDORFF; STEINKE, 2004).

Mouton (2001) describes research design as a form of architectural design, while the research methodology would be the equivalent of the construction process using methods and tools defined by the researcher. The research methodology consists of the rules and methods that researchers use to make their work open to analysis, criticism, replication, repetition and/or adaptation (GIVEN, 2008).

Although, according to Cohen, Manion and Morrison's definition (2013) the term ‘research method’ means a variety of methods used to collect data that should be used as a basis for intervention and understanding for rationalization and extrapolation. As argued by Bhattacherjee (2012), the scientific method refers to a set of techniques for the construction of scientific knowledge, which, although they should be standardized, are not linear, continuous, or even consistently cohesive (HARREVELD et al., 2016).

Additionally, the research design of a study must recognize the type and form of data required to provide answers to the research questions, as well as describe the methods for acquiring that data and the process(es) used for evaluating and analyzing that data (CRESWELL, 2014; MARTINS; THEÓPHILO, 2017). The design of a study is driven by the current awareness of the researcher about the subject under consideration and the goals relating to the consequences of the inspection and description of data (PATTON, 2001).

As briefly mentioned in the Introduction to this thesis, Design Science Research (DSR) was adopted as the research methodology to be conducted in this study (MARCH; SMITH, 1995; HEVNER et al., 2004). Accordingly, this chapter will provide the methodological characterization of this research, an overview of the foundations of the scientific research that employs Design Science Research, the research process using this methodology and the approaches employed for data collection in this study.

3.1 Methodological Characterization

This research is epistemologically located in the field of Information Science and explores inter and multidisciplinary[7] topics that touches areas such as Human Computer Interaction, Software Engineering, Psychology, Computer Science and Ergonomics. Precisely because it is a research whose boundaries are tenuous, diffuse and deal with nomadic objects, this research holds some parallel with Morin's complexity paradigm (2008), and does not intend to lead to the dissolution of problems for other disciplines, but to propose the articulation between them.

The main goal of this work is not to bring explanations, descriptions or predictions of phenomena. Instead of inductive reasoning, in which particular findings lead to theoretical generalizations, or deductive reasoning, in which general theories explain specific cases, the challenge of this research work is of an abductive nature (GIVEN, 2008; HAIG, 2018). That said and considering the scope and objective of this research, it is convenient to describe the methodological characterization, which will be done in four dimensions: nature, approach, objectives and technical procedures.

The nature of this research can be described as applied, since its purpose is to provide solutions to specific practical problems and to develop innovative technology. Simply put, it is research that can be applied to real-life situations (PATTON, 2001; BLANCHE; DURRHEIM; PAINTER, 2008).

As for the approach, this research is considered qualitative, understanding that qualitative research aims to analyze the dynamics between the concrete world and subjectivity, seeking to interpret phenomena and assign meaning to them (PATTON, 2001; YIN, 2011). According to Strauss and Corbin (1998), qualitative methods can be used to explore areas where

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[7] Hadorn et al. (2008) offers a definition on the concepts of Multidisciplinarity and Interdisciplinarity. According to the author, “multidisciplinary” refers to something that combines or involves several academic disciplines or professional specializations in order to address a topic or problem. Also, according to the author, “interdisciplinary” is an adjective that describes relationships in more than one branch of knowledge. Both definitions are articulated throughout this entire research work.

existing knowledge is scarce, or applied to areas where knowledge is expressive, as a way to provide new points of view. Merriam and Tisdell (2015) cited that, despite the difficulties in collecting and analyzing qualitative methods, these have been adopted in research where deepening the understanding of phenomena in their natural context is an important factor in analyzing the results.

However, this research also employs quantitative methods to develop some of its steps, especially in the validation phase, more specifically, in the treatment of the data from the survey. In the context of this research, the use of quantitative methods, either summarizing or using descriptive statistical techniques, allowed the exploration of relationships between data in order to highlight their meaning in a specific context. Qualitative researches do not present an aversion to the quantification of variables, but emphasize the capture of the perspectives and interpretations of the individuals studied. In qualitative researches the focus is on the understanding of a certain phenomenon, product of interpretation and meanings attributed to it by the researcher, and not on the frequency with which this phenomenon occurs (CRESWELL, 2014).

As for the objectives, this research is founded on Bhattacherjee (2012) and in Poupart et al. (1997) to consider it with a triple character: it is exploratory, descriptive and explanatory. The reason for classifying this research as exploratory comes from the fact that it enters a recent and still little explored theoretical field. According to Bhattacherjee (2012) Exploratory research is often conducted in new areas of research, where the objectives of the research are: (1) to amplify the magnitude or extent of a phenomenon, problem or behavior, (2) to generate initial ideas about this phenomenon, or (3) to test the feasibility of further studies about this phenomenon. In the specific case of this research, the exploration of technologies as well as the combination of such technologies that are in full development and present an innovative character justifies the definition of this research as exploratory.

This research is classified as descriptive because it presents the development report of a specific case, providing contextual information. Bhattacherjee (2012) cites that descriptive research is guided by careful observations and detailed documentation of a phenomenon of interest. These observations must be based on the scientific method (i.e., they must be replicable and accurate) and are therefore more reliable than casual observations. In the context of this research the description is a predominant factor and permeates all the research work on the subject of this thesis.

Considering the fact that this research culminates in the proposition of a design method that is built from the articulation of tacit and explicit knowledge (POLANYI, 1966; NONAKA; VON KROGH, 2009; DALKIR; LIEBOWITZ, 2011) and repeatedly subject to the scrutiny of experts and professionals as well as academics from its original conception to its latest version, this research can also be defined as explanatory. This is because, according to Bhattacherjee (2012), while descriptive research assesses the "what," "where," and "when" of a given phenomenon, explanatory research seeks answers to "why" and "how" questions.

Regarding the technical aspects, this research presents a series of items, starting with the literature review, which in the context of this thesis uses two distinct methods. The first is the Systematic Literature Review (SLR) (KITCHENHAM et al., 2009), applied in the search and review of academic literature, and the second, known as Computational Literature Review (CLR) (MORTENSON; VIDGEN, 2016; KUNC; MORTENSON; VIDGEN, 2018; LEE; SHIN, 2019), applied in the search for patents.

Another technical aspect of this research is linked to its applied nature and, therefore, of practical character, through the development of a method and its validation. This method, also called secondary artifact[8], is developed based on the Design Science Research methodology, and is originated from practice, with the development of a Virtual Reality simulator prototype, here called primary artifact. During the development of this prototype, each part was validated and discussed by academics and industry professionals with experience in Virtual Reality until a final version of the method was obtained. Finally, this method was submitted to the evaluation of a larger number of experts and academics from several countries, all with experience in Virtual Reality and from several of the areas addressed in this research.

In relation to the different ways of generating and analyzing data employed in this research, it is worth mentioning that the consultation with specialists (HOFFMAN et al., 1995; RUBIO et al., 2003a) and survey (FLICK; KARDORFF; STEINKE, 2004; GIVEN, 2008), both with a qualitative character, were applied during the development and validation phases of the method respectively.

Design Science Research is a scientific paradigm for conducting research based on the proposal of building a new reality (in other words, solving problems) instead of explaining an existing reality, or striving to make sense of it (HORVÁTH, 2007; VOM BROCKE et al., 2020, 2020). This research therefore assumes a deep and inextricable connection with practice, guided

[8] A detailed explanation of the concept and classification of artifacts can be found in topic 3.3.2 The concept of artifacts in the context of Design Science Research.

by theory, but above all with a focus on solving real-world problems. By positioning itself this way, the choice of Design Science Research as the paradigm that guides this research is well justified. Table 6 presents the methodological characterization of this thesis and the main authors that support the methodological pillars that underpin this research work.

Table 6 - Methodological characterization of this thesis

Dimension	Characterization	Theoretical Support
According to Nature	Applied Research	(PATTON, 2001; BLANCHE; DURRHEIM; PAINTER, 2008)
According to Approach	Qualitative Research	(PATTON, 2001; YIN, 2011)
According to Objectives	Exploratory, Descriptive and Explanatory Research	(POUPART, 1997; BHATTACHERJEE, 2012)
According to the Technical Procedures	Systematic Literature Review Computational Literature Review Primary artifact (prototype) Secondary artifact (design method) Consultation with specialists Survey	(HOFFMAN et al., 1995; RUBIO et al., 2003a; FLICK; KARDORFF; STEINKE, 2004; GIVEN, 2008; KITCHENHAM et al., 2009; MORTENSON; VIDGEN, 2016; KUNC; MORTENSON; VIDGEN, 2018; LEE; SHIN, 2019)

Source: Elaborated by the author.

Dresch et al. (2015) postulate that Design Science seeks knowledge through the interaction between the observer and his or her object of study, which is something built, not a given object. Because it is a scientific modality that is concerned with the methodology adopted, that is, the way things should be to achieve certain objectives, either to solve a problem or to design something that does not exist, one perceives in it the great advantage of generating knowledge that can be easily applied, reducing the distance between theory and practice (VOM BROCKE et al., 2020). Therefore, it is appropriate to establish the methodological and epistemological bases of Design Science Research, given its importance for this research, which will be done in the following.

3.2 Bases of Design Science Research

As argued by Filstead (1981), a research paradigm is defined by a set of interconnected assumptions about the social world that provide a philosophical and conceptual framework for the organized study of this world. Oates (2006), in turn, implies that the purpose of research paradigms is to describe the basic views of groups of people about the world they inhabit and the studies they perform. Regarding research in Information Techology (IT) and Information

Systems (IS), Olivier (2004) states that a research paradigm not only directs research, but also the creation and operation of systems.

Scientific research, in the context of IS and IT, is explained by three main philosophical foundations: ontology, axiology and epistemology (HIRSCHHEIM; KLEIN; LYYTINEN, 1995; OLIVIER, 2004; OATES, 2006). These three cornerstones, in turn, directly influence the methodological choices of scientific work (HEGDE, 2015). Consequently, it is imperative to clearly define these philosophical bases before detailing each and every methodological procedure.

In the areas of Information Systems and Computer Science, the branch of research used for knowledge management and sharing is generally referred to as ontological study or ontological engineering (LI *et al.*, 2007).

According to Hirschheim, Klein, and Lyytinen (1995), ontology can be described as the nature of what is under investigation. In scientific studies the philosophical perspective of the researcher defines the way in which he will describe ontologically the details associated with a domain of knowledge. While a positivist point of view emphasizes the revelation of truths about a particular context of an event, a phenomenological point of view emphasizes the researcher's mentality rather than real-world events (DIETZ, 2006). In another definition, ontology is described as the study that illustrates the character of existence or the mode of the research areas to be studied (VAISHNAVI; KUECHLER, 2015).

Axiology means the values of the researcher in terms of establishing the foundations that support the research (ADEBESIN; KOTZÉ; GELDERBLOM, 2011; VAISHNAVI; KUECHLER, 2015). In addition, axiology is the analysis of values and takes into account those defended by individuals or groups, along with their possible effects on the development of research (ADEBESIN; KOTZÉ; GELDERBLOM, 2011; VAISHNAVI; KUECHLER, 2015). In addition, the values held or advocated by a researcher or research community can be reaffirmed to denote what is advantageous to that community or researcher.

As an example of this judgment, the researcher can define, for example, whether the artifact produced during the research is of greater value or more advantage to the community or researcher than the problem itself (PEFFERS et al., 2007; VAISHNAVI; KUECHLER, 2015). Typically, values are associated with ethics, and encompass notions of what is good and right in personal and social behavior, and aesthetics, considering notions of harmony and beauty.

It is imperative to recognize that a value or consequence of a choice may be related to a goal, even if a certain goal may not be supported by certain values. Therefore, it is of merit to broaden the discussion about values that allow one to take into account additionally whether the achievement of a goal is advantageous for the researcher or for the objective proposed in the research. Vaishnavi and Kuechler (2015) suggest that a possible motivation for a researcher is the evaluation in recognition of their efforts and findings by themselves or by the wider community of other researchers. Furthermore, the evaluation of such choices is intrinsically related to the achievement of a specific research goal.

Epistemology, the third fundamental principle, reflects on the relationship between the researcher as an individual and the objective of the research conducted by this researcher. It means, ultimately, the way in which research produces knowledge about the phenomenon of interest (CHRISTOPOULOS, 2006; CHAVALARIAS; COINTET, 2013; MARTINS; THEÓPHILO, 2017). In other words, the focus is on how the character of the knowledge is considered or how the facts about the knowledge obtained in the process are described by the researcher.

Hirschheim et al. (1995) state that epistemology represents the nature of human knowledge and the understanding that can be acquired through different types of research and alternative research methods designed for this purpose. In the context of Design Science Research, Vaishnavi and Kuechler (2015) suggest that an epistemology of "knowing by doing", in other words, learning by means of the act of producing practical solutions to problems, links the association between the researcher and his purpose. The association between the researcher and the participants establishes the degree to which they can have an effect on each other. It is recognized, therefore, that the assumptions, hypotheses and background information of the researcher can powerfully affect the phenomenon under study (CRESWELL, 2014; MERTENS, 2014).

The three pillars of scientific research, in turn, directly affect the research methodology, which in its essence consists in "developing or building". In other words, the methodology can denote the approach by which the researcher advances logically to verify everything he believes can be taken into consideration (LAKATOS; MARCONI, 2003). From a philosophical point of view, methodology deals with the way knowledge is acquired and is a combination of processes, methods, artifacts and guidelines (PATTON, 2001; CRESWELL, 2014; HEGDE, 2015).

3.2.1 Alignment of this thesis with the Design Science Research methodology

According to Lacerda et al. (2013) the methodological framework of a research should not be considered a bureaucratic act, but seen as a tool to support the researcher in conducting a rigorous and also relevant research. The author also states that many researchers, in their eagerness to have their studies accepted by the scientific community, end up forcing some methodological frameworks. This problem causes methodological confusion and sometimes gross errors. These errors, in turn, produce distortions and the potential to harm the quality of academic work.

Considering that applied research seeks, in general, to solve problems or design and create artifacts that can be used in everyday life by professionals, research that describes or explains a particular situation may not be sufficient to achieve this goal (DRESCH; LACERDA; MIGUEL, 2015). Therefore, the choice of research method requires a deeper analysis of the diversity of existing methods (LACERDA et al., 2013).

Thus, it is necessary to distinguish analytically these methods in comparison to the DSR to justify the choice since, according to Dresch, Lacerda and Miguel (2015), such choice is a result of positions defined by the researcher from the epistemological point of view to guide the conduct of research in order to increase the reliability of the results obtained. According to Lacerda et al. (2013) in academic research, two of the most common methods are Case Study and Action Research.

The main differences and similarities between these three methods can be identified in Table 7. This table summarizes the comparison in terms of epistemological paradigm, objectives that can be achieved, main activities foreseen for the proper conduct of the research, research results, knowledge generated, role of the researcher, collaboration between researcher and research subject, empirical basis, implementation, evaluation of the results obtained by the research, nature of the data, and specificity of the research results. It is important to emphasize, however, that DSR is a research framework, therefore, for its application, it is possible to use other approaches in each phase that composes it (OFFERMANN et al., 2010; LACERDA et al., 2013).

Table 7 - Comparison of DSR, Case Study, and Action Research characteristics

Element	DSR	Case Study	Action Research
Objectives	Develop artifacts that enable satisfactory solutions to practical problems. Design and prescribe.	Assist in the understanding of complex phenomena. Test or create theories. Explore, describe, explain, and predict.	Solve or explain problems of a system generating knowledge for both practice and theory. Explore, describe, explain, and predict.
Main activities	Define the problem. Suggest. Develop. Evaluate. Conclude. Communicate.	Define conceptual framework. Plan case(s). Conduct pilot. Collect Data. Analyze Data. Generate report.	Plan the action. Collect data. Analyze data. Plan action. Implement action. Evaluate results. Monitor (continuous).
Results	Artifacts (Constructs, Models, Methods, Instantiations, Design Propositions).	Constructs, Hypotheses, Propositions, Descriptions, Explanations.	Constructs, Hypotheses, Descriptions, Explanations, Actions.
Kind of Knowledge	About how things should be.	About how things are or how they behave.	About how things are or how they behave.
Researcher's Role	Artifact builder and/or evaluator.	Observer.	Multiple, depending on the type of action research.
Empirical basis	Not mandatory.	Mandatory.	Mandatory.
Collaboration between researcher and research subject	Not mandatory.	Not mandatory.	Mandatory.
Implementation	Not mandatory.	Not applicable.	Mandatory.
Results Evaluation	Applications, simulations, experiments with the artifact.	Confrontation with theory.	Confrontation with theory.
Approach	Qualitative and/or Quantitative.	Predominantly Qualitative.	Predominantly Qualitative.
Specificity	Generalizable to a certain class of problems.	Specific situation.	Specific situation.

Source: Adapted from Dresch, Lacerda, and Miguel (2015, p. 1129).

Besides the main differences explained on the table, one can also highlight the distinction between the epistemological paradigm to which each of the methods submits. Case studies and action research traditionally submit to the Natural and Social Sciences, while Design Science Research submits to the paradigm of the Sciences of the Artificial, that is, to Design Science. The justification for choosing DSR in this research is based on the following points:

I. This method is suitable to seek answers to the research problem, of prescriptive nature, which aims to design artifacts;

II. The execution of the research allows to evaluate the proposed artifacts and their demonstrations, based on consultation with experts and through survey; and

III. The development of the artifacts is based on a theoretical and empirical approach.

Therefore, it is important to present and detail the paradigm of Design Science Research as a method, given its importance for this work, which will be done in the following.

3.3 The Design Science Research paradigm

Design Science Research (DSR) is a scientific problem solving methodology[9] that was initially developed for the Information Systems (IS) domain (HEVNER et al., 2004; GREGOR; HEVNER, 2013; VOM BROCKE et al., 2020). DSR is also described as a research method used to create inventive concepts designed to solve everyday issues and, therefore, to promote the theory of the field where it is used (LUKKA, 2003). In addition, March and Smith (1995) consider the DSR as a method that involves itself in the analysis of innovative or alternative resolutions to problems, clarifies the course of exploration, and strives to develop the course of problem solving and assist human objectives.

Many academics have employed the DSR iterative process to create artifacts in the field of information technology (IT). DSR entails the generation of new knowledge through the design of new or creative artifacts, as well as the analysis of their use and performance in order to improve Information Systems (VAISHNAVI; KUECHLER, 2015). Essentially, the purpose of the DSR is to produce scientific awareness with the intention of facilitating the design of artifacts or mediation by professionals and to draw attention to their centrality of knowledge. In other words, action is not the focus of the DSR, but the knowledge generated and used in the elaboration of solutions. Design-based action is a subsequent step (VAN AKEN, 2004, 2005).

There are two significant features of DSR. The first is that it is driven by problem solving and the second that the results of a study are of a prescriptive nature. Hevner et al. (HEVNER et al., 2004; HEVNER; CHATTERJEE, 2010) highlighted the contributions of the Design Science Research method:

- Well defined identification and depiction of a problem;
- Proof of the inexistence of a distinct solution;
- Design, elaboration and demonstration of an artifact (for example, construction, method, model or instantiation);

[9] There is a discussion about whether Design Science Research, from a methodological point of view, is a paradigm or one can also be an approach in Weber (2010). The author offers a unified perception of DSR.

- Exhaustive examination and evaluation of the utility of the artifact;
- Description of the addition of value of the artifact, both practical and conceptual; and
- Clarify the results of implementing an artifact and its potential impacts.

While Van Aken (2004) states that DSR seeks to develop valid and reliable knowledge to design solutions, he leaves out of this description the actual use and problem solving capabilities. Both Horváth (2007) and Baskerville et al. (2015) highlight the dual essence of DSR:

1. Use the knowledge acquired to solve problems, create changes or improve existing solutions; and
2. Generate new knowledge, insights and theoretical explanations.

Horváth (2007) also describes a subtype of DSR that includes a study of real creative design actions between exploratory and confirmatory research actions - *Design Inclusive Research* or *Inclusive Design Research* (hereafter DIR). In summary, DIR divides the DSR into three phases:

1. In addition to the specification of the actions and hypothesis, exploration, induction, and deduction of the problem and context are required;
2. Design and testing of solutions;
3. Verification of the hypothesis, validation of research and generalization to other applications.

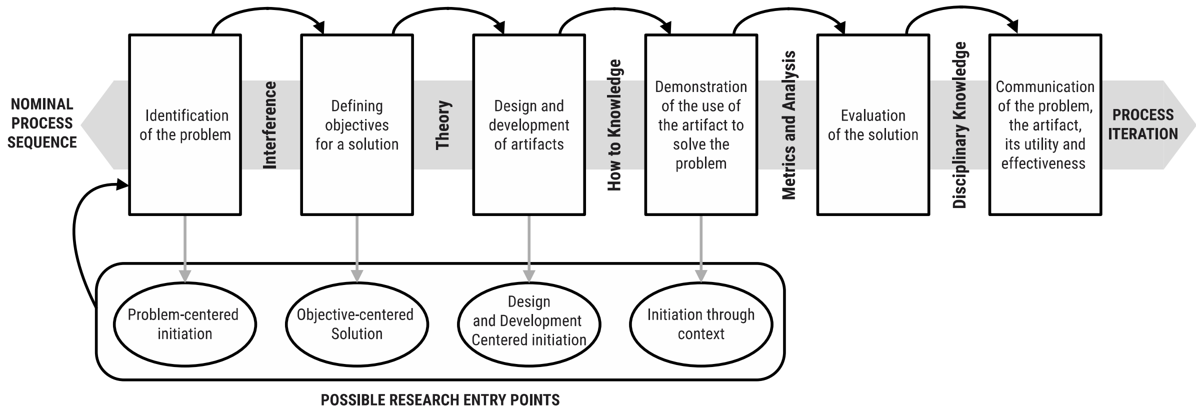
The DSR process usually includes six steps or activities (HEVNER et al., 2004; PEFFERS et al., 2007; BECK; WEBER; GREGORY, 2013; VOM BROCKE; MAEDCHE, 2019):

1. Identification of the problem, definition of the research question, and justification of the importance of a solution;
2. Defining objectives for a solution;
3. Design and development of artifacts (prototypes, models, methods, etc.);

4. Demonstration of the artifact to solve the problem;
5. Evaluation of the solution, including a comparison of the objectives and the actual outcomes obtained from the usage of the artifact, as well as the use of other validation methods; and
6. Communication of the problem, the artifact (solution), its utility and possible value to other researches and practitioners.

According to Peffers et al. (2007), the nominal process of the research conducted through the Design Science Research method consists of a sequence of elements and transitions, presented in Figure 10.

Figure 10 - Sequence of elements and transitions of the DSR Methodology



Source: Adapted from Peffers et al. (2007).

Although the author state that research does not always have to start from the first step (i.e., identification), most of the time goes through all the steps in one way or another (PEFFERS et al., 2007). The result of the project guided by the DSR premises is always a purposeful artifact that "can be a product or a process, can be a technology, a tool, a methodology, a technique, a procedure, a combination of any of these, or any other means to achieve some human purpose" (VENABLE; BASKERVILLE, 2012, p. 142).

As most projects focus on people (users) and the research result will be used or practiced by people to achieve interaction between people, or between products and people, designers and researchers need to focus on people (PRIES-HEJE; BASKERVILLE; VENABLE, 2008; ADEBESIN; KOTZÉ; GELDERBLOM, 2011).

According to Enninga et al. (2013) the focus on people and their individual experiences, needs and habits has become a common point and forms the basis of virtually all design processes. Another common point is the fact that they all adopt divergent and convergent thinking at different stages (ENNINGA et al., 2013), which generates a large number of ideas, uses trial and error to learn from mistakes and eradicate those that are not possible to implement, experiment solutions by prototyping and in general, intervene and observe instead of describing or analyzing, process called *Design Reasoning* (MCDONNELL, 2015), to find the best solution considering the established constraints (time, money, scope, etc.).

According to Chammas et al. (2015) and Mao et al. (2005), the technical criteria of the user-centered design approach are determined by the International Organization for Standardization (ISO 9241-210, ISO 13407 and ISO TR 18529). Chammas et al. (CHAMMAS; QUARESMA; MONT'ALVÃO, 2015, p. 5399–5400) point out six characteristics of a user-centered design approach:

1. It is based on the explicit understanding of the users, their activities and environments, as well as the context of use;
2. Users are involved in every part of the process;
3. It implements a progressive assessment focusing on the needs and desires of users and how and if these needs are met;
4. Iterative by nature, anticipates reviewing and refining the solution based on new knowledge acquired during the design process;
5. Addresses the entire user experience;
6. Includes multidisciplinary skills and perspectives.

In the context of this thesis, the proposed solution should comprise a user-centered approach as advocated by Chammas et al. (2015) and the solution development process will take into account user participation in all its phases, as endorsed by Mcdonnell (2015).

3.3.1 Activities in Design Science Research

Despite several proposals of DSR variations (HEVNER; CHATTERJEE, 2010), in general, the activities are usually divided into four large clusters, which according to Vaishnavi and Kuechler (2015) are:

1. Awareness of the problem;
2. Suggestion for a solution;
3. Evaluation of development; and
4. Conclusion.

According to Hevner et al. (2004), the Design Science Research methodology consists of seven main directives:

1. *Design as an Artifact:* research using DSR should produce a viable artifact in the form of a construction, a model, a method or an instantiation;
2. *Relevance of the problem:* Develop technology-based solutions to solve important and relevant problems;
3. *Project evaluation:* The utility, quality and effectiveness of a project artifact must be rigorously demonstrated through well conducted evaluation methods;
4. *Research contributions:* Research conducted through effective DSR should provide clear and verifiable contributions in the areas of design artifact, design fundamentals and/or design methodologies;
5. *Research rigor:* Depends on the application of rigorous methods in both construction and design artifact evaluation;
6. *Design as a research process:* The search for or research into an effective design artifact requires the use of available means to achieve the desired ends, while satisfying the laws and environmental constraints of the problem; and
7. *Research communication:* DSR research must be presented effectively to both the technology-oriented audience and other stakeholders and serve as the basis for future research.

The creation, modification and evaluation of artifacts (HEVNER et al., 2004) is an important part of the iterative nature of DSR. Therefore, it is necessary to understand the concept of artifact in the context of Design Science Research, as well as the types of artifacts produced by this research.

3.3.2 The concept of artifacts in the context of Design Science Research

The artifacts are considered as research results (MARCH; SMITH, 1995) or the final objectives of projects conducted through the Design Science Research methodology (HEVNER; CHATTERJEE, 2010). Therefore, it is important to conceptualize them, since this research will generate, as a result, an artifact. As for their characterization, Peffers et al. (2012) states that artifacts can be defined as:

Algorithms: An approach, method, or process described largely by a set of formal logical instructions;

Constructs: May include concepts, syntax or language (vocabulary and symbols) used in a specific context to describe a problem and find a solution;

Framework: Meta-model;

Instantiations: It can be the realization of an artifact in IT. Other examples include the implementation of systems or when prototype systems are developed;

Methods: Series of steps that explain how to achieve something like, for example, algorithms or practices; and

Models: Statements or propositions describing a set of constructions to solve a problem, such as abstractions and representations.

Another way to classify and define artifacts is in relation to their nature. Therefore, according to the classification given by Engeström (1990), Collins et al. (2002) and Offermann et al. (2010), artifacts can be divided into three types: primary, secondary and tertiary artifacts.

Primary artifacts are tools used directly in production to mediate the relationship between the subject and the object of activity. That is, primary artifacts aim to solve problems or achieve goals in an objective way. *Secondary artifacts* are representations of modes of action, such as models, methods, or frameworks, used to preserve and transmit skills in the production or use of primary artifacts, which is consistent with the primary goal of this research. *Tertiary artifacts* are imaginative or visionary and give identity and global perspective to collective activity systems. These, in turn, can be framed in a more holistic and theoretical perspective, and are not necessarily tangible.

3.3.3 Demonstration and evaluation of artifacts in Design Science Research

Evaluation in DSR should consider how the artifact contributes to the scientific knowledge base, that is, how the cycle of artifact construction and evaluation provides utility and additional knowledge for science (BASKERVILLE; KAUL; STOREY, 2015). To this end, evaluations in DSR can be formative or summative and both produce useful evidence (VENABLE; PRIES-HEJE; BASKERVILLE, 2016). According to these authors, a formative evaluation of a designed artifact identifies weaknesses and areas of improvement for the artifact during its development, i.e., its goal is to produce empirically based interpretations for the improvement of the artifact's features. This perspective captures the possibility of reducing risk by evaluating early, before committing the cost and effort of building the artifact. Summative evaluations, on the other hand, are empirical interpretations that provide a basis for knowledge creation in the face of different contexts, judging the extent to which the results match the artifact's expectations (VENABLE; PRIES-HEJE; BASKERVILLE, 2016).

Formative evaluations are often iterative or cyclical to measure improvement as the artifact development progresses, and can quickly reject bad designs or suggest promising designs, which makes it possible to find an effective outcome that can be tested again through later summative evaluations (EASTERDAY; LEWIS; GERBER, 2016). Formative evaluations also allow the researcher to mitigate risks, for example, by avoiding the use of costly methods such as randomized controlled trials (EASTERDAY; LEWIS; GERBER, 2016). Summative assessment episodes are most often used to measure the outcomes of a completed development, and there can be a chronological progression from formative assessments to more summative assessment (VENABLE; PRIES-HEJE; BASKERVILLE, 2016).

It is also noteworthy that the generated artifact must be demonstrated and evaluated rigorously so that the research results are reliable (LACERDA et al., 2013). For this, methods available in the knowledge base are used (HEVNER et al., 2004) that minimize bias in the generated solutions (LACERDA et al., 2013). Hevner et al. (2004) classify demonstration and evaluation methods into five types: observational, analytical, experimental, testing, and descriptive. These classifications and descriptions are presented in Table 8. The choice of method goes according to the artifact developed and the demands of its performance, besides having to demonstrate rigor, that is, demonstrate and justify the procedures adopted to increase the reliability of the artifact and its results when in use (LACERDA et al., 2013).

Table 8 - Artifact evaluation methods

Form of Evaluation	Proposed Methods
Observational	Case Study: Study artifact in depth in business environment Field Study: Monitor use of artifact in multiple projects
Analytical	Static Analysis: Examine structure of artifact for static qualities (e.g., complexity) Architecture Analysis: Study fit of artifact into technical IS architecture Optimization: Demonstrate inherent optimal properties of artifact or provide optimality bounds on artifact behavior Dynamic Analysis: Study artifact in use for dynamic qualities (e.g., performance)
Experimental	Controlled Experiment: Study artifact in controlled environment for qualities (e.g., usability) Simulation: Execute artifact with artificial data
Testing	Functional (Black Box) Testing: Execute artifact interfaces to discover failures and identify defects Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artifact implementation
Descriptive	Informed Argument: Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility Scenarios: Construct detailed scenarios around the artifact to demonstrate its utility

Source: Adapted from Hevner et. Al (2004, p. 86).

Peffers et al. (2012) goes further and suggests the following list of possible methods to be applied in the validation process:

Logical Argument: An argument with face validity;

Expert Evaluation: Assessment of an artifact by one or more experts (e.g., Delphi study);

Technical Experiment: A performance evaluation of an algorithm implementation using real-world data, synthetic data, or no data, designed to evaluate the technical performance, rather than its performance in relation to the real world;

Subject-based Experiment: A test involving subjects to evaluate whether an assertion is true;

Action Research: Use of an artifact in a real-world situation as part of a research intervention, evaluating its effect on the real-world situation;

Prototype: Implementation of an artifact aimed at demonstrating the utility or suitability of the artifact;

Case Study: Application of an artifact to a real-world situation, evaluating its effect on the real-world situation; and

Illustrative Scenario: Application of an artifact to a synthetic or real-world situation aimed at illustrating suitability or utility of the artifact.

On a more specific way, Offermann et. al (2010) present the following methods that can be used for the demonstration and evaluation of artifacts in DSR: expert judgment, laboratory experiment, case study and action research.

The Design Science Research paradigm is centered on a dynamic of design evaluation, in which designs are not only created, but also put to the test in working environments. From the amount and variety of artifact evaluation methods available in the literature, one can infer the importance of evaluating and testing designs.

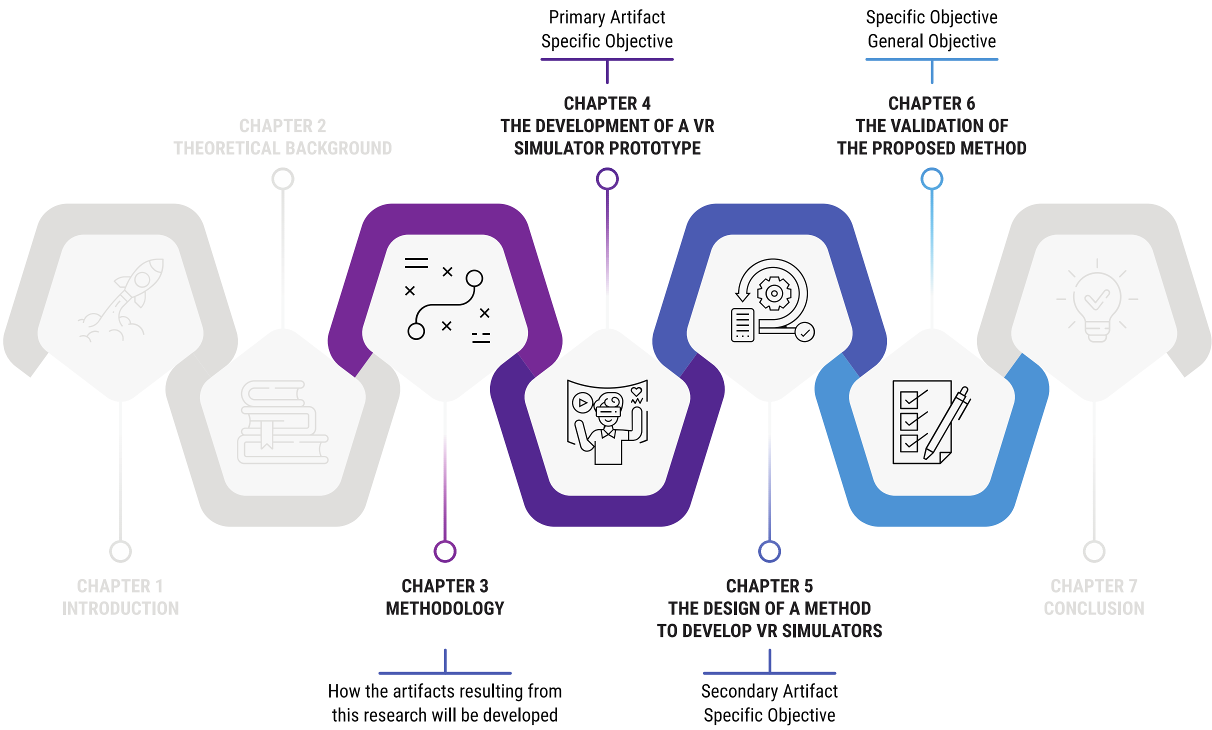
However, it is important to stress that the concept of artifact in the context of DSR does not have such a rigid character that only those that can be or have been put to test are classified as valid. That said, it is worth highlighting the work of Rob Gleasure (2014), who emphasizes the role, validity, and importance of abstract and untested meta-artifacts in the field of Information Systems, something the author calls conceptual DRS.

According to the author, meta-artefacts can be created from the analysis and rigorous study of existing artifacts, in which one should seek desired behavioral outcomes, which would enable the creation of predictive meta-artifacts. The author also states that the idea of using existing artifacts and practices to inform the creation of new designs is not new, and is widely adopted in both academia and practitioners (GLEASURE, 2014).

3.4 The artifacts generated in this research

Taking into consideration the context, the objectives, and the chosen methodology, this research produced two types of artifacts: a primary and a secondary one. The primary artifact is a Virtual Reality simulator prototype. The development of this prototype gives origin to the secondary artifact and of greater relevance to this research, which is a method to guide the development of Virtual Reality simulators applied to the specialized training of security professionals and law enforcement agents. Figure 11 presents the organization of the chapters of this thesis that reflect the development of the artifacts. The figure highlights the sequence that begins in Chapter 3, which deals with the methodology adopted, passes through Chapters 4 and 5, which present the development of the artifacts, and culminates in Chapter 6, which presents the validation of the results of the artifact presented in Chapter 5.

Figure 11 - Chapters of this thesis that reflect the development of the artifacts



Source: Elaborated by the author.

In Chapter 4, 5 and 6 of this thesis the development and validation process of both artifacts is presented in detail. For methodological purposes and to ensure scientific rigor, it is important to detail aspects such as the approach chosen to demonstrate and evaluate the artifacts, as well as the technical criteria adopted in the evaluation process of both artifacts, which will be done in the following.

3.5 Demonstration and evaluation of the artifacts in this research

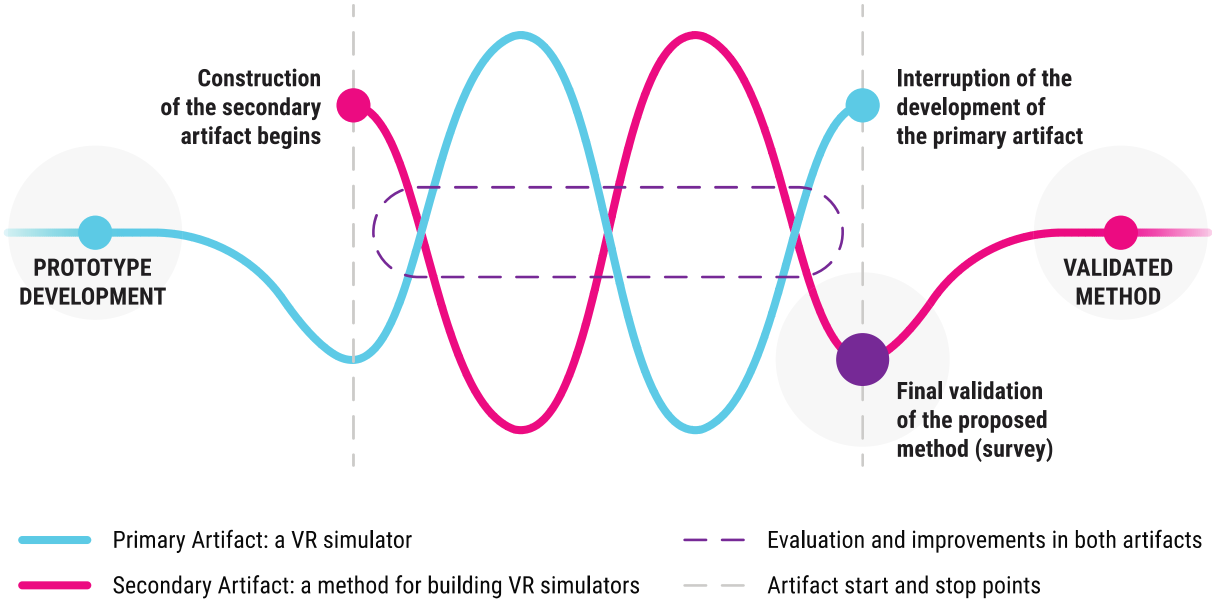
According to Venable, Pries-Heje, and Baskerville (2016), artifact evaluations are considered one of the most crucial points of research that uses Design Science Research as a paradigm. According to the authors, there are six purposes in testing prototypes produced by DSR:

1. Determine how well a designed artifact or set of artifacts achieves its expected environmental utility (the primary purpose of an artifact);
2. Substantiate the design theory in terms of the quality of the knowledge outcomes;
3. Evaluation may also relate to comparing a new artifact (or design theory) against previous artifacts (or design theories) to determine whether the new artifact/design theory brings an improvement to the state of the art;
4. Utility is a complex concept composed of a number of different criteria, far beyond simply realizing the main purpose of an artifact, as is the concept of style. Hence the importance of testing the artifact in order to identify its usefulness in the context of application;
5. An artifact can be evaluated in reaction to undesirable impacts, also known as side effects; and
6. Evaluation can further elaborate knowledge by discerning why an artifact does or does not work.

This research uses formative evaluation of the designed artifacts with the goal of identifying weaknesses and areas of improvement for the artifacts during their development. This choice is natural and is due to the fact that, in the context of this research, the generation of a primary artifact (a virtual reality simulator prototype) gives rise to a secondary artifact (a method for simulator development).

Figure 12 schematically presents the dynamics and relationship between both artifacts and how this research articulates the development of these artifacts highlighting the evaluation process employed in the development of both artifacts generated during this research.

Figure 12 - Artifacts generated by this research and their intersections



Source: Elaborated by the author.

According to what is presented in Figure 12, the dynamics of this research was given by the construction of two artifacts. The first of them was a Virtual Reality simulator (represented by the blue line) that employed, in its construction, the Design Science Research methodology and whose development process is presented in Chapter 4. The second artifact was the method for building Virtual Reality simulators (represented by the lighter purple line), which was proposed from the knowledge acquired during the construction of the first artifact and is detailed in Chapter 5. Each intersection (represented by the dotted purple line) represents a new iteration or improvement in both artifacts. At the end of the cycle, the simulator development was suspended and a validation of the proposed method was performed with experts and the academic community. This validation process is explored in Chapter 6.

Peffers et al. (2012) suggests that the evaluation method depends directly on the type of artifact, and it is up to the researcher to define the method or combination of methods. In the context of this research and considering the nature and specificity of the artifacts generated, it was decided to adopt a combination of four types of evaluation:

I. *Prototype:* Implementation of an artifact aimed at demonstrating the utility or suitability of the artifact. In the particular case of this research, the primary artifact is the prototype of a simulator.

II. *Technical Experiment:* A performance evaluation of an implementation using real-world data, synthetic data, or no data, designed to evaluate technical performance, rather than its performance relative to the real world. This method was used throughout the development of the prototype.

III. *Subject-based Experiment:* A test involving subjects to evaluate whether an assertion is true. At various times, users were invited to test the prototype and evaluate issues such as usability, comfort, and simulator experience; and

IV. *Expert Evaluation:* Involves the evaluation of an artifact by one or more experts. Both artifacts produced as a result of this research were submitted to expert evaluation.

In order to synthesize the evaluation methods adopted in this research, Table 9 presents the two artifacts generated by this research, as well as the evaluation methods applied to each one of them.

Table 9 - Artifact evaluation methods adopted in this research

Type of Artifact	Artifact Identification	Evaluation Methods	Context
Primary Artifact	A Virtual Reality simulator prototype	Prototype Technical Experiment Subject-based Experiment Expert Evaluation	The first artifact is itself a prototype; The prototype was tested extensively during development; Tests with real users were performed; The prototype and its development phases have been subjected to expert evaluation.
Secondary Artifact	A method for Virtual Reality simulator prototype design	Expert Evaluation/Survey	The method was built on rounds of expert evaluations; The method was subjected to final evaluation by practitioners and academics from several countries.

Source: Adapted from Peffers et al. (2012).

Peffers et al. (2018) state that one of the biggest problems in relation to the Design Science Research paradigm refers to the plethora of diversities of purpose, methodologies and mental models, which ultimately creates a problem for reviewers and editors when it comes to evaluating scientific papers and the effectiveness of their contributions. According to the authors, for some researchers, an artifact of value is a system or a system component, while for others, artifacts should be theories or theoretical components. The authors point out that one way to handle the conflict is to combine theory and practice in research, either by conducting and evaluating the research itself or even by pointing out possible practical applications of theoretical contributions.

In this thesis, practice and theory are inextricably combined by developing a prototype (primary artifact) and using the knowledge gained from this prototype to generate a method for simulator developments (secondary artifact). According to Baskerville et al. (2009), prototypes assume different shapes and serve different purposes. According to the author, the simplest type of prototype can be a mock-up that emulates the physical aspects of the final system, or even a part of a system that is continuously improved until it is mature enough to definitively integrate the system. The prototype developed as the primary artifact of this research was built using both approaches: the first versions of the prototype were only schematic and simple, but evolved into a larger and more complex system as it was developed.

As for the technical experiment, this form of evaluation was, without a doubt, the most applied during the development of the prototype. Following the guidance of Sedano et al. (2019), the following approaches were used to test the Virtual Reality simulator prototype produced as the primary artifact of this research:

- Usability testing;
- Feature validation;
- Frequent releases; and
- Participatory design.

At some point in the prototype development, it was possible to test a number of systems with real users and receive feedback from these users. These evaluations took place in several sections, some of which have been recorded and are presented in the chapter reporting on the development of the simulator.

The expert evaluation was performed both on the primary artifact (the Virtual Reality simulator) and the secondary artifact (the method for developing Virtual Reality simulators). The use of this method provides a constructive result about the quality of the artifact developed and the criteria with which to evaluate each item (RUBIO et al., 2003b), since it aims to reveal, represent, preserve and disseminate knowledge from experts (HOFFMAN et al., 1995).

These evaluations occurred at different times and using different approaches, specifically the Knowledge of Experts and the Survey method (SONNENBERG; VOM BROCKE, 2012), with professionals and academics from various fields but with solid experience in Virtual Reality and different countries. The selection criteria and a description of the experts involved in the evaluation processes of both artifacts from this research are presented in the following topic.

3.5.1 Evaluation of the first artifact: consultation with experts

This research adopts two different approaches to evaluate artifacts derived from this research. This is due to the fact that both artifacts are of different natures, being the first, a Virtual Reality simulator prototype and the second, the proposed method for developing Virtual Reality simulators. Given the specificity of each artifact, it was necessary to use different validation approaches. The first approach was consultation with experts and the second, a survey.

The use of expert knowledge is an alternative to empirical data (DRESCHER; EDWARDS, 2019), and can be extracted and elucidated in several different ways (HOFFMAN et al., 1995; HOFFMAN; LINTERN, 2006). Despite this increasing use, the validity of expert knowledge as a data source is still questioned by many experts, editors and reviewers, who label it as biased or unreliable. Transparency in the methods applied in the use of expert knowledge allows confirmation of the methodological rigor and reproducibility of the study, key steps in promoting the acceptance of expert knowledge as a valid data source.

One way to improve the reliability of this type of method is to combine it with some other validation method in addition to the experts' knowledge (LANDETA; BARRUTIA; LERTXUNDI, 2011; SONNENBERG; VOM BROCKE, 2012; DRESCHER; EDWARDS, 2019), approach that was adopted by this research.

The generation of the first artifact of this research counted on the constant evaluation of a body of experts and academics with vast experience in software development and more specifically, in immersive technologies, especially Virtual Reality. This research also counted with the support of two security professionals, one of them being a retired police officer and the other, a professional who works with private security. The collaboration of both professionals was extremely important in parts where knowledge about police and security officer training was imperative. In addition, one of the experts who actively collaborated on issues related to capturing vital signs has years of experience in the field of the Internet of Things, and teaches and conducts research in the area.

The literature diverges on the required number of experts, but according to Grant and Davis (1997) the final decision on the number of experts needed for a content validation panel is based on the desired experience and range of representation, although the number may also be contingent on resource or even expert limitations. The experts selected to support the validation of the artifacts are presented in Table 10, as well as a description of their characteristics.

Table 10 - Profile of the experts who validated the first artifact generated in this study

Expert	Profile	VR Experience
Expert 1	University professor and researcher focusing on Game Design and Interaction Design	7 years
Expert 2	Professor of Multimedia and Hypermedia Systems, with research in the area of Usability and Interaction	4 years
Expert 3	Professor and researcher in Immersive Systems with emphasis on Augmented and Virtual Reality	7 years
Expert 4	Software Developer with extensive experience in games, Augmented Reality and Virtual Reality	5 years
Expert 5	Professor and researcher with several years of experience in the area of Internet of Things	6 years
Expert 6	Retired police officer with more than two decades of experience in the security force	2 years
Expert 7	Private security professional specializing in valuables transportation and asset security	1 year

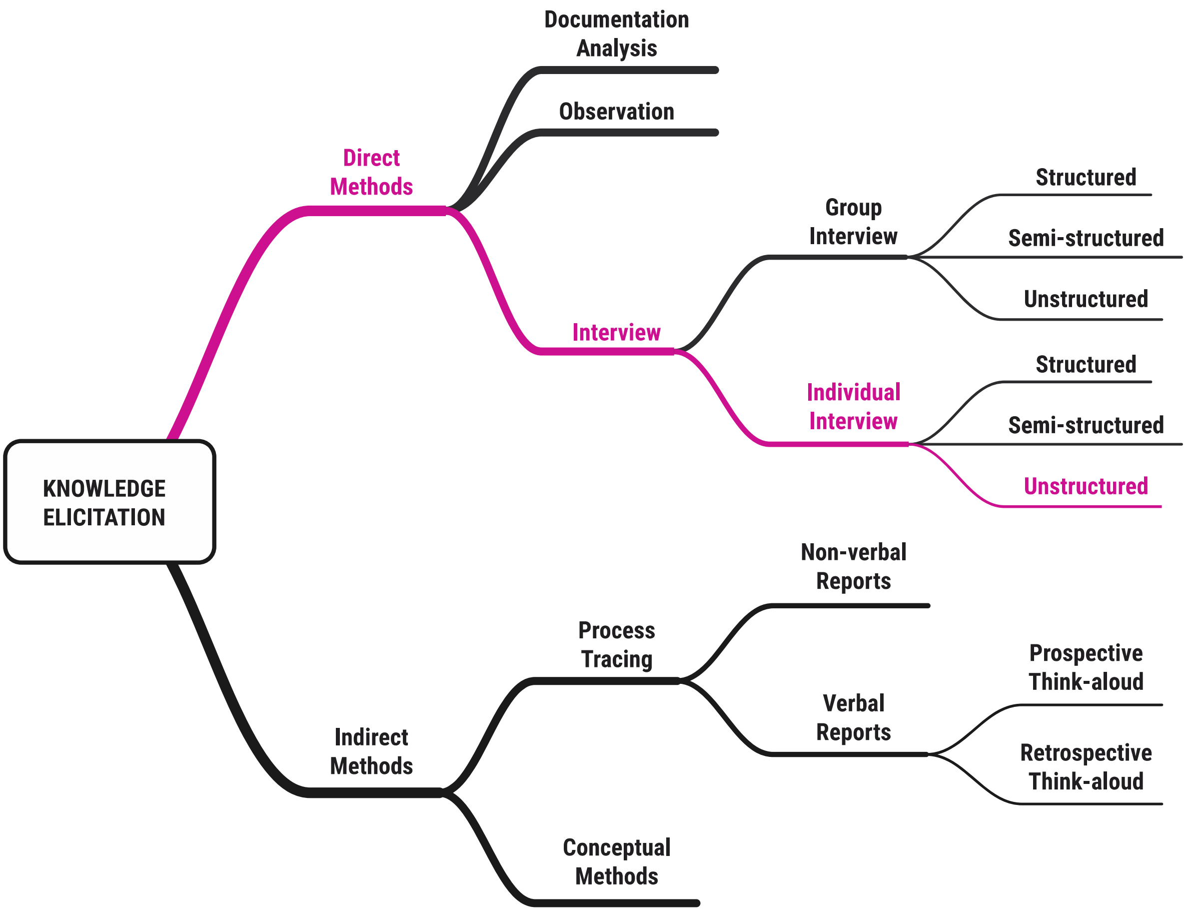
Source: Elaborated by the author.

The consultation with the experts did not occur at the same time and concomitantly, but care was taken to consult them mainly at times when the development cycle of the two main artifacts (prototype and proposed method) were in progress. This is due to a number of factors, among which we can highlight the availability of the experts and logistical and practical issues, especially at times when social distance was a requirement.

Although the interviews followed an unstructured format, there was a general protocol that was followed in all interview sections. This protocol comprised the presentation of the simulator up to the point where the evaluation was done (interview) as well as the processes or steps involved in the construction of the prototype and that should figure in the proposed method. The presentation of the progress of the prototype and the method was also followed by justifications for such processes to be included in the proposed method. After a brief discussion, the interviewees' observations were duly registered and applied in the development of the next iteration of the prototype and, subsequently, of the method.

According to Clewley et al. (2019) expert knowledge can be obtained through various direct or indirect methods. Figure 13 presents the various types, and highlights the choice adopted in this research.

Figure 13 - Different expert knowledge elicitation methods



Source: Adapted from Clewley et al. (2019, p. 140).

The specialists followed the development of the artifacts and participated in different moments and in an isolated way due, mainly, to schedule and space limitations. This is due to the fact that this research was developed in a physical space and fixed time, but without the physical availability of the specialists most of the time. One way to remedy limitations like this was to set up virtual meetings, by means of the audio-conferencing tool Skype[10]. Some

[10] https://www.skype.com/en/

presentation meetings also took place via Virtual Reality, through applications such as Spatial[11] and Mozilla Hubs[12].

The participation of the experts took place through unstructured interviews and individual feedback sections, mostly due to the limitations already explained. Although there are methodological advantages of structured interviews (CRESWELL, 2014), unstructured interviews offer, in specific cases, a more appropriate result. Especially when it comes to research where the intention is not to make comparisons with the responses among a group of respondents, and researchers most often use unstructured interviews when the research are in an unexplored area (WETHINGTON; MCDARBY, 2015).

Another application where unstructured interviews are often used relates to the development of grounded theory from everyday experience, and are usually used to add depth or offer critique to existing theoretical paradigms (MCADAMS, 2013). Both scenarios justify and support the decision of this research to use unstructured interviews, since this research is in an area that has been little explored and aims to formulate a method based on theories and real-world practices. The participation of the experts as well as the description of the evaluation sections are reported in Chapter 4 of this thesis, along with the development of the Virtual Reality simulator prototype.

Besides the expert knowledge, used for the construction of both artifacts, this research also made use of a survey in order to evaluate the second artifact, whose respondents profile comprises a larger group, more heterogeneous in terms of professional experience and areas of activity, but with something in common: experience in Virtual Reality. The methodological procedure, the construction of the evaluation instrument as well as the criteria for choosing and approaching the respondents of this survey are described in the following topic.

3.5.2 Evaluation of the second artifact: survey with professionals and academics

Surveys have been used as a tool to collect information in various fields of knowledge (THOMPSON et al., 2003). According to Vannette and Krosnick (2018), this type of research has a number of advantages:

- They are easy to apply, to code and to convert into scores;

[11] https://spatial.io/
[12] https://hubs.mozilla.com/

- Allow the researcher to determine values and relationships between variables and constructs;
- Can be reused, thus offering the opportunity to compare responses across different groups, times, and locations;
- Allow theoretical propositions to be objectively tested; and
- Assist in confirming and quantifying qualitative hypotheses.

This method of data collection has yet another relevant characteristic: the voluntary participation of the respondents. This has a significant impact on the quality of the data collected. The success of a questionnaire depends fundamentally on the quality of the data collected, and these depend deeply on the cooperation of the people who voluntarily spend time and effort to answer the questions (THOMPSON et al., 2003).

Regarding the questionnaires, attention must be paid to the design of the questions to ensure the validity of the data since they will be filled out without the presence of the researcher. Other problems to be faced are the small response rates that can affect the representativeness of the sample and the generalizability of results (KITCHENHAM et al., 2009; MERRIAM; TISDELL, 2015). Questionnaires can be sent electronically or through specific websites with the advantage of performing the collection with more efficient costs, covering a greater number of users and being able to perform the collection in different geographical regions (KITCHENHAM et al., 2009).

3.5.3 The selection of the respondents' profile

The sample choice was non-random and was composed of professionals with experience in developing Virtual Reality projects, chosen by the researcher through indication of their peers and through careful selection of profiles on social networks such as LinkedIn and specialized discussion groups. In qualitative research, non-random sampling is indicated, where respondents or interviewees are selected to represent the phenomenon being investigated (MERRIAM; TISDELL, 2015).

There is no consensus in the literature as to the desirable quantity of experts. Furthermore, some methods do not require representative samples for statistical purposes

(WILLIAMS; WEBB, 1994; POWELL, 2003). Therefore, the sample size varies according to the researcher (WILLIAMS; WEBB, 1994) and his or her resources, time, and money. Its representativeness is evaluated by the quality of the panel of experts and not by the number of people involved (POWELL, 2003).

In some research, the selection of the sample of experts involves non-probability sampling techniques, purposive sampling or criterion sampling, where the participants are not randomly selected, so representativeness is not guaranteed (HASSON; KEENEY; MCKENNA, 2000; LAKATOS; MARCONI, 2003; OATES, 2006) as is the case with the selection for the research in this thesis. This is because experts are selected to apply their knowledge to a given problem based on criteria developed from the nature of the problem under investigation (HASSON; KEENEY; MCKENNA, 2000).

For Curvin and Slater (2002), if a certain group is part of the population to be researched but presents resistance in engaging with the subject, it can be excluded from the sample. If this group has different views on the research subject than the other surveyed groups, this view may not be represented in the final survey results, which characterizes a non-probability sampling. According to Aaker, Kumar, Leone and Day (2018), non-probability sampling is typically used in the following situations:

1. Exploratory stages of a research project;
2. Pre-testing of questionnaires;
3. When dealing with a homogeneous population;
4. When the researcher does not have sufficient statistical knowledge; and
5. When the operational facility factor is required.

In other words, there are situations in which research with non-probability sampling is adequate and even preferable to probabilistic research. Curvin and Slater (2002) and Burns, Veeck and Bush (2020) confirm this statement, claiming that a well-conducted non-probability sampling survey can produce satisfactory results faster and at less cost than a probability sampling survey.

Considering the multidisciplinary nature of this research, the sample of respondents was composed of professionals and academics with experience in the development of Virtual Reality projects from the various areas tangential to this thesis. The desired profiles for the respondents were professionals from the fields of User Experience and Interface Design

(UX/UI), Software Development, Education, Games and Industry 4.0, but other professionals could participate, as long as they had experience in the development of Virtual Reality projects.

The main sources where possible candidates with desired profiles for this research were sought were the social network LinkedIn and communities specialized in topics such as Game Design and User Experience. In addition, several of the interviewees were nominated by peers and evaluated by the researcher. This is another feature of the non-probability sampling in this research, also known as chain referral samples or popularly known as "snowball sampling". This sampling technique consists of individuals selected to be studied inviting new participants from their network of contacts (BURNS; VEECK; BUSH, 2020). As the informal name implies, the sample grows just as a snowball grows when it is rolled down. Initially the search for professionals took place in Austria and Brazil, but due to the specificity of the technologies and the requirement that professionals had some experience with Virtual Reality projects, it became necessary to expand the search beyond the boundaries of both countries.

In addition to broadening the search, it was necessary to change the approach to approaching potential respondents due to the low response from the first contacts made and the fact that some responses were incomplete. Forza (2002) warns that non-respondents alter the structure of the sample and can lead to distortions in the results. The author suggests that non-respondents can be managed in two ways: (i) - by trying to increase the response rate and (ii) - by trying to identify non-respondents to control when they are different from respondents. In the context of this thesis, the first tactic was adopted.

The increased response rate was achieved after the change in approach and invitation to the respondents. At first, the survey was only directed by email. When noting the low number of respondents as well as a high number of people who started and did not finish the survey, it was decided to change the approach. The sending of emails to the target audience became personalized and contained an invitation to a virtual meeting where the interviewee filled out the form while the researcher followed along without intervening. After submitting the form, the researcher was available to talk about the project and ask questions.

The process of filling out the form under the supervision of the researcher ensured that all answers were imputed. The process describing the workflow and approach to respondents is presented in Chapter 6 of this research.

3.5.4 The survey instrument

The questionnaires were prepared and made available on the web, using the Google Forms tool, which allows to prepare, publish and collect responses to questionnaires. The questionnaire used in the data collection for this research has two parts. The first part contains the general instructions for filling it out, and has the objective of orienting the respondent as to the use of the questionnaire, as well as stimulating its full completion. In addition, this first part presents a hypothetical scenario in which the respondent needs to develop a Virtual Reality simulator for training professionals in situations of risk and stress, such as police officers, firefighters, or security professionals. More specifically, this scenario defines that the simulator that needs to be developed will have some form of biofeedback to support the professional's evaluation process and adopts serious game mechanics to increase engagement.

Once the initial scenario is presented, the respondents are directed to the second part of the survey, which consists of the questionnaire, which was divided into eight blocks. The first block presents demographic questions that include questions such as field of work, country where they work, years of professional experience, years of experience with VR and gender[13]. The other blocks refer to each of the major phases presented in the final version of the proposed method and represent activities or tasks to be performed in each cycle or phase.

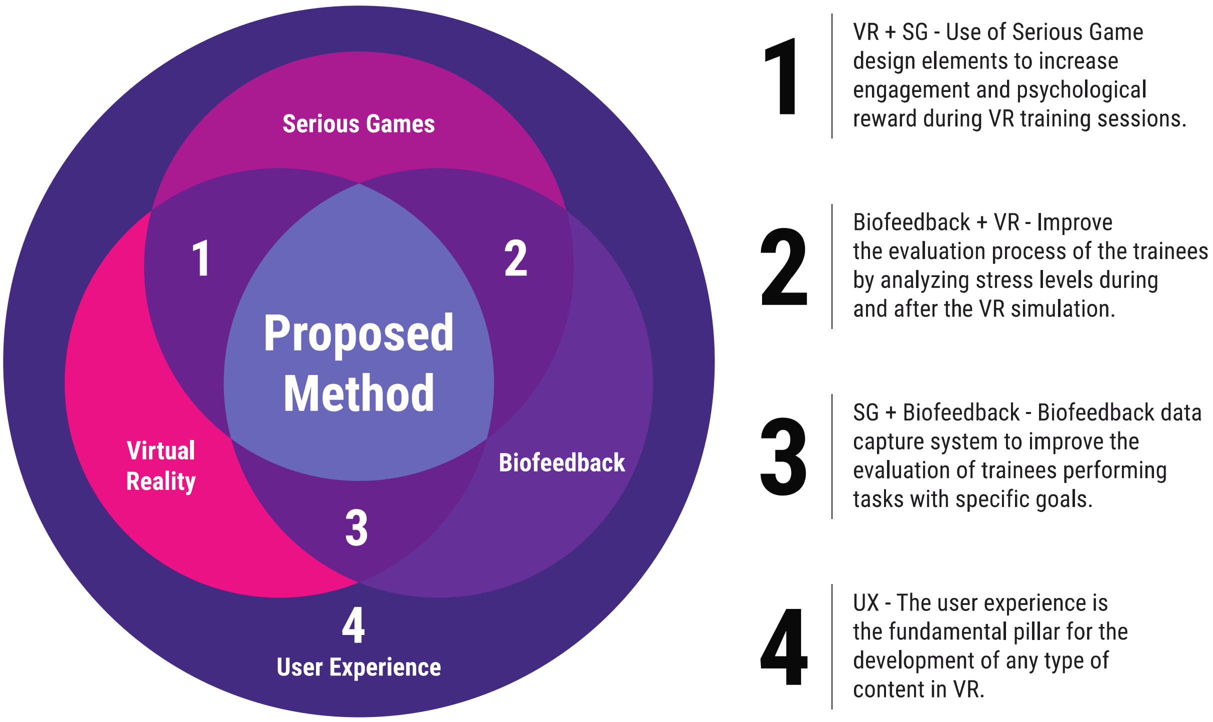
As a way to help the respondents understand the context and purpose of the research, as well as a general explanation of the research objective, a figure containing the pillars supporting this research and their possible interactions was presented. Despite the concern with providing enough information so that the respondent could understand the context of the research and be able to answer the questionnaire without interruptions, care was also taken to avoid mistakes common to some field research that could incur the influence of the respondents.

Burns, Veeck e Bush (2020) states that there are two major mistakes when dealing with respondents in surveys: (i) - the researcher cheats or deceives the respondent and (ii) - the researcher leads or interferes with the respondent's responses. For the sake of clarity and scientific rigor, at no time was the image of the final method presented to the respondents, and the researcher, despite following all the response sections, did not interfere and even refused to

[13] It is important to emphasize that no personal information such as the name of the respondent or the company he or she works for was requested. In addition, and in accordance with the General Data Protection Regulation (GDPR), no data such as IP or cookies of any nature was captured, which guarantees the absolute anonymity of the survey. For more information on GDPR, please visit https://gdpr-info.eu/.

answer any questions that might cause distortions in the responses. Figure 14 shows the image that was presented to the respondents at the beginning of the questionnaire and was duly accompanied by an explanation about the general purpose of the research as well as other previously presented information.

Figure 14 - Image presented to the respondents of the survey



Source: Elaborated by the author.

Besides the image containing the theoretical pillars and an explanation about the research, the second part of the questionnaire, which consisted of questions about the relevance of the activities performed in each cycle or phase, also contained a brief explanation about each of the activities. This allowed the respondents to have complete autonomy while filling out the questionnaire, even though the researcher followed the sections. This measure, as already stated, ensured that the respondents were not directly influenced by the views, perceptions, or particular interests of the researcher.

Table 11 presents the themes of the eight blocks of questions and a brief explanation of the context of each one, which were presented to each of the respondents as a way to provide more subsidies for them to answer the survey.

Table 11 - The themes of the eight blocks of questions and a brief explanation

Block	Theme	Explanation
01	Demographic questions	Area of expertise/industry, country, years of professional experience, years of professional experience with VR and gender
02	Initial planning and general objective	This is the starting point. At this stage of the simulator development method proposed by this research, there are actions such as defining the simulator's objectives, brainstorming, and raising initial hypotheses.
03	Research Cycle	The research cycle gathers functions such as context research (to better understand the corporation), research about the target audience (to better understand the user), and analysis about existing solutions (to know about possible solutions already developed).
04	Technological and pedagogical decisions cycle	In this cycle, some decisions affect several aspects of the simulator, including immersion level, visual style (which impacts the decision by the type of technologies to be adopted), and aims to establish the pedagogical criteria and objectives to be evaluated.
05	Design cycle	The design cycle has the most stages. In this cycle, fundamental concepts of the simulator are developed and refined. Among them, elements of serious games, the user experience, the interaction design, and the aesthetic and narrative aspects of the simulator, ranging from the characters and scenarios to the interface.
06	Prototyping Cycle (VR)	In the VR prototyping cycle, tasks such as creating and importing the assets that will be used in the construction of the simulator and fundamental activities such as coding, testing, and optimization.
07	Prototyping Cycle (Biofeedback)	In the Biofeedback prototyping cycle, there are activities related to the system's development or configuration that will capture vital data during the simulation.
08	Demonstration and Evaluation Cycle	The demonstration and evaluation cycle is a fundamental step and has activities such as user experience tests and possible refinements and improvements and a previous phase before the publication called reflection and learning.

Source: Elaborated by the author.

The respondent is then asked to evaluate the level of relevance of each of the activities within the predetermined phases. The questionnaire for evaluating the proposed method for developing Virtual Reality Simulators applied to the training of professionals in situations of stress and risk is available in APPENDIX A - Survey used to evaluate the proposed method.

3.5.5 Pilot testing of the survey instrument

The pilot test of a questionnaire is an absolutely essential activity of a survey, and has the following objectives: (i) - to clarify if the instructions provided are clear and objective; (ii) - to verify if the questions are objective and without dubious interpretations and (iii) - to ascertain any problems of understanding by the respondents of what the expected answers would be (FORZA, 2002). According to Forza (2002) the best way to pre-test a questionnaire is to conduct it in two stages, each one completely different from the other, but with complementary objectives.

He suggests that in a first stage, the researcher applies the questionnaire to a small group of respondents, with the researcher present to observe how the respondents fill it out and get feedback from each of them. In a second stage, the researcher should send the questionnaire to a slightly larger group of respondents in order to assess the quality of the questionnaire and the quality of the responses. In this second stage, the researcher should perform a complementary analysis of the data with the aim of assessing: (i) - if the answers for certain questions are too concentrated, due to the choice of scale; (ii) - if the content of the answers differs from what was expected; (iii) - if the content of the answers modifies the meaning of the question; and (iv) - to evaluate the effect of the blank answers and a possible research bias that may exist due to this.

This study did not follow all of Forza's (2002) recommendations due to limitations related to the short time available to conduct the research and limitations related to social constraints imposed by the pandemic situation in which this phase of the research was developed. In the context of this research, only one pre-test was carried out, with six respondents, three of whom were followed up in loco by this author, and the other three sent and answered by e-mail, but with many comments from the respondents, since each one was asked to make a careful analysis.

The comments and results of this pre-test led to significant changes in the questionnaire, the two main ones being: (i) - the reduction of the number of demographic questions for reasons of agility and privacy, and (ii) - the inclusion of helpful information or additional explanations about each of the processes proposed by the method and evaluated by the questionnaire. This was due to the fact that the respondents' fields of work and professional backgrounds were absolutely different, and many of them did not have sufficient knowledge about several of the processes, methods, or even certain technologies. In addition, the pilot test allowed us to verify that the chosen scale was adequate.

After analyzing the results and comments arising from this validation, the final version of the questionnaire was prepared and submitted to the group of selected professionals, whose structure was presented in the previous section.

3.5.6 Data processing

Regarding the type of scale used in the survey to evaluate the proposed method (secondary artifact), it was decided to use a linear relevance scale also known as Interval Rating Scale, instead of a Likert scale (LIKERT, 1932), commonly applied in survey research (VANNETTE; KROSNICK, 2018). Respondents are presented to a rating scale and are asked to rate the importance of the items. An interval rating scale requires a consistent unit of measure. The cognitive distance between pairs of adjacent points must equal intervals. The distance from a 1 to a 2 must equal 2 to a 3 and so on (TAHERDOOST, 2019).

The choice for a linear relevance scale is due to two factors. The first is due to the multidisciplinary character of this research (HADORN et al., 2008), which brings together technologies, concepts, theories, and involves professionals from various fields. Therefore, it would be presumptuous to expect someone with experience in Software Engineering to evaluate issues such as usability with the same agility as someone from the Human-Computer Interaction area, just as it would be to ask someone with experience in Industry 4.0 to evaluate design-related issues with the same propriety as a UX professional.

The disparity of opinions is something constant in any scientific research, especially qualitative research, and it is up to the researcher to seek consensus or to evidence such disagreements in the light of the method and aiming to meet the objectives stipulated by the research (HADORN et al., 2008; CRESWELL, 2014). In the context of this research, the choice for a linear relevance scale had as its main objective to evaluate how relevant was each item or task proposed for the context of the task in relation to each phase or cycle of the method. It is considered, therefore, that opting for a relevance scale instead of a Likert-type scale has the benefit that this option would avoid the abundance of neutral answers, especially when answering questions from other areas or that are beyond the respondent's domain (THOMPSON et al., 2003; VANNETTE; KROSNICK, 2018).

However, considering that the common characteristic among all selected survey participants is experience in Virtual Reality projects, this research recognizes the possibility that some of the answers coming from a non-homogeneous group of professionals may still have value. This is because the knowledge shared by the opinions of several respondents fits the concept of "collective intelligence" as advocated by Pierre Levy (LEVY, 1999).

The second reason for adopting a linear relevance scale instead of a Likert scale is due to the fact that the secondary artifact to be evaluated through the survey had already passed through previous evaluations. In fact, it was built in a participatory manner, and based on the knowledge of the experts who supported the construction of the primary artifact. Therefore, evaluating how relevant each activity or task is for each of the phases or cycles was the choice that guided the development of this survey.

According to Burns, Veeck e Bush (2020) descriptive statistics summarizes numerical information in a structured way with the purpose of obtaining a general picture of the variables measured in a sample. Inferential statistics, on the other hand, allows, by applying statistical tests, to determine the possibility of confirming or not the relationship between the variables under study. In the particular case of this study, descriptive statistics was used to characterize the sample, whose data were presented in tables and graphs for a better understanding of the data collected. In addition, each of the answers in the questionnaire is also presented with their respective frequency distributions. As a way of presenting the survey results and making them easier to read, the answers for each of the questions within the Phase/Cycless will be presented in percentage form. As measure of dispersion, the Standard Deviation (SD) was used.

To process the data obtained from the survey responses, the R programming language (R CORE TEAM, 2021) was used, through the R-Studio development environment (RSTUDIO TEAM, 2021), to help generate graphs and summarize the data. The result of the survey as well as the tables and graphs and analysis of all responses are presented in Chapter 6 of this thesis.

Once the methodological choices and evaluative instruments or methods have been presented, the next chapters are dedicated to presenting the development of the artifacts generated during the course of this research.

4 THE DEVELOPMENT OF A VR SIMULATOR PROTOTYPE

4.1 Introduction and context

This chapter presents the development of the Virtual Reality simulator that originated the method for developing Virtual Reality simulators that constitutes part of the main objective of this research. Considering that the Design Science Research methodology that guides this research has a series of steps or activities, it was decided to present the simulator development as the method recommends. However, it is important to note that, although the method suggests a sequence, research that adopts this methodology does not always start from the initial point. According to Peffers et al. (2007) almost always research that adopts DSR goes through all the steps or activities at least once.

As explained earlier, several authors suggest different numbers of steps or activities (HEVNER; CHATTERJEE, 2010). According to Vaishnavi and Kuechler (2015) these activities can be divided into four major clusters:

1. Awareness of the problem;
2. Suggestion for a solution;
3. Development and evaluation; and
4. Conclusion.

In the context of this thesis, this sequence was adopted as a way to guide the development and to narrate the way the simulator was developed. As explained previously and considering that two artifacts were produced during this research, not all steps or activities were used or adopted in the same way in both artifacts. Therefore, the next topics are dedicated to present, in general lines, the development of the simulator as well as the validation and improvement process that gave rise to the method proposed by this research and whose development will be presented in Chapter 5.

The presentation of the prototype development begins, therefore, with the awareness of the problem, which in this case was based on three main sources: academic literature on police performance, routine and training, interviews with police officers from different countries, and the cross-checking of what was collected with data from more specific investigations.

Next, a suggestion for a solution is offered, which in this case consists, in the long run, of a simulator that gathers characteristics that aim to address the problems raised during the awareness of the problem, followed by the development of the solution itself. Besides the development of this simulator, the set of technical and practical decisions taken during its construction is also presented. These decisions range from the choice of tools to approaches such as scenario design, interface, and the adoption or not of narratives, as well as other issues that can impact the user experience such as the type of interaction and representations of real-world elements.

Finally, the evaluation process of the artifact itself is presented and involved continuous testing, consultation with experts, and evaluations with users. While conducting the evaluations and developing the simulator itself, it was possible to obtain subsidies to formulate the basis of the second artifact, which, in this case, is a proposed method for building simulators that can be applied to the training of security professionals and law enforcement officers.

4.2 Simulator Development: awareness of the problem

According to Braga (2003) the police perform one of the most significant roles among all state institutions. This is due, above all, to the practical results it seeks to achieve in the control of conflicts that affect social order and directly impact people's lives. Its importance goes far beyond conflict control. Nowadays, the police, besides its constitutional attributions, performs several other duties that, directly or indirectly, influence people's daily lives, acting, guiding, collaborating with all segments of the community, reducing conflicts and generating the sense of security that the community longs for.

Therefore, when police officers commit operational or behavioral deviations, such violations reflect directly on the perception of the efficiency of the organization as a whole by the society. In the end, society judges the action and performance of the police (DADDS; SCHEIDE, 2000). Police mistakes or law enforcement misconduct can have devastating consequences and have a major impact on public perceptions of police forces and their long-term performance (MACDONALD et al., 2003).

However, it is important to note that the nature of police work is marked by inherent risks, and while on duty, police officers are exposed to a variety of acute stressful and life-threatening situations (GIESSING et al., 2020). In stressful or threatening situations, people tend to react impulsively, losing cognitive control (SARASON et al., 1979; ROBERT J. HOCKEY, 1997; GUTSHALL et al., 2017).

According to Porcelli and Delgado (2017) and Selye (1936) stress can be defined as the body's non-specific response to any demand for change, which can cause a "fight-or-flight" response. The fight-or-flight response (also called the hyperarousal response or acute stress response) is a physiological reaction that occurs in response to a perceived dangerous event, an attack or a threat to survival, as first described by Cannon (1915). This type of reaction, as natural as it is, can further increase the chances of police officers making mistakes. For this reason, police officers must train as often as possible to maintain control of their responses to threats and levels of stress when dealing with dangerous situations.

Police training is, therefore, essential to form professionals better prepared not only to serve society, but also to deal with situations where stress levels can pose a real threat to police conduct and whose immediate consequences can be disastrous. However, police training is very expensive, complex, time-consuming and not very flexible, since only a small variety of real-life scenarios and situations can be included during police academy training (CORDNER; SHAIN, 2011; BERTRAM; MOSKALIUK; CRESS, 2015). In addition, police training involves potential risks to the physical integrity of the officers in training (ACHIM, 2019). Considering all these aspects, it becomes important to look into various aspects of police training in order to get a big picture of how it is conducted, its characteristics, implications and limitations.

Although there is not much research dedicated to comparing police performance in different parts of the world, and the task itself seems absolutely Herculean given the cultural, economic and social differences in each country, there are works published decades ago that have looked at general aspects of police training. Breci (1989) and Sherman (1986) criticize police academy training by claiming that it overemphasizes physical danger to police officers while neglecting aspects such as interpersonal skills that are so important in situations such as, for example, family disputes. This view is shared by more recent authors such as Blumberg et al. (2019) who argue that the complexities of modern policing require police forces to expand the way officers are trained to do their jobs. The authors state that it is not enough for training to focus only on the law or on skills that require the use of force such as arrest and control, defensive tactics, driving, and firearms.

However, police training in various places in the world has some similarities, even if it is conducted in absolutely different ways. There are obvious explanations for this, ranging from the disproportionate investment that each state in each country invests in the training of its officers, to issues such as the time and rigor in the training of police professionals. Therefore, understanding how police training is conducted and the consequences of this can be interesting in order to contribute to proposing solutions.

According to Blumberg et al. (2019), police academy training has two general aspects. The first is the academic component, which takes place in classrooms and involves basics of law, procedures, radio codes, penal codes, etc. The second component of police training involves practical training and includes rehearsals and performance evaluations in areas including arrest and control, defensive tactics, weapons use, and driving. Also, according to the authors, most police academies allow recruits to fail a certain number of domains and try again. If any domain is not passed satisfactorily, the recruit is dismissed from the academy.

With regard to the time spent at the academy, the disparity is enormous. Taking the United States as an example, it is possible to get an idea of the huge difference between the training time and the level of demand for police officers to carry weapons and work in the community. According to data from the Institute for Criminal Justice Training Reform[14], a American non-governmental organization whose mission is to reform training models, policies, and procedures for employees of the U.S. Criminal Justice System, more than 5,500 people were killed by American police forces between 2015 and 2019. Many of the victims were minorities living in Native American, African American, and Latino communities, many of whom were experiencing a mental health crisis. In addition, more than half of all citizens killed were not in possession of a firearm.

Many of these incidents can be directly linked to a series of training failures that also encourage a culture after training that is marked by a lack of accountability, particularly in response to excessive, irrational, and unnecessary use of force. These training failures range from inadequate minimum training hours to ineffective training of future law enforcement officers ("The Institute for Criminal Justice Training Reform", 2021).

One of the flaws pointed out by the organization regarding police training refers precisely to the attitudes of the policeman who is, in some cases, trained in a culture known as "warrior cop" (HEYER, 2014; STOUGHTON, 2014). The behavior and mentality of the warrior cop consists of creating an environment in which officers operate as through omnipresent threats. Such a mindset, when applied to all aspects of police work, supports fewer

[14] https://www.trainingreform.org/

restrictions on the use of lethal force and a disregard for the integrity of suspects assumed (INGRAM; TERRILL; PAOLINE III, 2018; MCLEAN et al., 2020). The behavior of the warrior police officer is described as a direct consequence of militarized police training (HEYER, 2014).

Over time, this kind of police behavior and culture can have the effect of spreading such deviant behavior as normal and acceptable. The direct repercussion of this is to cause a supportive reaction from part of society to believe that the brutalization of police forces is the only solution to decrease crime rates (PASSOS, 2021). This, in turn, can further reinforce the culture of extreme use of police force, especially against minorities or people in situations of social vulnerability (SØRBØE, 2020).

With regard to the rigor, time spent, and type of training at the academy, there is clear variation between police training in various parts of the world. Taking the United States again as an example, recruits spend significantly less time at police academies than those in most European countries. Basic training programs in the U.S. take an average of twenty-one weeks, while similar European programs can last more than three years. In Finland and Norway, recruits study policing at national colleges, spending part of their time in an internship with the local police. At the end, they receive diplomas in criminal justice or related fields (DEKANOIDZE; KHELASHVILI, 2018).

As a way to confirm what the literature states, this research adopted an approach based on anonymous interviews with on-duty police officers from different groups and different countries. The adoption of the interview method applied, although methodologically questionable, is justified by practical factors such as the researcher's little exposure to the police academies or even to the policemen who, in all approaches, answered the questions during working hours. The researcher tried to contact different police corporations in Brazil and Europe during several months and there was no official answer or formal interest from the consulted police institutions to participate in the research.

In addition, there are specific regulations that discourage police officers in various countries from giving interviews or statements in an official way, which justifies anonymity. The questions asked, however, were exactly the same:

1. How long have you been on the police force?
2. How long did it take for you to carry a gun and start working as a police patrol officer?

3. Briefly, how does police training go from entering the police academy to your first day on the job?

The same three questions were asked of police officers in Brazil, Portugal, Spain, Germany, and Austria. The answers corroborate the research work of Dekanoidze and Khelashvili (2018), who undertook an analysis of the police training ecosystem in eight European countries, as well as the United States and Canada, and compared factors such as training time, curriculum, and academic structure.

In order to collect information about different models of education and training, institutions from the USA, Canada, Austria, Croatia, Estonia, Germany, Latvia, Montenegro, the Netherlands and Poland were selected. The main instrument of the exploratory research was the use of a questionnaire with eighty-seven questions designed to obtain comprehensive information about three main research areas: police structure, basic training, and continuing education. Both multiple-choice and open-ended questions were designed. In addition to this questionnaire, interviews were also conducted. The electronic questionnaire was sent to identified officers who fulfilled relevant roles within the institutions prior to the interview to facilitate data collection, and the interviews were conducted on-site at the police education and training institutions (DEKANOIDZE; KHELASHVILI, 2018, p. 10). The research was conducted at the request of the Ministry of Internal Affairs of Ukraine with the support of the OSCE[15] Project Coordinator in Ukraine, within the framework of the Project "Assisting Ukrainian police in institutionalizing improvements in training". The research report is rich in information and helps provide an overview of how each country deals with the training of its police forces.

After providing an overview of the operation of police education and training systems, analysis of curricula for basic and specialized police training, evaluation of in-service police training and development, the research concludes by offering a number of recommendations for improvement. Some of the suggestions for improvement draw attention and are particularly interesting for the context of this research (DEKANOIDZE; KHELASHVILI, 2018, p. 29–32):

1. Expand the basic training curriculum by increasing the relationship between practice and theory.

[15] Organization for Security and Co-operation in Europe. https://www.osce.org/

2. Involve more trainers with relevant policing backgrounds in all types of training and provide them with mandatory courses.
3. Introduce a clear evaluation system for all types of training. Each course should have clearly defined learning outcomes.
4. Standardize the evaluation process for all types of training, specifically, theory exams should be computerized for greater transparency, and more detailed evaluation criteria for practical (skills) exams should be developed.
5. Implement a transparent and standardized trainer evaluation system that will constantly assess the quality of trainer performance.
6. Modernize existing facilities and resources (e.g. modern shooting ranges, firearms, driving and other training simulators, laboratories, etc.).

It is noticeable that the recommendations brought forward go through the same point: improvements in the training curriculum, in the evaluation processes, and in the training structure. Increasing practical aspects without ignoring theory, implementing better forms of evaluation and investing in a better structure to train more prepared officers. Improving training involving practical aspects has two major results: increased engagement of police officers in training (LAGESTAD, 2013; HOEL, 2020) and better absorption of the concepts and contents, especially when there is a combination of theory and practice in simulated environments (BLUMBERG et al., 2019). The simulation-based training can improve self-efficacy, interprofessional collaboration, and provide numerous benefits for professionals dealing with person-centered care, especially in extremely stressful situations that require a high level of emotional competence (UDDIN et al., 2020).

Another point for improvement raised by the report refers to better and more transparent ways of evaluating the performance of police officers in training. A very common problem in evaluations and pointed out in the literature is human bias. Normally, police training is conducted under the supervision of a dedicated training professional or an experienced police officer who assesses and judges the trainee's performance (CORDNER; SHAIN, 2011; MCGINLEY et al., 2019). This can cause obvious problems in the evaluation process, especially when they are based only on the supervisor's feeling, which makes them less than transparent.

Finally, it is important to point out that, notwithstanding its importance and benefits, police training involves often prohibitive costs and logistical efforts that often make constant training difficult (DE ARMAS; TORI; NETTO, 2020), as well as real risks to the safety of the professionals being trained. In addition, the costs associated with police action and the maintenance of the public security structure increase every year (MALM et al., 2005). This is even more aggravating in poorer countries or even in states and cities where public funding for public security is limited.

Spending on law enforcement also varies widely even among equally wealthy countries. Finland spends less than 0.5% of its gross domestic product (GDP), while Hungary spends about 1.4% (OECD, 2021). The United States spends about 1 percent of its GDP on police (BEA, 2021). For comparison, according to a technical study released by Eduardo Granzotto in 2018, it is verified the percentage of the Gross Domestic Product employed in Public Security in Latin American and Caribbean countries in the year 2014, shows that Brazil occupied the fifth position among 17 countries, committing 3.78% of GDP (GRANZOTTO, 2018). However the voluminous spending of money does not necessarily imply better results for public security. According to Santos and Junior (2021), in the interval between 2011 and 2018, there was a jump 47,215 to 57,358 in the number of homicides. The high operational costs impact on numerous areas of public security and have a direct impact on training, continuous education, and even security equipment such as weapons and vests.

Table 12 succinctly presents the problems raised related to police training or the consequences of the lack of adequate preparation of security professionals or law enforcement officers, as well as their respective references as a way of synthesizing the knowledge gained during problem awareness.

Table 12 - Synthesizing the stage of awareness of problems related to police training

Problem	Theoretical Reference
Need for constant training	(CORDNER; SHAIN, 2011)
High cost of training	(DE ARMAS; TORI; NETTO, 2020)
Possible danger to the physical safety of the officer in training	(ACHIM, 2019)
Little flexibility of scenarios	(BERTRAM; MOSKALIUK; CRESS, 2015)
Short training time	(BLUMBERG et al., 2019)
Culture of the "warrior cop”	(HEYER, 2014), (STOUGHTON, 2014)
Implicit human bias during evaluations	(CORDNER; SHAIN, 2011), (MCGINLEY et al., 2019)
Lack of data to support trainee evaluation	(DEKANOIDZE; KHELASHVILI, 2018)

Problem	Theoretical Reference
Improve engagement, motivation and increase trainee participation	(LAGESTAD, 2013), (HOEL, 2020)
Need for improvement in physical structure of training	(DEKANOIDZE; KHELASHVILI, 2018)

Source: Elaborated by the author.

After the problem-awareness phase and the identification of issues whose impact may directly or indirectly affect police training, the next step, according to the DSR methodology adopted by this research, is to propose solutions. However, it is important to stress that at no time will this research be dedicated to solving all the problems raised here, given that many of them are issues that are far beyond the academic boundaries. Nevertheless, this research is not opposed to the idea of proposing solutions for some of these problems. Another point to keep in mind is that there may be other problems or factors affecting police training that may have been overlooked by this research. This is due, above all, to the research sources adopted and, therefore, to the limitations inherent to the scope and universe of such sources.

After the problem awareness phase and the raising of possible consequences, the following is the presentation of possible solutions proposed by this research for the problems detected.

4.3 Simulator Development: suggestion for a solution

Considering each of the points raised during the problem awareness phase, the next step, according to the Design Science Research methodology, is to propose solutions to the problems that can be solved within the scope of this academic research.

Accordingly, the following is a brief presentation of the solutions pointed out by this research and the problems that these solutions aim to solve. For practical purposes, considering the scope and nature of the problems, they were grouped into clusters, which received a name in order to facilitate identification. This grouping is presented on Table 13, as well as the proposed solution for each set of problems, as well as a theoretical reference that supports each of the solutions. However, considering that there is an entire chapter dedicated to the theoretical background that supports all the solutions presented, each of the solutions is justified very briefly.

Table 13 - Solutions proposed by this research for the problems raised

Cluster	Problem	Proposed solution	Theoretical Reference
Training/Education	Need for constant training High cost of training Possible danger to the physical safety of the officer in training Little flexibility of scenarios Short training time Culture of the "warrior cop" Need for improvement in physical structure of training	Virtual Reality training simulator.	(MOSKALIUK; BERTRAM; CRESS, 2013b), (MOSKALIUK; BERTRAM; CRESS, 2013a), (BERTRAM; MOSKALIUK; CRESS, 2015), (BENEDEK; VESZELSZKI, 2017), (BAILENSON, 2018), (TEIXEIRA et al., 2018), (CISNEROS et al., 2019), (FUCHS et al., 2017), (GADIA et al., 2018), (JENSEN; KONRADSEN, 2018), (DE ARMAS; TORI; NETTO, 2020)
Training/Evaluation	Implicit human bias during evaluations Lack of data to support trainee evaluation	Biofeedback data capture system to improve the evaluation of trainees during the use of the simulator.	(BERNHARDT et al., 2019), (KOS et al., 2019), (KAHNEMAN; LOVALLO; SIBONY, 2011), (CORNISH; JONES, 2013), (LAI; HOFFMAN; NOSEK, 2013)
Training/Engagement	Improve engagement, motivation and increase trainee participation	Use of Serious Game design elements to increase engagement and psychological reward.	(BERTRAM; MOSKALIUK; CRESS, 2015), (LIU et al., 2017), (SILVA et al., 2017), (WU et al., 2018), (SHEWAGA et al., 2017), (CASERMAN et al., 2018), (KOLB, 2015), (KOLB, 2015; JANTJIES; MOODLEY; MAART, 2018)

Source: Elaborated by the author.

4.3.1 Proposed solution for the Training/Education cluster

Proposed solution: Virtual Reality training simulator.

Justification: Environments provided by Virtual Reality are useful in simulations of complex training scenarios, especially if training in real situations is not possible (MOSKALIUK; BERTRAM; CRESS, 2013b, 2013a). Simulations and virtual environments enabled by Virtual Reality have several significant advantages over other training approaches, such as the quality of the experience, learning through practice, customization of the learning experience that can be designed to meet specific needs with flexibility and immediacy impossible in real life and the possibility of allowing past events to be re-experienced or reused in new scenarios (BERTRAM; MOSKALIUK; CRESS, 2015; BENEDEK; VESZELSZKI, 2017; BAILENSON, 2018; TEIXEIRA et al., 2018; CISNEROS et al., 2019). The technological leap combined with the significant reduction in the cost of VR devices has contributed greatly to its evolution, making the VR available to both common consumers and companies and, eventually, has also allowed increased interest in this technology (FUCHS *et al.*, 2017; GADIA *et al.*, 2018; JENSEN; KONRADSEN, 2018; DE ARMAS; TORI; NETTO, 2020).

4.3.2 Proposed solution to the Training/Evaluation cluster

Proposed solution: Biofeedback data capture system to improve the evaluation of trainees during the use of the simulator.

Justification: The use of data collected from the performance of the users of a simulator can be a way to improve the evaluation of the performance of trainees (BERNHARDT et al., 2019; KOS et al., 2019), often performed by specialized and more experienced professionals, which can cause distortions of judgment, even if involuntary (KAHNEMAN; LOVALLO; SIBONY, 2011; CORNISH; JONES, 2013; LAI; HOFFMAN; NOSEK, 2013).

4.3.3 Proposed solution for the Training/Engagement cluster

Proposed solution: Use of Serious Game design elements to increase engagement and psychological reward.

Justification: The ability to simulate stressful or potentially dangerous experiences in the safe and controlled environment of Virtual Reality (VR) enables the creation of Serious Games with a high level of immersion (BERTRAM; MOSKALIUK; CRESS, 2015). The Virtual Reality Serious Games can simulate real life experiences that offer a high level of interactivity and realism, allowing training professionals to actively build knowledge (LIU et al., 2017; SILVA et al., 2017; WU et al., 2018). Virtual Reality Serious Games can lead to a higher level of immersion, which can result in greater engagement and motivation (SHEWAGA et al., 2017; CASERMAN et al., 2018). Another positive aspect that can result from the combination of Serious Games and Virtual Reality refers to experiential learning, as it involves experiences and processing these experiences so that those who are subject to the training acquire significant knowledge, skills and insights (KOLB, 2015; JANTJIES; MOODLEY; MAART, 2018).

4.4 Simulator Development: development and evaluation

After the phases of problem awareness and suggestion for a solution, this step is dedicated to present, in general lines, the development of the first artifact generated by this research: a Virtual Reality simulator. This simulator was developed following a logic of iterative development, with constant improvements since its conception.

However, it is important to note that the purpose or main goal of the development of this simulator was never to obtain a functional product at the end of the development, but to explore different aspects of the development. In other words, the purpose of the simulator was never the simulator itself, but the knowledge generated from its construction. This knowledge, in turn, served as subsidy for the proposition of the second artifact generated by this research, which in this case is the proposal of a method for the development of Virtual Reality simulators applied to the training of security professionals and law enforcement agents.

In order to make the description of the development process clear, the simulator development will be explained in a linear way and in stages. This form of presentation, however, does not faithfully reflect the development of the prototype, but more or less strictly follows the process that was adopted. This is mainly due to the exploratory nature of the development of the prototype itself and of this research, as a whole. Therefore, the next topics aim to present the development of the prototype considering its multiple characteristics and requirements and aiming to summarize the knowledge acquired and the decisions made in each of the development stages. At the end of each stage, a summary of the technical decisions, possibilities evaluated, and decisions that were made will be presented. This synthesis and the cognitive path that led to such decisions served as the main subsidy for the development of the method proposed by this thesis and whose development and evolution will be presented in Chapter 5.

It is also important to note that the main discussions about all aspects of the simulator were taken under the supervision of the advisors of this thesis. However, the closest follow-up was done by Professor Jeremiah Diephuis, who supervised this research project while this researcher was doing a sandwich PhD program with a scholarship offered by the Coordination for the Improvement of Higher Education Personnel (CAPES)[16], an agency linked to the Brazilian Ministry of Education. The scholarship period was from July 2019 to August 2020.

[16] https://www.gov.br/capes/pt-br

The feedbacks and technical and practical discussions shared with professor Jeremiah Diephuis enriched and were absolutely fundamental in several moments, given his expertise with game development and with immersive technologies.

The entire development of this research took place in the Playful Interactive Environments[17], a research group founded by the Department of Digital Media at the University of Applied Sciences Upper Austria, School of Informatics, Communication and Media in Hagenberg.

4.4.1 Simulator development overview

Virtual Reality has become popular in recent years, but it is still a new, constantly developing media. So, it is understandable that there are no consolidated models, guides or methods and no clear ways to achieve certain goals through this technology. Therefore, it is normal that when it comes to applications in more specific contexts, as is the case with this research, several questions are asked, such as:

- When and why should one choose to design in VR?
- Where can one start?
- What steps should be taken?
- In an industry that is constantly changing, would a high-level planning tool provide appropriate guidance for designers?

All these questions and many more were raised by this researcher at the beginning of this thesis and throughout its development, and these questions were imperative to drive this research.

According to what was stated in section 1.2[18] of this thesis, in the context of this work, the research gap lies in the intersection of Virtual Reality and Biofeedback technologies with Serious Games methods and strategies as essential pillars for the development of simulators applied to the training of security professionals and law enforcement officers. More specifically,

[17] https://pie-lab.at/
[18] Topic 1.2 deals with the research gap of this thesis

in the absence of a method that guides the development of simulators with this level of specificity.

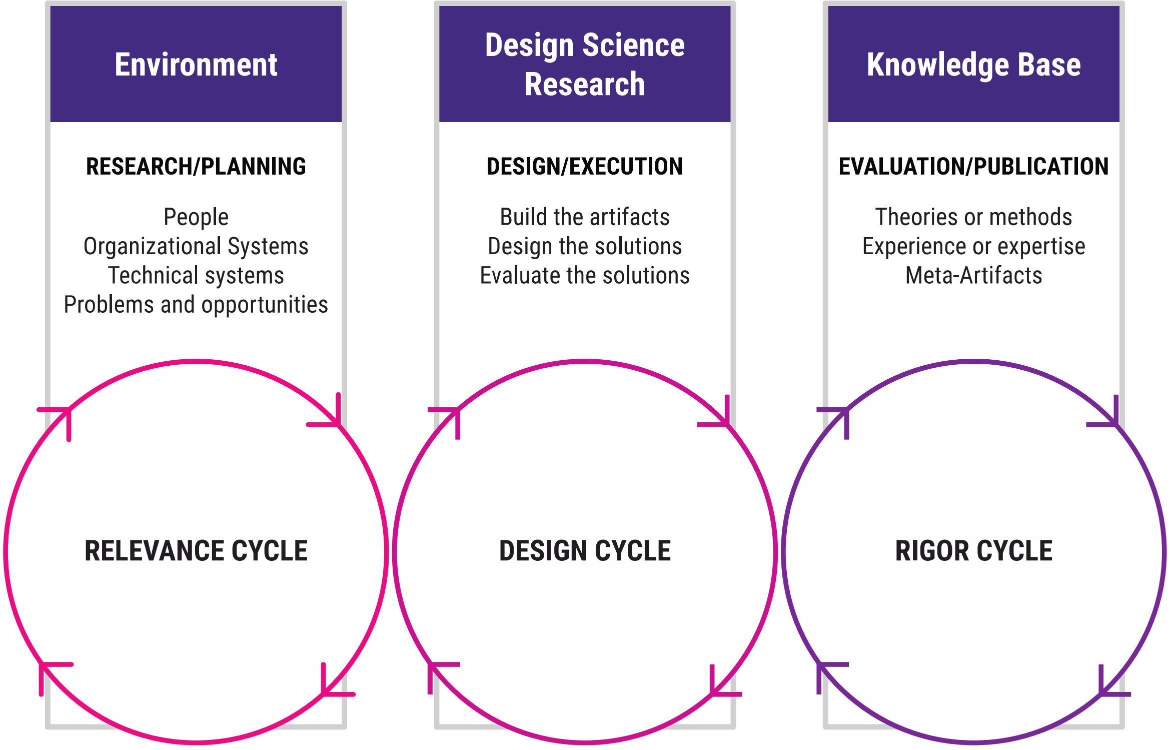
However, this does not mean that there are no development methods and that such methods are not widely adopted in the development of Virtual Reality simulators for a variety of applications, especially when considering that it is ultimately a piece of software. Not having a specific method for a specific application may not be exactly a problem, but it is certainly a gap. Therefore, this research starts from the assumption that there is prior, consensus knowledge, adopted by companies and professionals in various industries around the world, and does not ignore such knowledge.

It is important to note that the Design Science Research methodology that guides the development of the artifacts in this research envisions the appropriation or use of prior knowledge to generate new knowledge, which is not only indicated, but also mandatory. However, not all the knowledge applied in the development of the Virtual Reality simulator prototype presented in this thesis is found in the academic literature, but is part of the professional practice and experience of the researcher and the body of professionals who participated in the development and validation of the prototype. For more details about the professionals and academics who supported the construction of this prototype, see topic 3.5.1[19].

As a starting point, and putting into practice what the Design Science Research methodology recommends, the development of the simulator itself was divided into four major phases, each one coinciding with one of the three cycles of Design Science Research: the Relevance cycle, the Project cycle, and the Rigor cycle introduced by Hevner (2007), and presented in Figure 15.

[19] Topic 3.5.1 deals with the validation process of the Virtual Reality simulator prototype developed in the context of this research.

Figure 15 - A three cycle view of Design Science Research



Source: Adapted from Hevner (2007).

However, for practical and developmental reasons, the first cycle of the method (Relevance cycle) was subdivided into two parts: Research and Planning. This does not imply that both necessarily belong to different dimensions. This is due to the fact that the Design Science Research method allows adaptations, which can be interpreted as a weakness in methodological terms. As already discussed earlier in the methodology chapter of this thesis, the flexibility of the method is exactly one of its strengths and does not affect at all the methodological and scientific rigor of the process itself.

In the context of the simulator construction proposed in this topic, the Relevance Cycle gave rise to the Research and Planning phases, the Design Cycle gave rise to the phase called Design and Development, and finally, the Rigor Cycle gave rise to the phase called Demonstration and Evaluation. In the original method there are cycles, which presupposes that those activities are or can be performed several times, which is something characteristic in models or methods that anticipate iterations during development. For practical purposes and although this is not explicit at this point, development cycles were applied at various times during the construction of the prototype and this research does not ignore their relevance.

That said, the starting point of this research was to determine, in a general way, the stages that had to be accomplished and the main tasks or activities within each of these major stages, as presented in Table 14.

Table 14 - Stages of simulator development and tasks or activities within each stage

Cycle in the original method	Phase	Activity
Relevance Cycle	Research	Define the objective of the simulator
		Context research
		Research on the target audience
		Research on existing solutions
	Planning	Definition of the simulator type
		Definition of the visual style
		Definition of the technologies to be adopted
		User Experience Design
		Goals and evaluation criteria
Design Cycle	Design and Development	Definition of scenarios
		Definition of the characters
		Scriptwriting & Storytelling
		Concept art
		Interaction Design & UI
		Assets preparation
		Asset import/integration
		Coding (VR)
		Coding (Biofeedback)
		Test and Performance Optimizations
Rigor Cycle	Demonstration and Evaluation	User experience evaluation
		Additional refinements and optimizations

Source: Elaborated by the author.

In Table 14 there is also a reference to the cycle of Hevner's original method duly accompanied by the name of the phase adopted during the development of the simulator prototype presented in this topic. Within each of these steps, activities were defined and within each of these activities, specific objectives were outlined. Some of the activities also involved technical choices that impacted other decisions, which will also be presented in the following.

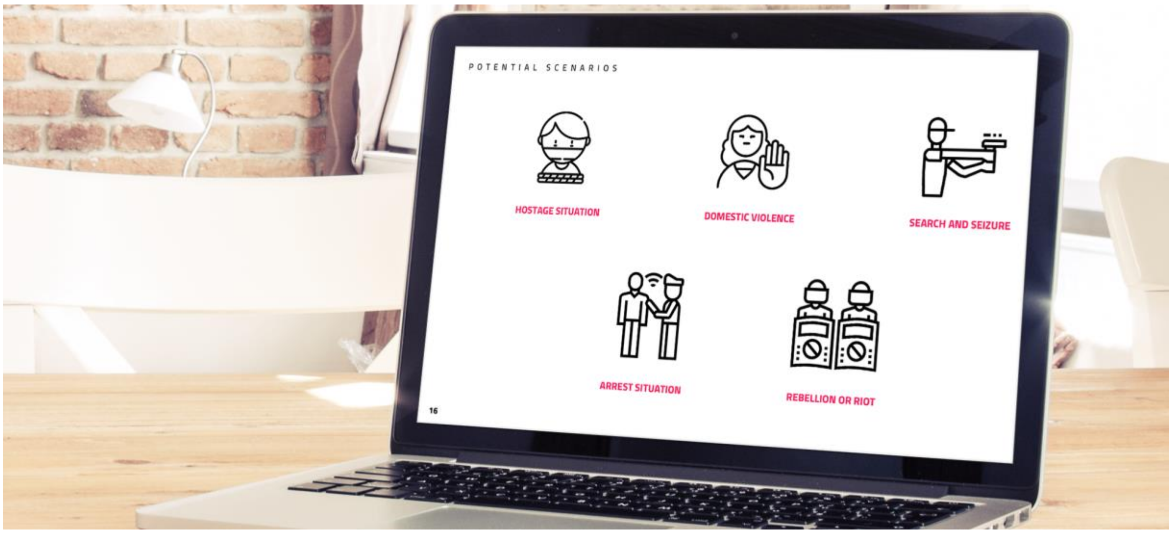
4.4.2 Simulator Research phase

The research phase started with the definition of the objective for the simulator itself. After a discussion of possible objectives and the evaluation of some possibilities, a few conclusions were reached. The first refers to the fact that the simulator should not be focused only on simple repetitions of real-world activities, such as training with a firearm. Despite the fact that Virtual Reality has the ability to simulate quite realistically the activities performed in the real world, it was decided that the simulator should be more than just an environment to replace real world mechanical training. Many commercial products already accomplish this goal, as presented in the theoretical backgroud chapter of this thesis.

Therefore, the first decision made was what features the simulator prototype should have, even though at first not all of these features could be met and many others had not yet been anticipated. Considering that one of the many research gaps is precisely the lack of data to assist or support the trainee evaluation process, one of the suggestions is that the simulator should expose the user to some situation where not only physical or technical skills are required. To be more specific, the idea of the simulator from the beginning was that it could have scenarios where social and emotional skills of the trainees were required. This kind of feature could be not only a differentiator, but would also cover some of the gaps raised in the problem awareness phase. This choice is obviously conditioned by the fact that the simulator must also provide some kind of system for capturing vital signs so that they can be used to support the evaluation process. In addition, the simulator should offer some sort of mechanic or mechanics to increase user engagement. This is to ensure that the simulator is not just a sequence of boring activities, but also a tool where the user can feel motivated to continue and evolve.

The simulator should also be based on a specific scenario, so that its development in such a short period of time could be accomplished. Figure 16 presents the original scenario ideas that were presented and discussed before development of the simulator began.

Figure 16 - Original scenario ideas discussed prior to simulator development



Source: Elaborated by the author.

The scenario chosen was that of domestic violence. The justification for this choice was due to a number of factors. The first one is that, unfortunately, it is a common scenario in almost every country in the world. Estimates published by the WHO[20] indicate that globally, about 1 in 3 (30%) of women worldwide have been subjected to intimate partner physical and/or sexual violence or non-partner sexual violence during their lifetime. Furthermore, Violanti et al. (2016) states that of all the most stressful factors for police activity, calls to deal with family disputes top the list of most stressful events (83%).

After defining the purpose of the simulator and the scenario to be addressed, it was necessary to understand a little more about how police training is done. Part of this information came from the academic literature, part came from research conducted with secondary data and available on the internet, and part came from the experience of two professionals who contributed their expertise. The first of them is a retired police officer with decades of experience and the other, a private security professional who works with transportation of valuable cargo. Both offered a complementary view and shared their knowledge in a general way, although they belong to different areas.

In addition, there was also an effort on the part of the researcher to obtain information with the police forces of two countries, which unfortunately did not occur due to lack of response from the police forces. However, the researcher did have access to reports from non-profit organizations that are dedicated to combating police violence and data from governments,

[20] https://www.who.int/news-room/fact-sheets/detail/violence-against-women

such as reports and statistics, all of which are freely accessible. Even with the limitation of not being able to have access to the police forces, the research phase provided enough material to support a series of decisions that were very important for the construction of the simulator. Thus, the context research and the research about the target audience took place through multiple data sources, in addition to the knowledge of experts.

The last activity was the research of existing solutions. This part of the research was done using, besides the academic literature, research by companies that specialize in developing and selling Virtual Reality solutions for military and police training. However, the evaluation of such solutions, given the restricted access to the simulators, was very superficial. Still, from the descriptions of the products and the answers obtained after consulting the manufacturers, it was possible to draw some conclusions and similarities. All solutions focus much more on practical or mechanical aspects (such as the use of firearms) or tactical aspects (such as organization and training), and none had solutions that combined or used biofeedback or vital signs for the same purpose outlined by this research.

Thus, the research phase was concluded with the result of a series of knowledge and theoretical inputs that are presented in Table 15.

Table 15 - Knowledge and theoretical contributions resulting from the research phase

Phase	Activity	Result
Research	Define the objective of the simulator	The simulator should not be focused only on simple repetitions of real-world activities. The simulator should expose the user to some situation where not only physical or technical skills are required. The simulator must provide some kind of system for capturing vital signs. The simulator should offer some sort of mechanic or mechanics to increase user engagement. The scenario chosen was that of domestic violence.
	Context research	It was not performed due to limitations.
	Research on the target audience	Expert knowledge was used.
	Research on existing solutions	Research in academic literature and research by companies that specialize in developing and selling Virtual Reality solutions for military and police training.

Source: Elaborated by the author.

Once the research phase was over, the knowledge gained from this phase was used in the simulator planning phase. However, it is important to note that there are a number of important activities related to the research that could not or were not performed. In the context research, it would be important to research the user environment and perhaps even the corporate culture, which in the case of the police is something that is extremely salient. Also, the research on the target audience could be better based if it were possible to create empathy maps and perform contextual consultation.

All these activities are very common to the User Experience area, and serve to better understand the user, his context, and the use he can make of a given product or solution. However, due to the aforementioned limitations, the researcher did not have access to any of the police corporations consulted. The simulator's planning phase is presented next.

4.4.3 Simulator Planning phase

The planning phase of the simulator was crucial in determining issues such as technologies to be used, decisions affecting the user experience, and learning objectives. To make planning easier, more organized and objective, this phase has been subdivided into three other parts. The first is related to technological decisions. The second, about decisions regarding the user experience, and the third, related to decisions about learning objectives and evaluation.

Starting with technology decisions, one of the first things to define refers to the type of experience you are looking to build. Depending on the level of immersion and realism of the simulator, the technology decision tends to narrow down. Considering that the main goal of the simulator is to promote a unique experience with high visual impact, the choice for a more realistic immersive experience was a predictable consequence. However, as discussed in the theoretical background chapter of this thesis, the absence of realism does not necessarily imply a less fruitful experience. However, more realistic experiences tend to be better accepted, especially by people without much prior experience with the technology.

The first step, therefore, is to determine the level of immersion that the trainee should have. When we talk about immersion in Virtual Reality (VR), we are actually talking about the perception of being physically present in a non-physical world. In a clearer perspective, Virtual Reality experiences can be divided into three levels of immersion:

- Non-immersive Virtual Reality;
- Fully Immersive Virtual Reality; and
- Semi-Immersive Virtual Reality.

Non-immersive Virtual Reality is a type of experience in which you interact with a virtual environment usually through a computer where you can control some characters or activities within the experience.

Fully immersive virtual reality is the opposite of non-immersive virtual reality. It guarantees a realistic virtual experience, since it is able to give the impression that the user is physically present in the virtual world and interacts in first person with the environment and the events taking place there. Furthermore, additional equipment such as gloves and other devices can be employed to enhance the user experience and the level of realism in the interaction with the virtual environment, which further increases the impression of presence.

Finally, semi-immersive Virtual Reality is something that is somewhere in between non-immersive virtual reality and fully immersive virtual reality. Using a computer screen or a VR headset, you can move around in a virtual environment, but other than your visual experience, you will have no physical sensations to enhance the experience. Semi-immersive Virtual Reality is also called Extended Reality (XR) by several authors.

For the context of this thesis, the choice was made to achieve as realistic an experience as possible, which led to the selection of the fully immersive experience. Another point that concerns immersion and realistic experience refers to the level of realism of the content and the environment with which one interacts in the experience. Although the VR simulator developed in the course of this research was designed to provide the highest level of realism and immersion possible, there are numerous limitations and impacts of this decision on several other decisions. Furthermore, even if the goal is to achieve the highest level of realism, the very concept of realism should be discussed, since it is an absolutely subjective aspect. There is even a theory known as "Uncanny Valley" which refers to the discomfort that some people feel when they are exposed to content that is highly realistic but at the same time not realistic enough (MACDORMAN; ISHIGURO, 2006).

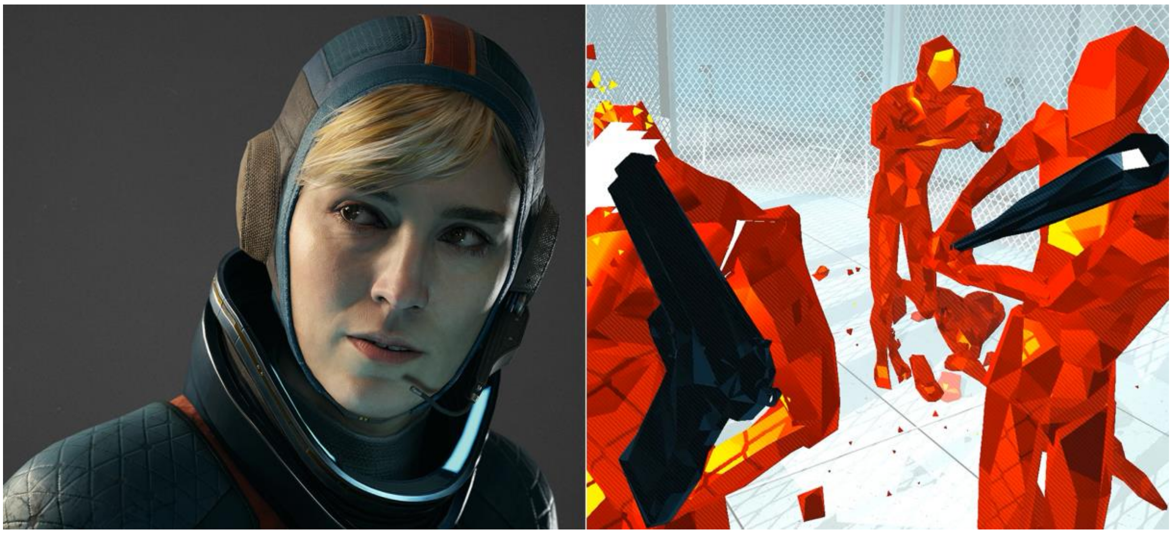
The concept of the "Uncanny Valley" is directly related to the concept of photorealism, which can be explained as a way of presenting as realistic as possible - from detailed textures to models with plausible physical scale, to lighting that simulates the behavior of light in the real world. While there are different variations of photorealism and each application is different, there are some common principles. The photorealistic style offers a user experience with maximum immersion, a realistic world that resembles actual movies and has a direct relation to the real world.

Stylization, on the other hand, does not obey most of the rules applied to photorealistic content and, contrary to what one might imagine, is incredibly popular in Virtual Reality applications. Explanations for this range from performance issues to art direction and artistic style issues, or even a combination of all of these.

Mixed style, in turn, is not a style per se, but an umbrella term, used for the endless possible combinations of different styles. For example, a given piece of content could use realistic lighting and textures, but exaggerate the proportions of the models. This is a stylized view of reality with a variable degree of abstraction.

As a way of exemplifying, Figure 17 shows two Virtual Reality games with very different styles. On the left side, the realist game Lone Echo, published by Ready at Dawn[21], and on the right side, the stylized game Superhot, published by Superhot Team[22].

Figure 17 - Example of realistic versus stylized visual style in Virtual Reality



Source: Ready at Dawn and Superhot Team.

Considering the purpose and context of the simulator, the decision was made in the direction of a photorealistic style. Furthermore, the dichotomy between realism versus stylization has a direct impact on the performance aspect, which in turn impacts the choice of hardware and software selected for the simulator development.

The next decision to be made was related exactly to the hardware and software to be used for the development of the simulator. However, this simulator has a unique feature, which

[21] http://www.readyatdawn.com/
[22] https://superhotgame.com/

is the adoption of vital sign capture during simulator use to improve trainee assessment. Therefore, the choice of hardware and software must contemplate both dimensions: Virtual Reality and Biofeedback.

When it comes to Virtual Reality hardware, there are several options on the market, and in recent years, prices have fallen and the quality of devices has increased. While there are numerous manufacturers and models of VR headsets, there are only a few different types of devices and all models basically fit into this classification. Tethered headsets are VR headsets that have a connection cable that connects the headset to a PC or console, depending on the system. A good example of this type of headset is the Oculus Rift. Untethered headsets are stand-alone devices that do not require a connecting cable to facilitate a VR experience. Instead, these headsets generally rely on a Wi-Fi connection to receive and stream VR content. A good example of this type of headset is the Oculus Quest. Mobile-type headsets are unique because the source of the VR content (i.e., your phone) is placed directly on the headset. A good example of this type of headset is Google Cardboard.

Obviously, there are pros and cons to each of the VR headset types. For example, one of the main selling arguments for cabled VR headsets is their inherent power, since the graphics processing is performed by a dedicated system (PC graphics card or game console). This is considered a major point in favor. However, the popularity of cable-free devices like the Oculus Quest shows that even if there is an advantage in terms of graphics quality and processing power, it does not mean that this is the most important factor for users in general. The choice of hardware for the simulator was defined as soon as the level of immersion and especially the style were defined. In the case of this research, it was decided to use a tethered headset, more specifically, Oculus Rift[23], as presented in Figure 18.

[23] https://www.oculus.com/

Figure 18 - Oculus Rift headset used in this research

Source: Elaborated by the author.

Regarding the hardware chosen for the Biofeedback part, two paths were followed at different times of the research and due to limitations encountered during its development. The first type of hardware used during the development of the prototype was a combination of sensors and controllers. The second type of hardware was a smart watch, which was used as a possible alternative to the first prototyped system.

The initial idea of the project was to work with prototyping a customized system for capturing vital signs and integrating these signals into the simulator. However, at some point in the research, there was a need to adapt the idea and use, instead of a set of sensors and modules, a smart watch. This change will be addressed during the report on the prototyping of the biofeedback system itself.

Among the main initial components selected to build the system are some devices common to IoT (Internet of Things) projects. The list included, among several other things, a Raspberry Pi Raspberry Pi 3 Model B, an Arduino Uno, an esp8266 Wemos D1 mini, and several sensors, such as the SEN-11574, a biometric pulse rate sensor, the MPU-9250, which is a 9-axis motion tracking device, the MAX30102, a high-sensitivity pulse oximeter and heart sensor, and a galvanic response sensor for measuring the electrical conductance of the skin. The smartwatch mentioned and used in the research was the Huawei Honor Band 3.

Figure 19 shows part of the hardware used in the Biofeedback part of the simulator. On the left side, the sensors and controllers, and on the right side, the smart watch used.

Figure 19 - Hardware used in the Biofeedback part of the simulator

Source: Elaborated by the author.

Regarding the software used during construction of the simulator, a number of options for specific tasks were chosen. The choices made were not limiting, much less excluding, and were almost always based on three criteria: technical knowledge of the researcher, ease of use, and best aesthetic result.

One choice in particular, however, deserves more emphasis and depth. It refers to the game engine used for the development of the simulator itself. A game engine is a software development environment that is used by game developers to build games and interactive experiences. The advantage of using a game engine is that it allows developers to add general features such as physics, user controls, rendering, scripting, collision detection, artificial intelligence, and more without the need to code them from scratch, since they are native and reusable components of this type of software.

Although there are many options on the market, the two most popular engines for developing Virtual Reality applications are exactly the most popular on the market for game development. The two choices are the Unreal Engine[24], produced by Epic Games, and the Unity engine[25], produced by Unity Technologies. Both currently have similar features, but technically they are quite different. Both engines are free for developers and only charge something once the developer publishes and profits from the application or game.

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24 https://www.unrealengine.com/en-US/
25 https://unity.com/

While both softwares have similar capabilities, Unreal Engine provides more built-in tools that make game development easier. Unreal has an extensive, built-in material editor as well as a cinematic content editor that allows developers to easily create cinematic sequences in their games. On the other hand, Unity relies on third-party addons from its asset store to provide similar functionality, and some of these addons are extremely popular and used by millions of users.

Based on the built-in tools provided by the engine, Unreal is the more powerful of the two options. But Unity is simpler to use. The same comparison can be seen regarding the programming language used by both engines. Unity uses C# as its main programming language, which is easier to use and learn. Unreal, on the other hand, uses C++, which is much more powerful, but also more difficult to learn and more prone to errors.

However, Unreal compensates for its complexity by offering an alternative, easy-to-use scripting language called Blueprint, which is a visual scripting language. Using this tool, developers without in-depth knowledge, such as artists and designers, are able to program gameplay events without relying on programmers or developers with more technical knowledge. This means that the prototyping process is accelerated by the ease and visual feedback of the tool. Table 16 presents a comparison of both engines, with some of their main features for comparison purposes.

Table 16 - Comparison between Unreal and Unity engines

Parameters	Unity	Unreal Engine
Developed by	Unity Technologies	Epic Games
Programming Languages	C#	C++
Features	Used for creating over 91% percent of Microsoft HoloLens VR content.	Supports 10+ VR platforms, including OpenVR, Windows Mixed Reality, Samsung Gear VR.
Source Code	The source code is not open-source.	The source code is open-source.
Best for	VR projects with no high-end rendering; mobile VR projects.	Non-mobile VR projects; mobile VR that needs high rendering quality.
Pricing	Free: if revenue/funding < $100K in the last 12 months.	Free: noncommercial projects or projects with up to $1 million lifetime gross revenue.

Source: Elaborated by the author.

For the development of the simulator presented in this thesis, the choice fell on the Unreal Engine. However, the Unity engine was considered for several reasons, mainly because of the ease of adaptation and the attractive assets and tools that could be integrated and used during development. However, the characteristics mentioned above and others such as the expertise and experience of the researcher were decisive for the choice of Unreal Engine.

To create content for the simulator, a large number of softwares were employed. Some are dedicated to very specific phases, while others were used during the development of most of the simulator. Table 17 summarizes the choices of various tools (softwares) used during the process of building the simulator at different times, as well as the tasks for which each was employed in the context of this research.

Table 17 - Various tools used during the simulator building process

Software	Application in this project	Link
Trello	Project management	https://trello.com/
Google Drive	File management	https://drive.google.com/
Google Docs	Collaborative online documents	https://docs.google.com/
MindNode	Information Architecture	https://mindnode.com/
Adobe XD	UI/UX design tool	https://www.adobe.com/products/xd.html
Adobe Illustrator	Interface elements	https://www.adobe.com/products/illustrator.html
Procreate	Concept creation and storyboards	https://procreate.art/
Autodesk Maya	Creation of 3D content and animations	https://www.autodesk.com/products/maya/
Quixel Megascans	Photorealistic textures	https://quixel.com/megascans/
Substance Painter	Advanced texturing of assets and characters	https://www.substance3d.com/products/substance-painter/
MocapX	Facial motion capture	https://www.mocapx.com/
Unreal Engine	Development of immersive environments and interactions	https://www.unrealengine.com/en-US/
Microsoft Visual Studio	Integrated Development Environment	https://visualstudio.microsoft.com/
GitHub	Version control	https://github.com/
Google Forms	Survey tool	https://www.google.com/forms/about/
R/RStudio	Data treatment and graphing	https://www.rstudio.com/

Source: Elaborated by the author.

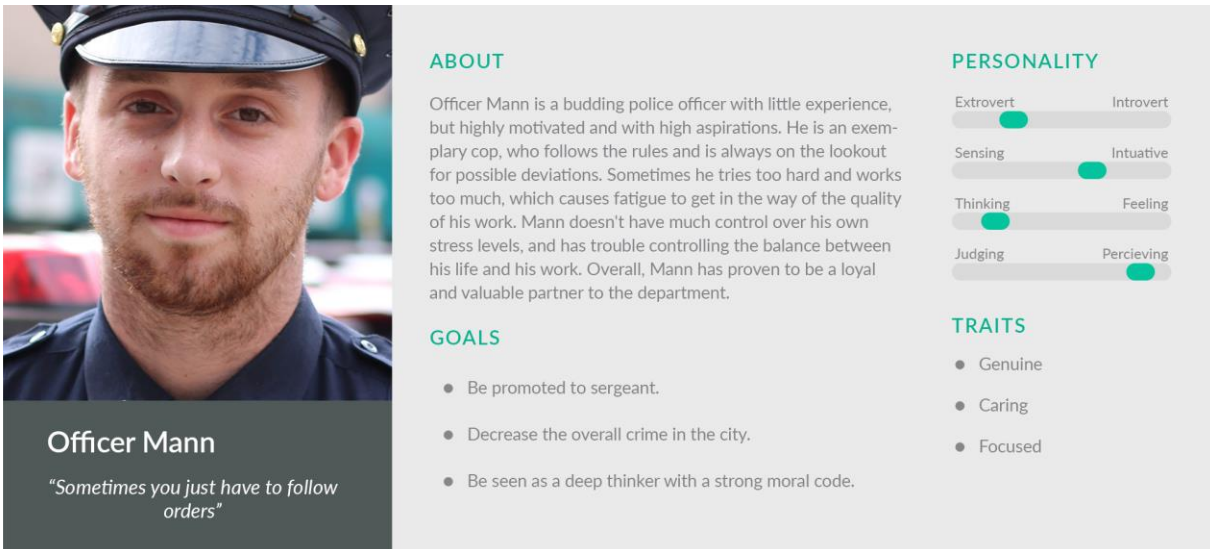
Once the tools that should be used had been decided, the next part of the simulator planning involved issues related to User Experience. The first of these concerns the definition of the user's role within the simulation itself.

Considering the nature of Virtual Reality as a medium for providing user experiences, these experiences need to be designed and planned in such a way that these users can achieve their goals efficiently. In this respect, the role that the user will play is extremely important to the design of the experience as a whole. One way to define this role was to design a persona.

The practice of designing personas helps identify the true user of a given product or service (or in this case, experience) and design tailored solutions for this user. However, it is important to differentiate persona from target audience. A target audience is a group of people who share similar characteristics, such as behavior and social class. It refers to a more general definition, not just a specific person. The persona, on the other hand, is represented by a fictitious ideal user with a specific definition of characteristics. It is formed from a survey of behavior and real customer characteristics with elaborate information. This is exactly why the research and even context phase is so important.

Unfortunately, it was not possible to have access to any police corporation and, therefore, to active police officers, which prevented the researcher from deepening the research and perhaps generating a more accurate profile of this persona. However, given the importance and impact of the choice, a persona was created based on a valid profile with one of the experts who accompanied this research. The persona profile is presented in Figure 20.

Figure 20 - The persona developed for the simulator use



Source: Elaborated by the author [26].

[26] The photo used was taken from Unsplash, wich is a website that grants an irrevocable, non-exclusive, worldwide copyright license to download, copy, modify, distribute, perform and use photos from its archive. All the photos are free of charge, including for commercial purposes, without permission or attribution from the photographer or even the Unsplash website https://unsplash.com/.

The persona developed and thought of as the ideal user of the prototype meets a specific profile. It is a police officer in the beginning of his police career, with little or no experience. This profile, as simple as it may seem, is an interesting starting point and denotes that, in principle, the ideal user for the simulator are police officers in training and that, even if they have a lot of experience, they can relate to some of the characteristics of the persona developed. However, this does not necessarily imply that the simulator is effective or can only be used by novice police officers.

After defining the technologies and starting the User Experience planning process, the next step is to work on decisions about learning objectives. This phase was designed to address one of the gaps identified during the literature review of this thesis. Many simulators and solutions on the market do not have a learning objective or even clear metrics. In addition, one of the differentiators of this research work is its ambition to provide a way to capture vital data to support the evaluation process of the trainees.

The objectives and criteria for evaluating the trainee go through a number of technical and knowledge issues that are beyond this thesis such as standard police procedures. However, this researcher made an effort to obtain more information, and although it was not possible, the professionals who followed much of the development of the simulator provided some important information. Some of it refers exclusively to standard procedures for some specific cases, such as approaches in cases of domestic violence. Other information comes from papers that dealt with stress and issues such as police officers' bias, as well as works dedicated to domestic violence carried out by police officers themselves and approached by other police officers. Therefore, it was defined that the educational goals should keep a very small distance to reality. In fact, if it were possible to reproduce real-world procedures, even better.

As for the tasks to be performed inside the simulator, it was defined that they should follow a sequence that would reproduce the interval of a few hours of a regular working day. However, as a suggestion from the experts, it was decided that two of the tasks should be related to the use of a firearm and patrolling, both very common in the daily life of police officers.

In addition to that, considerations were also made at this stage about the type of marker to measure the users' stress. Besides the literature and the exchange of experience with one of the specialists, the technology composed of devices and sensors available to the researcher was used as a basis. It was therefore defined that some of the best markers of stress would be, at first, heart rate, temperature, and electrodermal activity.

Ultimately, engagement mechanics were also defined to enhance the experience while using the simulator. However, this was only possible after defining the simulator's objectives, since there is little value in trying to gamify learning that you cannot accurately measure. The main form of mechanics designed in this phase included error induction and increased stress through a situation that could end in various ways, and which required decisions on the part of the police officer. It was therefore defined that safe training through error-induced learning could be beneficial for professionals who have to deal with highly stressful situations. The activity of defining educational objectives closed the planning phase. Table 18 summarizes the knowledge gained and decisions made in this phase.

Table 18 - Knowledge and theoretical contributions resulting from the planning phase

Phase	Activity	Result
Planning	Definition of the simulator type	Fully immersive simulator
	Definition of the visual style	Photorealistic simulator
	Definition of the technologies to be adopted	Unreal Engine/Blueprint, Autodesk Maya, Pixologic ZBrush, Substance Painter, Adobe Photoshop, Illustrator, Adobe XD and others.
	User Experience Design	Persona definition and validation.
	Goals and evaluation criteria	Reproduce real-world procedures. Heart rate, temperature, and electrodermal activity as biofeedback markers. Error-induced learning.

Source: Elaborated by the author.

4.4.4 Simulator Design and Development phase

After all the technological, user experience and educational goals decisions have been made, and after gathering valuable knowledge and initial foundational definitions, the next step is to start developing the solution itself.

As a development starting point, the first thing to define would be the scenarios that the simulator should have. At this point it should be noted that, at this stage, the term scenario refers to something tangible, physical, more specifically the environment in which the simulator's actions will develop. It is important to make this clear because in the research phase the term "scenario" is also used. However, in the research phase, the term refers to something more general, related to the situation.

The choice of scenarios for the simulator was reconsidered several times and a number of possibilities were raised. Among the possibilities, and considering the information and requirements gathered in the research and planning phases, it was decided to reproduce environments that were familiar to the daily routine of the officers in training. It is worth quickly recalling what was raised in the research and planning phases:

- The simulator should not be focused only on simple repetitions of real-world activities;
- The simulator should expose the user to some situation where not only physical or technical skills are required;
- The simulator should provide some sort of system for capturing vital signs;
- The simulator must provide some sort of mechanism or mechanics to increase user involvement; and
- The scenario chosen was domestic violence.

The first and most obvious scenario would be a police station. The second, a neighborhood or suburb of a city. The main question would be how to link both situations in such a way as to create a logic of actions that would be plausible enough for the police officers in training. Furthermore, this connection between both scenarios should make sense within the context and purpose of the simulator. It came to the idea of including a third scenario, which came to be defined as a patrol car.

Once the three scenarios that would be part of the simulator were defined, the next step was to determine the sequence in which they should take place. This sequence, in turn, should comprise clear activities or objectives to be achieved, so that each one of them could be fulfilled and, obviously, measured. The activities or objectives will obviously vary from scenario to scenario.

It was determined, for example, that the police station would be the starting and ending point for the trainee. The simulation begins with the trainee in the police station environment. In this place the trainee must perform activities ranging from simple ones, such as moving in space and interacting with objects, to very specialized ones, such as a little firearm training.

The explanation for this is simple: many people do not have enough knowledge or experience with Virtual Reality to feel comfortable with the technology from the very first moment. Even if this is the case, some people may need some time to get used to the controls, navigation, interactions and even to perform tasks that require more dexterity, such as handling a firearm. The practice of guiding, instructing, or even tutoring the user in virtual environments is very common in the games industry, and the theory behind this choice is known as "the magic circle” (KLABBERS, 2009).

The second scenario takes place inside a police car during a routine patrol, and would have as its main objective to exercise the focus and attention of the trainee to the central dispatcher's call. However, considering that one of the objectives is to work on the user's vital signs as well as measure stress responses to stimuli, it was decided to use this moment as a way to establish a few seconds of reference data. That is: before starting a possibly stressful sequence, a calmer situation would be appropriate in order to keep this vital sign data as a kind of reference value.

The third scenario is the climax of the simulator, and represents the conflict that the police officer will have to mediate. When arriving at the scene where they have been requested (suburban neighborhood), the policemen are faced with a family conflict and need to interact to resolve the conflict, which can end in various ways. The main objective of this scenario is to make the trainee reflect about his decisions, select whether or not to follow the protocol, what decision to take in the event of an escalation of violence, among other possible reactions.

After this scene is over, the trainee is taken back to the police station, to a special room where he can access a board containing some data about his performance. This last scene could be just a final screen with the same "theme" as the police station, but it is designed to reveal data about the trainee's performance to the trainee. Table 19 summarizes each of the planned scenarios and their objectives.

Table 19 - Scenarios and sequences to be represented in the simulator

Scenario	Sequence	Activities or Objectives
The police station	First	The trainee must perform activities ranging from simple ones, such as moving in space and interacting with objects, to very specialized ones, such as a little firearm training.
Police car during a routine patrol	Second	Exercise the focus and attention of the trainee to the central dispatcher's call and establish a few seconds of reference data.
Suburban neighborhood	Third	Reflect on his decisions, select whether or not to follow the protocol, what decision to make in the event of an escalation of violence, among other possible reactions.
A police station room/ final screen	Final	It is designed to reveal data about the trainee's performance to the trainee.

Source: Elaborated by the author.

The definition of the simulator's physical scenarios, in turn, has implications for other simulator decisions, such as the characters that will interact with the trainee during the simulation. A common practice when developing fictional characters is to establish a back story, a technique adopted by many writers and screenwriters. This practice is grounded in the concept that creating more plausible characters requires that these characters come as close to reality as possible, which can be achieved with features such as giving characters occasional flaws and inconsistencies, eschewing cultural stereotypes, and allowing characters to change over time. However, a vast majority of the information is never available to the audience, but can be used to plan possible future changes in the characters' behavior and reactions.

Three characters were thought up for the simulator. The first is a more experienced policeman who will serve as a guide for the trainee, accompanying and giving tips on what the trainee should do. This character is in every scene and accompanies the trainee closely. He is used, in a way, as a kind of guide, and can be used at times when the trainee feels lost. This policeman has been in the police force for 20 years, is 48 years old, and does not always act according to the rules.

The other two characters appear in the simulator's conflict scene and represent a couple who are in conflict. The man is 44 years old, a correctional officer, has a drinking problem, and an aggressive temperament. The woman is 38 years old and a housewife. She works on weekends in a coffee shop. Both have been married for ten years. For practical purposes, none of the characters have names and will be addressed by nicknames. The policeman accompanying the trainee will be called "the other guy", and in the case of the couple, we will call the man "the husband" and the woman "the wife". Table 20 summarizes the presentation of the three characters and a general description of each of them.

Table 20 - Description of the simulator characters

Scenario	Age	Backstory
The Other Guy	48 years	He has been in the police force for 20 years, and does not always act according to the rules.
The Husband	44 years old	A correctional officer, has a drinking problem, and an aggressive temperament.
The Wife	38 years	She is a housewife. She works on weekends in a coffee shop

Source: Elaborated by the author.

After defining the scenarios, the characters, their possibilities and main tasks, the next step is to work on script writing and storytelling. However, before moving on it is important to make it clear that the choice for a narration or even a story meets a requirement raised at the beginning of the research phase, which concerns the fact that the simulator should not be only for training mechanical tasks or routine activities. Therefore, the decision to go ahead with a narrative, although it was not unanimous, is justified by the numerous benefits that narrative offers, among them is the possibility of understanding complex concepts through examples that people can relate to (ALDAMA, 2015; HOKANSON; CLINTON; KAMINSKI, 2018). One of the biggest arguments in favor of storytelling is the theory of "suspension of disbelief", which is very common in various types of media, and refers to a semi-conscious decision in which the audience puts aside its disbelief and accepts the premise as being real for the duration of the story or experience (HOLLAND, 2003).

In the specific case of the Virtual Reality simulator presented in this topic, the narrative revolves around the rookie police officer, who has just arrived at his first day on the job. He is introduced to the policeman who will be his partner (the other guy), and help him perform tasks, understand what is going on around him, and even drive him to perform small but important tasks. The rookie cop (the trainee) in turn must follow the instructions and do what is asked, otherwise there will be no progression in the simulation.

After being welcomed at the police station by the more experienced officer and after a brief dialogue, the novice policeman is invited to go to the shooting booth and practice a little with the gun. The trainee should also have some freedom to interact and even interfere with the environment as a way to acquire knowledge about the environment and how to use the controls to navigate and interact.

After the firearms training has been completed and the trainee has become familiar with the controls and navigation, the trainee should go back to the more experienced officer, who will ask if the trainee is ready to start patrolling. If the answer is affirmative, the second scene begins, where both officers are inside a patrol car talking. After a few seconds a call from the central office occurs and the trainee has to answer the call.

Then the third scene begins. The policemen approach the entrance of a house where shouts and some commotions are heard. Suddenly, a woman comes out the front door and a man follows her with a knife in his hand. Upon seeing the policemen, the man takes the woman hostage. At this moment a series of possibilities can happen and the trainee is forced to make a decision. Among the possible options for the situation, some possible outcomes were drawn and are presented in Table 21.

Table 21 - Possible results of police action in the final simulator scene

Possibility	Possible outcome
Possibility 01	None of the policemen take weapons. You try to convince the suspect to drop the knife and turn himself in, and after some time, he gives in and surrenders to the police.
Possibility 02	Your partner draws his gun, yells at the suspect. You try to convince the policeman to stay calm and the suspect to drop the knife and surrender, and after some time, he gives in and turns himself in to the police.
Possibility 03	Your partner draws his gun and yells at the suspect. He tells you to shoot him as soon as you get a chance. You try to draw your gun, but the suspect gets scared and hurts the woman, who falls. Your partner shoots and knocks the suspect down.
Possibility 04	Your partner and you both draw your guns and yell at the suspect. The suspect gets scared, hurts his wife, and tries to run into the house. Your partner shoots the suspect in the back and knocks him out.
Possibility 05	You draw your gun and your partner tries to keep you calm but asks you to negotiate with the suspect. You try to convince the suspect to surrender. The suspect asks you to put the gun away. You do not respond. The suspect gets scared, hurts his wife, and tries to run into the house. Your partner shoots the suspect in the back and knocks him out.
Possibility 06	You draw your gun and your partner tries to keep you calm but asks you to negotiate with the suspect. You try to convince the suspect to surrender. The suspect asks you to put the gun away. You put the gun away. The suspect calms down, releases the woman, and surrenders to the police.
Possibility 07	You draw your gun and your partner tries to keep you calm but asks you to negotiate with the suspect. You try to convince the suspect to surrender. The suspect asks you to put the gun away. You put the gun away. The suspect calms down, releases the woman, and your partner shoots and knocks the suspect out.

Source: Elaborated by the author.

Some of the possible outcomes of police action are positive, while others are undesirable and others are just inevitable, should they happen. However, both the actions and each of the possible outcomes are designed to put the trainee in stressful situations that go beyond the encounter and the situation itself. The stress of having to decide what to do and anticipate what might happen is one of the main appeals of this type of simulation, and is consistent with the training of the police officer, who must follow the protocol and ensure the safety of the hostage.

Once the scenarios, the characters, the actions to be taken and a general definition of the narrative and possible outcomes of the final interaction were defined, the next step was to develop the visual style and aesthetic concept of the simulator. This was done in a few steps, each focusing on a specific type of simulator content. The visual concept of the simulator's environments were developed first. Besides visual references more specific to police stations, additional references were also researched, such as offices and accessories. The final scene was also planned in this phase. The definition of the type of suburb was based on research from various countries. No specific style was aimed for, but for the sake of visual language, a neighborhood based on the American suburbs of California cities was chosen, although this is not relevant. Next, some digital illustrations were made to serve as a general reference. Two of these are shown in Figure 21.

Figure 21 - Digital illustrations of some of the simulator's environments

Source: Elaborated by the author.

The concepts of the characters were based on the descriptions of each character and care was taken to avoid clichés or stereotypes during the visual construction of all of them. However, some aesthetic decisions are also consistent with the narrative as far as possible. The husband is an older man, who has a job that requires vigor and physical strength, and is also aggressive. From this description, it was almost inevitable to think of an older man with an athletic build.

The wife, on the other hand, is a fragile woman, and was conceived as a tired-looking but resilient woman. In addition, it would be good if the hair was not too long. The reason for this is technical and aesthetic. Hair requires a lot more detail, and therefore a lot more polygons. This could compromise performance, not to mention that, due to engine limitations, character animation could suffer. A lot of emphasis was given to the physical features, but especially to the facial features, where the detail was much greater, considering the search for realism and the psychological effect of the expressions.

Finally, the policeman should reflect some characteristics such as life experience and his posture, perhaps a bit arrogant, should be complemented by the mischievous look. The nature of the policeman is dubious and this characteristic should also be contemplated. Figure 22 presents the artistic concepts of each of the simulator's characters.

Figure 22 - Concepts of the simulator characters

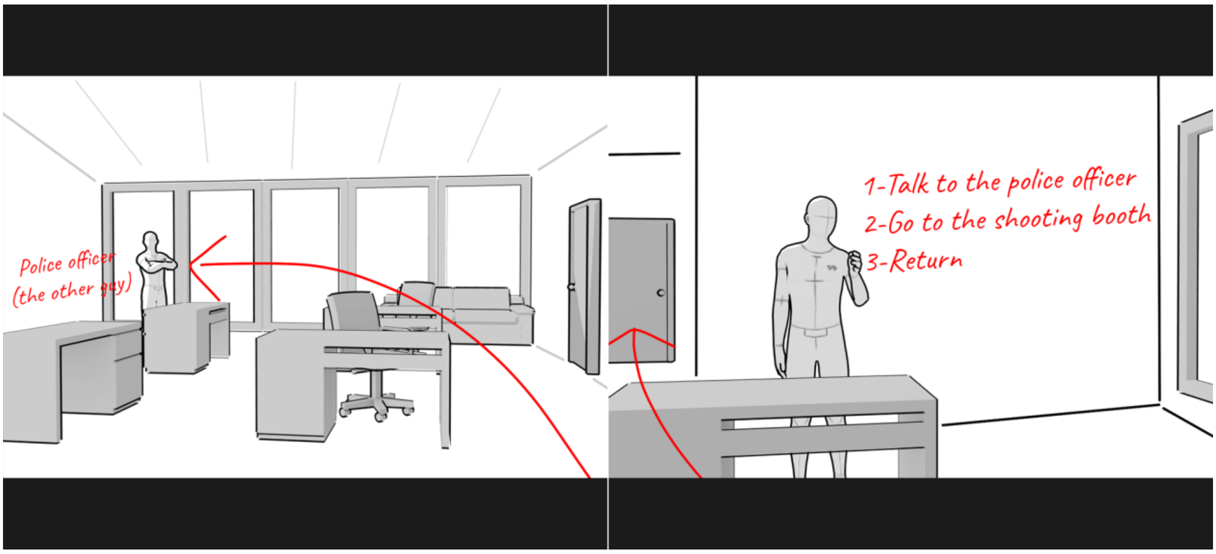
Source: Elaborated by the author.

Another important activity for the simulator was the development of a storyboard. A storyboard is nothing more than a "comic book" with a very specific purpose. It is a draft that shows what will happen in each of the scenes of a sequence to be created and according to the script. This storyboard should present the main moments of the simulation, and serves to determine character positions, interactivity flows and sequences to be played.

In the specific case of the simulator presented in this thesis, only storyboards were produced for the initial scene, which takes place at the police station, and the final scene, in front of a house in the suburbs and where the conflict situation that needs to be resolved by the trainee occurs.

Figure 23 presents part of the storyboard made for the simulator's initial moments, and shows the character with whom the simulator user interacts all the time during the simulation. The action described in the storyboard corresponds to what the trainee should do.

Figure 23 - Part of one of the storyboards made for the simulator



Source: Elaborated by the author.

Once the aesthetic aspects of the simulator's content were defined, the next step was to think about the simulator's interaction design and aspects of the user interface and experience. Immersion and the feeling of presence in virtual worlds is enhanced if the user can interact with this virtual world. This interaction should preferably be in the most natural way possible. There is a myriad of interaction techniques for Virtual Reality and these techniques basically support a combination of the three main action types:

- Selection;
- Manipulation; and
- Locomotion.

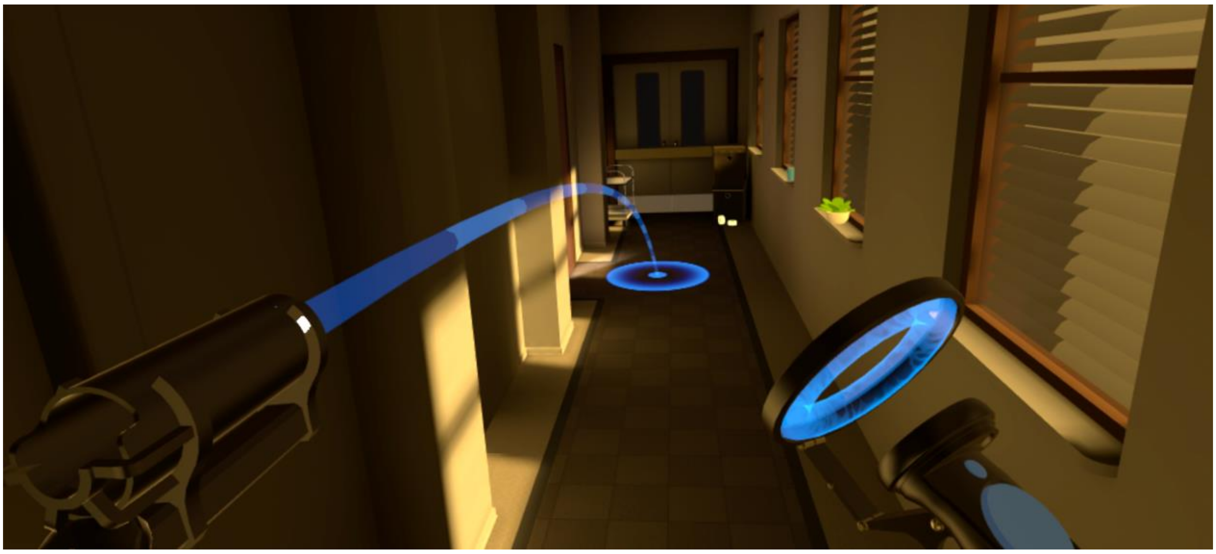
In its simplest form, selection consists of telling the system which object or interface element the user wants to interact with. Once the user confirms the selection, the selected entity becomes the focus of other possible interactions by the user. Selection can be done using controller input, gestures or gaze, and even a combination of all of these.

Manipulation refers to a set of interaction actions that occur once an object is selected by the user. It can consist of simple transformations, such as rotating, scaling or moving objects, or even more complicated ones, such as interacting with objects like levers and buttons, just like the real world. In the case of this simulator, the interaction with objects is close to the real world, allowing, for example, the user to open doors, interact with levers or triggers in a way analogous to the real world.

Locomotion, on the other hand, comprises a set of interaction techniques that allow the user's movement within the virtual world. They position or reorient the user in the virtual world. However, the biggest challenge of locomotion is to reduce or eliminate motion sickness. When a user performs locomotion in the virtual world, there is a high chance that they will experience a feeling of disorientation or even dizziness. The user's visual system sees movement while the body's balance apparatus indicates lack of movement. This manifests as visual-vestibular conflict and a common cause of nausea and motion sickness.

Therefore, choosing appropriately how to get around within the simulator is key to reducing negative effects. In the specific case of this simulator, a teleportation-based navigation, very common to Virtual Reality systems, was chosen. Users can use a controller-based raycast to select an area of the environment to which they wish to move or "teleport". This is often combined with a rotation element, so that when selecting an area to teleport to, the user can also specify the orientation in which they wish to be positioned when teleporting. Figure 24 shows an example of teleportation locomotion that is very common in Virtual Reality experiences.

Figure 24 - Locomotion in Virtual Reality using teleportation



Source: Elaborated by the author.

Motion sickness is a serious problem in Virtual Reality projects, since the technology has the ability to easily confuse the brain by giving the impression of movement while the perceptual system receives the information that it is not moving. As a result, there is a high chance that the user will experience mismatches between the physical and visual motion signals. Motion sickness in Virtual Reality can lead to fatigue, headaches, and general discomfort. The choice for teleportation-based locomotion stems from development guidelines for accessible virtual experiences produced by Virtual Reality device manufacturers, such as Oculus, which has extensive documentation on the topic[27].

VR environments allow users to interact with the digital world in the same way that we interact with the physical world. The user can interact with 3D objects in the VR space by holding and moving them. However, it is important to consider that because it is a new and under development media, various forms of interaction still need constant validation and depend heavily on the intention behind each interaction.

PCs and mobile devices like tablets and modern cell phones have a standardized set of inputs (keyboard, mouse, touch-screen). They also implement a standardized set of interactions. For example, the command Ctrl+C is recognizable as the command to copy content. On the other hand, the inputs and interactions in Virtual Reality are not standardized. The creator of a virtual world has to make critical decisions about how accessible his or her world will be to the user. These decisions are based on the choice of hardware and the interactions required for the experience one plans to develop.

In this respect, the user interface plays a vital role in creating immersion in Virtual Reality. Usually, when we talk about interfaces in interaction design, it is more about the visual aspect, since today's devices and technology are more focused on the visual medium. But in the virtual world, when designing an interface for immersion, we are not limited to just the visual aspect.

To create content and interfaces for immersive media, it is necessary to understand the concept of "Diegesis" which refers to the famous concept of the "fourth wall," common to theater. Using the concept of diegesis, elements are divided into two categories: diegetic and non-diegetic, based on their existence in relation to the fourth wall and their existence in the virtual world, which are not limited to visual elements, but also include sound and other features.

Diegetic means that it is part of the scene (world space), and non-diegetic means that it exists outside the scene. It is the difference between music played by the character in the scene

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[27] https://developer.oculus.com/learn/design-accessible-vr/

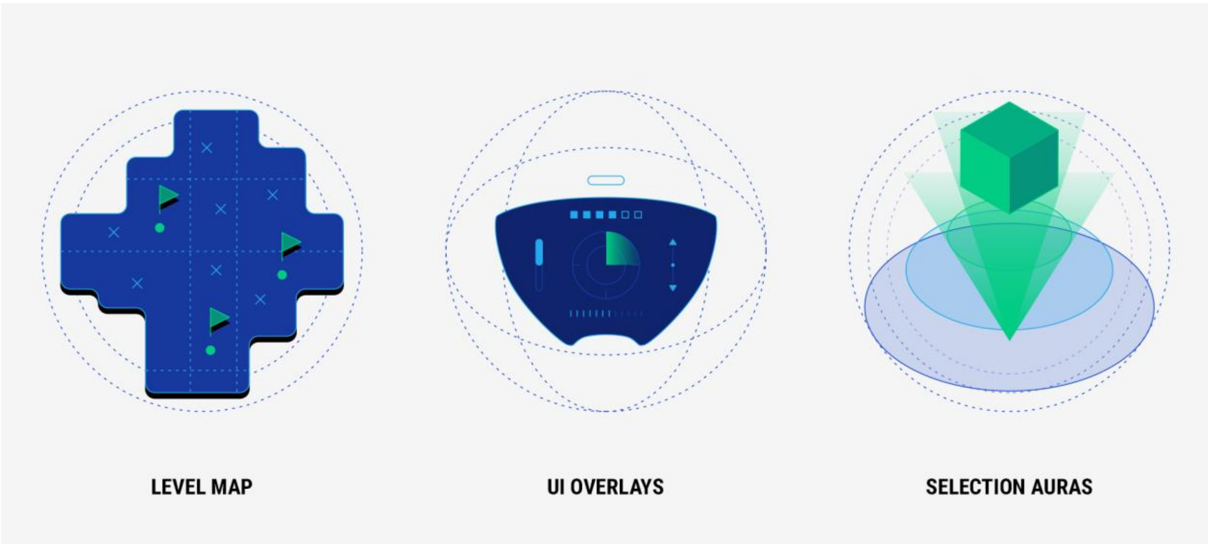
(diegetic) and an external voiceover or a background soundtrack played to enhance the scene (non-diegetic).

In the specific case of this simulator, it was opted for non-diegetic interface elements that accompany the user all the time, such as maps and visual indicators like vital signs, but also diegetic elements, such as devices with which the user can interact, like the gun and the police radio.

Besides these interface elements, some other elements were planned for the interface always with the objective of facilitating and improving the user experience. Among them, navigation maps indicating the next action points, screen overlays with context-sensitive indications and alerts, and auras around objects to facilitate selection and interactions.

Figure 25 shows some of the elements that were originally selected to compose the simulator's interface.

Figure 25 - Some elements originally selected to compose the simulator's interface

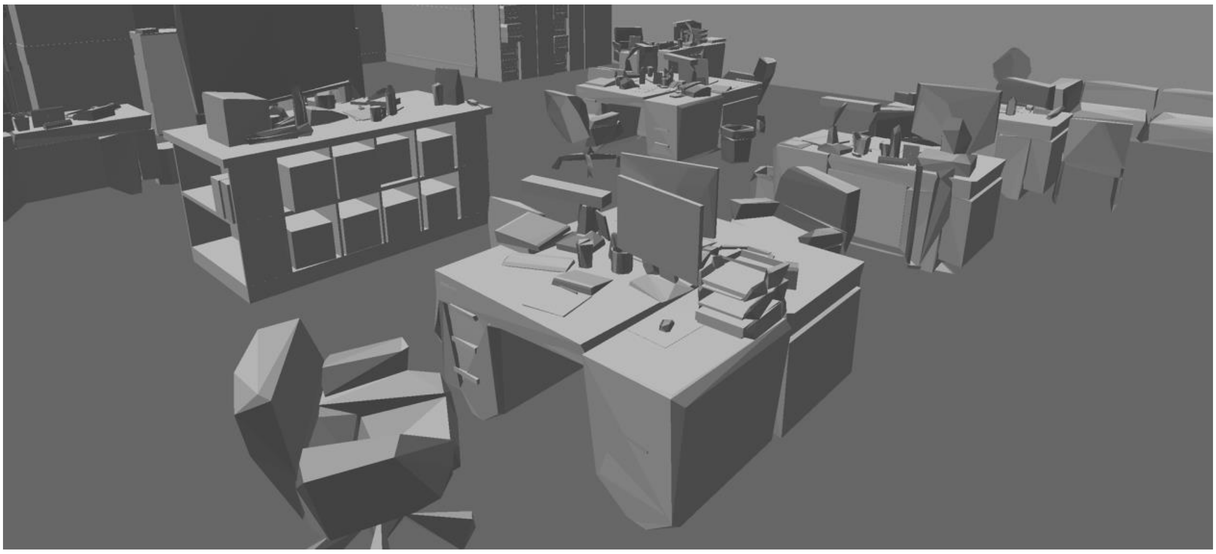


Source: Elaborated by the author.

The next thing to do was to prototype and validate ideas. In the case of the simulator presented in this topic, the prototyping of the simulator environment itself and the biofeedback system happened simultaneously, and each will be discussed briefly.

The prototyping of the simulator was focused, at first, on the simulator's environments and was performed in low polygon count. The main objective was to establish the scenes, proportions, scales of the physical spaces and objects, as well as the layout, and the flow of movement of the user. The need for this step is justified by the fact that the user will have freedom of locomotion in the scene, and his movements need to be foreseen, as well as the flow that this user will perform. This kind of planning helps to avoid the development of unnecessary interactions that the user will never deal with. Figure 26 shows an image of one of the low polygonal count prototypes of the police station with an initial layout and without any textures applied.

Figure 26 - Police station low polygon count prototype



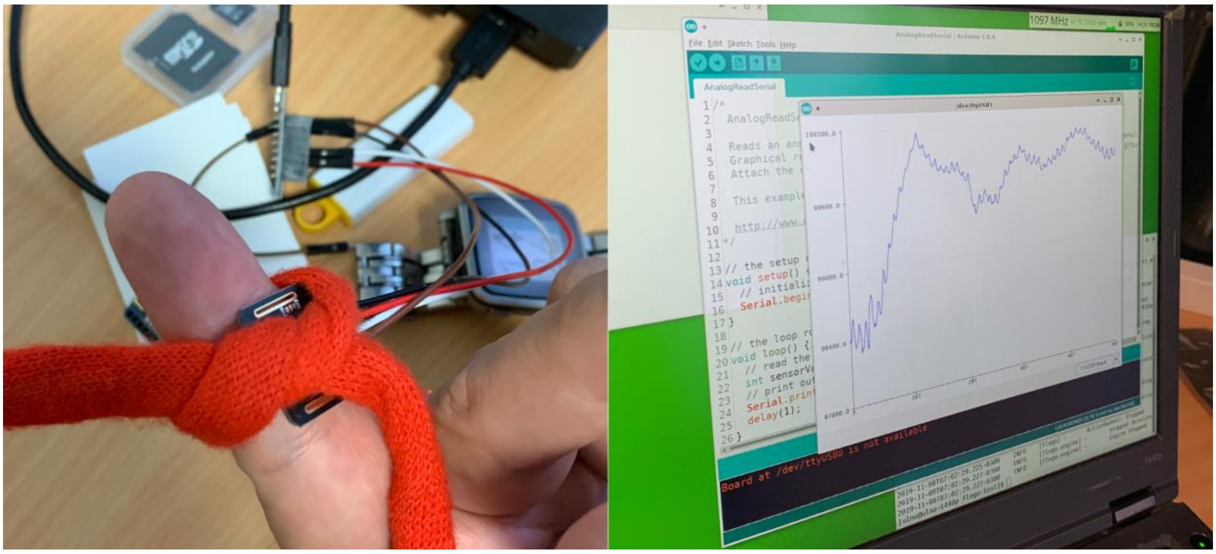
Source: Elaborated by the author.

The biofeedback system was intended, as previously stated, to use sensors and devices and to be fully customized for the simulator. However, during the prototyping process a series of problems were detected. The most significant of these concerned the lack of accuracy of the signals from some of the sensors tested. This type of discovery, which can only be detected during prototyping, forced the researcher to take other measures and evaluate alternatives. In the end, it was decided to conduct tests with a biofeedback system that uses a smart watch and captures heartbeat signals from the user.

As a consequence, the integration of the signals into the system could not be completed, but it was tested as a plausible solution, since there are numerous researches, open-source frameworks, and even hardware dedicated to this kind of adaptation. Still, it was possible to perform a series of experiments and evaluate all the sensors originally considered for this research.

Figure 27 represents images generated during the prototyping process of the biofeedback system, and shows graphs generated from a heartbeat sensor.

Figure 27 - Prototyping process of the biofeedback system



Source: Elaborated by the author.

Immediately after the prototyping and validation process, the production of the final simulator content began. In this stage the processes of modeling, texturing, rigging, and animating all environments, assets, and characters of the simulator were performed. Highly efficient modeling principles and practices were applied, always keeping in mind that, since this is a real-time application, asset optimizations were absolutely necessary. This basically involves two processes: efficient texturing, which in other words means trying to replace polygonal geometry with different types of textures, and the use of levels of detail (LOD).

Figure 28 shows the different textures of one of the assets used in the simulator, as well as the final textured object.

Figure 28 - Different textures of one of the assets used in the simulator

Source: Elaborated by the author.

Physically Based Rendering (PBR) is a shading and rendering technique that delivers a more accurate portrayal of how light interacts with surfaces and it is also known as or Physically Based Shading (PBS). PBS is usually related to shading concepts, while PBR is specific to rendering and lighting, depending on which component of the pipeline is being discussed. Both terms, however, define the act of describing assets in a physically precise manner, and this is exactly how modern game engines work.

However, every aspect of the objects' appearance is controlled with textures that fulfill very specific roles and are usually used together. During the production of this simulator a set of three textures (also called maps) was used for all assets, scenarios and characters: Albedo, Roughness and Normal.

The Albedo map contains the color information of the objects and nothing else. The Roughness map is responsible for defining how rough or shiny a certain surface is, and is usually represented by a grayscale texture, where lighter values represent more reflection and darker values represent less reflection. Finally, the Normal map is a special texture that defines how light should behave when in contact with the surface of objects. This texture is extremely important in causing realism in the representation of deformations on the surface of objects. Normal maps are widely applied in the gaming industry for one important technical aspect: they do not add real geometry to objects, which makes them ideal for real-time applications.

The three textures combined help to describe the surface of objects, but it is important to note that this is not the only way to work with materials in game engines, and different engines take different approaches.

Besides efficient texturing, another important factor concerns the polygon count of the simulator's objects. Using a large number of polygons in the production of real-time experience content is not the only reason for decreased performance, but it is certainly one of the most impactful factors. Therefore, producing content that balances polygon count and high visual fidelity is certainly one of the biggest production challenges.

Some strategies and practices are commonly adopted by the industry and were adopted by this research, such as the aforementioned use of different levels of detail. Level of Detail (LOD) is a technique for reducing the complexity of the mesh as objects become more distant from the player. With this technique, various objects with different levels of polygonal resolution are superimposed and literally replaced in the scene depending on the distance from the camera or the size of the object on the screen. Figure 29 shows the same asset presented earlier with different levels of polygonal mesh resolution.

Figure 29 - Asset with different levels of polygonal mesh resolution

Source: Elaborated by the author.

In this aspect, the production of the simulator kept as main guideline to save polygons in the environments and put as many polygons as possible in the characters, especially in the areas of greater deformation, more specifically in the characters' faces. This is due to the fact that meshes with little polygon count make it very difficult to deform the geometry in a more realistic way, which can compromise the result as a whole. Figure 30 shows one of the simulator's characters with a polygonal mesh where the resolution is optimized for real-time performance.

Figure 30 - One of the simulator's characters with optimized polygonal mesh

Source: Elaborated by the author.

Besides the modeling and texturing of all the assets, the rigging and animation of the characters were also performed. This process allowed the creation of realistic animations of the characters' bodies and faces. For the body animations a combination of motion capture and manual animations and corrections of the data from the motion capture were used. For the facial animations a unique pipeline was generated (BATISTA, 2021), which combines several animation techniques such as facial motion capture using an iPhone and lip sync using an alignment algorithm called Montreal Forced Aligner[28].

All three characters in the simulator have been carefully designed to express emotions and facial expressions based on the system known as FACS, or Facial Action Coding System (EKMAN, 2002). This system consists of a taxonomy of facial movements and human expressions that is comprehensive and anatomically oriented to describe all visually discernible facial movements. Among the many application areas for FACS there are a few that stand out in particular. In psychology, the system is used to identify signs of stress or latent emotions. In computer science, the system is used in applications such as face recognition. In animation the

[28] https://github.com/MontrealCorpusTools/Montreal-Forced-Aligner

system is applied to develop realistic and appealing facial animations for characters. Figure 31 shows one of the simulator characters with facial expressions that represent happiness, sadness, surprise, and disgust, respectively.

Figure 31 - Some facial expressions of one of the simulator's characters

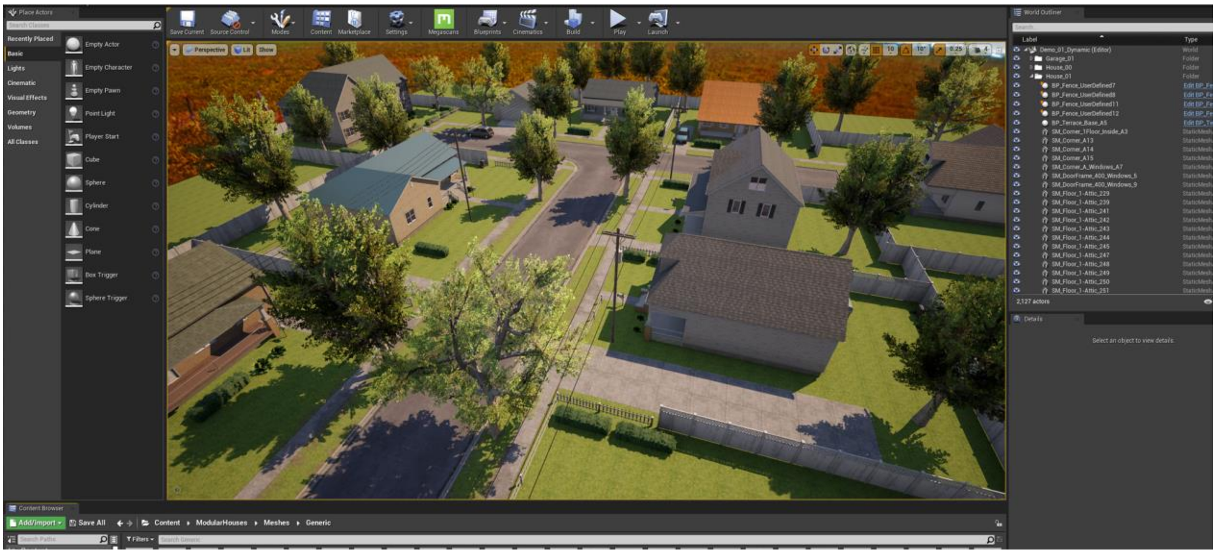
Source: Elaborated by the author.

After the design phase, where all assets have been produced, the development phase itself has begun. However, it is important to note that the boundary between the phases is often a blurry line, mainly due to the fact that certain stages happen at the same time. And these stages need to happen simultaneously for reasons of production agility. The prototyping phase is usually the starting point of the development phase, and sometimes even before. The sooner errors or technical difficulties are found, the better for the final product itself. Taking these observations into consideration, the development phase is described as the longest and most complex of the entire process, and therefore comprises the largest part of the simulator's development.

As stated earlier, the tool chosen for the development of the prototype was the Unreal Engine, currently in version 4. The Unreal Engine 4 (UE4) is a game engine for developing games, architectural projects, product visualizations, and currently employed in several other industries. The tool supports cross-platform publishing and is a very popular game engine. Many AAA developers and indie studios use it to create modern games and real-time applications consumed by millions of people around the world.

After the assets were produced, all the assets were imported into the engine and the construction of the environments was started. This phase is commonly described as level design in game development. The workflow at this point is exactly the same as for the production of a game or any real-time application. The importing of the assets is done using a file format known as FBX (Filmbox) which is a commonly used interchange format in the industry. Once all the objects, characters and animations have been imported, the process includes the creation and application of materials, lighting and programming for each of the objects and interactions. Figure 32 shows one of the simulator scenarios within the engine after the process of importing, creating materials and lighting.

Figure 32 - One of the simulator scenarios within the game engine

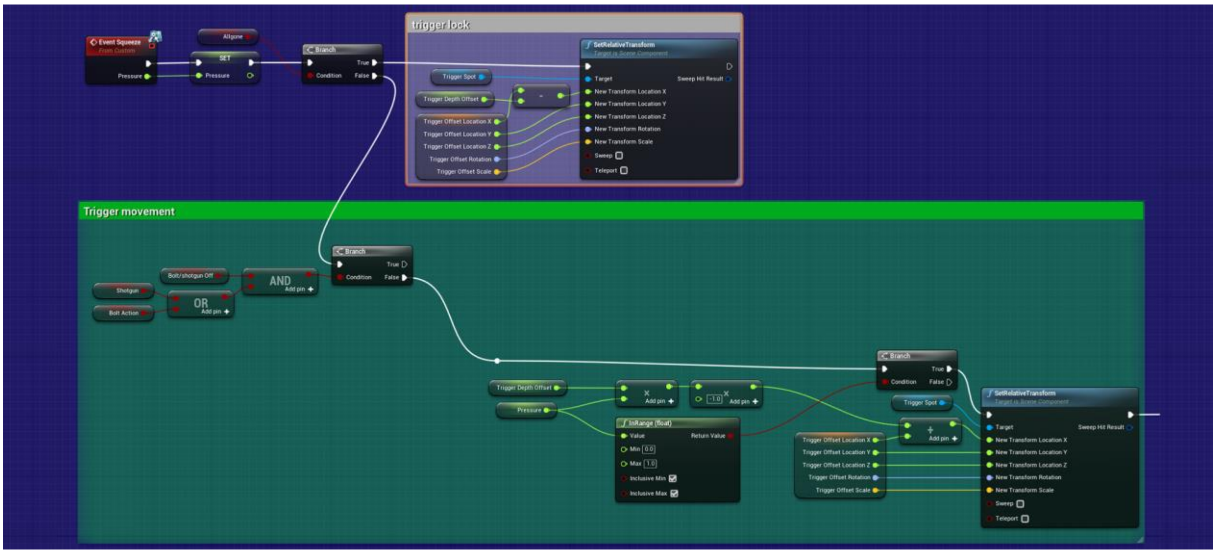


Source: Elaborated by the author.

For the development of all the interactions, the programming language known as Blueprint was used, which is a visual gameplay scripting language based on a node graph in which the user connects the nodes from left to right. It is capable of creating complete games or simple or complex game mechanics. The biggest advantage of Blueprints is that the user does not need a programmer to create the logic. Artists can easily make whatever they want using Blueprints and share them later with a developer, which radically speeds up the prototyping process.

This system is extremely powerful because it offers the artist a full range of tools that are usually only available to advanced level developers. In addition, C++ programmers can create base systems that can be accessed or modified by Blueprints users. Figure 33 shows part of one of the scripts for one of the simulator's weapons, more specifically, the part responsible for what happens when the gun's trigger is pressed.

Figure 33 - Part of the script for one of the weapons used in the simulator



Source: Elaborated by the author.

The development process also covered the interactions of the characters with the environments, programming of mechanics, programming of the interface, sounds and special effects. However, it is important to emphasize that this is an iterative process that accompanies the vast majority of interactive digital product development, and it does not end even after its release or delivery. This is due to the fact that all kinds of software require constant updates and improvements until they reach a certain point of maturity where no further improvements are required. Table 22 gives an overview of the results of all the processes put in place during this phase.

Table 22 - Contributions resulting from the design and development phase

Phase	Activity	Result
Design and Development	Definition of scenarios	Three scenarios. Police station, police car, and a suburban neighborhood.
	Definition of the characters	Three characters. A policeman, a woman (wife) and a man (husband).
	Scriptwriting & Storytelling	Narrative that represents a normal workday.
	Concept art	Concepts created for environments and characters.
	Interaction Design & UI	Simple, natural interaction that comes close to the real world. Diegetic and non-diegetic interface elements.
	Assets preparation	Hundreds of objects have been modeled, textured and animated.

Phase	Activity	Result
	Asset import/integration	The objects made were imported into the engine and used in production.
	Coding (VR)	The simulator has been prototyped and tested in various ways, including with real users.
	Coding (Biofeedback)	A multi-sensor vital sign capture system has been prototyped and tested.
	Test and Performance Optimizations	The performance of the prototype was evaluated during the entire development process.

Source: Elaborated by the author.

4.4.5 Simulator Demonstration and Evaluation phase

The prototype demonstration and validation phase aimed to provide subsidies not only to improve the prototype itself, but also to generate valuable knowledge about the simulator development process as a whole. In this phase, a number of approaches were used. For practical purposes, it is convenient to recall what was stated in topic 3.5.1 about the validation process of the first artifact:

- The first artifact is itself a prototype;
- The prototype was tested extensively during development;
- Tests with real users were performed; and
- The prototype and its development phases were submitted to expert evaluation.

For practicality and objectivity reasons, the validation processes will be described in an straightforward manner, as well as a brief explanation about the context of each of the evaluation processes of the first artifact generated by this research.

The tests with the prototype took place in two ways: during the production of the prototype itself, and with real users, who experienced the product in different phases of development. The first type of testing was done using the chosen development tool itself. Unreal Engine has diagnostic tools that allow the generation of usage profiles and information about the impact of content on the system's memory consumption and graphics processing.

Performance is a ubiquitous issue in the development of real-time applications such as games and simulators. In order to create the illusion of moving images, a frame rate of at least 15 frames per second (FPS) is required. Depending on the platform and application, 30, 60, or even more frames per second can be set as the target.

The Unreal Engine offers many features, tools, and possibilities, and each of these has different performance characteristics. In order to optimize the content or code to achieve the required performance, it is necessary to identify where performance is most required and at what point in time.

For this it is possible to use the profiling tools in the engine itself. Each case is different and some knowledge of the system's internal hardware and software components is required. However, the tool is intuitive, and even if the user does not have a high level of technical knowledge, it can identify and treat performance related issues.

However, optimization is a subject that is not limited to the use of tools. It also requires a combination of techniques and production processes that were used as much as possible in the construction of the prototype and were presented in the topic where the development is described.

To be more specific, two tools were used for testing during the entire development process: CPU Profiling, dedicated to diagnosing CPU consumption and GPU Profiling, dedicated to monitoring the demand for graphics processing. Both are important, but the main focus of monitoring is the GPU, since the vast majority of graphics processing is done by the graphics card. Figure 34 shows a picture of the diagnostics generated by GPU Profiling.

Figure 34 - The diagnostics generated by Unreal Engine's GPU Profiling

Source: Elaborated by the author.

Also, regarding the optimization process, it is important to point out that the development of the prototype followed recommendations and practices which aimed at the optimization and performance of the system. This set of practices is adopted by the entire industry and is agnostic in relation to the platform or game engine, since they all have similar documentation and recommendations.

Although the intention was never to generate a complete, polished and optimized product at the end, the prototype reached a certain level of detail that, even if far from ideal for a finished product, could be tested and evaluated by real users. One of these public tests took place in January 2020, during the second edition of the event called Mixed Reality Day, organized by the University of Applied Sciences Upper Austria, Campus Hagenberg. Figure 35 shows an image of the testing of the simulator prototype by one of the visitors of the event.

Figure 35 - Testing the simulator prototype during the Mixed Reality Day event

Source: Elaborated by the author.

During this event, an initial version of the prototype was presented and had, already at that moment, one of the environments (the police station) and some of the main interaction mechanics in its first versions. Two aspects could be tested at this point: the locomotion mechanics and the interaction with firearms in a shooting booth located inside the police station. The feedback from users was important to improve a number of aspects of the simulator. Unfortunately, the remaining tests that had already been scheduled had to be canceled due to social distancing measures that affected the development and evolution of the simulator.

In addition to testing with real users, the prototype was submitted to experts, who suggested changes and improvements. Thus, more tests and improvements were performed, but the simulator achieved its objective, which was to generate knowledge about the production process. This knowledge, in turn, was used to propose the method presented as the second artifact of this research. The development and evolution of this method is presented in Chapter 5 of this thesis. Table 23 provides a summarized view of the results of the demonstration and evaluation phase.

Table 23 - Contributions resulting from the demonstration and evaluation phase

Phase	Activity	Result
Demonstration and Evaluation	User experience evaluation	The simulator was tested with real users and feedbacks were used for the improvement of the artifact.
	Additional refinements and optimizations	Adjustments, improvements, and optimizations were made using a combination of techniques and tools.

Source: Elaborated by the author.

4.4.6 Final considerations about the simulator prototype

This chapter presented the process of developing a Virtual Reality simulator, explaining all the decisions, implications of such decisions, and the results of each. The production process of this first artifact was divided into phases inspired by the Design Science Research method. Each phase corresponded to one of the cycles of the method, and keeps similarity, in general lines, with the purposes of each cycle derived from the method. However, for narrative and knowledge structuring purposes, they were presented in this chapter in a linear fashion, although this does not mean that they were executed in a linear fashion and in sequence, which is made clear at all times when processes, methods, or activities were developed at the same time.

At the end of each of the phases a table is presented with a summary of the main knowledge and theoretical or practical contributions arising from each of the phases as a way of synthesizing the knowledge acquired. This knowledge, in turn, is the primary reason for building the simulator. By executing the development and documenting the entire process, it was possible to generate subsidies that served to develop the bases of what became the second artifact produced by this thesis: the proposition of a method for the development of simulators for the training of security professionals and law enforcement agents.

Chapter 5 of this thesis focuses on the development of this method and starts exactly from the point where this chapter stops. The knowledge and experience gained from the development of the simulator prototype are summarized in Table 24.

Table 24 - Knowledge and experience gained from the development of the simulator

Phase	Activity	Result
Research	Define the objective of the simulator	The simulator should not be focused only on simple repetitions of real-world activities. The simulator should expose the user to some situation where not only physical or technical skills are required. The simulator must provide some kind of system for capturing vital signs. The simulator should offer some sort of mechanic or mechanics to increase user engagement. The scenario chosen was that of domestic violence.
	Context research	It was not performed due to limitations.
	Research on the target audience	Expert knowledge was used.
	Research on existing solutions	Research in academic literature and research by companies that specialize in developing and selling Virtual Reality solutions for military and police training.
Planning	Definition of the simulator type	Fully immersive simulator
	Definition of the visual style	Photorealistic simulator
	Definition of the technologies to be adopted	Unreal Engine/Blueprint, Autodesk Maya, Pixologic ZBrush, Substance Painter, Adobe Photoshop, Illustrator, Adobe XD and others.
	User Experience Design	Persona definition and validation.
	Goals and evaluation criteria	Reproduce real-world procedures. Heart rate, temperature, and electrodermal activity as biofeedback markers. Error-induced learning.
Design and Development	Definition of scenarios	Three scenarios. Police station, police car, and a suburban neighborhood.
	Definition of the characters	Three characters. A policeman, a woman (wife) and a man (husband).
	Scriptwriting & Storytelling	Narrative that represents a normal workday.
	Concept art	Concepts created for environments and characters.
	Interaction Design & UI	Simple, natural interaction that comes close to the real world. Diegetic and non-diegetic interface elements.
	Assets preparation	Hundreds of objects have been modeled, textured and animated.
	Asset import/integration	The objects made were imported into the engine and used in production.
	Coding (VR)	The simulator has been prototyped and tested in various ways, including with real users.
	Coding (Biofeedback)	A multi-sensor vital sign capture system has been prototyped and tested.
	Test and Performance Optimizations	The performance of the prototype was evaluated during the entire development process.
Demonstration and Evaluation	User experience evaluation	The simulator was tested with real users and feedbacks were used for the improvement of the artifact.
	Additional refinements and optimizations	Adjustments, improvements, and optimizations were made using a combination of techniques and tools.

Source: Elaborated by the author.

5 THE DESIGN OF A METHOD TO DEVELOP VR SIMULATORS

5.1 Method development

5.1.1 Overview of the proposed method development

Beck et al. (2013) state that a challenge often mentioned in research using Design Science Research methodology is the generation of new theoretical contributions above and beyond information technology artifacts. This research proposes to contribute in this direction by presenting two artifacts arising from the symbiosis of practice, theory, and knowledge of experts and academics.

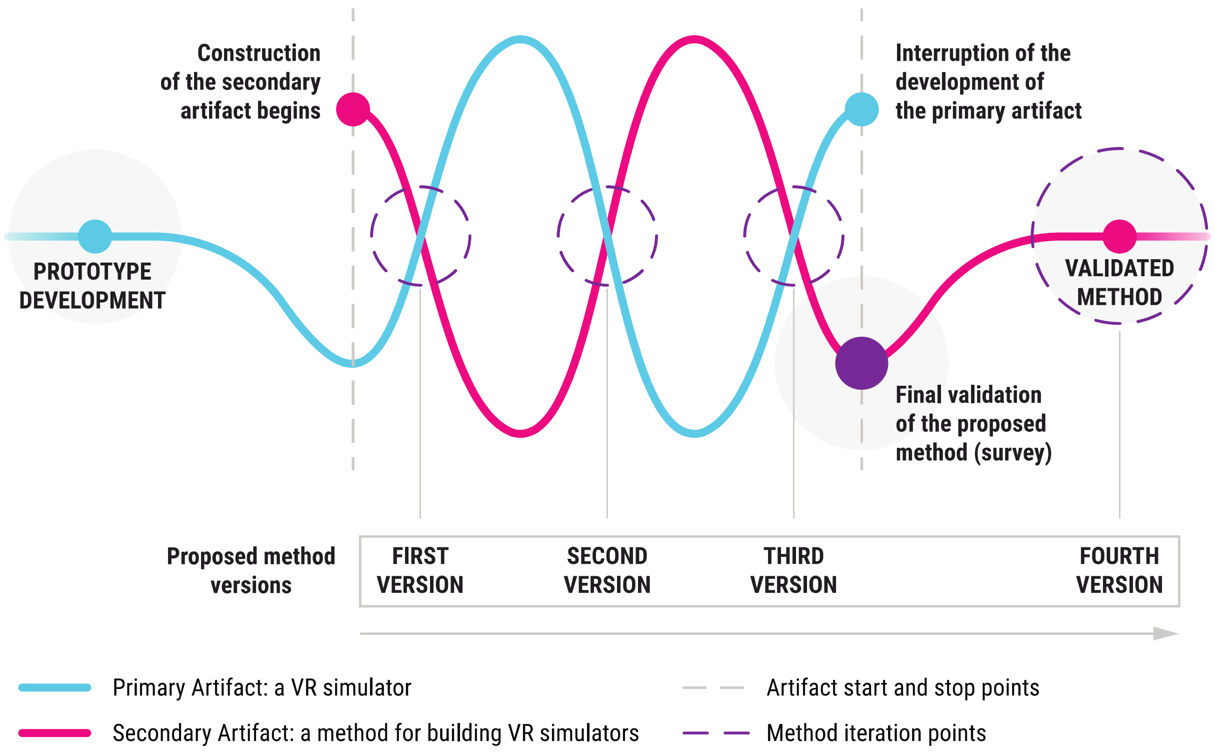
The first artifact, whose evolution and development are presented in Chapter 4 of this thesis, is the prototype of a Virtual Reality simulator applied to the training of security professionals and law enforcement agents. This first artifact had the sole purpose of generating subsidies to support the development of the second artifact originated from this research: a method for developing Virtual Reality simulators that can be applied to the training of professionals in situations of risk and stress, more specifically, security professionals and law enforcement agents.

This chapter, therefore, presents the development and evolution of this second artifact, besides showing, at the end of this chapter, the final version of the proposed method with considerations and suggestions for improvement originated after the validation process of this second artifact. The validation process that led to the generation of this last version is presented in Chapter 6 of this thesis.

The proposed method had three main iterations and at each one, suggestions for improvement were proposed by the specialists consulted and already presented in the methodology chapter of this thesis. These suggestions were used to improve the method, which was submitted to a new round of evaluations, until the third version was submitted to a wider validation through a survey with 141 experts and academics from 11 countries and different areas of professional activity. Among the areas of activity whose respondents participated in the validation are User Experience and Interface Design (UX/UI), Software Development, Education, Games and Industry 4.0, and all participants had experience in developing Virtual Reality projects.

After analyzing the data from the survey responses, some final points for improvement were identified and a fourth version was produced taking these observations into account. As a way to make this chapter easier to understand, Figure 36 presents a scheme that highlights each of the versions, the iteration points of the method, and the sequence that was followed. This sequence comprising each of the versions will be presented in the following.

Figure 36 - Overview of iterations and versions of the proposed method

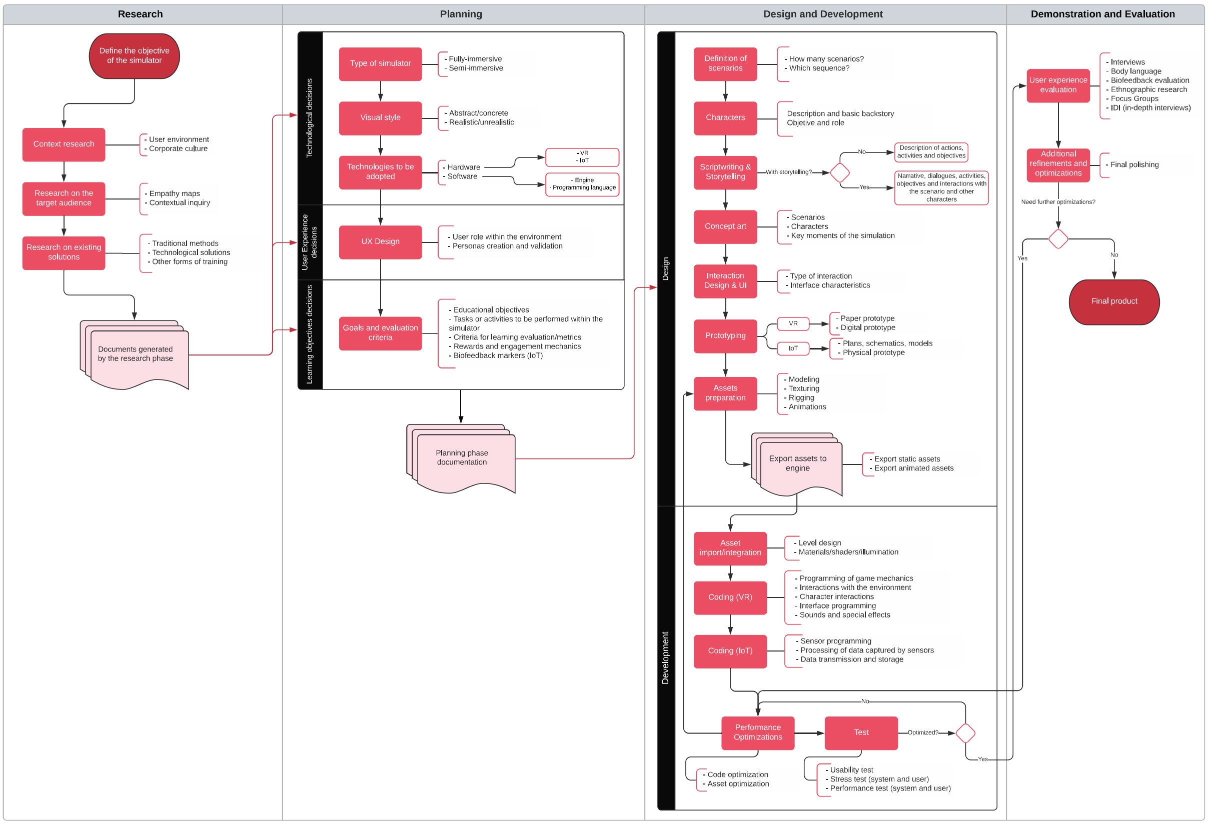


Source: Elaborated by the author.

5.1.2 First version of the proposed method

The proposed method had its development initiated during the production of the Virtual Reality simulator prototype and was strongly inspired by the principles of the Design Science Research methodology. Its origin was explained at the beginning of Chapter 5, where the development of the Virtual Reality simulator prototype is presented. The first interaction was determined, therefore, by the activities performed during the construction of the prototype. The method, as well as the tasks or activities are presented in Figure 37.

Figure 37 - The first version of the proposed method



Source: Elaborated by the author.

A larger scale image of the first version of the method is presented in APPENDIX B - The first version of the proposed method.

Although each of the phases and activities that comprise this version of the method have already been presented, it is worth explaining, even if only superficially, the purpose of each of the four phases included in this first version. The Research and Planning phases were dedicated, as the name suggests, to substantiate the artifact itself, and are close to the Cycle of Relevance of the Design Science Research method proposed by Hevner (2007). Both could be performed at once, but for the context of this research they were treated separately, which is allowed by the method. The Design and Development phase is the heart of the artifact and brings together activities directly linked to the development of the project itself. It is the largest phase in relation to the quantity of actions and, therefore, the most complex. This phase is close to the Design Cycle of the DSR method. Finally, the Demonstration and Evaluation phase is where activities related to the validation of the artifact were performed.

One way or another, all the proposed activities were performed. Some of these activities were performed more than once, and this is mainly due to the exploratory nature of the project, and not necessarily due to a demand of the proposed method or of the Design Science Research methodology.

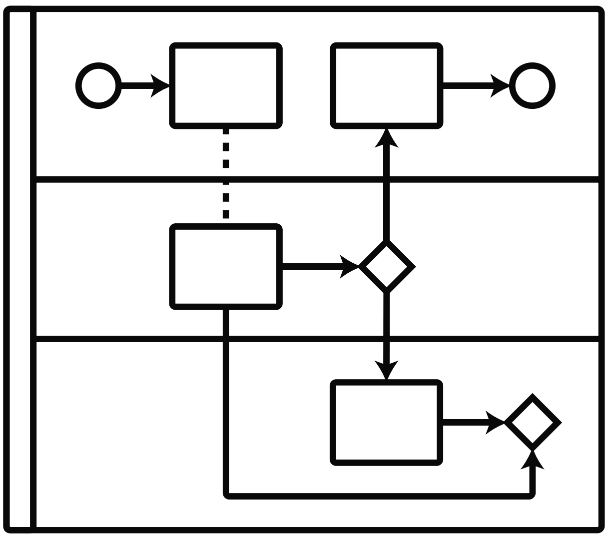
After presenting the proposed method to some of the experts who accompanied this research, several feedbacks were offered, and each of the points served to move towards improving the version. Each of the main considerations about this version will be addressed below, and represent the synthesis of the opinion of more than one expert.

"The method assumes linearity of processes that are not necessarily linear".

This same observation was made by several of the experts, and points to something that was identified already during the production of the prototype. The method, although it was not developed based on a totally linear sequence of tasks or activities, presupposes linearity when presented in such a way.

This first version was based on functional flowcharts, whose main characteristic is to provide clarity and responsibility by positioning steps from different processes within horizontal or vertical "lanes". Figure 38 shows the structure of a functional flowchart.

Figure 38 - The structure of a functional flowchart



Source: Elaborated by the author.

The diagram shows the connections, communication, and deliverables between these lanes, and can serve to highlight waste, redundancy, and inefficiency in processes. This type of diagram is also known as a Rummler-Brache diagram, in reference to Geary Rummler and Alan Brache, creators of the flowchart model in the 1990s.

Although the idea of representing the first version of the method using this type of flowchart seemed appropriate for that time, it was noted that the main observation that the experts to whom this version was presented had referred to the linearity and even the similarity with the waterfall model. In the waterfall model, tasks and phases are completed one by one in a strict order. It is necessary to complete one phase before moving on to another. Furthermore, there is no going back. And each phase depends on the previous one. The suggestion for a better way of representing the method therefore had to be taken into consideration for a new version.

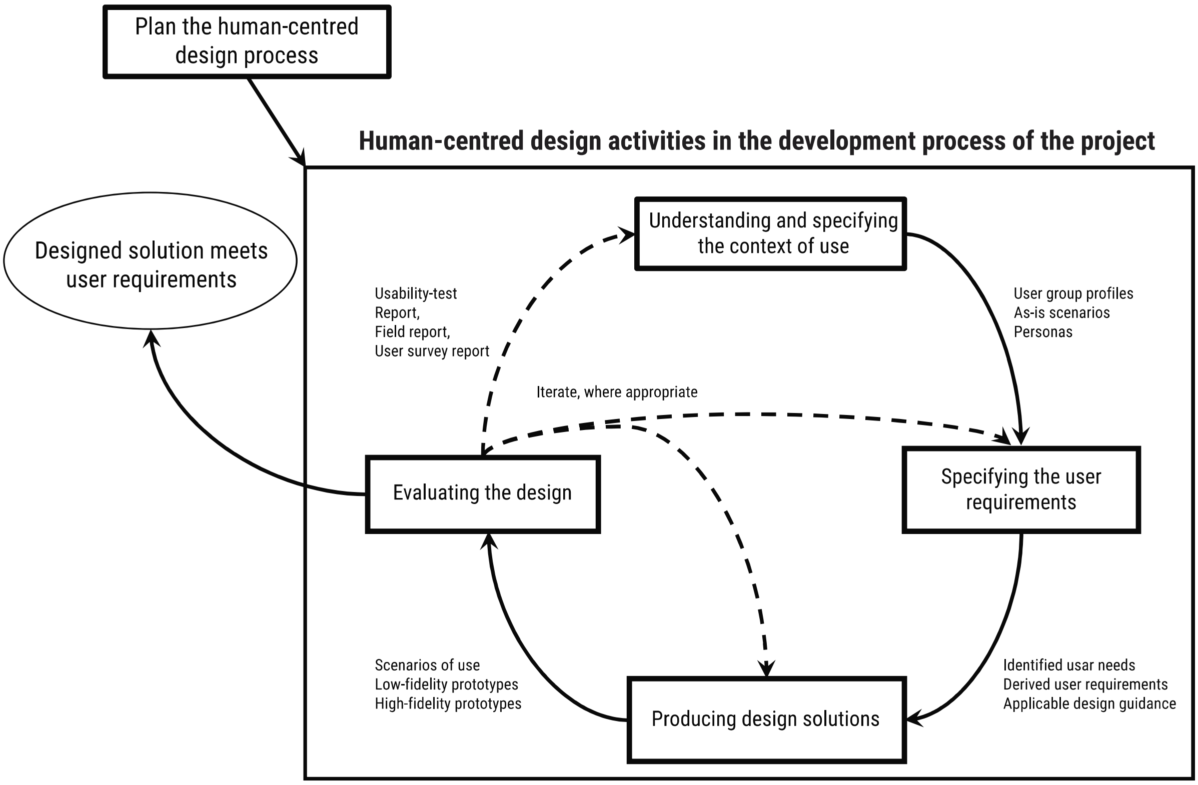
“The phases and activities of the method should be conducted in cycles”.

The observation about the method being extremely linear led to a number of other suggestions raised by the consulted experts. Among them, the possibility of performing certain steps in incremental cycles was suggested several times. The reason for this is because it is increasingly common, especially when it comes to software development, to perform activities several times in an incremental way. Often these deliveries can even be subdivided into smaller, constant deliveries.

However, it is important to note that there is a distinction between the terms "incremental" and "iterative". In general terms, incremental development suggests dividing the product into fully functional slices that are called increments. Iterative development, on the other hand, is when teams gradually build features and functions, but do not wait until each one is complete before releasing. Both terms are currently used, mainly because they are common to teams adopting agile methodologies.

It should be noted that this version of the method, was strongly inspired by the human-centered design cycle for interactive systems, governed by ISO 9241-210:2019 (ISO, 2019), and presented in Figure 39.

Figure 39 - Standard iterative human-centered design process



Source: Adapted from (ISO, 2019).

Among the similarities in terms of structure, it can be noted that in ISO 9241-210:2019 there are four main phases: understand and specify the context of use, specify user requirements, produce design solutions, and evaluate the design. In the first version of the method, each of these phases corresponds to one of the phases already presented: research, planning, design and development, and demonstration and evaluation.

From the observations of the experts, it is clear that this version was not able to reflect the iterative nature or even the flexibility that was intended, even if the method has, in its essence, a proximity to the ISO standard already mentioned. As a result, the suggestion to represent the steps iteratively had to be taken into consideration in a new version.

"The method should be inspired by Agile methodologies".

This observation summarizes the first two more objectively and made it evident that the method needed to be represented in a way that encompassed cycles, iteration, and increments. The Design Science Research methodology chosen for this research provides a high level of flexibility and even adaptability, which makes it ideal for this research. However, as a scientific methodology, it is a bit distant from the reality of software development. However, this is not necessarily a problem, since it was never intended to be applied as a software development methodology, but rather as a way to solve problems and generate solutions, which may or may not be software.

To address this limitation, Conboy et al. (2015) proposed what they called the Agile Design Science Research Methodology (ADSRM), and which aimed to propose a methodological solution for the development of creative artifacts.

According to the authors, the agile perspective balances methodological and procedural rigor with the need to consider the empirical evolution of the problem/solution paradigm, which would allow development to address more significant and unforeseen problems. The proposal of the Agile Design Science Research Methodology is to combine the already consolidated practices of DSR with practices from Agile Methodologies, such as blacklog and sprints.

In a more practical perspective, the suggestion to represent certain phases iteratively makes sense and is totally consistent with the practice adopted during the development of the simulator and explained several times in this work. However, it is important to define what is meant by agile methodology. The definition of "agile" adopted in the context of this research comes from Conboy (2009), who defines it as a method for creating change quickly or inherently, proactively or reactively, and learning from change while contributing to customer value perception. The suggestion for a new iteration of the method to reflect aspects of Agile methodologies was therefore accepted.

"The method should be as flexible as possible".

One of the most curious suggestions came from a conversation with two of the experts consulted in this research: make the method flexible enough so that it could be adopted and developed by different people in different contexts. The suggestion came from the assumption that the method, although originating from a very specific use case (security professionals and law enforcement officers), could be used, presumably for any application involving a risky or stressful situation. The method, therefore, should enable the application and even participation of professionals from diverse contexts of different ways of thinking.

In this context, the use of a methodology that allowed the participation and even inclusion of the point of view of different types of professionals could be advantageous for creating robust solutions to similar problems. With this in mind, and after an intense investigation of different methodologies, the conclusion was reached that the method could have some advantage if it could represent at least some of the characteristics of Design Thinking.

Design Thinking is a design methodology known as a way to solve problems, develop products and projects based on different points of view, empathy, collaboration and experimentation (COMBELLES; EBERT; LUCENA, 2020). Some of these ideas were already present since the first conception of the method, but certainly not in such an explicit way. An example of this is the "empathy" factor, which is foreseen in research and user experience evaluation phases, but does not have the same emphasis suggested by Design Thinking. Without empathy, it is impossible to understand the user's needs and pains, which in turn prevents the construction of robust solutions to these problems (AHMED; DEMIREL, 2020).

Based on Herbert Simon's seminal work "The Sciences of the Artificial" (1996), the design process has always been based on defining, researching, ideating, prototyping, choosing, implementing, and learning. These steps have been the cornerstone of the design process for decades, and one can notice these same processes repeating themselves throughout this work, with greater or lesser intensity. Likewise, the classical design process has also strongly influenced the Design Thinking methodology, which can be defined as a mixture of hearts, heads, and hands.

Design Thinking is an approach that has as its main characteristic the change in the mental state of those who develop projects. It consists, fundamentally, in stimulating the resolution of problems with new perspectives, finding solutions and giving answers by always putting people at the center of the decisions and involving them in the whole process. The Design Thinking methodology proposes five stages of project thinking:

- **Empathize** - Understand people, their behaviors, and their motivations. Since people often don't know or can't properly articulate these things, they can try to understand this by looking at users and their behavior in context to identify patterns, ask questions, and challenge assumptions.
- **Define -** Develop an actionable problem statement to define the right challenge, as well as the set of requirements that need to be met, based on the business, its goals, and the end user's perspective.

- **Ideate** - Use techniques such as brainstorming, mind mapping, sketching, or prototyping to develop more innovative or impactful solutions that were not originally anticipated.
- **Prototype** - Bring ideas to life by showing but not telling, create working prototypes quickly to get something into the hands of users and start collecting feedback.
- **Test** - Learn from the user experience and repeat the process as needed until a Minimum Viable Product (MVP) is reached.

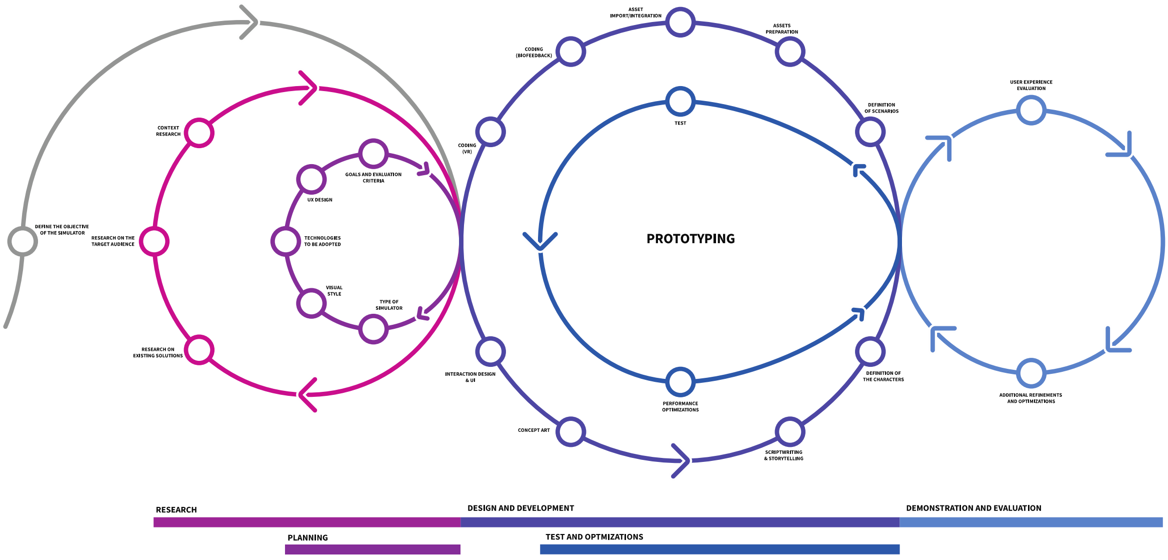
It is important to note that the experts consulted suggested the adoption of agile methodologies, which led the researcher to consider ways to combine the benefits and features of both. After all, Agile development helps development teams achieve the best results by incrementally developing new solutions with a focus on more communication and collaboration. However, Agile methodology alone is no guarantee that teams will consistently deliver engaging and impactful solutions (PEREIRA; RUSSO, 2018). While Agile provides a very effective way to solve problems, it does not guarantee that teams will actually solve the right problems.

While Agile is a problem-solving approach, Design Thinking is a problem-finding approach. It requires a high level of empathy, understanding of end users, and an iterative process of developing new ideas, challenging assumptions, and redefining problems with the goal of finding alternative solutions that are not immediately obvious. So, it makes perfect sense to consider combining Agile and Design Thinking.

5.1.3 Second version of the proposed method

After observing the suggestions offered by the consulted experts, a new iteration of the method was produced and is shown in Figure 40.

Figure 40 - The second version of the proposed method



Source: Elaborated by the author.

A larger scale image of the second version of the method is presented in APPENDIX C - The second version of the proposed method.

This new iteration of the method has a cycle-based format, although the starting (or entry) point is more of a phase than a cycle. The cycles as well as their objectives presented in this version of the method are:

- **Research Cycle -** This cycle has activities related to the research of already existing solutions, of possible users of the simulator and of the environment where this possible user will be.
- **Planning Cycle -** This cycle has activities related to definitions about the level of immersion, visual style, technologies to be adopted, user experience, and evaluation criteria for the simulator itself.
- **Design and Development Cycle -** This cycle contains activities related to the design or conception of the simulator and also activities related to the development of the simulator.
- **Testing and Optimization Cycle -** This cycle is dedicated to the testing, performance, and optimization tasks of the simulator.
- **Demonstration and Evaluation Cycle -** This cycle has activities related to testing the simulator with users and involves evaluations of the user experience and possible refinements and optimizations.

It starts with defining the simulator's objective. The main point of this activity is to define, in an objective way, what is intended with the simulator, and it is close to the task of defining the objectives and evaluation criteria, although its objective is at a broader level. The importance of both is crucial, and a criticism frequently found in the literature refers precisely to the lack of definition of educational objectives or even of a form of learning evaluation (DE ARMAS; TORI; NETTO, 2020). Once the simulator's purpose is defined, we enter the Research Cycle, and in parallel, the Planning Cycle, with activities that although different, complement each other and can be performed in parallel.

These cycles, in turn, feed the Design and Development Cycle, which in turn generates practical subsidies for the Test and Optimization Cycle. Within the Design and Development Cycle are all the activities related to the design, interaction, content production, and programming of both the simulator and the biofeedback system.

At the end of the activities and in possession of a product that can be tested by people (a Minimum Viable Product), the Demonstration and Evaluation Cycle begins, where the tasks of evaluating the User Experience take place and where possible adjustments, corrections, and optimizations may also take place, depending on the results obtained from user evaluations, and that could lead the simulator development back to the Design and Development Cycle and, consequently, to the Test and Optimization Cycle, if necessary.

Once elaborated, this new version was presented to the experts, who once again pointed out suggestions for improvement. These suggestions, like the first time, were considered and evaluated, and are summarized in the following.

"The method needs reflection points".

The same suggestion came from several experts, but in different forms. The expression "reflection points" was mentioned at the same time as "learning", "retrospective", and "lessons learned" came up during the meetings to discuss the proposed method.

Although all the concepts cited appear to orbit knowledge management, they belong to different dimensions. When conducting further research and seeking to better understand how to absorb these types of suggestions and include them in the method, it was possible to find a number of incidences or practices that involve reflection in different areas.

In Agile Software Development (ASD) there is a principle known as "inspection and adaptation". This principle provides for the practice of meetings designed for Agile software teams to reflect on and adjust their operations. These meetings are known as retrospective meetings. Andriyani et al. (2017) state that important aspects focused on during retrospective meetings include identifying and discussing obstacles, discussing feelings, analyzing previous action points, identifying underlying reasons, identifying future action points, and generating a plan.

The practice of retrospective meetings can therefore be considered a knowledge management practice whose main purpose is to provoke fine adjustments during project execution. This concept is very close to the concept of Lessons Learned, common in project management practices. A Lesson Learned is knowledge acquired through experience that is captured, recorded, analyzed, and shared (MILTON, 2010; LEVY, 2017).

Another important factor that was considered is the adherence of the idea of managing the knowledge generated during the execution of the project (or artifact) and its relationship with the generation of knowledge advocated by the Design Science Research methodology. Most of the Design Science contributions refer to the creation of the artifact itself (ALISMAIL; ZHANG; CHATTERJEE, 2017). The artifact must be a solution to a previously unsolved problem. As a consequence, it may constitute an expansion of the knowledge base or the application of existing knowledge from an innovative perspective (VOM BROCKE et al., 2020).

The importance of managing knowledge acquired either through meetings and sharing of ideas or even through knowledge management practices such as lessons learned goes far beyond any application and should be practiced in every type of project, especially projects with a high level of complexity. This suggestion was therefore accepted and considered for a new iteration of the proposed method.

Where is the end of it?

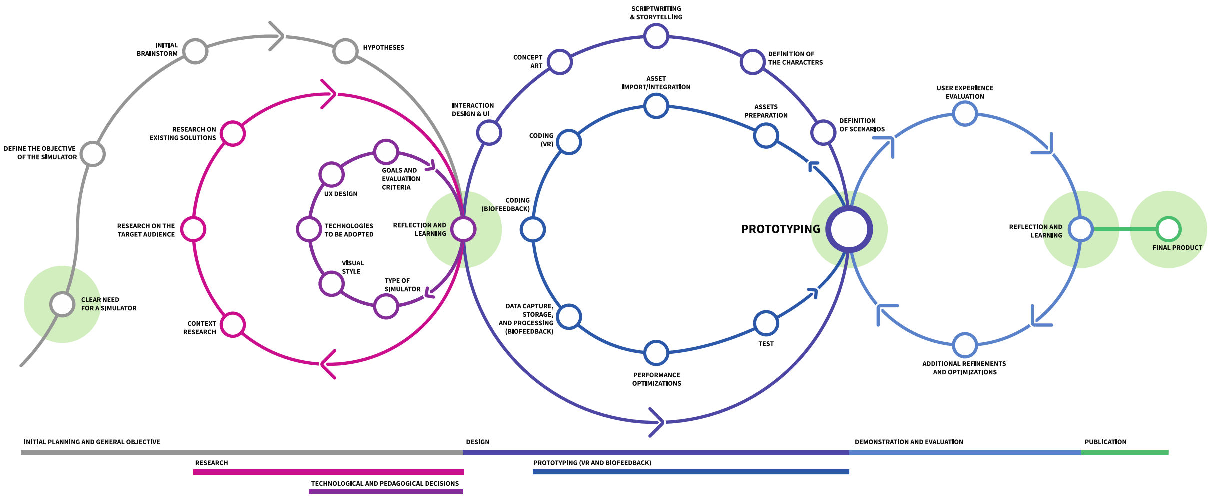
Finally, some remarks were made regarding the way of presenting the method with "loops that never end". It is obvious that the research has an end point, but this end point is not evident in this version. It is important to note that the interpretation of "end point" used here loosely and informally does not necessarily mean something literal, but something that can be identified.

Considering the Design Science Research methodology, this end point would be something that happens after the "Demonstration and Evaluation" phase, or more specifically, the Rigor Cycle of the framework presented by Hevner (2007). Therefore, it makes sense to have an exit point, or something like the publication of the artifact, a suggestion that was understandably accepted.

5.1.4 Third version of the proposed method

After considering the suggestions of the experts, a third version of the method was developed based on the version presented and evaluated by the experts previously. This third version is presented in Figure 41.

Figure 41 - The third version of the proposed method



Source: Elaborated by the author.

A larger scale image of the third version of the method is presented in APPENDIX D - The third version of the proposed method.

This new version has a few more activities and a redistribution of other activities for clarity of reading and clear separation between the types of activities performed. As a way of making explicit the goals and general context of each of the parts of this new iteration, the initial phase, the cycles, as well as their respective goals are presented as follows:

- **Initial planning and general objective -** This phase starts with the clear definition of the need for a simulator and is followed by the definition of the simulator's objectives. This phase also provides for an initial brainstorm and the gathering of design hypotheses.

- **Research cycle -** This cycle has activities related to the research of possible simulator users, the environment in which this possible user is inserted and performs his activities, and the research for already existing solutions.
- **Technological and pedagogical decisions cycle -** This cycle has activities related to definitions about the level of immersion, visual style, technologies to be adopted, user experience, and evaluation criteria for the simulator itself.
- **Design cycle -** This cycle contains activities related to the design or conception of the simulator.
- **Prototyping cycle (VR and Biofeedback) -** This cycle contains activities related to the development of the simulator, including testing, performance, and optimization tasks.
- **Demonstration and evaluation cycle -** This cycle has activities related to testing the simulator with users and involves evaluations of the user experience and possible refinements and optimizations.

Most of the activities included in this version of the method are located near the starting point of the process, which in this version begins with clearly defining the need for a simulator. As obvious as it may seem, establishing the clear need for a simulator is a necessary step for the simple fact that there are situations that cannot and will not have the same effect as real-world training.

The argument in favor of this activity seems to advocate against the existence and use of simulators applied to training, which is precisely why it was decided to include this activity as the first one in the method, followed by the activity of defining the simulator's objectives.

A recent study conducted by Angel-Urdinola et al. (2021) provides a meta-analysis evaluating the effects of virtual reality training on student learning and skill development in different educational fields. The study reviews 92 different experiments evaluating the effects of Virtual Reality training on student learning through robust evaluations. Most of the experiments were conducted in higher education settings on topics related to health and safety and virtual labs for engineering, science, and technical education.

The results of the study show that Virtual Reality training is, on average, more effective than traditional training in developing students' technical, practical, and social-emotional skills. The results also reveal that students exposed to Virtual Reality training score higher on learning assessments than students exposed to the same curricular content delivered by traditional means.

All these results corroborate many of the factors already raised as advantageous for the adoption of Virtual Reality technology applied to education and training. However, the same study signals that the use of Virtual Reality may not be suitable as a mechanism for instruction in all educational fields, which raises a question about using the same cure for all illnesses. This is exactly the point that justifies not only the definition of the need for the use of simulators, but also, and mainly, the clear definition of their objectives.

The other two additions refer to the creative process evoked by the Design Thinking methodology: brainstorming and hypotheses. Brainstorming is one of the many approaches that can be adopted in order to stimulate creativity and broaden the possibilities of potential solutions to problems (BONNARDEL; DIDIER, 2020). According to Bonnardel and Didier (2020) there are basically two variants of brainstorming: idea evocation (IE) and constraint evocation (CE). Both approaches can be used to solve problems, but from different perspectives, from divergent or convergent thinking, depending on the needs of the participants. Their necessity, therefore, is justified, and especially so, at the beginning of project development.

The next addition refers to the raising of hypotheses. In design, a hypothesis can be defined as an assumption of why something happens or how a problem will be solved (KROGH; KOSKINEN, 2020). A scientific hypothesis is a premise within a given theory that can be observed (or not) through experimentation (PEFFERS; TUUNANEN; NIEHAVES, 2018). Strange as it may seem, both concepts, although in different universes, are deeply related. The search for a scientific basis to support the development of projects in Design is exactly one of the central points of methodologies such as Design Science Research. Therefore, it makes sense that the raising of hypotheses is an activity to be considered, especially in the early stages of the development of artifacts that propose to solve real world problems.

Furthermore, the middle part defined in this version by the Design and Development cycles have been reorganized. Besides the addition of tasks dedicated to Serious Game design and Interaction design, both of which also happen before the prototyping phase is even started. The interaction design task has also been split in two, since in the previous version, both tasks happened at the same time. Although both happen in the Design Cycle, it is appropriate to suggest an order, which in this case, happens at different times, with interaction design before prototyping and interface design after prototyping begins. However, it is important to reaffirm what has already been said about this order: it is not a strict and immutable rule, which implies that the order of the activities can be changed, provided there is logic and necessity for doing so. The intention of the new additions and reorganization is to improve readability and make it clear that several of these activities happen in parallel, an observation made since the first version of the method.

Another significant addition has been made to the method and concerns the inclusion of two "Reflection and Learning" points. The first point tangents all the initial activities and, in addition, the Design cycle. The second point is at the end and serves as an exit point from the Demonstration and Evaluation cycle before the "Final Product", which in the case of the method presupposes the publication of the artifact. The addition of these reflection and learning points makes the method robust in terms of anticipating tools or processes for managing the knowledge generated during execution and directly addresses the suggestions made by some of the experts consulted.

Finally, it is important to note that, with the addition of new activities, there was a shift of the Prototyping activity to the right. It sits at the tangency point of the Design, Development and Demonstration and Evaluation cycles. However, the shift of the Prototyping activity to the right does not affect the reading or flow of the process, since there is a logical sequence to be followed that is pointed out by the larger arrows indicating the flow.

After these modifications and new additions, a new validation was performed, but this time, through a survey, which was answered by professionals and academics from various areas involved in this research, but with one particularity: experience in developing Virtual Reality projects. As a way of consolidating the version that was submitted to the final evaluation, Table 25 presents the phase or cycles defined in the third iteration of the method, as well as all thirty-one activities proposed in each of the cycles and a brief explanation of the objective or purpose of each one.

Table 25 – Phase/Cycles and activities of the third version of the proposed method

Phase/Cycle	Activity	Purpose/Objective
	01. Clear need for a simulator	Define whether the simulator is really necessary.
	02. Define the objective of the simulator	Define the simulator's main objective.

Phase/Cycle	Activity	Purpose/Objective
01 - Initial planning and general objective	03. Initial brainstorm	Generate general ideas about the simulator.
	04. Hypotheses	Define hypotheses about related to the simulator's design.
02 - Research cycle	05. Context research	Understand the environment in which users or potential users of the simulator perform their activities.
	06. Research on the target audience	Better understand the simulator's potential user.
	07. Research on existing solutions	Survey existing solutions.
03 - Technological and pedagogical decisions cycle	08. Definition of the Type of simulator	Define the level of immersion that this simulator should have.
	09. Definition of the Visual style	Define the simulator's visual style.
	10. Technologies to be adopted	Define the technologies that will be adopted to build the simulator.
	11. UX Design	Define the user's role within the simulator and how to handle their needs.
	12. Goals and evaluation criteria	Define objectives and evaluation criteria to be evaluated during and after using the simulator.
04 - Design cycle	13. Serious Game design	To define the serious game mechanics that will be adopted in the simulator.
	14. Interaction design	Define the type of interaction the simulator will have.
	15. Definition of scenarios	Definition of the possible scenarios to be represented in the simulator.
	16. Definition of the characters	Define the simulator's characters (NPCs), if any.
	17. Scriptwriting & storytelling	Definição de uma narrativa e roteiro, caso haja.
	18. Concept art	Creation of the simulator's concept and visual style.
	19. User interface design (UI)	Definition of the user interface elements.
	20. Reflection and learning	Consolidate what has been learned up to this point in the development and evaluate possible changes based on new knowledge.
05 - Prototyping cycle (VR)	21. Assets preparation (VR)	Preparation of the simulator assets, which includes modeling, texturing, and animation, among other things.
	22. Asset import and integration (VR)	Export objects and animations and import them into the engine or development environment.
	23. Coding (VR)	Coding of the simulator, the mechanics and possible interactions.
	24. Test (VR)	Testing the simulator during development.
	25. Performance optimizations (VR)	Improve the simulator's performance during development.
06 - Prototyping cycle (Biofeedback)	26. Coding (Biofeedback)	Coding of the vital signs capture system.
	27. Data capture, storage, and processing (Biofeedback)	Development of ways to capture biofeedback data for possible use during or after simulation.
	28. Test (Biofeedback)	Testing the biofeedback system during development.
07 - Demonstration and evaluation cycle	29. User experience evaluation	Evaluation of the user experience by various evaluation procedures and methods.
	30. Additional refinements and optimizations	Possible adjustments or optimizations from user feedbacks or expert evaluations.
	31. Reflection and learning	What was possible to learn from the experience of building the simulator.

Source: Elaborated by the author.

Once submitted to the evaluation of professionals and academics from different areas and countries through a survey that evaluated the relevance of each of the activities proposed within the cycles, a final version of the proposed method was elaborated.

The next chapter presents the validation process of the method whose evolution was presented in this chapter, as well as the presentation of the results of the survey applied with the objective of validating the proposed method. In addition, a brief discussion of the survey results and possible explanations for some of the results obtained are also offered. At the end of the next chapter, the final version of the proposed method is presented along with some reflections generated from the survey responses.

6 THE VALIDATION OF THE PROPOSED METHOD

This chapter presents an overview of the data collected in the validation phase of the method proposed by this research and is divided into three main parts. The first part is dedicated to present a general description of the approach adopted in this research for the selection of the participants, as well as the characterization of the respondents by area of expertise, country where they work professionally, years of professional experience in their fields, years of experience with Virtual Reality, and gender. The second part is dedicated to present the results of each of the seven stages (hereinafter also referred to as Phase/Cycles) of the proposed method, within which the thirty-one activities that the proposed method suggests are distributed. The third part is a discussion of the results obtained from the survey.

6.1 Description of the approach to final validation of the method

As explained briefly in the methodology chapter, the sample chosen for the validation of the method proposed by this thesis was not random. This sample was composed of professionals and academics with experience in the development of Virtual Reality projects. The participants of this validation phase were chosen by the researcher through the indication of their peers and through a careful selection of profiles on social networks such as LinkedIn and specialized discussion groups.

The first contact was made by email or through the social network LinkedIn. After a positive response, the respondent was invited to a virtual section where the researcher explained the context of the research and the objective of the evaluation, and the respondent filled out the form without any intervention or help from the researcher. At no time was the final method presented. This is due to the fact that the researcher had no intention of causing any form of influence on the responses. After completion, the researcher was available to answer additional questions. At this point the respondent was also asked to indicate someone with the mentioned characteristics who could participate in the model validation by answering the survey.

After selecting the profile of potential respondents, there was a preliminary analysis that determined which of them should be approached. The desired profiles for the respondents were professionals in the areas of User Experience and Interface Design (UX/UI), Software

Development, Education, Games and Industry 4.0, but other professionals could participate, provided they had experience in developing Virtual Reality experiences.

It was possible, at first, to raise 237 candidates who met the requirements. However, after a second analysis, only 169 profiles were selected and invited to answer the questionnaire, of which only 141 responded (83.432% response rate), which is much higher than the recommended minimum for exploratory surveys. According to Forza (2002), the minimum should be 50% response rate.

Once the data has been collected from the application of the survey to the selected sample and after its statistical treatment, it is possible to proceed to its organization, systematization, and analysis. To this end, it was decided to structure them in the same order they were presented in the questionnaire delivered to the respondents.

The demographic data (first part of the survey) are presented in absolute numbers (n), and always accompanied by percentages to facilitate understanding. In the case of the validation of the activities within each of the cycles, the data are presented here only in percentages. However, additional tables with the absolute number of votes for each activity can be found in APPENDIX F - Additional survey , as well as other tables with data generated from the answers obtained in the survey, and which will be addressed hereafter in a unitary way.

6.2 Characterization of the respondents

6.2.1 Distribution of respondents by area of expertise/industry

Table 26 presents the distribution of respondents by area of expertise/industry. The data are presented in order of relevance (quantity) of respondents in each of the areas of activity or industries represented.

Table 26 - Distribution of respondents by area of expertise/industry

Area of Expertise/Industry	Count (n)	% of total
Software Development	46	32.62%
UX/UI	41	29.08%
Education	34	24.11%
Games	11	7.80%

Area of Expertise/Industry	Count (n)	% of total
Industry 4.0	6	4.26%
Other	3	2.13%

The distribution of the 141 survey respondents by area of expertise/industry is characterized as follows: Software Development professionals (n=46 or 36.52%), UX/UI professionals (n=41 or 29.08%), Education professionals (n=34 or 24.11%), Games professionals (n=11 or 7.80%), Industry 4.0 professionals (n=6 or 4.26%), and other segments (n=3 or 2.13%).

6.2.2 Distribution of respondents by country

Table 27 presents the distribution of respondents by country. The data are presented in order of relevance (quantity) of respondents in each of the countries represented.

Table 27 - Distribution of respondents by country

Country	Count (n)	% of total
Austria	51	36.17%
Estonia	19	13.48%
United States	17	12.06%
Canada	11	7.80%
Mexico	10	7.09%
Brazil	9	6.38%
Australia	8	5.67%
United Kingdom	6	4.26%
Portugal	4	2.84%
France	3	2.13%
Germany	3	2.13%

The distribution of the 141 survey respondents by country in which they work professionally is characterized as follows: Austria, with 51 respondents or 36.17% of the total, Estonia with 19 respondents or 13.48% of the total, United States with 17 respondents or 12.06% of the total, Canada with 11 respondents or 7.80% of the total, Mexico with 10 respondents or 7.09% of the total, Brazil with 9 respondents or 6. 38% of the total, Australia with 8 respondents or 5.67% of the total, United Kingdom with 6 respondents or 4.26% of the total, Portugal with 4 respondents or 2.84% of the total, and France and Germany each with 3 respondents or 2.13% of the total per country.

6.2.3 Distribution of respondents by years of professional experience

Table 28 presents the distribution of respondents by years of professional experience. The data are presented in order of relevance (quantity) of respondents in each of the categories.

Table 28 - Distribution of respondents by years of professional experience

Years of Professional Experience	Count (n)	% of total
3 years	26	18.44%
6 years	20	14.18%
5 years	19	13.48%
8 years	15	10.64%
2 years	13	9.22%
4 years	13	9.22%
7 years	12	8.51%
10 or more years	11	7.8%
9 years	9	6.38%
1 year	3	2.13%

As for the distribution of the 141 respondents in terms of professional experience, most of the respondents (n=26 or 18.44%) stated that they had 3 years of professional experience in their field or industry. In second place, the survey had professionals who stated they had 6 years of professional experience (n=20 or 14.18%), followed by professionals with 5 years of experience (n=19 or 13.48%), and professionals with 8 years of experience (n=15 or 10.64%). The survey was also answered by professionals who stated they had 2 years of professional experience (n=13 or 9.22%), 4 years of professional experience (n=13 or 9.22%), 7 years of professional experience (n=12 or 8.51%), 10 or more years (n=11 or 7.8%), 9 years (n=9 or 6.38%), and professionals who stated they had 1 year of professional experience (n=3 or 2.13%).

6.2.4 Distribution of respondents by years of experience with Virtual Reality

Table 29 presents the distribution of respondents by years of experience with Virtual Reality. The data are presented in order of relevance (quantity) of respondents in each of the categories.

Table 29 - Distribution of respondents by years of experience with Virtual Reality

Years of Experience with Virtual Reality	Count (n)	% of total
Between 3 and 5 years	41	29.08%
Between 1 and 3 years	33	23.4%
At least 1 year	29	20.57%
More than 5 years	25	17.73%
Less than 1 year	13	9.22%

One of the initial questions of the survey aimed to determine the level of experience with Virtual Reality of the respondents. Most of the 141 professionals who answered the survey said they had between 3 and 5 years of experience with VR (n=41 or 29.08% of the total), followed by professionals who said they had between 1 and 3 years of experience (n=33 or 23.4% of the total). Professionals who said they had at least 1 year (n=29 or 20.57% of the total) were followed by professionals who said they had more than 5 years of VR experience (n=25 or 17.73%). Finally, the survey included professionals who claimed to have less than 1 year of experience with VR projects (n=13 or 9.22%).

6.2.5 Distribution of respondents by gender

Table 30 presents the distribution of respondents by gender. The data are presented in order of relevance (quantity) of respondents in each of the categories.

Table 30 - Distribution of respondents by gender

Gender	Count (n)	% of total
Male	128	90.78%

Gender	Count (n)	% of total
Female	13	9.22%

Most of the professionals and academics who responded to the survey are male (n=128 or 90.78% of the total respondents), while women represented only 9.22% of the total (n=13).

6.3 Results and discussion of the validation of the proposed method activities

After characterizing the respondents, it is presented in the following each of the activities divided into phase/cycles of the proposed method. In the first part, an overview of all thirty-one activities of the proposed method is presented. For this first part, it was decided to present a heat map as a way of providing a general reading of all the answers, as well as a table containing the number of votes for each of the activities in each of the items of the relevance scale. Then each of the thirty-one activities from each of the seven cycles will be presented, and a brief discussion of the results is offered immediately afterwards.

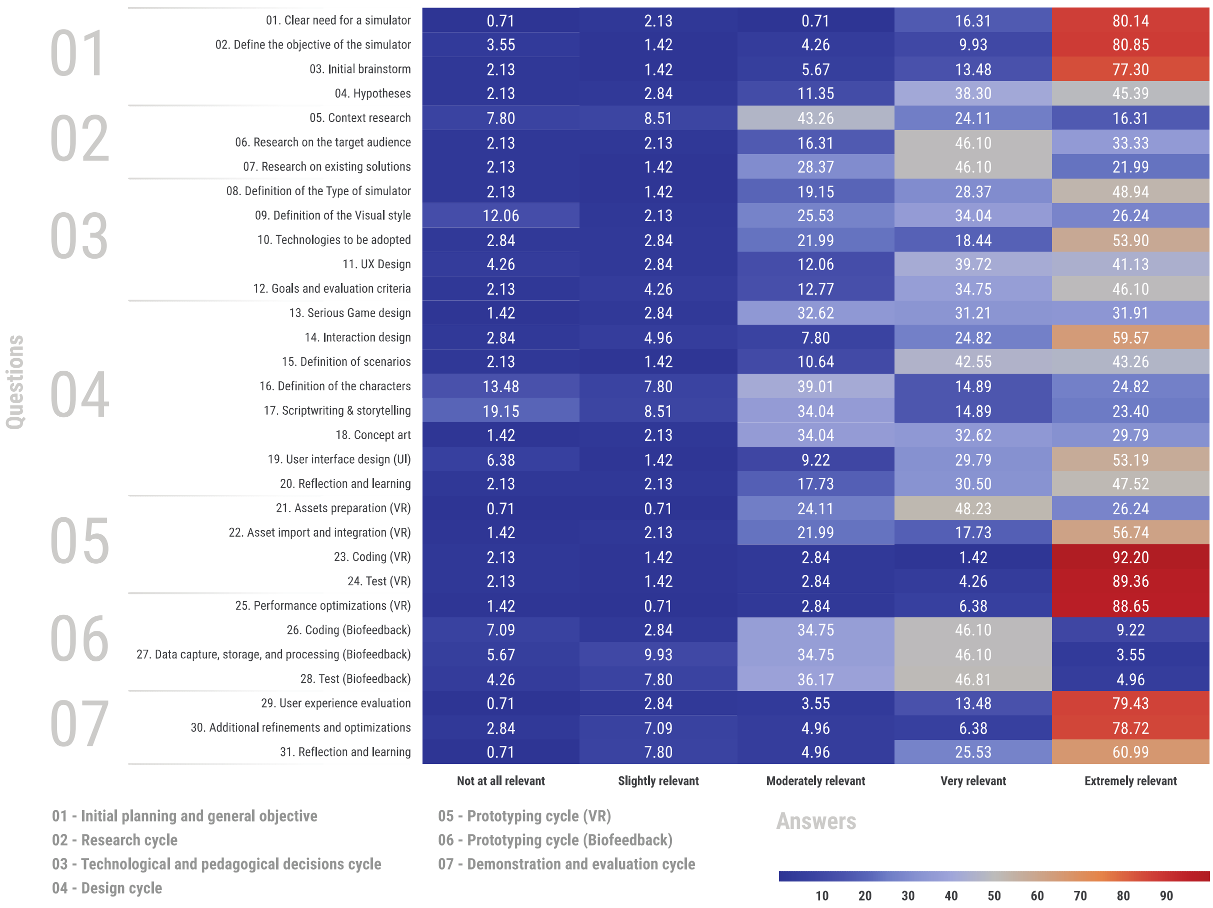
As a way of making the presentation a little more dynamic, the questions will be presented in the same order they appear in the survey and following the same grouping by phase/cycle presented to the respondents.

An important observation regarding the questionnaire applied to the respondents refers to the open question asked at the end of each block of questions that evaluated the activities of each phase/cycle. In the vast majority of responses there was no contribution from the respondents about additions. Therefore, it was decided to ignore the few responses coming from the open questions and use only the responses given to the relevance scale. This choice has a methodological character of rigor and standardization, and in no way alters the relevance or value of the answers obtained, which will be exposed in the following. As previously mentioned, the complete questionnaire applied in this phase of the research can be found at APPENDIX A - Survey used to evaluate the proposed method.

6.3.1 Overview of the validation of all activities in the proposed method

Figure 42 presents the 141 respondents' answers for all activities of the proposed method in the form of a heatmap. The color variation is due to the total number of answers that each of the respondents gave for each of the thirty-one activities, and the level of relevance is given in percentages in order to facilitate reading. In addition, the mean and standard deviation for each of the thirty-one survey questions is presented in this figure.

Figure 42 - Heatmap of the validation of all activities of the proposed method



The values within each of the cells are indicated in this heatmap chart as percentages, and the colors indicate the frequency of answers on each of the variables ranging from "Not at all relevant" to "Extremely relevant". It is possible to note that, in general, the respondents have attributed a high level of relevance (Extremely Relevant) to most of the activities. However, it is important to note that there was no consensus in all items, and none of them reached a mark higher than 92.20%. It is noticeable that some specific activities were considered not at all relevant by a significant number of people, even though most respondents decided otherwise.

To facilitate the understanding of the tables that will be presented in the following, and aiming at a better understanding of the overall result of the validation, Table 31 presents the number of votes for each of the activities in each of the cycles of the proposed method.

Table 31 - Absolute number of votes for each of the activities in terms of relevance

Phase/Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
01 - Initial planning and general objective	01. Clear need for a simulator	1	3	1	23	113
	02. Define the objective of the simulator	5	2	6	14	114
	03. Initial brainstorm	3	2	8	19	109
	04. Hypotheses	3	4	16	54	64
02 - Research cycle	05. Context research	11	12	61	34	23
	06. Research on the target audience	3	3	23	65	47
	07. Research on existing solutions	3	2	40	65	31
03 - Technological and pedagogical decisions cycle	08. Definition of the Type of simulator	3	2	27	40	69
	09. Definition of the Visual style	17	3	36	48	37
	10. Technologies to be adopted	4	4	31	26	76
	11. UX Design	6	4	17	56	58
	12. Goals and evaluation criteria	3	6	18	49	65
04 - Design cycle	13. Serious Game design	2	4	46	44	45
	14. Interaction design	4	7	11	35	84
	15. Definition of scenarios	3	2	15	60	61
	16. Definition of the characters	19	11	55	21	35
	17. Scriptwriting & storytelling	27	12	48	21	33
	18. Concept art	2	3	48	46	42
	19. User interface design (UI)	9	2	13	42	75
	20. Reflection and learning	3	3	25	43	67
05 - Prototyping cycle (VR)	21. Assets preparation (VR)	1	1	34	68	37
	22. Asset import and integration (VR)	2	3	31	25	80
	23. Coding (VR)	3	2	4	2	130
	24. Test (VR)	3	2	4	6	126
	25. Performance optimizations (VR)	2	1	4	9	125
06 - Prototyping cycle (Biofeedback)	26. Coding (Biofeedback)	10	4	49	65	13
	27. Data capture, storage, and processing (Biofeedback)	8	14	49	65	5
	28. Test (Biofeedback)	6	11	51	66	7
07 - Demonstration and evaluation cycle	29. User experience evaluation	1	4	5	19	112
	30. Additional refinements and optimizations	4	10	7	9	111

Phase/Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
	31. Reflection and learning	1	11	7	36	86

The results of the survey are presented as follows with the questions grouped by phase/cycle. Immediately following the presentation of the results is a discussion of each of the activities within each of the cycles is provided.

6.3.2 Initial planning and general objective

In this phase of the method proposed by this research there are actions such as defining the simulator's objectives, brainstorming, and raising initial hypotheses. Table 32 presents the validation results for each of the activities within this phase.

Table 32 - Validation of the phase "Initial planning and general objective"

Phase	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
01 - Initial planning and general objective	01. Clear need for a simulator	0.71%	2.13%	0.71%	16.31%	80.14%	1.74	1.52
	02. Define the objective of the simulator	3.55%	1.42%	4.26%	9.93%	80.85%	1.55	1.27
	03. Initial brainstorm	2.13%	1.42%	5.67%	13.48%	77.30%	1.68	1.41
	04. Hypotheses	2.13%	2.84%	11.35%	38.30%	45.39%	2.77	1.86

The first activity in this phase called "Clear need for a simulator" had most of the respondents defining it as "Extremely relevant", with 80.14% (n=113) of the total votes. The same activity had 16.31% (n=23) of "Very relevant". The second activity in this phase is called "Define the objective of the simulator" and was defined as "Extremely relevant" by 80.85% (n=114) of the respondents and "Very relevant" by 9.93% (n=14) of the respondents. The third activity entitled "Initial brainstorm" had relevance indicated as "Extremely relevant" by 77.30% (n=109) of respondents and "Very relevant" by 13.48% (n=19) of respondents. The fourth and final activity in this phase is entitled "Hypotheses" and was defined as "Extremely relevant" by 45.39% (n=64) of the total votes and "Very relevant" by 38.30% (n=54) of the respondents.

6.3.3 Research cycle

The research cycle gathers activities such as context research (to better understand the corporation), research about the target audience (to better understand the user), and analysis about existing solutions (to know about possible solutions already developed). Table 33 presents the validation results for each of the activities within this cycle.

Table 33 - Validation of the cycle "Research"

Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
02 - Research cycle	05. Context research	7.80%	8.51%	43.26%	24.11%	16.31%	2.81	1.45
	06. Research on the target audience	2.13%	2.13%	16.31%	46.10%	33.33%	3.11	1.84
	07. Research on existing solutions	2.13%	1.42%	28.37%	46.10%	21.99%	3.21	1.73

The first activity in this cycle is called "Context research" and had most of the respondents defining it as "Moderately relevant", with 43.26% (n=61) of the total votes. The same activity had 24.11% (n=34) of the votes as "Very relevant". The second activity in this cycle is called "Research on the target audience" and was defined as "Very relevant" by 46.10% (n=65) of the respondents and "Extremely relevant" by 33.33% (n=47) of the respondents. The third activity entitled "Research on existing solutions" had relevance indicated as "Very relevant" by 46.10% (n=65) of the respondents and "Moderately relevant" by 28.37% (n=40) of the respondents.

6.3.4 Technological and pedagogical decisions cycle

In this cycle, some decisions are likely to affect various aspects of the simulator, including the level of immersion, visual style (which impacts the decision for the type of technologies to be adopted). In addition, this cycle aims to establish the pedagogical criteria and objectives to be evaluated. Table 34 presents the validation results for each of the activities within this cycle.

Table 34 - Validation of the cycle "Technological and pedagogical decisions"

Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
03 - Technological and pedagogical decisions cycle	08. Definition of the Type of simulator	2.13%	1.42%	19.15%	28.37%	48.94%	2.41	1.72
	09. Definition of the Visual style	12.06%	2.13%	25.53%	34.04%	26.24%	2.92	1.64
	10. Technologies to be adopted	2.84%	2.84%	21.99%	18.44%	53.90%	2.1	1.53
	11. UX Design	4.26%	2.84%	12.06%	39.72%	41.13%	2.88	1.84
	12. Goals and evaluation criteria	2.13%	4.26%	12.77%	34.75%	46.10%	2.69	1.82

The first activity in this cycle is called "Definition of the Type of simulator" and had most respondents defining it as "Extremely relevant", with 48.94% (n=69) of the total votes. The same activity had 28.37% (n=40) of the votes as "Very relevant". The second activity in this cycle is called "Definition of the Visual style" and was defined as "Very relevant" by 34.04% (n=48) of the respondents and "Extremely relevant" by 26.24% (n=37) of the respondents. The third activity entitled "Technologies to be adopted" had relevance indicated as "Extremely relevant" by 53.90% (n=76) of the respondents and "Moderately relevant" by 21.99% (n=31) of the respondents. The fourth activity in this cycle is titled "UX Design" and was defined as "Extremely relevant" by 41.13% (n=58) of the total votes and "Very relevant" by 39.72% (n=56) of the respondents. The fifth activity in this cycle, called "Goals and evaluation criteria", was defined as "Extremely relevant" by 46.10% (n=65) of the total votes and "Very relevant" by 34.75% (n=49) of the respondents.

6.3.5 Design cycle

The design cycle has the largest number of activities. In this cycle, the fundamental concepts of the simulator are developed and refined. These include elements of serious games, the user experience, interaction design, and the aesthetic and narrative aspects of the simulator, ranging from the characters and scenarios to the interface. Table 35 presents the validation results for each of the activities within this cycle.

Table 35 - Validation of the cycle "Design"

Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
04 - Design cycle	13. Serious Game design	1.42%	2.84%	32.62%	31.21%	31.91%	2.69	1.67
	14. Interaction design	2.84%	4.96%	7.80%	24.82%	59.57%	2.28	1.73
	15. Definition of scenarios	2.13%	1.42%	10.64%	42.55%	43.26%	2.89	1.89
	16. Definition of the characters	13.48%	7.80%	39.01%	14.89%	24.82%	2.49	1.34
	17. Scriptwriting & storytelling	19.15%	8.51%	34.04%	14.89%	23.40%	2.57	1.34
	18. Concept art	1.42%	2.13%	34.04%	32.62%	29.79%	2.74	1.68
	19. User interface design (UI)	6.38%	1.42%	9.22%	29.79%	53.19%	2.45	1.77
	20. Reflection and learning	2.13%	2.13%	17.73%	30.50%	47.52%	2.5	1.76

The first activity in this cycle is called "Serious Game design" and had most of the respondents defining it as "Moderately relevant", with 32.62% (n=46) of the total votes. The same activity had 31.91% (n=45) of the votes as "Extremely relevant". The second activity in this cycle is called "Interaction design" and was defined as "Extremely relevant" by 59.57% (n=84) of the respondents and "Very relevant" by 24.82% (n=35) of the respondents. The third activity entitled "Definition of scenarios" had relevance indicated as "Extremely relevant" by 43.26% (n=61) of the respondents and "Very relevant" by 42.55% (n=60) of the respondents. The fourth activity entitled "Definition of the characters" had relevance indicated as "Moderately relevant" by 39.01% (n=55) of the respondents and "Extremely Very relevant" by 24.82% (n=35) of the respondents.

The fifth activity entitled "Scriptwriting & storytelling" had relevance indicated as "Moderately relevant" by 34.04% (n=48) of respondents and "Very relevant" by 23.40% (n=33) of respondents. The sixth activity entitled "Concept art" had relevance indicated as "Moderately relevant" by 34.04% (n=48) of the respondents and "Very relevant" by 32.62% (n=46) of the respondents. The seventh activity entitled "User interface design (UI)" had relevance indicated as "Extremely relevant" by 53.19% (n=75) of the respondents and "Very relevant" by 29.79% (n=42) of the respondents. The eighth and final activity in this cycle is titled "Reflection and learning" and had an indication of relevance as "Extremely relevant" by 47.52% (n=67) of the respondents and "Very relevant" by 30.50% (n=43) of the respondents.

6.3.6 Prototyping cycle (VR)

In the VR prototyping cycle, there are tasks such as creating and importing the assets that will be used to build the simulator and fundamental activities such as coding, testing and optimization. Table 36 presents the validation results for each of the activities within this cycle.

Table 36 - Validation of the cycle "Prototyping (VR)"

Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
05 - Prototyping cycle (VR)	21. Assets preparation (VR)	0.71%	0.71%	24.11%	48.23%	26.24%	3.21	1.79
	22. Asset import and integration (VR)	1.42%	2.13%	21.99%	17.73%	56.74%	2.02	1.51
	23. Coding (VR)	2.13%	1.42%	2.84%	1.42%	92.20%	1.17	0.67
	24. Test (VR)	2.13%	1.42%	2.84%	4.26%	89.36%	1.28	0.92
	25. Performance optimizations (VR)	1.42%	0.71%	2.84%	6.38%	88.65%	1.33	1.03

The first activity in this cycle is called "Assets preparation (VR)" and was defined as "Very relevant" by 48.23% (n=68) of the respondents. The same activity had 26.24% (n=37) of votes as "Extremely relevant". The second activity in this cycle is called "Asset import and integration (VR)" and was defined as "Extremely relevant" by 56.74% (n=80) of the respondents and "Moderately relevant" by 21.99% (n=31) of the respondents. The third activity entitled "Coding (VR)" had relevance indicated as "Extremely relevant" by 92.20% (n=130) of respondents and "Moderately relevant" by 2.84% (n=4) of respondents. The fourth activity of this cycle is titled "Test (VR)" and was defined as "Extremely relevant" by 89.36% (n=126) of the total votes and "Very relevant" by 4.26% (n=6) of the respondents. The fifth and last activity of this cycle, called "Performance optimizations (VR)", was defined as "Extremely relevant" by 88.65% (n=125) of the total votes and "Very relevant" by 6.38% (n=9) of the respondents.

6.3.7 Prototyping cycle (Biofeedback)

In the Biofeedback prototyping cycle, there are activities related to the development or configuration of the system that will be used to capture vital data during simulation. Table 37 presents the validation results for each of the activities within this cycle.

Table 37 - Validation of the cycle "Prototyping (Biofeedback)"

Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
06 - Prototyping cycle (Biofeedback)	26. Coding (Biofeedback)	7.09%	2.84%	34.75%	46.10%	9.22%	3.42	1.56
	27. Data capture, storage, and processing (Biofeedback)	5.67%	9.93%	34.75%	46.10%	3.55%	3.6	1.44
	28. Test (Biofeedback)	4.26%	7.80%	36.17%	46.81%	4.96%	3.55	1.49

The first task in this cycle is called "Coding (Biofeedback)" and had most respondents defining it as "Very relevant", with 46.10% (n=65) of the total votes. The same activity had 34.75% (n=49) of the votes as "Moderately relevant". The second activity in this cycle is called "Data capture, storage, and processing (Biofeedback)" and was defined as "Very relevant" by 46.10% (n=65) of the respondents and "Moderately relevant" by 34.75% (n=49) of the respondents. The third and final activity entitled "Test (Biofeedback)" had relevance indicated as "Extremely relevant" by 46.81% (n=66) of respondents and "Moderately relevant" by 36.17% (n=51) of respondents.

6.3.8 Demonstration and evaluation cycle

The demonstration and evaluation cycle is a key step and has activities such as user experience testing and possible refinements and improvements of the simulator. In addition, this cycle has an earlier phase before publication called reflection and learning. Table 38 presents the validation results for each of the activities within this cycle.

Table 38 - Validation of the cycle "Demonstration and evaluation"

Phase/Cycle	Activity/Task	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant	Mean	SD
07 - Demonstration and evaluation cycle	29. User experience evaluation	0.71%	2.84%	3.55%	13.48%	79.43%	1.67	1.43
	30. Additional refinements and optimizations	2.84%	7.09%	4.96%	6.38%	78.72%	1.57	1.23
	31. Reflection and learning	0.71%	7.80%	4.96%	25.53%	60.99%	2.32	1.77

The first task in this cycle is called "User experience evaluation" and had most of the respondents defining it as "Extremely relevant", with 79.43% (n=112) of the total votes and 13.48% (n=19) of the votes as "Very relevant". The second activity in this cycle is called "Additional refinements and optimizations" and was defined as "Extremely relevant" by 78.72% (n=111) of the respondents and "Slightly relevant" by 7.09% (n=10) of the respondents. The third and final activity titled "Reflection and learning" had relevance indicated as "Extremely relevant" by 60.99% (n=86) of respondents and "Very relevant" by 25.53% (n=36) of respondents.

6.4 Discussion of the results

Some interesting conclusions can be drawn from the results of the survey, which served not only to validate the proposed method as a whole, but also characteristics and aspects that make this method unique. Three of these characteristics concern aspects involving Serious Games, Biofeedback and User Experience, which, by the way, are part of the theoretical pillars of this thesis, which besides the three already mentioned, also counts on the Virtual Reality technology.

It is possible to notice that, in general, the respondents attributed a high level of relevance ("Very Relevant" or "Extremely Relevant") to most of the activities. However, it is important to note that there was not absolute consensus on all items, and none of them reached a mark higher than 92.20%. This means that analyzing the answers and trying to understand the context of some of them may provide some grounds for improving the method or even identify the points where it was not well evaluated, which will be done in the following, in the order they were presented in the previous topic, and divided by Phase/Cycle.

The first set of activities concerns the *Initial planning and general objective phase*. If the percentages of answers for "Very relevant" and "Extremely relevant" for each of the first three activities (*Clear need for a simulator*, *Define the objective of the simulator*, and *Initial brainstorm*) are added together, the results are over 90%. This indicates that the respondents considered these activities to be of an extremely high degree of relevance. However, the fourth activity of this phase, entitled *Hypotheses* obtained only 83.69% of total relevance if the percentages of answers for "Very relevant" and "Extremely relevant" are added, which indicates that the respondents attributed to this activity a lower degree of relevance compared to the first three activities of the phase. Nonetheless, it should be considered that a level of relevance above 70% should not be considered negligible.

A Design Hypothesis, is basically an assumption or conjecture, something that someone believes to be true. Hypotheses help to prove or disprove assumptions, which in turn are proved or disproved using research and experiments (KROGH; KOSKINEN, 2020). Each hypothesis that is tested has the potential to generate new knowledge for future rounds of product or idea development. Therefore, the use of hypotheses and their construction based on research and evidence is fundamental to any user-centered design.

A possible explanation for a lower score for the *Hypotheses* activity is most likely due to the background of some of the respondents. Perhaps some of the professionals who answered the survey did not have experience with hypothesis building as a common activity in the projects in which they participated. However, professionals from the Education and UX/UI fields certainly do. Professionals who claimed to be from the Education area corresponded to 24.11% of the respondents (n=34). Professionals who declared to be from the UX/UI area corresponded to 29.08% of the respondents (n=41). As a way to better understand the response behavior of each of the professional groups, Table 39 presents the number of votes for each level of relevance divided by Area of Expertise.

Table 39 - Answers by Area of Expertise for the "Hypotheses" activity

Area of Expertise	04. Hypotheses	Total
Education	Extremely relevant	21
	Moderately relevant	2
	Slightly relevant	1
	Very relevant	10
Games	Extremely relevant	8
	Moderately relevant	1
	Very relevant	2
Industry 4.0	Moderately relevant	1
	Not at all relevant	1
	Slightly relevant	2
	Very relevant	2
Other	Not at all relevant	1
	Slightly relevant	1
	Very relevant	1

Area of Expertise	04. Hypotheses	Total
Software Development	Extremely relevant	17
	Moderately relevant	7
	Very relevant	22
UX/UI	Extremely relevant	18
	Moderately relevant	5
	Not at all relevant	1
	Very relevant	17

The table presents only the relevance scale values for each activity that received at least one vote. By analyzing the table, it is possible to notice that among the areas of professional activity where there was an incidence of at least one classification as "Not at all relevant" is the area of UX/UI. This is an interesting fact and shows that, even in areas where most professionals recognize the importance of certain practices, there are exceptions, but it doesn't necessarily mean that this is something negative. By observing the number of total classifications as "Extremely relevant" it is clear that the areas of Education and UX/UI recognize and evaluate the practice of hypothesis raising as something extremely relevant.

Still, although it was not defined as an activity of very high relevance (given by the sum of "Very relevant" and "Extremely relevant" above 90%), it ended up being classified as very relevant by scoring more than 80%. This means that most respondents consider hypothesis raising an important activity for the development of user-centered projects.

There are some peculiarities regarding the *Research Cycle*, starting with the *Context research* activity, which was considered "Moderately relevant" by 43.26% (n=61) of the participants. Context Research is a common activity when it comes to User Experience, and the explanation for its existence is simple: asking what people do or how they do something is not always the best way to understand how, in fact, they do it. Many people are unable to verbalize or explain certain tasks explicitly, and there are several explanations for this limitation. To name just one: tacit knowledge. The knowledge that a particular person has about a specific activity is not always something that can be found in books, guides, procedure manuals, or any other type of document (POLANYI, 1966). Often this knowledge resides within the person and comes from personal experience, professional experiences, and even personal beliefs and positions (NONAKA, 1994).

Therefore, analyzing the environment where these people perform their activities is common when researching users and their behaviors, since the context affects a user's behavior

(STULL, 2018). However, the activity of observing the environment in which the user performs his or her activities is not unique to the User Experience area. There is a scientific methodology known as Action Research (COUGHLAN; COGHLAN, 2002) in which the observation of the subject in his or her environment is not only a common practice, but also mandatory. Thus, *Contextual Research* is of utmost importance to better understand not only the user, but the context in which this user performs his activities.

This leads us to the next evaluated activity called *Research on the target audience*, which was considered by 46.10% (n=65) of the respondents as "Very relevant" and by 33.33% (n=47) of the respondents as "Extremely relevant". When both percentages are added together, we get 79.43%, which is almost double if compared to the score of the previous activity. One can see that the respondents consider the user research much more relevant than the research of the context in which this user is inserted. However, although the combination of both is not absolutely mandatory, it is common that both are carried out as part of the efforts to try to better understand the user and his activity context (STULL, 2018). Also in the *Research Cycle*, the activity titled *Research on existing solutions* got 68.09% when adding the percentages of votes for "Very relevant" and "Extremely relevant", which denotes that research on existing solutions, although important, was not considered crucial. While it seems logical to look into possible solutions that already exist, this is not a determining factor, which perhaps explains the ranking.

Table 40 presents the absolute count of relevance ratings for the *Research on existing solutions* activity, and helps to give a dimension of its relevance based on the responses obtained from the survey and broken down by area of expertise.

Table 40 - Answers by Area of Expertise for the "Research on existing solutions" activity

Area of Expertise	07. Research on existing solutions	Total
Education	Extremely relevant	9
	Very relevant	11
Games	Extremely relevant	1
	Very relevant	4
Industry 4.0	Extremely relevant	3
	Very relevant	1
Other	Very relevant	3
Software Development	Extremely relevant	10
	Very relevant	25
UX/UI	Extremely relevant	8

Area of Expertise	07. Research on existing solutions	Total
	Very relevant	21

The table presents only the relevance scale values for each activity that received at least one vote. It can be seen that professionals from all areas considered the activity highly relevant. However, Software Development, UX/UI and Education professionals were the ones that most defined this activity as "Extremely relevant" in absolute numbers.

Next come the activities that are part of the *Technological and pedagogical decisions cycle*. In general, all activities had many "Very relevant" and "Extremely relevant" ratings, and almost all activities of this cycle had an absolute majority for "Extremely relevant", which gives an idea of the importance of these activities. The sums of the percentages of ratings for "Very relevant" and "Extremely relevant" for each of the activities were: *Definition of the Type of simulator* (77,31%), *Technologies to be adopted* (72,34%), *UX Design* (80,85%) and *Goals and evaluation criteria* (80,85%).

However, one of them draws attention for not getting the same number of votes as the others: *Definition of the visual style*. Despite the fact that 34.04% (n=48) of the respondents defined it as "Very relevant" and 26,24% (n=37) of the respondents defined it as "Extremely relevant", the same activity was defined as "Not at all relevant" by 12.06% (n=17) of the respondents. If observed alone, this does not seem like a large number, but if we add this percentage to the votes of those who considered it "Slightly relevant" 2.13% (n=3) and "Moderately relevant" 25.53% (n=36), it is not something to be neglected. The sum of the percentages of ratings for “Very relevant” and “Extremely relevant” resulted in only 60.28%.

Table 41 presents the number of relevance ratings for the activity Definition of the visual style by professional practice area.

Table 41 - Answers by Area of Expertise for the "Definition of the visual style" activity

Area of Expertise	09. Definition of the visual style	Total
Education	Extremely relevant	8
	Moderately relevant	8
	Not at all relevant	4
	Slightly relevant	1
	Very relevant	13
Games	Moderately relevant	2

Area of Expertise	09. Definition of the visual style	Total
	Not at all relevant	1
	Very relevant	8
Industry 4.0	Moderately relevant	1
	Not at all relevant	1
	Slightly relevant	1
	Very relevant	3
Other	Moderately relevant	2
	Very relevant	1
Software Development	Extremely relevant	15
	Moderately relevant	9
	Not at all relevant	5
	Slightly relevant	1
	Very relevant	16
UX/UI	Extremely relevant	14
	Moderately relevant	14
	Not at all relevant	6
	Very relevant	7

The table presents only the relevance scale values for each activity that received at least one vote. It can be seen that this is one of the activities where there was less consensus on the level of relevance, which is denoted by the distribution of votes in multiple levels of relevance and by professionals from all areas who responded to the survey.

Although it may seem like a purely aesthetic decision, the implications of this decision affect other decisions, such as determining the technologies that should be adopted, which, by the way, is the subsequent task. A highly realistic simulator, for example, demands more robust hardware than a merely stylized or simplistic application. Therefore, the choice of visual style, while not considered as relevant, can have a significant impact on other decisions.

The next two activities, entitled *UX Design* and *Goals and evaluation criteria* had similar behavior. When adding up the percentages for "Very relevant" and "Extremely relevant" in both activities, both had exactly the same value of 80.85%. The individual scores for each vary a bit, but in the end, both were considered very relevant activities. In both cases, the majority of the respondents considered both tasks to be "Extremely relevant". In the activity entitled *UX Design* several activities related to User Experience can be performed, which explains the high relevance score indicated by respondents and confirms what the theoretical framework of this thesis supports (STULL, 2018; ISO, 2019). The activity named *Goals and evaluation criteria* meets a problem pointed out in the literature regarding several simulators applied to professional training (DE ARMAS; TORI; NETTO, 2020; ZIEGLER et al., 2020), and the high relevance score pointed out by the respondents corroborates its importance for the simulator construction context.

The next cycle, the largest in number of activities, called the *Design Cycle*, also presented some interesting findings when the responses of the survey were analyzed for each of the activities in the cycle. Starting with the activity called *Serious Game design*, which ironically resulted in a total of 63.12% when adding up the percentages of answers for "Very relevant" and "Extremely relevant". However, it is interesting to note that the respondents' scores were mostly dispersed between the "Moderately relevant" with 32.62% (n=46), "Very relevant" with 31.21% (n=44) and "Extremely relevant" with 31.91% (n=45) levels of relevance.

This indicates that there was no consensus on the level of relevance, but certainly on the fact that it is relevant. Considering the importance that Serious Games have for the context of this research, one can offer two possibilities for the dispersion of scores among the three highest levels of relevance. The first is that perhaps, given the heterogeneity of the groups of professionals who participated in this validation, a considerable part of the professionals were not able to understand or envision the application of Serious Games for the context proposed by this research. The second possibility is that most of the respondents considered that Serious Games are not essential to a simulator. It is also perfectly plausible to hypothesize that a mixture of the two factors has occurred in the case of this particular activity.

In fact, the application of Serious Games principles or mechanics is not necessarily essential to the method, but its use, as already explored at various points in the thesis, was intended to increase engagement and make the experience more meaningful for the trainee. Furthermore, its application is advocated by several incidences of success in the literature that supports this thesis (CAI; VAN JOOLINGEN; WALKER, 2019; CHECA; BUSTILLO, 2020; HALLINGER; WANG, 2020; LARSON, 2020; MARTINEZ; MENÉNDEZ-MENÉNDEZ; BUSTILLO, 2020).

At the same time, the *Interaction design*, *Definition of scenarios* and *User interface design (UI)* tasks had very similar summed upper extremity scores and always above 80%, although the dispersion behavior of the scores is absolutely different. In the case of the *Interaction design* activity, 59.57% (n=84) stated that the activity is "Extremely relevant". In the case of the *Definition of scenarios* activity, there were almost the same amount of votes for "Very relevant" with 42.55% (n=60) and "Extremely relevant" with 43.26% (n=61). Regarding the *User interface design (UI)* activity 53.19% of the respondents (n=75) defined it as "Extremely relevant".

Meanwhile, the activities *Definition of the characters, Scriptwriting & storytelling* and *Concept art* had similar performance: most respondents considered them "Moderately relevant" tending to higher degrees of relevance. The fact is that these specific tasks, which are activities directly related to content production, were considered less relevant, but not irrelevant, by a large majority of the respondents. The importance is denoted by the fact that none of them obtained a higher number of negative relevance compared to the amount of positive relevance.

However, it is worth reinforcing the importance of some of these concepts for the nature of the simulator proposed by this thesis, such as narrative and storytelling. It enables the understanding of complex concepts through examples that people can relate to (ALDAMA, 2015; HOKANSON; CLINTON; KAMINSKI, 2018). In addition, as mentioned earlier, there is the effect known as "suspension of disbelief", which consists of a semi-conscious decision in which the audience momentarily sets aside their disbelief and accepts the premise as real for the duration of the experience (HOLLAND, 2003).

Finally, the *Reflection and learning* activity was considered "Extremely relevant" by 47.52% (n=67) of the respondents. The sum of the relevance values at the positive extreme results in 78.02%, which indicates a considerable level of relevance. The activity has to do with knowledge management practices and even serves as a turning point, in case it is needed, besides being a practice foreseen by Agile methods (ANDRIYANI; HODA; AMOR, 2017).

The next cycle evaluated was *Prototyping (VR)*, and starts with the activities *Assets preparation (VR)* and *Asset import and integration (VR)*. The sum of the relevance values at the positive extreme, in the case of both, in the same value: 74.47%. The only difference between both is that *Assets preparation (VR)* had most of the respondents classifying it as "Very relevant" 48.23% (n=68), while *Asset import and integration (VR)* was defined by most of the respondents as "Extremely relevant" (n=80). This indicates that, according to the survey results, import and integration is considered more relevant than production, but neither production nor import and integration of assets is irrelevant.

This dichotomous view between the role of both in the context of this research should obviously not exist, but the difference in gradation in both may be the result of lack of sufficient exposure to what the activity or process meant. The dilemma lies in the fact that providing more information or exaggerating the amount of information given could cause detrimental effects ranging from resistance to complete the survey (because it is exhausting) to even the implicit cognitive bias in filling in influenced by an explanation given by the researcher, even if such an effect was unintentional.

Also in the *Prototyping Cycle*, the activities *Coding (VR)* – (92,20% of “Extremely relevant”), *Test (VR)* - (89,36% of “Extremely relevant”) and *Performance optimizations (VR)* - (88,65% of “Extremely relevant”), obtained the highest number of evaluations as "Extremely relevant", which confirms their very high relevance. It is not surprising that almost all respondents attributed maximum relevance to activities without which it is simply impossible to develop any kind of application.

On the other hand, in the *Prototyping Cycle (Biofeedback)* all suggested activities got the lowest number of ratings as "Extremely relevant". *Coding (Biofeedback)* scored 9,22% of "Extremely relevant", *Data capture, storage, and processing (Biofeedback)* got 3,55% of "Extremely relevant", and *Test (Biofeedback)* got 4,96% of "Extremely relevant". However, these activities were not necessarily further classified as "Not at all relevant" or "Slightly relevant", which may indicate that, according to the respondents, these activities have some level of relevance, but not so irrelevant or slightly relevant. However, there is the question of the relevance of the principle for the purposes of the research.

This case is very similar to the case of the activity related to Serious Games. It is possible to imagine that the main reason for the performance of all the activities in this cycle not getting the maximum score has something to do with the specificity of the theme and the heterogeneity of the group of respondents.

When considering that the group of respondents has individuals from many fields, and some of them do not necessarily deal with topics such as capturing or treating vital signs, it is to be expected that the subject itself will not be familiar to all participants. On the other hand, the fact that the evaluations of the relevance of the activity were not mostly negative ("Not at all relevant" or "Slightly relevant") reveals that, even though the subject of biofeedback may not be extremely widely known, it is expected that a considerable part of the respondents at least has a good idea of what the technique is. Especially considering the popularization of wearable devices such as smart watches that are capable of capturing and displaying vital signs in real time. (SIIRTOLA, 2019; DA-YIN LIAO, 2020; HAFIZ; BARDRAM, 2020)

Finally, the activities in the *Demonstration and evaluation cycle* were rated as "Extremely relevant" by an absolute majority of the respondents, which reveals not only their importance to the respondents, but also reinforces their importance to the proposed method. The activity *User experience evaluation* scored 79,43% of "Extremely relevant" and *Additional refinements and optimizations* got 78,72% of "Extremely relevant". A curiosity of this cycle is the presence of a second activity *Reflection and learning*, which in this specific case had a better performance (60.99% of "Extremely relevant") than the first activity *Reflection and learning* located in the *Design cycle* (47.52% of "Extremely relevant").

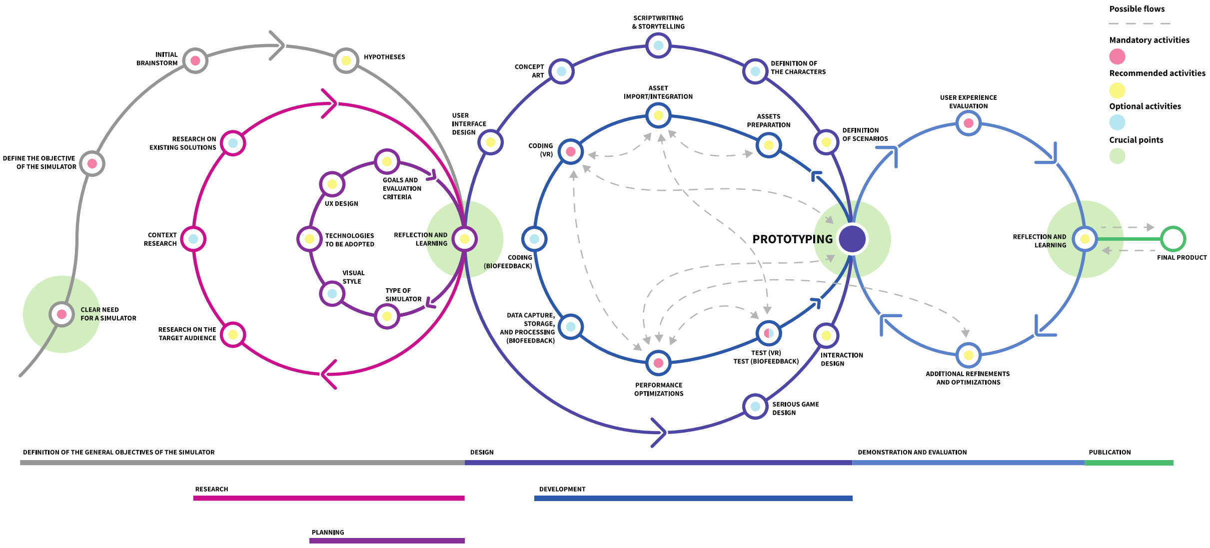
Among the possibilities to explain the difference between both activities, it is possible to highlight the specific moment in which it happens, or even the understanding of the intention of having a reflection and learning activity at the beginning or middle of the project and not at the end. Another possibility refers to the interpretation of what reflection and learning means to different professionals in different areas of knowledge, a discussion that obviously goes far beyond the scope and proposal of this thesis.

Considering the original intention of proposing a method that was centered on the user and his needs the activities related to User Experience had, in general, excellent evaluations. The same cannot be said for activities related to Serious Games and even Biofeedback. However, absolutely none of them performed so poorly or negatively as to indicate or suggest that they should be eliminated from the final version of the method. Thus, it is appropriate to present a final version of the method developed from the answers, reflections, and knowledge derived from the survey answered by 141 respondents from 11 countries and several fields of knowledge, which will be done in the following.

6.5 Final version of the proposed method - post validation

After validation of the third version of the method proposed by and after analyzing the survey responses, some changes were proposed in a fourth and final version of the method, shown in Figure 43. The changes are discussed in the following.

Figure 43 - Final version of the proposed method after validation and improvements

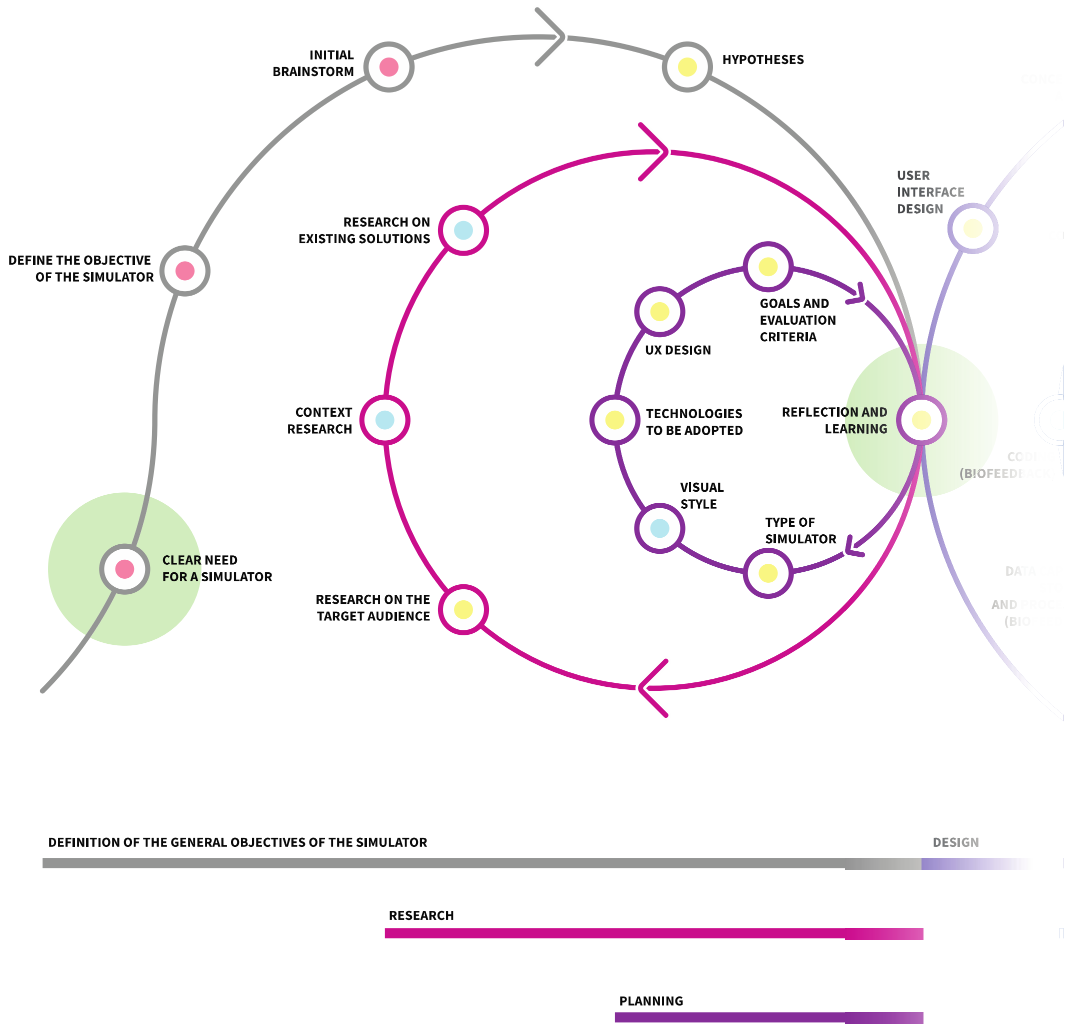


Source: Elaborated by the author.

A larger scale image of the third version of the method is presented in APPENDIX E - The final version of the proposed method. As a way of making this version of the method easier to read and visualize, the following are three images of each part of the method in a larger size.

Figure 44 shows the first part of the method, where it is possible to see the Phase/Cycle 1 - Definition of the general objectives of the simulator phase (4 activities), Phase/Cycle 2 - Research cycle (3 activities) and the Phase/Cycle 3 - Planning cycle (5 activities).

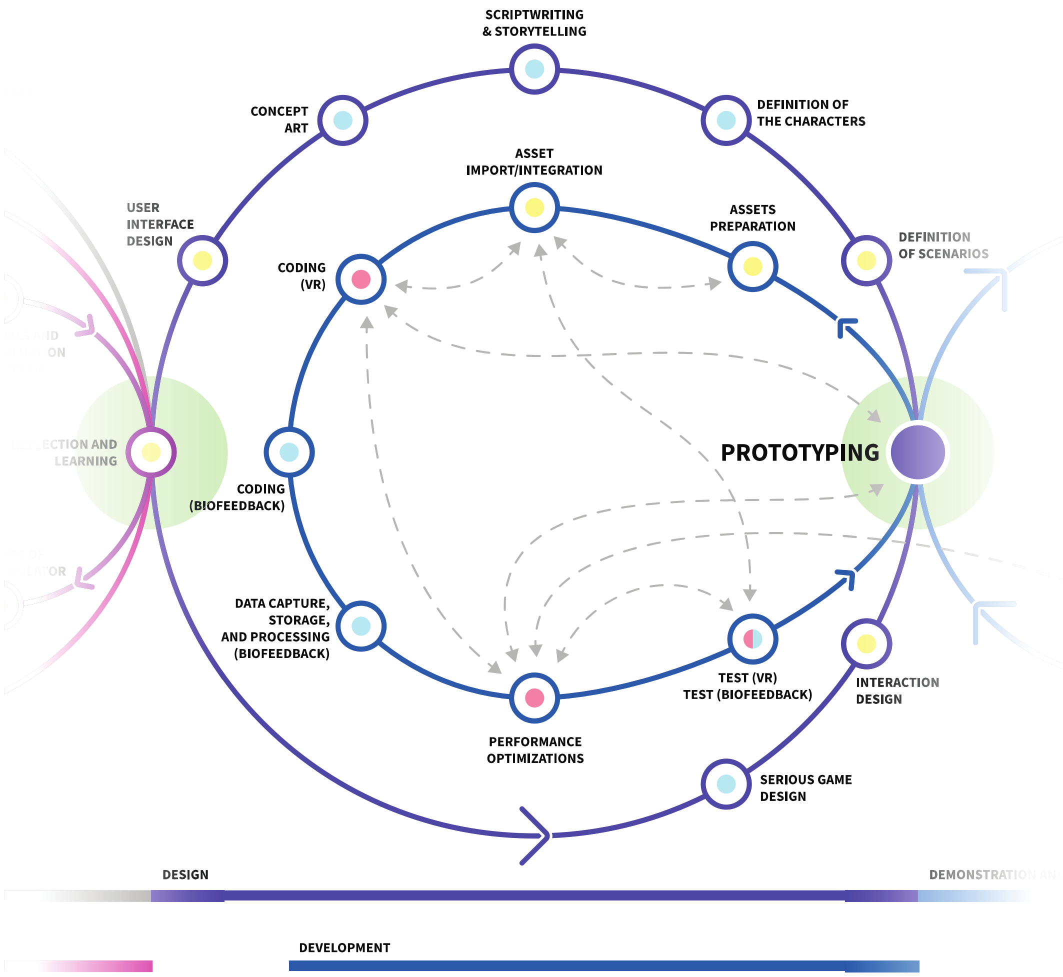
Figure 44 - Final version of the proposed method - Detail 01



Source: Elaborated by the author.

Figure 45 shows the second part of the method, where it is possible to see the Phase/Cycle 4 - Design cycle (8 activities), Phase/Cycle 5 - Development cycle (VR) (5 activities), and the Phase/Cycle 6 - Development cycle (Biofeedback) (3 activities).

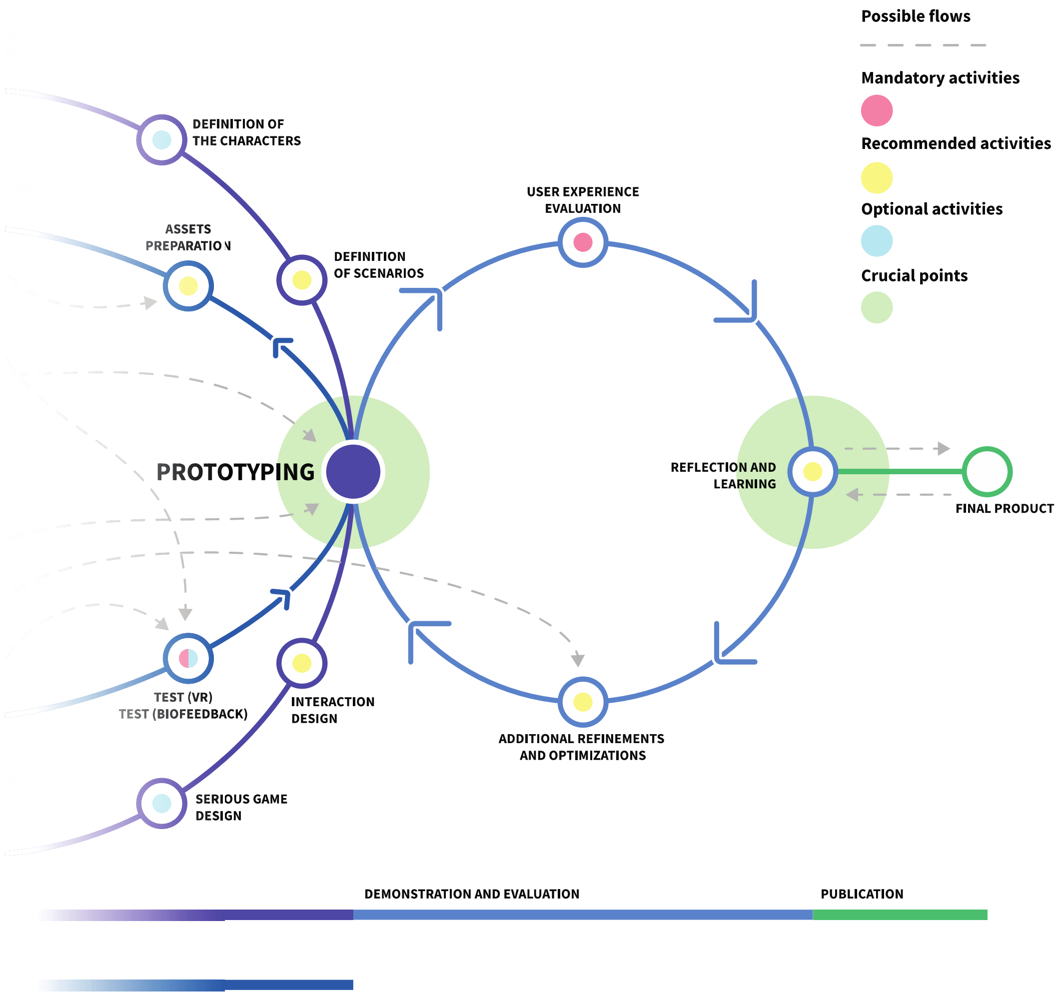
Figure 45 - Final version of the proposed method - Detail 02



Source: Elaborated by the author.

Figure 46 shows the third part of the method, where it is possible to see the Phase/Cycle 7 - Demonstration and evaluation cycle (3 activities).

Figure 46 - Final version of the proposed method - Detail 03



Source: Elaborated by the author.

This version has no significant differences from the version validated by the survey in terms of activities, and all phases or cycles and activities have been kept exactly as the version submitted for final evaluation. Even though some of the activities were not considered to be of high relevance compared to others, it was decided to keep them.

The choice to keep all the processes rather than simply remove some of them is due to a number of factors. The first refers to the fact that the method validated in the survey was already being improved until it reached the third version, and its construction process was already being followed by experts and professionals with vast experience in Virtual Reality projects, which means that all the included activities are relevant. The second reason to keep all the activities the same as they were after validation is due to the fact that, although in some specific points there was a large distribution of votes and not necessarily unanimity regarding the maximum relevance levels of the activities ("Very relevant" or "Extremely relevant"), all the items were considered relevant by the professionals and academics who answered the survey.

Thus, keeping the seven stages (Phase/Cycles) and thirty-one activities that constitute the proposed method is plausible and even recommendable, although not mandatory. The reason for this has to do with the possibility of flexibility and applicability of the method that allows it to contemplate different scenarios and specific needs of different development projects. This flexibility, by the way, is totally consistent with the Design Science Research methodology that underlies this thesis (HEVNER; CHATTERJEE, 2010; GREGOR; HEVNER, 2013; VOM BROCKE et al., 2020).

However, after analyzing the answers and identifying some points that did not have a high level of agreement (in other words, indicated as "Very relevant" or "Extremely relevant" by most of the respondents), it was decided to keep all the tasks, but to indicate three different levels of recommendation for the activities.

For the purposes of this research, three criteria based on the "sum of relevance" were adopted to determine whether an activity should be classified as mandatory, recommended or optional. By the first criterion, if the sum of the votes for a given activity defined as "Very relevant" and "Extremely relevant" is equal to or greater than 90%, this activity is defined as mandatory, given the high level of relevance assigned by the respondents. By the second criterion, if the sum of the votes for a given activity defined as "Very relevant" and "Extremely relevant" is something between 70 and 89.99%, it was defined that this activity should be labeled as recommended. On the other hand, if the sum of the votes for an activity defined as "Very relevant" and "Extremely relevant" is something below 69.99%, it was decided to label this activity as optional.

Table 42 presents the "Very relevant" and "Extremely relevant" values assigned to each of the activities, and a column with the sum of both, where it is possible to clearly see the results that corroborate the recommendation levels of the activities.

Table 42 - The sum of “Very relevant” and “Extremely relevant”

Activity/Task	Very relevant	Extremely relevant	Sum
01. Clear need for a simulator	16,31%	80,14%	96,45%
02. Define the objective of the simulator	9,93%	80,85%	90,78%
03. Initial brainstorm	13,48%	77,30%	90,78%
04. Hypotheses	38,30%	45,39%	83,69%

Activity/Task	Very relevant	Extremely relevant	Sum
05. Context research	24,11%	16,31%	40,42%
06. Research on the target audience	46,10%	33,33%	79,43%
07. Research on existing solutions	46,10%	21,99%	68,09%
08. Definition of the Type of simulator	28,37%	48,94%	77,31%
09. Definition of the Visual style	34,04%	26,24%	60,28%
10. Technologies to be adopted	18,44%	53,90%	72,34%
11. UX Design	39,72%	41,13%	80,85%
12. Goals and evaluation criteria	34,75%	46,10%	80,85%
13. Serious Game design	31,21%	31,91%	63,12%
14. Interaction design	24,82%	59,57%	84,39%
15. Definition of scenarios	42,55%	43,26%	85,81%
16. Definition of the characters	14,89%	24,82%	39,71%
17. Scriptwriting & storytelling	14,89%	23,40%	38,29%
18. Concept art	32,62%	29,79%	62,41%
19. User interface design (UI)	29,79%	53,19%	82,98%
20. Reflection and learning	30,50%	47,52%	78,02%
21. Assets preparation (VR)	48,23%	26,24%	74,47%
22. Asset import and integration (VR)	17,73%	56,74%	74,47%
23. Coding (VR)	1,42%	92,20%	93,62%
24. Test (VR)	4,26%	89,36%	93,62%
25. Performance optimizations (VR)	6,38%	88,65%	95,03%
26. Coding (Biofeedback)	46,10%	9,22%	55,32%
27. Data capture, storage, and processing (Biofeedback)	46,10%	3,55%	49,65%
28. Test (Biofeedback)	46,81%	4,96%	51,77%
29. User experience evaluation	13,48%	79,43%	92,91%
30. Additional refinements and optimizations	6,38%	78,72%	85,10%
31. Reflection and learning	25,53%	60,99%	86,52%

As a way of making explicit the suggested recommendation levels for each of the activities, Table 43 presents each of the thirty-one activities duly labeled based on the criteria previously presented and accompanied by the reference values obtained from the sums of the "Very relevant" and "Extremely relevant" columns.

Table 43 - Suggested recommendation level for the activity

Activity/Task	Recommendation level	Sum
01. Clear need for a simulator	Mandatory	96,45%
02. Define the objective of the simulator	Mandatory	90,78%
03. Initial brainstorm	Mandatory	90,78%
04. Hypotheses	Recommended	83,69%
05. Context research	Optional	40,42%
06. Research on the target audience	Recommended	79,43%
07. Research on existing solutions	Optional	68,09%
08. Definition of the Type of simulator	Recommended	77,31%
09. Definition of the Visual style	Optional	60,28%
10. Technologies to be adopted	Recommended	72,34%
11. UX Design	Recommended	80,85%
12. Goals and evaluation criteria	Recommended	80,85%
13. Serious Game design	Optional	63,12%
14. Interaction design	Recommended	84,39%
15. Definition of scenarios	Recommended	85,81%
16. Definition of the characters	Optional	39,71%
17. Scriptwriting & storytelling	Optional	38,29%
18. Concept art	Optional	62,41%
19. User interface design (UI)	Recommended	82,98%
20. Reflection and learning	Recommended	78,02%
21. Assets preparation (VR)	Recommended	74,47%
22. Asset import and integration (VR)	Recommended	74,47%
23. Coding (VR)	Mandatory	93,62%
24. Test (VR)	Mandatory	93,62%
25. Performance optimizations (VR)	Mandatory	95,03%
26. Coding (Biofeedback)	Optional	55,32%
27. Data capture, storage, and processing (Biofeedback)	Optional	49,65%
28. Test (Biofeedback)	Optional	51,77%
29. User experience evaluation	Mandatory	92,91%
30. Additional refinements and optimizations	Recommended	85,10%
31. Reflection and learning	Recommended	86,52%

However, it is important to understand that the proposed method is intended to provide a starting point, not a set of immutable rules that cannot be changed. Adaptability, by the way, is crucial for the execution of any kind of project that involves a huge number of processes and that aims to meet the needs of people in specific contexts of use. That said, it is important to note that the terms employed here as "mandatory", “recommended” or "optional" have more of a sense of recommendation and less of an imperative stance. In fact, the recommendation to use such concepts in an absolutely rigorous way would contradict the essence of the Design Science Research methodology that is the foundation of this research, which advocates the combination of scientific rigor and adaptability or flexibility.

A small change from the previous version refers to the initial phase, which although it was named and evaluated through the survey as *Initial planning and general objective*, has been renamed in this version as *Definition of the general objectives of the simulator*. This is due to a few factors. The first refers to the fact that this phase has activities clearly linked to the initial moments of the project development and therefore not necessarily part of the product planning itself. It is obvious that some of these tasks have a planning character and precisely for this reason this phase is presented, in this version, in a flow format, but not in an iterative or cyclical way, as the other phases of the method. This flow, in turn, leads to the first two cycles of the method, named in this version *Research cycle* and *Planning cycle*.

That said, it is clear that this stage of the simulator is more of a phase than a cycle, since its activities are performed, in general, only once. However, the proposed method was never intended to be immutable or inflexible, and it is important to raise the possibility that one or another activity proposed here in a certain way may be carried out in another way or at another time, which will depend much more on the specificities of the projects than on the nature of the activities themselves. An example of this could be the activity named *Hypotheses*. It may be that during the research or even the planning phase something is discovered that forces the raising of new hypotheses. In this case the method is still valid and applicable, since it is intended to be a starting point and not a set of immutable rules or processes. This characteristic can provide multiple possibilities for applying the method in different scenarios and with different levels of complexity.

In a similar way, there was a change in the labeling of the cycle previously called *Technological and pedagogical decisions cycle*, which in this final version is called *Planning cycle*. The change, in this case, was proposed as a matter of logic, since this cycle gathers a series of activities entirely dedicated to the planning of the prototype itself. This planning, in turn, involves issues ranging from practical and technical decisions to pedagogical issues, and several of the decisions taken have the potential to affect other decisions. A discussion of some of these potential consequences is provided during the construction of the simulator exposed in this thesis and again briefly presented in the presentation of the first version of the proposed method.

Another small change was made in the *Research Cycle* and it concerns the order in which the activities *Context research* and *Research on the target audience*, which in this version had their order reversed. The reason for the inversion is due to two factors. The first one is for a matter of sense, since it makes sense to understand the user (or possible user) and then his context than the other way around. The second is because, as seen in the validation results of the survey, most people considered the Context research activity as "Moderately relevant", which makes it, by the defined recommendation criteria, an "optional" activity, while Research on the target audience was classified as "recommended". The order obviously does not change the final product, but serves an aesthetic and logical function in this case.

It is also important to note that the *Development* cycle, which was called the Prototyping cycle in the previous version, comprises activities related to Virtual Reality and Biofeedback, and although represented with a series of activities that are part of the same universe, they do not necessarily need to be developed together. There is the possibility that a system that captures vital signs may not even be developed as part of the simulator. An external solution could be adopted for this purpose, which would make the development of a biofeedback system unnecessary. However, the method opens up the possibility of the system being developed in parallel, tested, and optimized.

This flexibility, moreover, is confirmed by the fact that the activities related to the biofeedback system remain in the method, but have been labeled as optional, considering the classification criteria adopted and already exposed. Again, the decision to keep such processes is something to be evaluated, and will depend solely and exclusively on the needs of the project itself.

Finally, another characteristic to be observed in this version concerns the possible flows that can happen especially between the *Design* and *Development* cycles and even in the *Demonstration and evaluation* cycle. A possible scenario to understand the reason for pointing out some "possible flows" has to do with user testing results. Assuming performance problems, it is necessary to go back to the *Development* cycle and work, perhaps, with the simulator code. Maybe the problem is not in the code, necessarily, but in some of the assets. Perhaps the problem is the polygonal density of some of the objects, and this requires that they be optimized, re-exported and re-imported into the engine. For these and other reasons, pointing out possible flows was considered a good idea.

However, like the definition of mandatory, recommended and optional tasks, the flows don't (and most likely won't) always happen in the way indicated in the method. But for the sake of organization and in an attempt to enhance the flexible character of the method, it was decided to suggest such flows.

Finally, it is important to note that the only activity that does not appear in this version as mandatory or optional is the one called *Final Product*. The reason for this is simple: this activity was not even considered an activity that is actually part of the method, but rather a natural consequence of the effort to produce a product (in this case, a simulator) following a method. therefore, there is no sense in determining that such activity is mandatory, since it is a consequence, a goal, a result.

In order to make the objectives and the general context of each part of the final version of the method more explicit, the initial phase, the cycles, as well as their respective objectives are presented as follows:

- **Phase/Cycle 1 - Definition of the general objectives of the simulator phase -** This phase starts with the clear definition of the need for a simulator and is followed by the definition of the simulator's objectives. This phase also provides for an initial brainstorm and the gathering of design hypotheses.
- **Phase/Cycle 2 - Research cycle -** This cycle has activities related to the research of possible simulator users, the environment in which this possible user is inserted and performs his activities, and the research for already existing solutions.
- **Phase/Cycle 3 - Planning cycle -** This cycle has activities related to definitions about the level of immersion, visual style, technologies to be adopted, user experience, and evaluation criteria for the simulator itself.
- **Phase/Cycle 4 - Design cycle -** This cycle contains activities related to the design or conception of the simulator.
- **Phase/Cycle 5 and 6 - Development cycle (VR and Biofeedback) -** This cycle contains activities related to the development of the simulator, including testing, performance, and optimization tasks. It can be described as one or two cycles, depending on whether or not a biofeedback system needs to be developed and integrated.

- **Phase/Cycle 7 - Demonstration and evaluation cycle -** This cycle has activities related to testing the simulator with users and involves evaluations of the user experience and possible refinements and optimizations.

As a way of consolidating the final version of the method, Table 44 presents the phase or cycles defined in this version, as well as the thirty-one activities proposed in each of the cycles and a brief explanation of the objective or purpose of each.

Table 44 - Phase/Cycles and activities of the final version of the proposed method

Phase/Cycle	Activity	Purpose/Objective
01 - Definition of the general objectives of the simulator phase	01. Clear need for a simulator	Define whether the simulator is really necessary.
	02. Define the objective of the simulator	Define the simulator's main objective.
	03. Initial brainstorm	Generate general ideas about the simulator.
	04. Hypotheses	Define hypotheses about related to the simulator's design.
02 - Research cycle	05. Context research	Understand the environment in which users or potential users of the simulator perform their activities.
	06. Research on the target audience	Better understand the simulator's potential user.
	07. Research on existing solutions	Survey existing solutions.
03 - Planning cycle	08. Definition of the Type of simulator	Define the level of immersion that this simulator should have.
	09. Definition of the Visual style	Define the simulator's visual style.
	10. Technologies to be adopted	Define the technologies that will be adopted to build the simulator.
	11. UX Design	Define the user's role within the simulator and how to handle their needs.
	12. Goals and evaluation criteria	Define objectives and evaluation criteria to be evaluated during and after using the simulator.
04 - Design cycle	13. Serious Game design	To define the serious game mechanics that will be adopted in the simulator.
	14. Interaction design	Define the type of interaction the simulator will have.
	15. Definition of scenarios	Definition of the possible scenarios to be represented in the simulator.
	16. Definition of the characters	Define the simulator's characters (NPCs), if any.
	17. Scriptwriting & storytelling	Definição de uma narrativa e roteiro, caso haja.
	18. Concept art	Creation of the simulator's concept and visual style.
	19. User interface design (UI)	Definition of the user interface elements.
	20. Reflection and learning	Consolidate what has been learned up to this point in the development and evaluate possible changes based on new knowledge.
05 – Development cycle (VR)	21. Assets preparation (VR)	Preparation of the simulator assets, which includes modeling, texturing, and animation, among other things.
	22. Asset import and integration (VR)	Export objects and animations and import them into the engine or development environment.
	23. Coding (VR)	Coding of the simulator, the mechanics and possible interactions.

Phase/Cycle	Activity	Purpose/Objective
	24. Test (VR)	Testing the simulator during development.
	25. Performance optimizations (VR)	Improve the simulator's performance during development.
06 – Development cycle (Biofeedback)	26. Coding (Biofeedback)	Coding of the vital signs capture system.
	27. Data capture, storage, and processing (Biofeedback)	Development of ways to capture biofeedback data for possible use during or after simulation.
	28. Test (Biofeedback)	Testing the biofeedback system during development.
07 - Demonstration and evaluation cycle	29. User experience evaluation	Evaluation of the user experience by various evaluation procedures and methods.
	30. Additional refinements and optimizations	Possible adjustments or optimizations from user feedbacks or expert evaluations.
	31. Reflection and learning	What was possible to learn from the experience of building the simulator.

Source: Elaborated by the author.

With the presentation of this last version of the method with changes made after validation, this chapter is concluded. The next chapter presents the conclusions and summarizes the contributions of this research, as well as reflections on the limitations and offers suggestions for future research.

7 CONCLUSION

In a world characterized by rapid change, uncertainty and increasing interconnectedness, there is a growing need for science to contribute to the solution of persistent and complex problems. One of these problems has a profound social impact and refers to the operational or behavioral deviations of security professionals and law enforcement officers, who, due to the inherent nature of their activities, are often exposed to a variety of acute stress and life-threatening situations. Such situations tend to force, besides quick decisions, correct judgments on the part of the professionals, who precisely because of this need to constantly train technical, operational and psychological aspects. However, police training is expensive, involves risks, has little flexibility of scenarios, and in many cases, besides being insufficient, it is also inefficient, both in terms of education and in terms of performance evaluation of the professional being trained.

This research started exactly from this point and, evaluating the exposed context, its intention was to propose a solution that could contribute to solve the problems related to the training of security professionals and law enforcement agents. To this end, this research proposed a unique combination of technologies, techniques, and methods aimed at contributing to the solution of the problem.

However, this research encountered in its early stages a specific issue that came to be identified as a research gap that forced this researcher to reevaluate his original approach. This gap refers to the absence of specific methods, processes, or even frameworks to guide the development of Virtual Reality simulators that can be applied to the training of professionals in situations of risk and stress. More specifically, simulators that have features or mechanisms that allow for greater engagement, that envisage some form of capture or use of vital signs to measure stress conditions during simulator use, and that have their development centered on the user and his needs.

Taking this gap into consideration, the purpose of this research was not only to produce and validate the production steps of a simulator prototype, but also to offer a way to solve different types of problems involving similar situations or use cases.

The main objective of this thesis, therefore, was to propose and validate the design of a method to guide the development of Virtual Reality simulators that combine Biofeedback and Serious Games applied to the specialized training of security professionals and law enforcement agents that consider the User Experience as the predominant factor. This method, in turn, was originated from an exploratory research based on the production of a Virtual Reality simulator prototype whose sole purpose was to generate knowledge to support the proposition of a method for the development of Virtual Reality simulators with the characteristics and applications already described.

To achieve this goal, this research was based on the use of Design Science Research because it is a research methodology driven by problem solving and because the results of its application are of prescriptive nature.

The construction of the simulator, also called primary artifact, took place over the course of a few months and was accompanied by the evaluation of a group of specialists from various fields of knowledge who helped validate the proposed activities and contributed with knowledge and personal and professional experience during its construction. During the construction of the simulator, carried out in an iterative manner, many methods, processes, approaches, and even assumptions were put to the test and duly documented.

The knowledge gained from building the simulator served as a basis for proposing the first version of the proposed Virtual Reality simulator development method. This method, also called a secondary artifact, was submitted to expert evaluations and went through several modifications and improvements. The first version had a linear structuring, even if strongly inspired by the human-centered design cycle for interactive systems, governed by ISO 9241-210:2019.

After several suggestions for improvements by the consulted experts, the second version incorporated elements and principles from Agile and Design Thinking methodologies, which provided the method with flexibility as it became based on iterative cycles. After a new round of evaluations, new suggestions were incorporated into a third version, which kept the structure in cycles but had added to its scope elements of Knowledge Management called "Thinking Points", an activity that is also supported by Agile methodologies. Besides that, a visual reorganization of the method was proposed as a way to improve the graphic representation of the activities and cycles. This third version was submitted to a wider evaluation, with 141 professionals and academics from 11 countries from several areas of expertise that this research tangents, such as Software Development, User Experience, Education, Games and Industry 4.0.

The validation of this third version of the method, conducted through the application of a survey and that served not only to validate the proposed method as a whole, but also characteristics and aspects that make this proposed method unique, such as aspects involving Serious Games, Biofeedback and User Experience, which together with Virtual Reality technology constitute the theoretical pillars of this thesis. After analyzing the answers from the survey, it was possible to identify different levels of relevance, determined by the number of activities defined as very relevant or extremely relevant by the respondents. From these results a fourth and final version was elaborated and took into consideration different reflections from the validation performed by professionals and academics.

The final version of the method is composed of Phase/Cycle 1 - Definition of the general objectives of the simulator phase (01. Clear need for a simulator, 02. Define the objective of the simulator, 03. Initial brainstorm, 04. Hypotheses); Phase/Cycle 2 - Research cycle (05. Research on the target audience, 06. Context research, 07. Research on existing solutions); Phase/Cycle 3 - Planning cycle (08. Definition of the Type of simulator, 09. Definition of the Visual style, 10. Technologies to be adopted, 11. UX Design, 12. Goals and evaluation criteria); Phase/Cycle 4 - Design cycle (13. Serious Game design, 14. Interaction design, 15. Definition of scenarios, 16. Definition of the characters, 17. Scriptwriting & storytelling, 18. Concept art, 19. User interface design (UI)); Phase/Cycle 5 - Development cycle (VR) (21. Assets preparation (VR), 22. Asset import and integration (VR), 23. Coding (VR), 24. Test (VR), 25. Performance optimizations (VR)); Phase/Cycle 6 - Development cycle (Biofeedback) (26. Coding (Biofeedback), 27. Data capture, storage, and processing (Biofeedback), 28. Test (Biofeedback)); and Phase/Cycle 7 - Demonstration and evaluation cycle (29. User experience evaluation, 30. Additional refinements and optimizations, 31. Reflection and learning). For a better visualization and understanding of the validated method, please refer to topic 6.5. Final version of the proposed method - post validation.

It was possible to identify, among other things, that activities related to User Experience had, in general, excellent evaluations, while activities related to Serious Games and even Biofeedback were not considered as having the same level of relevance as activities related to User Experience. However, none of the activities had such low relevance ratings as to suggest or indicate that these activities should be excluded from the method.

The final version of the method has the indication of all thirty-one activities distributed in each of the seven stages of the method (Phase/Cycles), duly labeled as "Mandatory", "Recommended" or "Optional". The criterion developed to determine the order of relevance of each of the activities was the sum of the positive extremes of the relevance scale derived from the survey.

The general and specific objectives of this thesis were satisfied and, therefore, at the end of this journey, we obtained a method that is comprehensive, robust and flexible enough to cover different specificities of various contexts of VR solution development applied to the training of professionals in stressful situations.

7.1 Contributions of this study

This thesis has several notable contributions for academics and practitioners. The application of the method that underlies and sustains the entire realization of this thesis not only advocates but also reinforces that the contribution of an artifact should go beyond the artifact itself, which in this case is a development method. This implies contributing to increase the knowledge base of a given domain. It is precisely at this point that this thesis presents one of its main and most notable contributions to academics.

By applying the Design Science Research methodology not only systematically, but also thoughtfully, this research endeavor advances knowledge about the application of a scientific methodology whose main characteristic is to bring Academia and its scientific rigor closer to the real world. And it does this by proposing solutions that not only solve real-world problems, but that can be replicated in different scenarios.

At the other extreme, this research provides to professionals in the field a proposed Virtual Reality simulator development method that can ultimately be used to develop commercial solutions and guide the development of Virtual Reality simulators. Having a method or framework as a starting point can avoid waste, redundancy, and inefficiency in processes, which can mean greater production agility and competitive differentiation for many companies.

Another contribution of this research to both academia and professionals refers to the nature and execution of the research itself and its multidisciplinary character, which brings together not only technology, processes, and concepts, but also professionals and academics from many different areas, backgrounds, and levels of experience. Notwithstanding the complexity of the theme addressed, the way the research was structured brings in itself a valuable contribution whose development may serve to guide projects with the same characteristics, even if in different areas of knowledge, applications, or markets.

However, considering the academic nature of this thesis, it is important to highlight some limitations, which comprise the research development context, the specificity of the scenario that this research addresses, and some constraints to which the researcher was subjected.

7.2 Limitations of the research

A major limitation of this research is the fact that the method obtained was designed based on a very specific use case. Although there is flexibility to apply the obtained method in several scenarios and use cases, all its development was proposed and guided having as direction only one very specific use case. This limitation can be overcome by applying the method to the development of simulators with similar characteristics and demands, but not necessarily in the same segment or industry addressed in this thesis. Another limitation refers to the instrument used to evaluate the method, which has characteristics that are justified and conditioned by the context of this research. Although the evaluation and the instrument have proven to be effective, it is worth extending the evaluation not only to a larger group of professionals, but also with even more rigorous parameters. Another limitation is that the entire evaluation was mostly qualitative, which reinforces the aforementioned limitation. This limitation can be overcome by submitting the artifact to a quantitative evaluation, which requires, in turn, an expressive number of respondents to the point of achieving statistical significance.

Among the restrictions that need to be mentioned and should not be ignored is the lack of contact by the researcher with police forces, although there was an effort by the researcher to obtain information from the police forces in two different countries. Unfortunately, there was no response from the police forces, which forced the researcher to support part of the work on reports from non-profit organizations that are dedicated to tackling police violence and on data from governments, such as reports and statistics, all of which are freely accessible.

7.3 Recommendations for further research

At this point, some possibilities for future research are pointed out, which will be divided into two dimensions corresponding to both artifacts of this research. Starting with the Virtual Reality simulator, a proposed research front would be the use of artificial intelligence in the NPCs, such as Goal-Oriented Action Planning (GOAP), which is an AI architecture that provides game characters with the ability to select goals and make plans to achieve those goals based on the state of the environment and available resources. This type of implementation could provide a wealth of interactions within the simulator and enhance the trainee experience, if combined with a number of other approaches such as adopting engagement mechanics.

Another suggestion for the Virtual Reality simulator would be to insert a form of immersion for the instructor to see the action in first person within the simulator. This could happen as a passive camera or a second player inside the simulator, but in a way that does not interrupt the action. Another possibility would be to allow, via an external interface, direct interactions from the instructor, who could, among other things, select different reactions from NPCs or even trigger events. This could provide more control to the instructor or training supervisor, who would have at his disposal different ways to cause randomness or surprise.

Still about the simulator, the suggestion would be to implement a biofeedback system with real-time response that would show the simulator user how his signals behave in a HUD, a feature that could be controlled to be or not offered to the user as part of the simulation and that would be defined by the instructor or training supervisor.

Regarding the proposed method, a first suggestion would be to extend the validation to a larger group of professionals and academics, and this time, using even more rigorous methods to evaluate if, in fact, all the activities are relevant within the context presented, if there are suggestions for inclusions, substitutions, or even the proposition of a new arrangement of activities.

Still in relation to the proposed method, an important suggestion would be to apply it not only in other scenarios like the ones described in this thesis, but in other scenarios that involve stressful situations. There is a wide range of professions in which stress is a common component, and they go far beyond professions that involve risk to the professional's life, such as firefighters, for example. An excellent suggestion for the application of the method proposed in this thesis would be for the creation of simulators for training paramedics, or on-duty emergency physicians. Both cases involve an enormous amount of stress, as do several other health professions, but do not necessarily involve any risk to the life of the professional. However, using simulators to train professionals who will eventually work in chaotic environments seems to be a way to put the method to the test and prove how effective it is in guiding the simulator production.

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APPENDIX A - Survey used to evaluate the proposed method

Welcome to the questionnaire about the development of Virtual Reality simulators applied to professionals' training in situations of risk and stress.

Objective and general context: My name is Huoston Rodrigues, and I am an academic researcher and professor. Besides, I have almost 20 years of experience as a Digital Designer and have worked in several segments, including the Games industry. This questionnaire has a strictly academic purpose as part of the research developed during my Ph.D. It is the validation of an innovative method for creating Virtual Reality simulators applied to professionals' training in risk and stress situations. The proposed method brings together different technologies and fields such as Virtual Reality, Serious Games, and Biofeedback to suggest a way to guide the development of specialized simulators.

Data and confidentiality: The data collected in this research is totally anonymous, and privacy is guaranteed. The data will be analyzed together and never treated individually. To avoid potential conflicts of interest, the data will be treated in subsets. To protect your privacy, questions that may be used to identify an individual are not part of this survey. If you want to receive the final work results, there is a field to insert and e-mail at the end of the questionnaire. This is absolutely optional.

Responsibility: I developed this survey as part of my Ph.D. research at the Universidade Nove de Julho (Brazil) and under the supervision of Prof. Dr. Marcos Antonio Gaspar (UNINOVE) and Prof. Dr. Ulrich Norbisrath (University of Tartu). Contact/Doubts/Questions: You can contact me at any time at huostonrodrigues@gmail.com. The average response time to this questionnaire is 20 minutes. By starting the survey, you agree to participate in it.

[SECTION 1]

The next few questions are purely of a statistical nature and serve to describe general aspects of the population that will answer this survey.

Which option best defines your area of expertise/industry?

1. Education
2. Software Development
3. Games
4. UX/UI
5. Industry 4.0
6. Other

In which country do you work?

[List of 195 countries, which was suppressed for the sake of practicality]

How many years of professional experience do you have in your field?

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. 9
10. 10 or more

How many years of experience do you have with VR?

1. Less than 1 year
2. At least 1 year
3. Between 1 and 3 years

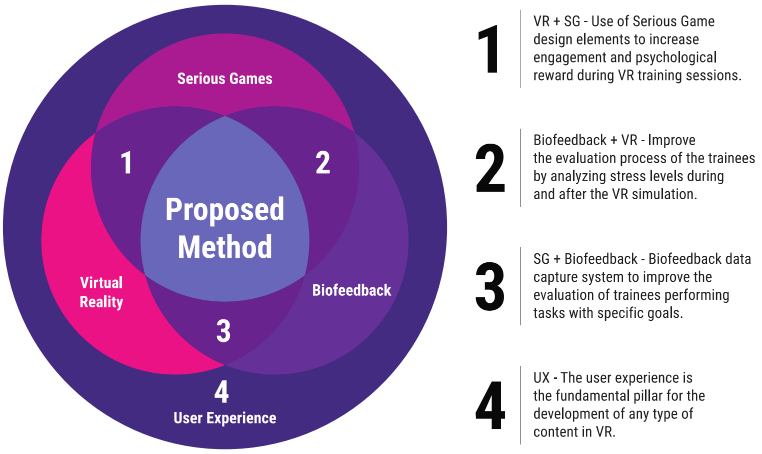
4. Between 3 and 5 years
5. More than 5 years

What is your gender?

1. Male
2. Female
3. Other/non-binary

[SECTION 2 - INTRODUCTION]

To support your decisions, I would like to introduce the general concept of the method proposed by this research. Let's suppose that you have to develop a Virtual Reality simulator used to train professionals in risk and stress situations, such as police officers, firefighters, or security professionals. Imagine that this Virtual Reality simulator has a form of Biofeedback to support the performance evaluation process, the adoption and use of Serious Games features to increase the engagement of professionals in training, and whose design process is user-centered. The simulator development method proposed by this research is divided into different steps, most of them in a cycle format. Each step or cycle has a series of activities or tasks. Please classify the following items according to the degree of relevance based on your experience. Tip: at the end of each question, there is a small summary of each step or cycle's general objective. Click on the question symbol to see more.



Proposed development method for simulators using Virtual Reality + Serious Games + Biofeedback

[SECTION 2 – BLOCK 1]

Explanation: *This is the starting point. At this stage of the simulator development method proposed by this research, there are actions such as defining the simulator's objectives, brainstorming, and raising initial hypotheses.*

01 - Initial planning and general objective - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
Clear need for a simulator	❑	❑	❑	❑	❑
Define the objective of the simulator	❑	❑	❑	❑	❑
Initial brainstorm	❑	❑	❑	❑	❑
Hypotheses	❑	❑	❑	❑	❑

Are there any other tasks that should be included in this step (01 - Initial planning and general objective)?

[SECTION 2 – BLOCK 2]

Explanation: *The research cycle gathers functions such as context research (to better understand the corporation), research about the target audience (to better understand the user), and analysis about existing solutions (to know about possible solutions already developed).*

02 - Research cycle - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
Context research	❑	❑	❑	❑	❑
Research on the target audience	❑	❑	❑	❑	❑
Research on existing solutions	❑	❑	❑	❑	❑

Are there any other tasks that should be included in this step (02 - Research cycle)?

[SECTION 2 – BLOCK 3]

Explanation: *In this cycle, some decisions affect several aspects of the simulator, including immersion level, visual style (which impacts the decision by the type of technologies to be adopted), and aims to establish the pedagogical criteria and objectives to be evaluated.*

03 - Technological and pedagogical decisions cycle - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
Definition of the Type of simulator	❑	❑	❑	❑	❑
Definition of the Visual style	❑	❑	❑	❑	❑
Technologies to be adopted	❑	❑	❑	❑	❑
UX Design	❑	❑	❑	❑	❑
Goals and evaluation criteria	❑	❑	❑	❑	❑

Are there any other tasks that should be included in this step (03 - Technological and pedagogical decisions cycle)?

[SECTION 2 – BLOCK 4]

Explanation: *The design cycle has the most stages. In this cycle, fundamental concepts of the simulator are developed and refined. Among them, elements of serious games, the user experience, the interaction design, and the aesthetic and narrative aspects of the simulator, ranging from the characters and scenarios to the interface.*

04 - Design cycle - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
Serious Game design	❑	❑	❑	❑	❑
Interaction design	❑	❑	❑	❑	❑
Definition of scenarios	❑	❑	❑	❑	❑
Definition of the characters	❑	❑	❑	❑	❑
Scriptwriting & storytelling	❑	❑	❑	❑	❑
Concept art	❑	❑	❑	❑	❑
User interface design (UI)	❑	❑	❑	❑	❑
Reflection and learning	❑	❑	❑	❑	❑

Are there any other tasks that should be included in this step (04 - Design cycle)?

[SECTION 2 – BLOCK 5]

Explanation: *In the VR prototyping cycle, tasks such as creating and importing the assets that will be used in the construction of the simulator and fundamental activities such as coding, testing, and optimization.*

05 - Prototyping cycle (VR) - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
Assets preparation (VR)	❑	❑	❑	❑	❑
Asset import and integration (VR)	❑	❑	❑	❑	❑
Coding (VR)	❑	❑	❑	❑	❑
Test (VR)	❑	❑	❑	❑	❑
Performance optimizations (VR)	❑	❑	❑	❑	❑

Are there any other tasks that should be included in this step (Prototyping cycle (VR))?

[SECTION 2 – BLOCK 6]

Explanation: *In the Biofeedback prototyping cycle, there are activities related to the system's development or configuration that will capture vital data during the simulation.*

06 - Prototyping cycle (Biofeedback) - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
Coding (Biofeedback)	❏	❏	❏	❏	❏
Data capture, storage, and processing (Biofeedback)	❏	❏	❏	❏	❏
Test (Biofeedback)	❏	❏	❏	❏	❏

Are there any other tasks that should be included in this step (Prototyping cycle (Biofeedback))?

[SECTION 2 – BLOCK 7]

Explanation: *The demonstration and evaluation cycle is a fundamental step and has activities such as user experience tests and possible refinements and improvements and a previous phase before the publication called reflection and learning.*

07 - Demonstration and evaluation cycle - How relevant is each of the following tasks within this stage to develop a VR simulator with the characteristics previously described (VR + Serious Games + Biofeedback applied to professionals' training in risk and stressful situations)?

	Not at all relevant	Slightly relevant	Moderately relevant	Very relevant	Extremely relevant
User experience evaluation	❏	❏	❏	❏	❏
Additional refinements and optimizations	❏	❏	❏	❏	❏
Reflection and learning	❏	❏	❏	❏	❏

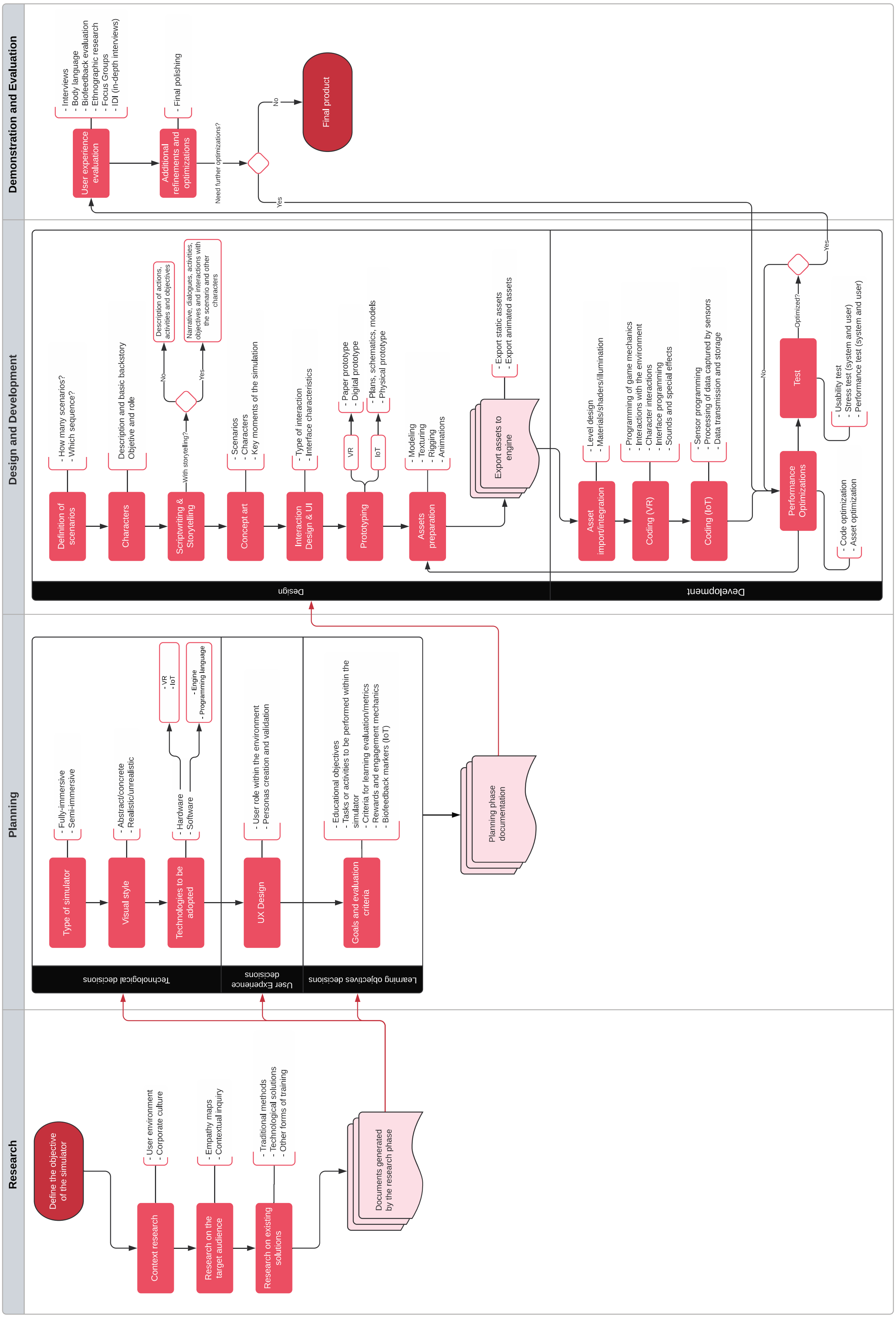
Are there any other tasks that should be included in this step (07 - Demonstration and evaluation cycle)?

[SECTION 2 – BLOCK 8]

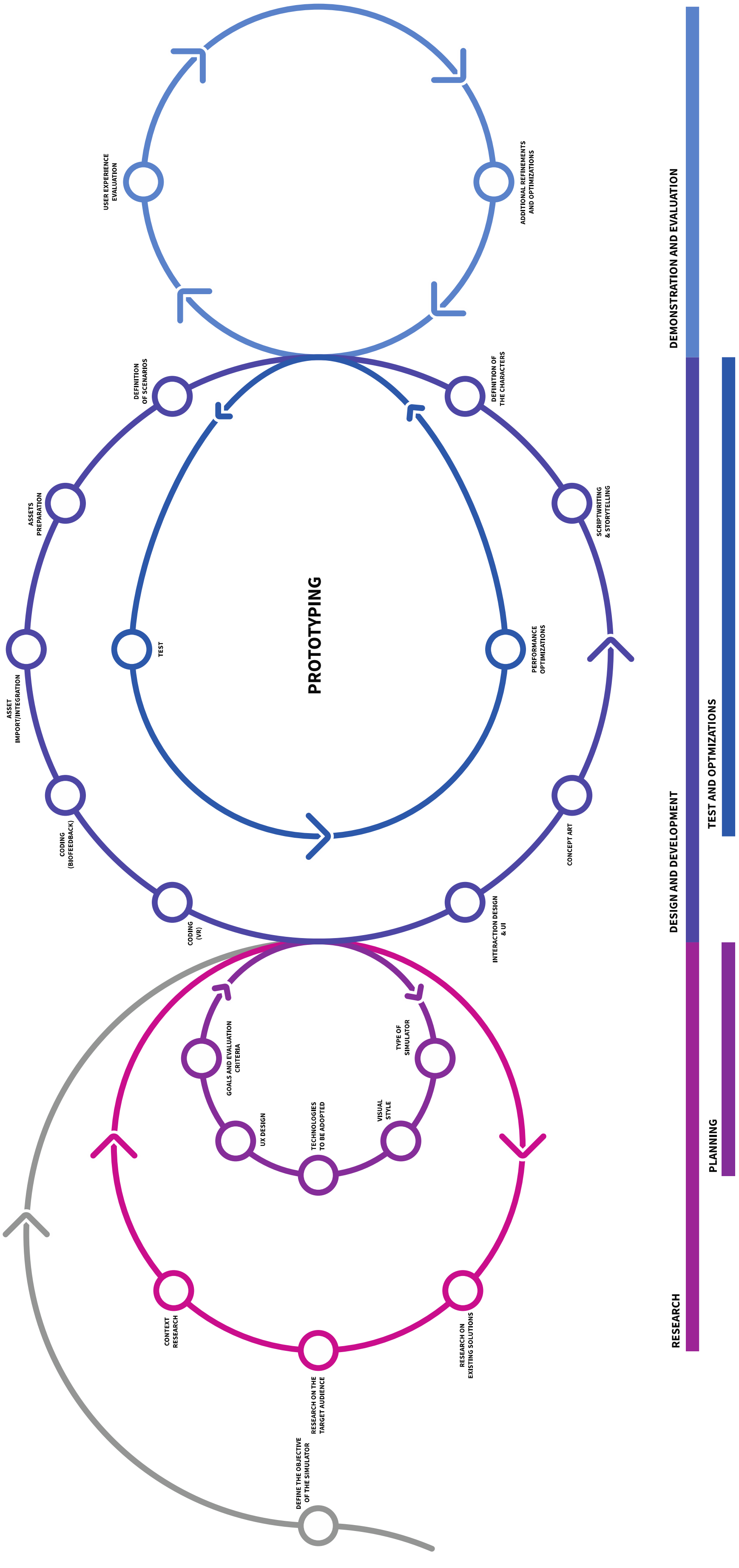
Thank you for answering this questionnaire!

You have reached the end of the questionnaire. If you are interested in receiving the final report after the results are published, please leave your email. This action is totally optional and your email will never be used for any other purpose.

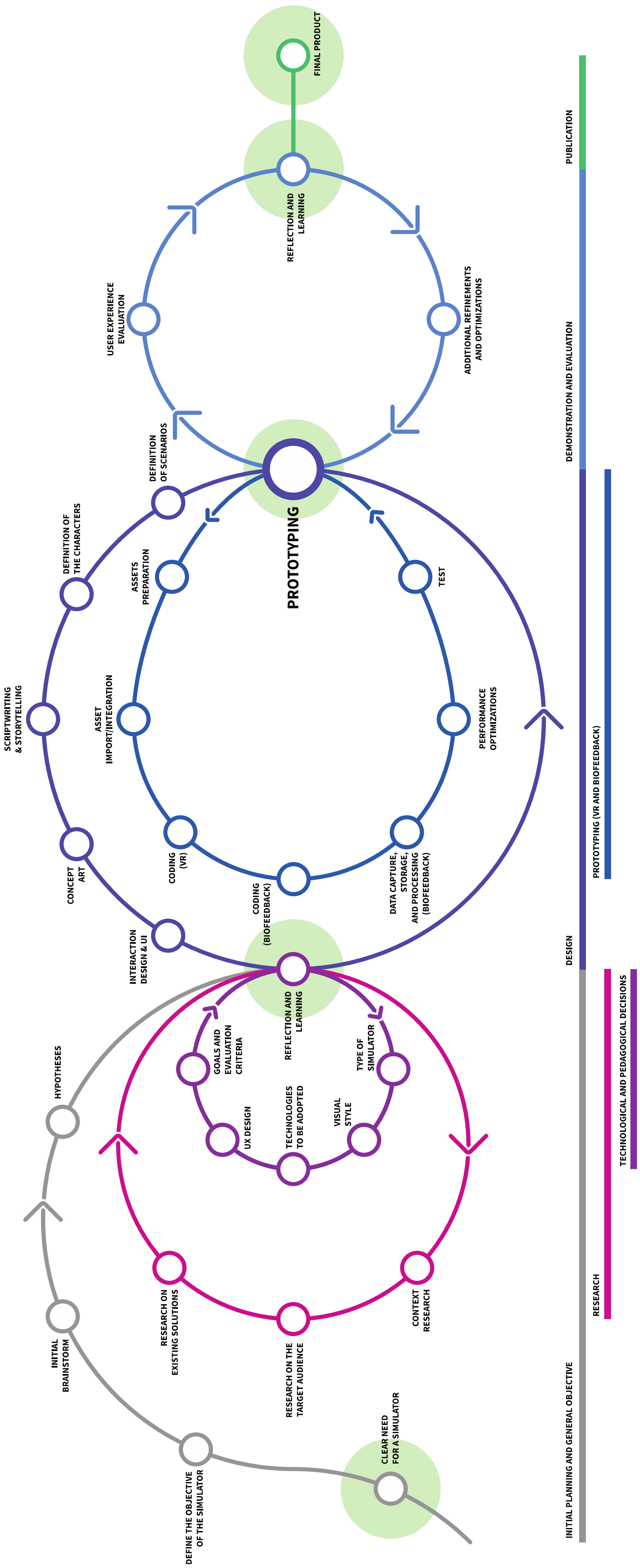
APPENDIX B - The first version of the proposed method



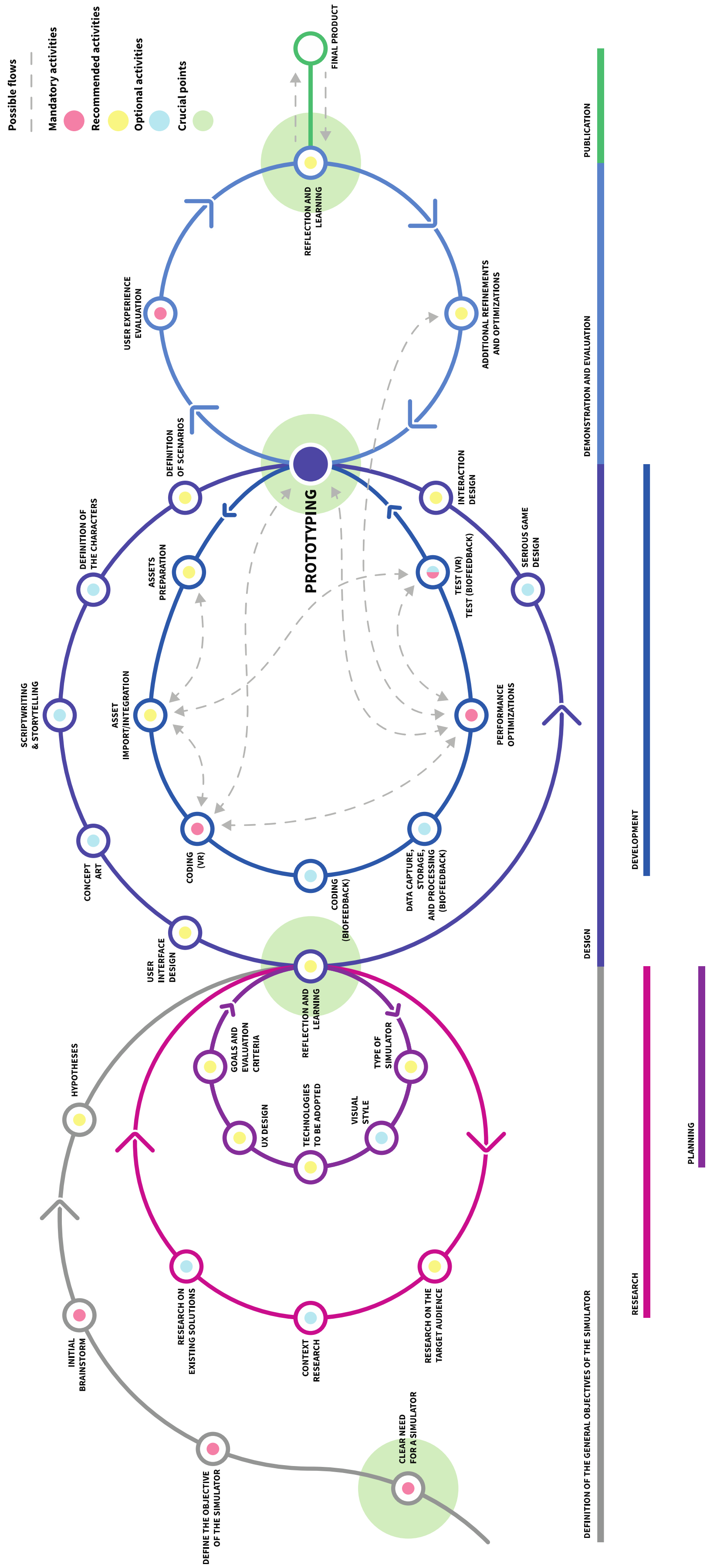
APPENDIX C - The second version of the proposed method



APPENDIX D - The third version of the proposed method



APPENDIX E - The final version of the proposed method



APPENDIX F - Additional survey data

Summary of all survey respondents by Area of Expertise, Country, Years of Professional Experience, Years of Experience with VR, and Gender.

Area of Expertise	Country	Years of Experience	Experience with VR	Gender	(n)
Education	Austria	10 or more years	Between 3 and 5 years	Male	1
Education	Austria	3 years	Between 1 and 3 years	Female	1
Education	Austria	3 years	Between 1 and 3 years	Male	2
Education	Austria	3 years	Between 3 and 5 years	Male	1
Education	Austria	4 years	At least 1 year	Male	1
Education	Austria	5 years	Between 1 and 3 years	Female	1
Education	Austria	5 years	Between 3 and 5 years	Male	1
Education	Austria	5 years	More than 5 years	Male	1
Education	Austria	7 years	Between 1 and 3 years	Male	1
Education	Austria	8 years	Between 1 and 3 years	Male	1
Education	Austria	9 years	At least 1 year	Male	1
Education	Austria	9 years	More than 5 years	Male	1
Education	Brazil	3 years	Between 3 and 5 years	Male	1
Education	Brazil	7 years	Between 3 and 5 years	Male	1
Education	Canada	5 years	Between 1 and 3 years	Male	1
Education	Canada	5 years	Less than 1 year	Male	1
Education	Canada	7 years	More than 5 years	Male	1
Education	Estonia	2 years	At least 1 year	Male	1
Education	Estonia	4 years	Between 3 and 5 years	Male	1
Education	Estonia	5 years	Between 3 and 5 years	Male	1
Education	Estonia	9 years	Between 1 and 3 years	Male	1
Education	Estonia	9 years	Between 3 and 5 years	Male	1
Education	France	6 years	Between 3 and 5 years	Female	1
Education	Mexico	10 or more years	Less than 1 year	Male	1
Education	Mexico	3 years	At least 1 year	Male	1
Education	Mexico	4 years	Between 1 and 3 years	Male	1
Education	Portugal	5 years	Between 3 and 5 years	Female	1
Education	Portugal	9 years	Between 3 and 5 years	Male	1
Education	United Kingdom	6 years	Between 3 and 5 years	Female	1
Education	United Kingdom	8 years	Between 1 and 3 years	Male	1

Area of Expertise	Country	Years of Experience	Experience with VR	Gender	(n)
Education	United States	1 year	Between 1 and 3 years	Male	1
Education	United States	10 or more years	Less than 1 year	Male	1
Education	United States	2 years	Between 3 and 5 years	Male	1
Games	Australia	6 years	Between 1 and 3 years	Male	1
Games	Austria	10 or more years	At least 1 year	Male	1
Games	Austria	4 years	Between 1 and 3 years	Male	1
Games	Austria	5 years	Between 1 and 3 years	Male	1
Games	Austria	7 years	Less than 1 year	Male	1
Games	Austria	8 years	Between 3 and 5 years	Male	1
Games	Canada	10 or more years	Between 3 and 5 years	Male	1
Games	Canada	8 years	At least 1 year	Male	1
Games	France	2 years	Between 3 and 5 years	Male	1
Games	France	3 years	Between 3 and 5 years	Male	1
Games	United States	6 years	Between 1 and 3 years	Male	1
Industry 4.0	Austria	6 years	Between 1 and 3 years	Male	1
Industry 4.0	Austria	7 years	At least 1 year	Male	1
Industry 4.0	Brazil	3 years	At least 1 year	Male	1
Industry 4.0	Canada	9 years	Between 3 and 5 years	Male	1
Industry 4.0	Estonia	10 or more years	Between 3 and 5 years	Male	1
Industry 4.0	United Kingdom	4 years	Less than 1 year	Male	1
Other	Austria	6 years	Between 3 and 5 years	Male	1
Other	Austria	8 years	At least 1 year	Male	1
Other	Brazil	3 years	Less than 1 year	Male	1
Software Development	Australia	1 year	Between 1 and 3 years	Male	1
Software Development	Australia	4 years	At least 1 year	Male	1
Software Development	Australia	5 years	Between 3 and 5 years	Male	1
Software Development	Australia	7 years	At least 1 year	Male	1
Software Development	Austria	1 year	Between 1 and 3 years	Female	1
Software Development	Austria	10 or more years	Less than 1 year	Male	1
Software Development	Austria	2 years	At least 1 year	Male	1
Software Development	Austria	3 years	At least 1 year	Male	1
Software Development	Austria	3 years	Between 1 and 3 years	Male	1
Software Development	Austria	3 years	More than 5 years	Male	1
Software Development	Austria	5 years	At least 1 year	Male	1
Software Development	Austria	5 years	Between 1 and 3 years	Male	1
Software Development	Austria	5 years	Between 3 and 5 years	Male	1
Software Development	Austria	6 years	Between 1 and 3 years	Male	1

Area of Expertise	Country	Years of Experience	Experience with VR	Gender	(n)
Software Development	Austria	7 years	Between 1 and 3 years	Male	2
Software Development	Austria	8 years	Between 1 and 3 years	Male	1
Software Development	Austria	8 years	Less than 1 year	Male	1
Software Development	Austria	8 years	More than 5 years	Male	1
Software Development	Brazil	3 years	At least 1 year	Female	1
Software Development	Brazil	4 years	At least 1 year	Male	1
Software Development	Brazil	7 years	More than 5 years	Female	1
Software Development	Brazil	9 years	Between 1 and 3 years	Male	1
Software Development	Canada	3 years	At least 1 year	Male	1
Software Development	Canada	5 years	More than 5 years	Male	1
Software Development	Canada	6 years	More than 5 years	Male	1
Software Development	Estonia	2 years	More than 5 years	Male	2
Software Development	Estonia	3 years	More than 5 years	Male	1
Software Development	Estonia	5 years	More than 5 years	Male	1
Software Development	Estonia	7 years	At least 1 year	Male	1
Software Development	Estonia	8 years	At least 1 year	Male	1
Software Development	Estonia	8 years	Between 3 and 5 years	Male	1
Software Development	Germany	3 years	Between 3 and 5 years	Female	1
Software Development	Germany	6 years	More than 5 years	Female	1
Software Development	Mexico	3 years	At least 1 year	Male	1
Software Development	Mexico	6 years	More than 5 years	Male	1
Software Development	Mexico	8 years	At least 1 year	Male	1
Software Development	Mexico	8 years	Between 1 and 3 years	Male	1
Software Development	Portugal	6 years	More than 5 years	Female	1
Software Development	United States	2 years	Between 3 and 5 years	Male	1
Software Development	United States	3 years	Between 1 and 3 years	Male	1
Software Development	United States	4 years	Less than 1 year	Male	1
Software Development	United States	6 years	Between 3 and 5 years	Female	1
Software Development	United States	7 years	More than 5 years	Male	1
Software Development	United States	9 years	Between 1 and 3 years	Male	1
UX/UI	Australia	2 years	Between 3 and 5 years	Male	1
UX/UI	Australia	3 years	Between 1 and 3 years	Male	1
UX/UI	Australia	3 years	Between 3 and 5 years	Male	1
UX/UI	Austria	10 or more years	Between 3 and 5 years	Male	1
UX/UI	Austria	2 years	Between 3 and 5 years	Male	2
UX/UI	Austria	3 years	At least 1 year	Male	1
UX/UI	Austria	3 years	More than 5 years	Male	1

Area of Expertise	Country	Years of Experience	Experience with VR	Gender	(n)
UX/UI	Austria	4 years	At least 1 year	Male	1
UX/UI	Austria	4 years	Between 1 and 3 years	Male	1
UX/UI	Austria	4 years	Less than 1 year	Male	1
UX/UI	Austria	5 years	At least 1 year	Male	1
UX/UI	Austria	5 years	More than 5 years	Male	1
UX/UI	Austria	6 years	At least 1 year	Male	1
UX/UI	Austria	8 years	At least 1 year	Male	1
UX/UI	Austria	8 years	Less than 1 year	Male	1
UX/UI	Austria	8 years	More than 5 years	Male	1
UX/UI	Brazil	6 years	Between 3 and 5 years	Male	1
UX/UI	Canada	6 years	More than 5 years	Male	2
UX/UI	Estonia	10 or more years	More than 5 years	Male	1
UX/UI	Estonia	3 years	Between 3 and 5 years	Male	1
UX/UI	Estonia	3 years	Less than 1 year	Male	1
UX/UI	Estonia	4 years	Between 1 and 3 years	Male	1
UX/UI	Estonia	6 years	More than 5 years	Male	1
UX/UI	Estonia	9 years	Between 3 and 5 years	Male	1
UX/UI	Germany	6 years	More than 5 years	Female	1
UX/UI	Mexico	2 years	Between 3 and 5 years	Male	1
UX/UI	Mexico	5 years	At least 1 year	Male	1
UX/UI	Mexico	5 years	Between 3 and 5 years	Male	1
UX/UI	Portugal	5 years	Between 3 and 5 years	Male	1
UX/UI	United Kingdom	2 years	Between 3 and 5 years	Male	1
UX/UI	United Kingdom	3 years	At least 1 year	Male	1
UX/UI	United Kingdom	6 years	Between 3 and 5 years	Male	1
UX/UI	United States	10 or more years	Less than 1 year	Male	1
UX/UI	United States	10 or more years	More than 5 years	Male	1
UX/UI	United States	2 years	Between 3 and 5 years	Male	1
UX/UI	United States	3 years	At least 1 year	Male	1
UX/UI	United States	4 years	Between 1 and 3 years	Male	1
UX/UI	United States	6 years	Between 3 and 5 years	Male	1
UX/UI	United States	7 years	Between 1 and 3 years	Male	1
				TOTAL	141

Responses by area of expertise for the activity "01. Clear need for a simulator". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	01. Clear need for a simulator	Total
Education	Extremely relevant	26
Education	Very relevant	8
Games	Extremely relevant	7
Games	Very relevant	4
Industry 4.0	Extremely relevant	4
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	1
Other	Extremely relevant	2
Other	Very relevant	1
Software Development	Extremely relevant	39
Software Development	Moderately relevant	1
Software Development	Not at all relevant	1
Software Development	Very relevant	5
UX/UI	Extremely relevant	35
UX/UI	Slightly relevant	2
UX/UI	Very relevant	4

Responses by area of expertise for the activity "02. Define the objective of the simulator". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	02. Define the objective of the simulator	Total
Education	Extremely relevant	28
Education	Moderately relevant	3
Education	Not at all relevant	1
Education	Very relevant	2
Games	Extremely relevant	9
Games	Not at all relevant	1
Games	Very relevant	1
Industry 4.0	Extremely relevant	6
Other	Extremely relevant	1
Other	Not at all relevant	1
Other	Slightly relevant	1
Software Development	Extremely relevant	38

Area of Expertise	02. Define the objective of the simulator	Total
Software Development	Moderately relevant	1
Software Development	Not at all relevant	2
Software Development	Very relevant	5
UX/UI	Extremely relevant	32
UX/UI	Moderately relevant	2
UX/UI	Slightly relevant	1
UX/UI	Very relevant	6

Responses by area of expertise for the activity "03. Initial brainstorm". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	03. Initial brainstorm	Total
Education	Extremely relevant	26
Education	Moderately relevant	2
Education	Not at all relevant	2
Education	Very relevant	4
Games	Extremely relevant	8
Games	Moderately relevant	1
Games	Very relevant	2
Industry 4.0	Extremely relevant	5
Industry 4.0	Slightly relevant	1
Other	Extremely relevant	1
Other	Moderately relevant	1
Other	Very relevant	1
Software Development	Extremely relevant	39
Software Development	Not at all relevant	1
Software Development	Very relevant	6
UX/UI	Extremely relevant	30
UX/UI	Moderately relevant	4
UX/UI	Slightly relevant	1
UX/UI	Very relevant	6

Responses by area of expertise for the activity "04. Hypotheses". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	04. Hypotheses	Total
Education	Extremely relevant	21
Education	Moderately relevant	2
Education	Slightly relevant	1
Education	Very relevant	10
Games	Extremely relevant	8
Games	Moderately relevant	1
Games	Very relevant	2
Industry 4.0	Moderately relevant	1
Industry 4.0	Not at all relevant	1
Industry 4.0	Slightly relevant	2
Industry 4.0	Very relevant	2
Other	Not at all relevant	1
Other	Slightly relevant	1
Other	Very relevant	1
Software Development	Extremely relevant	17
Software Development	Moderately relevant	7
Software Development	Very relevant	22
UX/UI	Extremely relevant	18
UX/UI	Moderately relevant	5
UX/UI	Not at all relevant	1
UX/UI	Very relevant	17

Responses by area of expertise for the activity "05. Context research". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	05. Context research	Total
Education	Extremely relevant	4
Education	Moderately relevant	12
Education	Not at all relevant	3
Education	Slightly relevant	2
Education	Very relevant	13
Games	Extremely relevant	2
Games	Moderately relevant	3
Games	Not at all relevant	1
Games	Slightly relevant	2

Area of Expertise	05. Context research	Total
Games	Very relevant	3
Industry 4.0	Moderately relevant	5
Industry 4.0	Not at all relevant	1
Other	Extremely relevant	1
Other	Moderately relevant	2
Software Development	Extremely relevant	14
Software Development	Moderately relevant	20
Software Development	Not at all relevant	2
Software Development	Slightly relevant	1
Software Development	Very relevant	9
UX/UI	Extremely relevant	2
UX/UI	Moderately relevant	19
UX/UI	Not at all relevant	4
UX/UI	Slightly relevant	7
UX/UI	Very relevant	9

Responses by area of expertise for the activity "06. Research on the target audience". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	06. Research on the target audience	Total
Education	Extremely relevant	4
Education	Moderately relevant	12
Education	Not at all relevant	3
Education	Slightly relevant	2
Education	Very relevant	13
Games	Extremely relevant	2
Games	Moderately relevant	3
Games	Not at all relevant	1
Games	Slightly relevant	2
Games	Very relevant	3
Industry 4.0	Moderately relevant	5
Industry 4.0	Not at all relevant	1
Other	Extremely relevant	1
Other	Moderately relevant	2
Software Development	Extremely relevant	14

Area of Expertise	06. Research on the target audience	Total
Software Development	Moderately relevant	20
Software Development	Not at all relevant	2
Software Development	Slightly relevant	1
Software Development	Very relevant	9
UX/UI	Extremely relevant	2
UX/UI	Moderately relevant	19
UX/UI	Not at all relevant	4
UX/UI	Slightly relevant	7
UX/UI	Very relevant	9

Responses by area of expertise for the activity "07. Research on existing solutions". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	07. Research on existing solutions	Total
Education	Extremely relevant	9
Education	Moderately relevant	13
Education	Not at all relevant	1
Education	Very relevant	11
Games	Extremely relevant	1
Games	Moderately relevant	6
Games	Very relevant	4
Industry 4.0	Extremely relevant	3
Industry 4.0	Moderately relevant	1
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	1
Other	Very relevant	3
Software Development	Extremely relevant	10
Software Development	Moderately relevant	10
Software Development	Slightly relevant	1
Software Development	Very relevant	25
UX/UI	Extremely relevant	8
UX/UI	Moderately relevant	10
UX/UI	Not at all relevant	2
UX/UI	Very relevant	21

Responses by area of expertise for the activity "08. Definition of the Type of simulator". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	08. Definition of the Type of simulator	Total
Education	Extremely relevant	12
Education	Moderately relevant	8
Education	Not at all relevant	1
Education	Very relevant	13
Games	Extremely relevant	5
Games	Moderately relevant	2
Games	Slightly relevant	1
Games	Very relevant	3
Industry 4.0	Extremely relevant	3
Industry 4.0	Moderately relevant	2
Industry 4.0	Very relevant	1
Other	Extremely relevant	1
Other	Moderately relevant	1
Other	Slightly relevant	1
Software Development	Extremely relevant	26
Software Development	Moderately relevant	8
Software Development	Not at all relevant	1
Software Development	Very relevant	11
UX/UI	Extremely relevant	22
UX/UI	Moderately relevant	6
UX/UI	Not at all relevant	1
UX/UI	Very relevant	12

Responses by area of expertise for the activity "09. Definition of the Visual style". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	09. Definition of the Visual style	Total
Education	Extremely relevant	8
Education	Moderately relevant	8
Education	Not at all relevant	4
Education	Slightly relevant	1
Education	Very relevant	13

Area of Expertise	09. Definition of the Visual style	Total
Games	Moderately relevant	2
Games	Not at all relevant	1
Games	Very relevant	8
Industry 4.0	Moderately relevant	1
Industry 4.0	Not at all relevant	1
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	3
Other	Moderately relevant	2
Other	Very relevant	1
Software Development	Extremely relevant	15
Software Development	Moderately relevant	9
Software Development	Not at all relevant	5
Software Development	Slightly relevant	1
Software Development	Very relevant	16
UX/UI	Extremely relevant	14
UX/UI	Moderately relevant	14
UX/UI	Not at all relevant	6
UX/UI	Very relevant	7

Responses by area of expertise for the activity "10. Technologies to be adopted". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	10. Technologies to be adopted	Total
Education	Extremely relevant	23
Education	Moderately relevant	3
Education	Very relevant	8
Games	Extremely relevant	6
Games	Moderately relevant	3
Games	Not at all relevant	1
Games	Very relevant	1
Industry 4.0	Extremely relevant	2
Industry 4.0	Moderately relevant	3
Industry 4.0	Very relevant	1
Other	Extremely relevant	2
Other	Moderately relevant	1

Area of Expertise	10. Technologies to be adopted	Total
Software Development	Extremely relevant	22
Software Development	Moderately relevant	11
Software Development	Not at all relevant	2
Software Development	Slightly relevant	1
Software Development	Very relevant	10
UX/UI	Extremely relevant	21
UX/UI	Moderately relevant	10
UX/UI	Not at all relevant	1
UX/UI	Slightly relevant	3
UX/UI	Very relevant	6

Responses by area of expertise for the activity "11. UX Design". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	11. UX Design	Total
Education	Extremely relevant	10
Education	Moderately relevant	6
Education	Not at all relevant	1
Education	Slightly relevant	1
Education	Very relevant	16
Games	Extremely relevant	3
Games	Moderately relevant	1
Games	Slightly relevant	1
Games	Very relevant	6
Industry 4.0	Extremely relevant	3
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	2
Other	Extremely relevant	1
Other	Moderately relevant	1
Other	Very relevant	1
Software Development	Extremely relevant	22
Software Development	Moderately relevant	4
Software Development	Not at all relevant	2
Software Development	Very relevant	18
UX/UI	Extremely relevant	19

Area of Expertise	11. UX Design	Total
UX/UI	Moderately relevant	5
UX/UI	Not at all relevant	3
UX/UI	Slightly relevant	1
UX/UI	Very relevant	13

Responses by area of expertise for the activity "12. Goals and evaluation criteria". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	12. Goals and evaluation criteria	Total
Education	Extremely relevant	15
Education	Moderately relevant	3
Education	Not at all relevant	1
Education	Very relevant	15
Games	Extremely relevant	8
Games	Not at all relevant	1
Games	Very relevant	2
Industry 4.0	Extremely relevant	3
Industry 4.0	Moderately relevant	1
Industry 4.0	Very relevant	2
Other	Extremely relevant	2
Other	Not at all relevant	1
Software Development	Extremely relevant	21
Software Development	Moderately relevant	9
Software Development	Slightly relevant	3
Software Development	Very relevant	13
UX/UI	Extremely relevant	16
UX/UI	Moderately relevant	5
UX/UI	Slightly relevant	3
UX/UI	Very relevant	17

Responses by area of expertise for the activity "13. Serious Game design". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	13. Serious Game design	Total
Education	Extremely relevant	9
Education	Moderately relevant	9
Education	Not at all relevant	1
Education	Slightly relevant	2
Education	Very relevant	13
Games	Extremely relevant	5
Games	Moderately relevant	4
Games	Very relevant	2
Industry 4.0	Extremely relevant	3
Industry 4.0	Moderately relevant	2
Industry 4.0	Very relevant	1
Other	Moderately relevant	1
Other	Very relevant	2
Software Development	Extremely relevant	15
Software Development	Moderately relevant	17
Software Development	Not at all relevant	1
Software Development	Slightly relevant	1
Software Development	Very relevant	12
UX/UI	Extremely relevant	13
UX/UI	Moderately relevant	13
UX/UI	Slightly relevant	1
UX/UI	Very relevant	14

Responses by area of expertise for the activity "14. Interaction design". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	14. Interaction design	Total
Education	Extremely relevant	17
Education	Moderately relevant	5
Education	Not at all relevant	1
Education	Slightly relevant	2
Education	Very relevant	9
Games	Extremely relevant	8
Games	Not at all relevant	1
Games	Very relevant	2

Area of Expertise	14. Interaction design	Total
Industry 4.0	Extremely relevant	3
Industry 4.0	Not at all relevant	1
Industry 4.0	Very relevant	2
Other	Extremely relevant	1
Other	Moderately relevant	1
Other	Very relevant	1
Software Development	Extremely relevant	27
Software Development	Moderately relevant	4
Software Development	Not at all relevant	1
Software Development	Slightly relevant	2
Software Development	Very relevant	12
UX/UI	Extremely relevant	28
UX/UI	Moderately relevant	1
UX/UI	Slightly relevant	3
UX/UI	Very relevant	9

Responses by area of expertise for the activity "15. Definition of scenarios". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	15. Definition of scenarios	Total
Education	Extremely relevant	17
Education	Moderately relevant	1
Education	Not at all relevant	1
Education	Slightly relevant	1
Education	Very relevant	14
Games	Extremely relevant	7
Games	Not at all relevant	1
Games	Very relevant	3
Industry 4.0	Moderately relevant	1
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	4
Other	Extremely relevant	2
Other	Moderately relevant	1
Software Development	Extremely relevant	19
Software Development	Moderately relevant	7

Area of Expertise	15. Definition of scenarios	Total
Software Development	Very relevant	20
UX/UI	Extremely relevant	16
UX/UI	Moderately relevant	5
UX/UI	Not at all relevant	1
UX/UI	Very relevant	19

Responses by area of expertise for the activity "16. Definition of the characters". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	16. Definition of the characters	Total
Education	Extremely relevant	7
Education	Moderately relevant	17
Education	Not at all relevant	4
Education	Slightly relevant	3
Education	Very relevant	3
Games	Extremely relevant	1
Games	Moderately relevant	4
Games	Not at all relevant	3
Games	Slightly relevant	2
Games	Very relevant	1
Industry 4.0	Extremely relevant	2
Industry 4.0	Moderately relevant	1
Industry 4.0	Not at all relevant	1
Industry 4.0	Very relevant	2
Other	Moderately relevant	2
Other	Very relevant	1
Software Development	Extremely relevant	12
Software Development	Moderately relevant	14
Software Development	Not at all relevant	6
Software Development	Slightly relevant	5
Software Development	Very relevant	9
UX/UI	Extremely relevant	13
UX/UI	Moderately relevant	17
UX/UI	Not at all relevant	5
UX/UI	Slightly relevant	1

Area of Expertise	16. Definition of the characters	Total
UX/UI	Very relevant	5

Responses by area of expertise for the activity "17. Scriptwriting & storytelling". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	17. Scriptwriting & storytelling	Total
Education	Extremely relevant	10
Education	Moderately relevant	13
Education	Not at all relevant	6
Education	Slightly relevant	1
Education	Very relevant	4
Games	Extremely relevant	1
Games	Moderately relevant	4
Games	Not at all relevant	3
Games	Slightly relevant	1
Games	Very relevant	2
Industry 4.0	Extremely relevant	2
Industry 4.0	Moderately relevant	1
Industry 4.0	Slightly relevant	3
Other	Moderately relevant	3
Software Development	Extremely relevant	13
Software Development	Moderately relevant	16
Software Development	Not at all relevant	7
Software Development	Slightly relevant	3
Software Development	Very relevant	7
UX/UI	Extremely relevant	7
UX/UI	Moderately relevant	11
UX/UI	Not at all relevant	11
UX/UI	Slightly relevant	4
UX/UI	Very relevant	8

Responses by area of expertise for the activity "18. Concept art". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	18. Concept art	Total
Education	Extremely relevant	7
Education	Moderately relevant	9
Education	Not at all relevant	1
Education	Slightly relevant	3
Education	Very relevant	14
Games	Extremely relevant	3
Games	Moderately relevant	3
Games	Very relevant	5
Industry 4.0	Extremely relevant	4
Industry 4.0	Moderately relevant	2
Other	Extremely relevant	1
Other	Moderately relevant	1
Other	Very relevant	1
Software Development	Extremely relevant	10
Software Development	Moderately relevant	19
Software Development	Not at all relevant	1
Software Development	Very relevant	16
UX/UI	Extremely relevant	17
UX/UI	Moderately relevant	14
UX/UI	Very relevant	10

Responses by area of expertise for the activity "19. User interface design (UI)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	19. User interface design (UI)	Total
Education	Extremely relevant	20
Education	Moderately relevant	3
Education	Not at all relevant	2
Education	Slightly relevant	1
Education	Very relevant	8
Games	Extremely relevant	4
Games	Moderately relevant	1
Games	Very relevant	6
Industry 4.0	Extremely relevant	3
Industry 4.0	Slightly relevant	1

Area of Expertise	19. User interface design (UI)	Total
Industry 4.0	Very relevant	2
Other	Extremely relevant	3
Software Development	Extremely relevant	24
Software Development	Moderately relevant	4
Software Development	Not at all relevant	4
Software Development	Very relevant	14
UX/UI	Extremely relevant	21
UX/UI	Moderately relevant	5
UX/UI	Not at all relevant	3
UX/UI	Very relevant	12

Responses by area of expertise for the activity "20. Reflection and learning". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	20. Reflection and learning	Total
Education	Extremely relevant	9
Education	Moderately relevant	6
Education	Not at all relevant	1
Education	Very relevant	18
Games	Extremely relevant	4
Games	Moderately relevant	3
Games	Not at all relevant	1
Games	Very relevant	3
Industry 4.0	Extremely relevant	3
Industry 4.0	Moderately relevant	2
Industry 4.0	Very relevant	1
Other	Extremely relevant	2
Other	Moderately relevant	1
Software Development	Extremely relevant	26
Software Development	Moderately relevant	6
Software Development	Very relevant	14
UX/UI	Extremely relevant	23
UX/UI	Moderately relevant	7
UX/UI	Not at all relevant	1
UX/UI	Slightly relevant	3

Area of Expertise	20. Reflection and learning	Total
UX/UI	Very relevant	7

Responses by area of expertise for the activity "21. Assets preparation (VR)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	21. Assets preparation (VR)	Total
Education	Extremely relevant	6
Education	Moderately relevant	8
Education	Very relevant	20
Games	Extremely relevant	3
Games	Moderately relevant	1
Games	Very relevant	7
Industry 4.0	Extremely relevant	1
Industry 4.0	Moderately relevant	3
Industry 4.0	Very relevant	2
Other	Extremely relevant	2
Other	Moderately relevant	1
Software Development	Extremely relevant	15
Software Development	Moderately relevant	8
Software Development	Slightly relevant	1
Software Development	Very relevant	22
UX/UI	Extremely relevant	10
UX/UI	Moderately relevant	13
UX/UI	Not at all relevant	1
UX/UI	Very relevant	17

Responses by area of expertise for the activity "22. Asset import and integration (VR)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	22. Asset import and integration (VR)	Total
Education	Extremely relevant	15
Education	Moderately relevant	13
Education	Not at all relevant	1
Education	Slightly relevant	1

Area of Expertise	22. Asset import and integration (VR)	Total
Education	Very relevant	4
Games	Extremely relevant	5
Games	Moderately relevant	4
Games	Very relevant	2
Industry 4.0	Extremely relevant	4
Industry 4.0	Very relevant	2
Other	Extremely relevant	3
Software Development	Extremely relevant	28
Software Development	Moderately relevant	8
Software Development	Not at all relevant	1
Software Development	Very relevant	9
UX/UI	Extremely relevant	25
UX/UI	Moderately relevant	6
UX/UI	Slightly relevant	2
UX/UI	Very relevant	8

Responses by area of expertise for the activity "23. Coding (VR)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	23. Coding (VR)	Total
Education	Extremely relevant	33
Education	Slightly relevant	1
Games	Extremely relevant	9
Games	Not at all relevant	1
Games	Slightly relevant	1
Industry 4.0	Extremely relevant	4
Industry 4.0	Moderately relevant	1
Industry 4.0	Very relevant	1
Other	Extremely relevant	3
Software Development	Extremely relevant	43
Software Development	Moderately relevant	1
Software Development	Not at all relevant	1
Software Development	Very relevant	1
UX/UI	Extremely relevant	38
UX/UI	Moderately relevant	2

Area of Expertise	23. Coding (VR)	Total
UX/UI	Not at all relevant	1

Responses by area of expertise for the activity "24. Test (VR)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	24. Test (VR)	Total
Education	Extremely relevant	31
Education	Moderately relevant	1
Education	Very relevant	2
Games	Extremely relevant	10
Games	Moderately relevant	1
Industry 4.0	Extremely relevant	6
Other	Extremely relevant	3
Software Development	Extremely relevant	41
Software Development	Moderately relevant	1
Software Development	Not at all relevant	1
Software Development	Very relevant	3
UX/UI	Extremely relevant	35
UX/UI	Moderately relevant	1
UX/UI	Not at all relevant	2
UX/UI	Slightly relevant	2
UX/UI	Very relevant	1

Responses by area of expertise for the activity "25. Performance optimizations (VR)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	25. Performance optimizations (VR)	Total
Education	Extremely relevant	32
Education	Moderately relevant	1
Education	Very relevant	1
Games	Extremely relevant	10
Games	Very relevant	1
Industry 4.0	Extremely relevant	5
Industry 4.0	Slightly relevant	1

Area of Expertise	25. Performance optimizations (VR)	Total
Other	Extremely relevant	3
Software Development	Extremely relevant	39
Software Development	Moderately relevant	1
Software Development	Not at all relevant	2
Software Development	Very relevant	4
UX/UI	Extremely relevant	36
UX/UI	Moderately relevant	2
UX/UI	Very relevant	3

Responses by area of expertise for the activity "26. Coding (Biofeedback)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	26. Coding (Biofeedback)	Total
Education	Extremely relevant	3
Education	Moderately relevant	10
Education	Not at all relevant	5
Education	Very relevant	16
Games	Extremely relevant	2
Games	Moderately relevant	5
Games	Very relevant	4
Industry 4.0	Extremely relevant	1
Industry 4.0	Moderately relevant	3
Industry 4.0	Not at all relevant	1
Industry 4.0	Very relevant	1
Other	Moderately relevant	2
Other	Very relevant	1
Software Development	Extremely relevant	2
Software Development	Moderately relevant	18
Software Development	Not at all relevant	1
Software Development	Slightly relevant	2
Software Development	Very relevant	23
UX/UI	Extremely relevant	5
UX/UI	Moderately relevant	11
UX/UI	Not at all relevant	3
UX/UI	Slightly relevant	2

Area of Expertise	26. Coding (Biofeedback)	Total
UX/UI	Very relevant	20

Responses by area of expertise for the activity "27. Data capture, storage, and processing (Biofeedback)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	27. Data capture, storage, and processing (Biofeedback)	Total
Education	Extremely relevant	3
Education	Moderately relevant	14
Education	Not at all relevant	3
Education	Slightly relevant	3
Education	Very relevant	11
Games	Moderately relevant	6
Games	Slightly relevant	1
Games	Very relevant	4
Industry 4.0	Moderately relevant	1
Industry 4.0	Very relevant	5
Other	Very relevant	3
Software Development	Extremely relevant	2
Software Development	Moderately relevant	16
Software Development	Not at all relevant	4
Software Development	Slightly relevant	6
Software Development	Very relevant	18
UX/UI	Moderately relevant	12
UX/UI	Not at all relevant	1
UX/UI	Slightly relevant	4
UX/UI	Very relevant	24

Responses by area of expertise for the activity "28. Test (Biofeedback)". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	28. Test (Biofeedback)	Total
Education	Extremely relevant	2
Education	Moderately relevant	10

Area of Expertise	28. Test (Biofeedback)	Total
Education	Not at all relevant	1
Education	Slightly relevant	4
Education	Very relevant	17
Games	Extremely relevant	1
Games	Moderately relevant	4
Games	Not at all relevant	1
Games	Very relevant	5
Industry 4.0	Moderately relevant	4
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	1
Other	Not at all relevant	2
Other	Very relevant	1
Software Development	Extremely relevant	1
Software Development	Moderately relevant	20
Software Development	Not at all relevant	1
Software Development	Slightly relevant	1
Software Development	Very relevant	23
UX/UI	Extremely relevant	3
UX/UI	Moderately relevant	13
UX/UI	Not at all relevant	1
UX/UI	Slightly relevant	5
UX/UI	Very relevant	19

Responses by area of expertise for the activity "29. User experience evaluation". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	29. User experience evaluation	Total
Education	Extremely relevant	30
Education	Very relevant	4
Games	Extremely relevant	6
Games	Moderately relevant	1
Games	Slightly relevant	1
Games	Very relevant	3
Industry 4.0	Extremely relevant	6
Other	Extremely relevant	2

Area of Expertise	29. User experience evaluation	Total
Other	Not at all relevant	1
Software Development	Extremely relevant	37
Software Development	Moderately relevant	2
Software Development	Slightly relevant	1
Software Development	Very relevant	6
UX/UI	Extremely relevant	31
UX/UI	Moderately relevant	2
UX/UI	Slightly relevant	2
UX/UI	Very relevant	6

Responses by area of expertise for the activity "30. Additional refinements and optimizations". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	30. Additional refinements and optimizations	Total
Education	Extremely relevant	24
Education	Moderately relevant	2
Education	Not at all relevant	1
Education	Slightly relevant	5
Education	Very relevant	2
Games	Extremely relevant	9
Games	Slightly relevant	2
Industry 4.0	Extremely relevant	6
Other	Extremely relevant	3
Software Development	Extremely relevant	37
Software Development	Moderately relevant	1
Software Development	Not at all relevant	3
Software Development	Slightly relevant	3
Software Development	Very relevant	2
UX/UI	Extremely relevant	32
UX/UI	Moderately relevant	4
UX/UI	Very relevant	5

Responses by area of expertise for the activity "31. Reflection and learning". The table shows only the relevance scale values for each activity that received at least one vote.

Area of Expertise	31. Reflection and learning	Total
Education	Extremely relevant	20
Education	Moderately relevant	2
Education	Slightly relevant	1
Education	Very relevant	11
Games	Extremely relevant	7
Games	Very relevant	4
Industry 4.0	Extremely relevant	4
Industry 4.0	Slightly relevant	1
Industry 4.0	Very relevant	1
Other	Extremely relevant	1
Other	Not at all relevant	1
Other	Very relevant	1
Software Development	Extremely relevant	29
Software Development	Moderately relevant	4
Software Development	Slightly relevant	2
Software Development	Very relevant	11
UX/UI	Extremely relevant	25
UX/UI	Moderately relevant	1
UX/UI	Slightly relevant	7
UX/UI	Very relevant	8