University of Bremen

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# Empowering Novices through Playful Self-Expression

## The Role of Creativity and Video Games in the Context of Virtual Reality Exposure Therapy

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# Declaration of Authorship

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified. The submitted printed and digital versions of this dissertation are identical in content.

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Many places I have been
Many sorrows I have seen
But I don't regret
Nor will I forget
All who took the road with me

Billy Boyd - The Last Goodbye

# Abstract

Video games elicit emotions of various kinds. From the simple joy of completing a level or the sense of achievement by overcoming a tough challenge to the emotional bonds players form to virtual characters when being enthralled in a captivating narrative, the spectrum of emotional responses stemming from playing games is wide. In addition to linear games, that focus on progression systems such as completing levels, advancing a story, or upgrading a virtual character, open-ended games offer emergent gameplay. These games define specific rules and mechanics but do not restrict the player to reach a distinct end goal in a certain way. They allow players to explore the game's content in a curious and free way. Game genres associated with such openness are sandbox games and city-builders that give players the means for playful creative self-expression. Using the toolsets the games provide, players create and shape worlds, they form the very terrain of these worlds by creating hills, valleys, rivers, and canyons. Moreover, players can embellish these worlds with urban structures like roads or buildings. These games stimulate creativity and create a sense of playfulness that lets players approach in-game challenges in curious and novel ways.

Besides the entertainment industry, the benefits of playing games for serious purposes have been recognized and examined by human-computer interaction (HCI) research for decades. Since games have the capability to satisfy emotional needs, they have been investigated regarding their potential to support learning, behavior change, motivation to exercise, and many other applications beyond entertainment. One such domain is psychotherapy. Specifically for the treatment of phobias, studies suggest that the inclusion of video games can be beneficial to the course of therapy. These games usually incorporate concepts from the domains of cognitive-behavioral therapy (CBT) and exposure therapy (ET), the most common treatment technique for simple phobias. By gamification of these techniques or the implementation of serious games, motivation to seek therapy can be increased, giving more people access to professional mental health interventions.

In this thesis, I examine the interplay of games that allow creative self-expression and psychotherapy for the treatment of phobias. The work reported here is composed of three distinct domains of examination that illuminate different aspects of this approach. First, based on requirement analysis and in-the-field evaluations with industry experts from the domains of animation, film, and theater, the thesis investigates the use of natural user interfaces (NUIs) to support professionals with low technical expertise but highly technical tasks in their everyday lives. Thus, I demonstrate how NUIs may support therapists in the configuration, maintenance, and usage of virtual reality exposure therapy (VRET) systems. The second domain is concerned with the definition of a game design strategy suitable for the treatment of phobias. In the course of this thesis, I argue that game design for the treatment of phobias needs to consider specific requirements that have not been covered by previous research in this field. Based on these requirements that have been identified with therapy practitioners, this thesis introduces a novel concept - playful user-generated treatment (PUT), that incorporates these requirements for an applicable addition to therapy. An evaluation in the form of a user study and an expert survey demonstrate opportunities and challenges that PUT involves. The third and last research topic is concerned with the inclusion of procedural content generation (PCG) into the PUT concept as a way to alleviate technical complexity and foster human-computer co-creation. This segment covers the impact of PCG on self-reported creativity support and user engagement in a playful city-building task as defined in the PUT concept.

Based on the work reported in this thesis, these key insights have been found. For the design of systems that are to be used by users with high technical demands and low technical expertise such as therapists and patients in a VRET context, NUIs can serve as tools to alleviate technical complexity whilst providing the benefits of novel technology. Furthermore, when implementing playful VRET systems, specific requirements need to be considered in the design process so as to not interfere with therapeutic success. The proposed PUT game design strategy fulfills these requirements and can be used to harness the positive effects of playful creative self-expression in a VRET scenario. Lastly, results from this thesis demonstrate that the inclusion of PCG into a PUT-based system does not interfere with self-reported creativity support.

By investigating these research topics, this thesis contributes to the domains of natural interaction as facilitated through NUIs, motivational aspects of games user research (GUR), PCG in video games, creativity and self-expression through playfulness, and the inclusion of playful elements into the VRET procedure.

# Zusammenfassung

Videospiele lösen Emotionen unterschiedlichster Art aus. Von der einfachen Freude über den Abschluss eines Levels oder dem Erfolgserlebnis beim Überwinden einer schwierigen Herausforderung bis hin zu den emotionalen Bindungen, die SpielerInnen zu virtuellen Charakteren aufbauen, wenn sie von einer fesselnden Geschichte in den Bann gezogen werden - das Spektrum der emotionalen Reaktionen beim Spielen ist breit. Neben linearen Spielen, die sich auf Fortschrittssysteme wie das Abschließen von Levels, das Fortschreiten einer Geschichte oder das Aufrüsten eines virtuellen Charakters konzentrieren, bieten Spiele mit offenem Ende ein emergentes Gameplay. Diese Spiele legen bestimmte Regeln und Mechanismen fest, zwingen SpielerInnen aber nicht dazu, ein festgelegtes Ziel auf eine bestimmte Weise zu erreichen. Sie erlauben es den SpielerInnen, den Inhalt des Spiels auf neugierige und freie Weise zu erkunden. Zu den Spielgenres, die mit einer solchen Offenheit in Verbindung gebracht werden, gehören Sandkastenspiele und City-Builder, die den SpielerInnen die Möglichkeit geben, sich spielerisch und kreativ auszudrücken. Mit den Werkzeugen, die die Spiele bereitstellen, erschaffen und gestalten die SpielerInnen Welten, sie formen das Terrain dieser Welten, indem sie Hügel, Täler, Flüsse und Schluchten erschaffen. Außerdem können die SpielerInnen diese Welten mit städtischen Strukturen wie Straßen oder Gebäuden verschönern. Diese Spiele regen die Kreativität an und schaffen ein Gefühl der spielerischen Auseinandersetzung, das es den SpielerInnen ermöglicht, die Herausforderungen im Spiel auf neugierige und neuartige Weise anzugehen.

Neben der Unterhaltungsindustrie wird der Nutzen von Spielen für ernsthafte Zwecke seit Jahrzehnten von der HCI-Forschung erkannt und untersucht. Da Spiele in der Lage sind, emotionale Bedürfnisse zu befriedigen, wurden sie auf ihr Potenzial hin untersucht, das Lernen, die Verhaltensänderung, die Motivation zur Bewegung und viele andere Bereiche jenseits der Unterhaltung zu unterstützen. Ein solcher Bereich ist die Psychotherapie. Speziell für die Behandlung von Phobien deuten Studien darauf hin, dass die Einbeziehung von Videospielen den Therapieverlauf positiv beeinflussen kann. Diese Spiele enthalten in der Regel Konzepte aus den Bereichen der Verhaltens- und Konfrontationstherapie, der gängigsten Behandlungstechnik für einfache Phobien. Durch die Gamifizierung dieser Techniken oder die Implementierung von Serious Games kann die Motivation, eine Therapie in Anspruch zu nehmen, gesteigert werden, so dass mehr Menschen Zugang zu professionellen psychotherapeutischen Interventionen erhalten.

In dieser Arbeit untersuche ich das Zusammenspiel von Spielen, die kreativen Selbstausdruck ermöglichen, und Psychotherapie zur Behandlung von Phobien. Die hier vorgestellte Arbeit setzt sich aus drei verschiedenen Untersuchungsbereichen zusammen, die unterschiedliche Aspekte dieses Ansatzes beleuchten. Zunächst untersucht die Arbeit auf der Grundlage einer Anforderungsanalyse und von Praxisevaluierungen mit BranchenexpertInnen aus den Bereichen Animation, Film und Theater den Einsatz von NUIs zur Unterstützung von Fachleuten mit geringem technischem Fachwissen, aber hochtechnischen Aufgaben in ihrem Alltag. So zeige ich, wie NUIs TherapeutInnen bei der Konfiguration, Wartung und Nutzung von VRET-Systemen unterstützen kann. Der zweite Bereich befasst sich mit der Definition einer Spiel-Design-Strategie, die für die Behandlung von Phobien geeignet ist. Im Verlauf dieser Arbeit argumentiere ich, dass das Spieldesign für die Behandlung von Phobien spezifische Anforderungen berücksichtigen muss, die von der bisherigen Forschung in diesem Bereich nicht abgedeckt wurden. Basierend auf diesen Anforderungen, die mit TherapeutInnen identifiziert wurden, wird in dieser Arbeit ein neuartiges Konzept - playful user-generated treatment (PUT) - vorgestellt, das diese Anforderungen für eine anwendbare Ergänzung der Therapie berücksichtigt. Eine Evaluation in Form einer Nutzerstudie und einer Expertenbefragung zeigt Chancen und Herausforderungen auf, die PUT mit sich bringt. Das dritte und letzte Forschungsthema befasst sich mit der Einbeziehung von PCG in das PUT-Konzept, um die technische Komplexität zu verringern und die Mensch-Computer-Ko-Kreation zu fördern. Dieser Abschnitt behandelt die Auswirkungen von PCG auf die selbsteingeschätzte Kreativitätsunterstützung und die Einbeziehung der BenutzerInnen bei einer spielerischen Stadtentwicklungsaufgabe, wie sie im PUT-Konzept definiert ist.

Auf der Grundlage der in dieser Thesis berichteten Arbeiten wurden die folgenden Erkenntnisse gewonnen. Bei der Entwicklung von Systemen, die von Nutzern mit hohen technischen Anforderungen und geringen technischen Kenntnissen wie TherapeutInnen und PatientInnen in einem VRET-Kontext verwendet werden sollen, können NUIs als Werkzeuge dienen, um die technische Komplexität zu verringern und gleichzeitig die Vorteile neuartiger Technologien zu nutzen. Darüber hinaus müssen bei der Implementierung von spielerischen VRET-Systemen spezifische Anforderungen im Designprozess berücksichtigt werden, um den Therapieerfolg nicht zu beeinträchtigen. Die vorgestellte PUT-Designstrategie erfüllt diese Anforderungen und kann verwendet werden, um die positiven Effekte des spielerischen kreativen Selbstausdrucks in einem VRET-Szenario zu nutzen. Schließlich zeigen die Ergebnisse dieser Arbeit, dass die Einbeziehung von PCG in ein PUT-basiertes System die selbstberichtete Kreativitätsförderung nicht beeinträchtigt.

Durch die Untersuchung dieser Forschungsthemen leistet diese Arbeit einen Beitrag zu den Bereichen der natürlichen Interaktion, wie sie durch NUIs ermöglicht wird, motivationale Aspekte von GUR, PCG in Videospielen, Kreativität und Selbstausdruck durch spielerische Auseinandersetzung und die Einbeziehung spielerischer Elemente in das VRET-Verfahren.

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# Glossary

**AI** artificial intelligence.
**AR** augmented reality.

**CBT** cognitive-behavioral therapy.
**CRediT** contributor roles taxonomy.
**CSI** creativity support index.
**CST** creativity support tool.

**ET** exposure therapy.

**FFM** five factor model.

**GUR** games user research.

**HCI** human-computer interaction.

**IQ** intelligence quotient.

**NUI** natural user interface.

**PCG** procedural content generation.
**PUT** playful user-generated treatment.

**RQ** research question.
**RT** research theme.

**SDT** self-determination theory.
**SOI** structure of intellect.
**SUS** system usability scale.

**TLX** NASA task load index.
**TTCT** Torrance test of creative thinking.
**TUI** tangible user interface.

**UES-FA** user engagement scale - focused attention.
**UES-SF** user engagement scale - short form.
**UX** user experience.

**VR** virtual reality.
**VRET** virtual reality exposure therapy.

# Part I.

# Thesis

# 1. Introduction

Play is a voluntary and free process that allows people (players) to temporarily leave their ordinary reality behind and step into a "sphere of activity" with its own rules and goals (Huizinga, 1949). Playing leads to Playfulness, a state of mind that entails creativity, curiosity, a sense of humor, pleasure, and spontaneity (Guitard et al., 2005). Adults play for various reasons: to indicate intimacy, trust, security, and interdependence, to communicate and deal with conflict, and to alleviate stress (Van Vleet and Feeney, 2015). In the realm of psychotherapy, playfulness has been identified as a factor beneficial to the therapeutic process when dealing with anxiety disorders (Schaefer and Greenberg, 1997). One core quality of play when translated to video games is the ability to stimulate creativity and self-expression of players (Bowman et al., 2015). Though there is a growing body of work investigating the use of video games for therapeutic purposes (Ceranoglu, 2010), this quality of video games - the capacity to trigger playful creative self-expression - has rarely been researched in the context of psychotherapy. This is the starting point of this thesis. I will investigate how playful creative self-expression as facilitated by video games, may benefit psychotherapy for both patients and practitioners. As an application domain, I have chosen the treatment of simple phobias via ET.

Simple phobias, which describe the fear of specific stimuli are among the most common mental health disorders in the world (Page, 1991). Those affected by simple phobias experience anxiety when exposed to animals or insects, blood or injury, situations, or other specific stimuli (Goisman et al., 1998). Studies show that 7-9 % of the population in western societies were, at some point in their lives, diagnosed with a simple phobia (Association, 2022), leading to psychosomatic symptoms such as dizziness, heavy sweating, loss of consciousness or panic attacks (WHO, 2022). Moreover, simple phobias often lead to accompanying diseases (comorbidities), depending on the type of phobia such as major depression, generalized anxiety disorder, panic disorder, alcoholism, and eating disorders (Goisman et al., 1998; Kendler et al., 1992).

One of the most common ways of treating simple phobias is to apply exposure therapy (ET) (Neudeck, 2005) which is a kind of cognitive-behavioral therapy (CBT) (Abramowitz, 2013). CBT entails a collection of interventions that aim to change maladaptive cognitions in order to treat mental disorders and thereby lower psychological and emotional distress as well as diminish problematic behaviors (Hofmann et al., 2012). Undergoing ET, patients are confronted with a fear-inducing stimulus as a way to steadily teach coping strategies for these situations and ultimately, counteract psychological and emotional stress (Foa and McNally, 1996).

For certain phobias, actual exposure to the fear-evoking stimulus is not feasible. For instance, treating fear of flying (aviophobia) with ET is economically challenging whereas exposing a survivor of child molestation to a real stimulus would be unethical (Richard and Lauterbach, 2011). Therefore, instead of exposing patients to stimuli in reality (*in-vivo*) or in an imaginative form (*in-sensu*) (Foa and Kozak, 1986), a growing body of work is investigating how to conduct ET *in-virtuo*, meaning that therapy includes some VR component (Opriş et al., 2012). Multiple studies show that VRET can be successfully incorporated into therapy, proving to be just as effective as traditional ET (Côté and Bouchard, 2008; Opriş et al., 2012; Parsons and Rizzo, 2008). However, the use of VRET also brings certain challenges with it like the high level of technical complexity that requires therapists and patients to acquire skills to use, design, and maintain those environments (Côté and Bouchard, 2008). Therefore, although having a lot of professional experience, therapists and patients alike have varying levels of technical expertise and thus, may be hindered to use these technologies effectively. This in turn creates a barrier that prevents VRET systems from being used more frequently in therapy scenarios. Even though such barriers exist, the positives of VRET still outweigh the negatives by overcoming the many problems that (*in-vivo*) therapy entails. Hence, one aim of this thesis is to examine how technology can support technical novices by empowering them instead of creating additional technological barriers.

Despite the grievous nature of phobias and the overall reduction of quality of life, affected people tend to avoid anxiety-inducing situations instead of seeking treatment via professional help as a way to cope with the phobia (Boyd et al., 1990; Magee et al., 1996). Moreover, even after seeking professional help, up to 45% of patients drop out of therapy (Botella et al., 2011). Reasons for abandoning therapy are (among others) a low perceived need for treatment (Andrade et al., 2014), perceiving therapy as threatening (Choy et al., 2007), general aversion to ET (Richard and Gloster, 2007) or an overall lack of motivation (Benbow and Anderson, 2019; Granic et al., 2014). To foster motivation to seek treatment, GUR may provide solutions for this problem in the form of *serious games* (Abt, 1970) and *gamification* (Deterding et al., 2011). Many approaches in this field are based on the concepts of self-determination theory (SDT) which postulates that human motivation is impacted by three basic needs that need to be fulfilled - autonomy, competence, and relatedness (Ryan and Deci, 2000). Autonomy describes the need to be in control of one's own life, set individual goals, and be able to express self-defined behavior. Competence expresses the need to be effective when dealing with situations and challenges of the outside world. Lastly, relatedness is the need to form connections with other people, to establish emotional and affectionate bonds. Since video games have the capacity to address these needs, they have been employed to foster motivation in various fields of study (Ryan et al., 2006). Previous studies have shown the potential of utilizing video games for the context of mental health interventions and therapy (Botella et al., 2011; Fernández-Aranda et al., 2012; Mandryk and Birk, 2017). However, ET requires thorough consideration when designing applications for the use of therapy since they should not interfere with therapeutic methods and thus, prevent successful treatment. Therefore, it is challenging to design playful applications for therapy since they may feel too game-like and thus, have only limited therapeutic use (Bouchard et al., 2006). This is another aspect that will be examined in the scope of this thesis by investigating how

GUR and psychotherapy can be combined whilst not interfering with therapy success.

There are already multiple studies that show that the use of video games for therapeutic purposes (e.g. alleviating anxiety) can be successful and comparable to traditional therapy measures (Abd-alrazaq et al., 2022). However, as stated before, the inclusion of interactive media into the workflow of therapy may overwhelm patients and therapists by introducing technical requirements that may not be met by these users (Lindner et al., 2017). As a way to counter this, PCG, defined as “the algorithmical creation of game content with limited or indirect user input” (Togelius et al., 2011), may be a helpful tool. In the form of *human-machine co-creation*, PCG has been demonstrated to be useful in helping players to achieve their goals by enabling and fostering human creativity (Alvarez et al., 2018; Liapis et al., 2016; Yannakakis et al., 2014). Therefore, as a final area of interest, this thesis will look into the applicability of PCG in the context of games created for therapy.

## 1.1. Research Contribution

The aim of this thesis is to provide a solution for empowering psychotherapy based on insights from GUR by investigating the following overall research theme (RT):

*How should playful applications that give the opportunity for creative self-expression be designed in order to be applicable in the context of exposure therapy whilst not interfering with therapeutic success and keeping technical complexity to a minimum?*

As an exemplary therapy scenario, I have picked the treatment of *acrophobia* which is defined by the WHO as a specific phobia characterized by a fear that is induced by exposure or anticipation of exposure to heights (WHO, 2022). Acrophobia was chosen since it is one of the most researched use case scenarios in HCI and VRET with earliest published studies dating back to the 1990s and early 2000s (Emmelkamp et al., 2002, 2001; Rothbaum et al., 1995). Based on the defined RT and located within the context of treatment for acrophobia, I have derived the following research questions to guide the work reported in this thesis:

**RQ1**: As a first step in addressing the research theme, RQ1 will examine what kind of interaction style fits best to support users who are novices in terms of technical expertise but have high technical demand to perform certain tasks. For psychotherapists, the use of technology for therapeutic treatments has been challenging due to a high requirement of technical skill to maintain and operate computer-assisted applications (Lindner et al., 2017). The question remains, how technology can be utilized to support novices such as therapists and patients when conducting VRET whilst making the interaction feel natural and without interfering with therapy success? Therefore, I will examine if natural user interfaces (NUIs) may be useful for this purpose. In summary, RQ1 investigates: What kind of interaction is suitable to support users who are novices in terms of technical expertise but have high technical demand in their everyday lives?

**RQ2**: The second research question is concerned with the design of playful VR applications and how they can be integrated into existing procedures in exposure therapy. Since exposure therapy poses specific challenges to the design of such applications, the first step in the design process is to investigate what specific requirements need to be met by a playful application so it becomes applicable in the context of therapy. Moreover, it needs to be examined what kind of game content the application should provide or more specifically, what *mechanics* and *dynamics* (Hunicke et al., 2004) should be included in the game that do not potentially prevent therapy success. In summary, the result of investigating the second research question will be a game design strategy that fulfills these needs. In summary, RQ2 investigates: What kind of game design strategy can be utilized in the context of psychotherapy without interfering with therapy success?

**RQ3**: Based on the outcome of investigating RQ2, the third research question addresses the level of technical complexity for the game design strategy derived in RQ2. As a way to support players, I will examine the use of PCG and investigate if the inclusion of PCG is perceived as helpful or disturbing during gameplay. Additionally, this research question is concerned with the impact of PCG on players' self-reported creativity. As a result, RQ3 will provide insights regarding the interplay of PCG and creativity in the context of a therapeutic game for the treatment of acrophobia. In summary, RQ3 investigates: In the context of a playful approach to psychotherapy, can PCG be applied to lower the level of technical complexity without notably decreasing creativity as perceived by players?

By addressing these research questions, this thesis contributes to the domains of games user research (GUR) and virtual reality exposure therapy (VRET) by identifying how the motivational pull of video games as well as various benefits of playing video games can be integrated into the procedure of therapy in an applicable way. More specifically, these are the main contributions that are included in the publications that make up this thesis:

- A case study based on a requirement analysis that investigates the use of natural user interface (NUI) for the support of users that have low technical expertise but high technical demand in their everyday work life ($P1$, $P4$ & $P5$).
- A requirement analysis for the use of playful elements in therapeutic applications based on expert interviews ($P2$).
- A formalization and evaluation of a game design strategy that allows for the integration of playful content into a series ET application ($P2$ & $P6$).
- A requirement analysis for the integration of procedural content generation (PCG) into playful multi-user scenarios ($P7$).
- An investigation of procedural methods to generate content in a playful creative application and how they impact creativity ($P3$).

These contributions were peer-reviewed and published in various venues and journals. At the end of this chapter, I have added an overview of all included publications. In Part II of this thesis, personal contributions will be depicted for each publication based on the contributor roles taxonomy (CRediT) (Brand et al., 2015).

## 1.2. Thesis Outline

The thesis document is divided into two parts. Part I addresses the research questions stated above and is structured as follows. First, I will provide an overview regarding all relevant scientific publications in correspondence to the stated research questions (RQ1, RQ2, RQ3). Following this, I will cover related research from various domains that touch on the topics discussed in this thesis, including NUIs, CBT, VRET, creativity and creativity support, and PCG. The subsequent chapters will illustrate my methodological approach to address the stated research theme and research questions by providing a summary and elaboration of my publications that were submitted to various scientific venues. The next chapter will discuss the implications of my work and will serve to reflect on the findings and their meaning for the stated research questions. Additionally, limitations and how this work is to be framed will be discussed in that chapter. Finally, the last chapter will give a brief outlook on future directions and will conclude this work. The second part of this thesis consists of a collection of all publications that this thesis is composed of. Moreover, an assessment of each author's contribution to a publication will be depicted there.

## 1.3. Overview of Publications

This is a concise list of all scientific papers that were published in the scope of this thesis. For a more comprehensive overview, full versions of each work can be found in part II of the thesis.

| | |
|---|---|
| *P*1 | Georg Volkmar, Thomas Münder, Dirk Wenig, and Rainer Malaka. (2020, April). **Evaluation of Natural User Interfaces in the Creative Industries.** In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (pp. 1-8).* (Volkmar et al., 2020b) |
| *P*2 | Dmitry Alexandrovsky, Georg Volkmar, Maximilian Spliethöver, Stefan Finke, Marc Herrlich, Tanja Döring, Jan David Smeddinck, and Rainer Malaka. (2020, November). **Playful User-Generated Treatment: A Novel Game Design Approach for VR Exposure Therapy.** In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (pp. 32-45).* (Alexandrovsky et al., 2020b) |
| *P*3 | Georg Volkmar, Dmitry Alexandrovsky, Asmus Eike Eilks, Dirk Queck, Marc Herrlich, and Rainer Malaka. (2022, October). **Effects of PCG on Creativity in Playful City-Building Environments in VR** In *PACM on Human-Computer Interaction, Vol. 6, No. CHI PLAY, Article 230* (Volkmar et al., 2022) |
| *P*4 | Thomas Muender, Georg Volkmar, Dirk Wenig, and Rainer Malaka. (2019, May). **Analysis of previsualization tasks for animation, film and theater.** In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (pp. 1-6).* (Muender et al., 2019) |
| *P*5 | Rainer Malaka, Tanja Döring, Thomas Fröhlich, Thomas Muender, Georg Volkmar, Dirk Wenig, and Nima Zargham. (2021). **Using Natural User Interfaces for Previsualization.** In *EAI Endorsed Transactions on Creative Technologies, 8(26), e5.* (Malaka et al., 2021) |
| *P*6 | Georg Volkmar, Dmitry Alexandrovsky, Jan David Smeddinck, Marc Herrlich, and Rainer Malaka. (2020, November). **Playful User-Generated Treatment: Expert Perspectives on Opportunities and Design Challenges.** In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play (pp. 398-402).* (Volkmar et al., 2020a) |
| *P*7 | Georg Volkmar, Nikolas Mählmann, and Rainer Malaka (2019, November). **Procedural content generation in competitive multiplayer platform games.** In *Joint International Conference on Entertainment Computing and Serious Games (pp. 228-234).* Springer, Cham. (Volkmar et al., 2019a) |
| *P*8 | Georg Volkmar, Nina Wenig, and Rainer Malaka. (2018, October). **Memorial Quest-A Location-based Serious Game for Cultural Heritage Preservation.** In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts (pp. 661-668).* (Volkmar et al., 2018) |
| *P*9 | Georg Volkmar, Johannes Pfau, Rudolf Teise, and Rainer Malaka (2019, October). **Player Types and Achievements–Using Adaptive Game Design to Foster Intrinsic Motivation.** In *Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts (pp. 747-754).* (Volkmar et al., 2019b) |
| *P*10 | Mehrdad Bahrini, Georg Volkmar, Jonas Schmutte, Nina Wenig, Karsten Sohr, and Rainer Malaka (2019). **Make my phone secure! Using gamification for mobile security settings.** In *Proceedings of Mensch und Computer 2019 (pp. 299-308).* (Bahrini et al., 2019) |

# 2. Background & State of Research

This chapter is concerned with covering the current state of research in regard to the various topics that this thesis touches on. I have divided this chapter into three broad segments that lay the theoretical foundations as well as showcase relevant related works for each research domain. The first section will address the area of psychotherapy and how technology and games have been incorporated into this context. This relates to research questions RQ1 and RQ2. Following this, the concept of creativity in the context of video games and self-expression is examined and a definition is derived for the scope of this thesis. This is important in the context of all research questions since creativity is a common theme among them and needs to be defined explicitly. Finally, the last section illustrated current approaches in PCG for the use in creating cityscapes and terrains which is vital in the context of RQ3.

## 2.1. Psychotherapy and Game Design

In the scope of this thesis, I investigate how therapeutic procedures from the domain of CBT and VRET can be supported by a game design strategy that does not interfere with the success of therapy. Therefore, the following sections will provide some background information on these topics.

### 2.1.1. Virtual Reality Exposure Therapy

Exposure therapy is based on the concept of cognitive-behavioral therapy which describes a structured approach to treating mental illnesses by investigating the links between people's emotions, thoughts, and behaviors (Fenn and Byrne, 2013). This model is based on the ideas postulated by Ellis (1962) and Beck (1970) who state that an individual's beliefs about themselves and the world around them, their expectancies, and assumptions directly impact their mental health and lead to unwanted behaviors. In the context of simple phobias, the unwanted behavior would entail avoidance of the fear-inducing stimuli to reduce emotional stress and fear and thus, create a sense of security. This behavior can be characterized as unwanted since it only reduces fear for the short term and prevents a sustainable treatment of the phobia offering no long-term solution to reduce anxiety (Abramowitz, 2013). Exposure therapy offers an alternative to avoidance strategies by confronting people affected by phobias with the anxiety-evoking stimulus either in reality (*in-vivo*) or by including some representation of the stimulus (*in-sensu*) (Foa and Kozak, 1986). In any case, exposure to the stimulus happens repeatedly over a period of multiple therapy sessions (Richard and Lauterbach, 2011). Hereby, the patient is exposed to the stimulus either in an immediate fashion (*flooding*) or by gradually increasing the intensity of the stimulus (*graded exposure*) which is a more common approach. Exposing patients to anxiety-inducing stimuli helps them to confront those fears in a safe environment which in turn reduces anxiety and the need for avoidance behavior in the long term (American Psychological Association, 2017). ET is usually considered to be successful if a state of *habituation* is reached which means that the stimulus no longer evokes any fear in phobic patients or that the feeling of fear has reached an acceptable level (Foa and Kozak, 1986). Additionally, ET aims to invoke a state of *cognitive reevaluation* in which patients reflect upon their experience of being exposed to anxiety-inducing stimuli and in the process, eliminate their maladaptive cognitions (Neudeck, 2005).

Performing ET *in-vivo* is challenging for many reasons. One major disadvantage of *in-vivo* exposure is that it can be economically demanding for certain phobias. For instance, treating *aviophobia* (fear of flying) with some kind of ET requires patients to book an airplane to face their fears which is simply not feasible for many people. Ethical concerns are another issue. Treating a victim of child abuse with traditional ET in an ethical way is nearly impossible (Richard and Lauterbach, 2011). For some patients, the thought of undergoing ET is simply too frightening (Emmelkamp et al., 2001). Therefore, a rather recent approach to perform ET comes in the form of *in-virtuo* therapy, implemented as virtual reality exposure therapy (VRET) (Opriş et al., 2012). This form of therapy includes some sort of VR technology, usually realized by a head-mounted display (HMD) which is capable of creating an immersive environment (Bowman and McMahan, 2007) and enables individual adjustments for each patient (Powers and Emmelkamp, 2008). Multiple studies indicate that VRET is not only a viable alternative to traditional ET in cases where it is cheaper or the more ethical variant but can actually be as effective (Botella et al., 2017; Coelho et al., 2009; Garcia-Palacios et al., 2007; Gregg and Tarrier, 2007). This effect is observable for various phobias. One prominent use case is the treatment of *acrophobia* or fear of heights. Starting in the early to mid-1990s, researchers began to examine the effects and potential benefits of VRET interventions (Hodges et al., 1995). The first reported controlled study that examined the efficacy of VRET in the context of acrophobia was conducted in 1995 by Rothbaum et al. (1995). In this study, a 19-year-old undergrad student suffering from a fear of heights underwent a series of VRET interventions using an HMD. Even though, VR technology at the time was still limited in terms of graphical fidelity and comfort in wearing, this study showed that VRET could be applied successfully by reducing fear, avoidance behavior, and distress (Rothbaum et al., 1995). Following these promising results, a number of studies were conducted that compared the efficacy of VRET with traditional *in-vivo* ET. One of the earliest comparative studies was conducted by Emmelkamp et al. (2001) who applied *in-vivo* and *in-virtuo* treatment for ten acrophobic patients in a within-subjects design. Interestingly, they found that VRET was not only as effective as *in-vivo* therapy but even more effective concerning certain attitudes towards heights (Emmelkamp et al., 2001). These results were confirmed in a follow-up between-groups study conducted by Emmelkamp et al. (2002) including 33 patients with acrophobia. Though VRET was not assessed to be more effective than *in-vivo* exposure in this study, it was still as effective on all deployed questionnaires measuring fear, attitude towards heights, and avoidance (Emmelkamp et al., 2002). Based on these results, Krijn et al. (2004a) compared VR technologies that differed in the extent of presence they were able to create. For both low presence technology (HMD) and high presence technology as realized by a computer automatic environment (CAVE), VRET proved to be more effective than the no treatment control group but showed no differences between these two groups (Krijn et al., 2004a). In addition to subjective, self-reported measures regarding anxiety and behavior, Diemer et al. (2016) investigated how physiological arousal may occur when being exposed to VRET applications. They found that VR exposition to heights leads to physiological reactions (e.g. rise in heart rate and skin conductance), in both healthy and acrophobic participants (Diemer et al., 2016). Freeman et al. (2018) conducted a large-scale between-groups study including 100 acrophobic participants and compared an automated VR intervention administered by a virtual coach to a traditional face-to-face treatment. In accordance with previous findings, they found that VRET was effective in reducing fear whilst not leading to a high level of discomfort for the patients (Freeman et al., 2018). The focus of this thesis lies in the treatment of acrophobia but VRET has been successfully applied to a variety of other phobias as well. Studies indicate the efficacy of VRET for fear of flying (*aviophobia*) (Krijn et al., 2007; Mühlberger et al., 2003; Rothbaum et al., 2000), social anxiety & public speaking (Klinger et al., 2005; Koller et al., 2019), fear of confined spaces (*claustrophobia*) (Botella et al., 1999; Malbos et al., 2008) and other anxiety disorders (Gorini and Riva, 2008; Krijn et al., 2004b).

### 2.1.2. Games for Therapy

The engaging quality of video games has been scrutinized by a number of psychological theories. Out of these, *flow theory* (Csikszentmihalyi, 1990) and self-determination theory (SDT) (Ryan and Deci, 2000) are the most prominent theories that current advances in the field of GUR are based on (Boyle et al., 2012; Tyack and Mekler, 2020). The potential of video games for uses that go beyond entertainment has been researched and discussed for decades. In particular, two game design approaches have demonstrated how games can facilitate motivation to learn, exercise, or outright change behavior (Susi et al., 2015) - *gamification* and *serious games* (Abt, 1970; Deterding et al., 2011). For both approaches, I have investigated the effects of playing in regard to learning and motivation in two publications. In publication $P8$ (Volkmar et al., 2018), a *serious game* for learning about the cultural heritage of memorials and landmarks in the player's vicinity was designed and evaluated. On the other hand, publication $P10$ (Bahrini et al., 2019) is concerned with the *gamification* of a security settings task for smartphone use and how this method can improve motivation to engage with this topic. For mental health-related issues, a number of studies illustrate how these game-based approaches can be beneficial in many ways. Since mental illnesses are one of the core challenges of our times, HCI can serve as a means to provide cost-effective, engaging, and accessible ways for treatment (Coyle et al., 2007). Over the past decades, many studies have investigated the value of video games in the context of psychotherapy (Griffiths, 2005). Games can be a useful addition in supporting mental health due to their motivational pull, broad appeal, accessibility, and potential for personalization (Mandryk and Birk, 2017). Multiple studies indicate that games that include concepts from CBT, *exergames* (a combination of exertion and video games (Oh and Yang, 2010)), and biofeedback games can successfully alleviate anxiety and are at the very least more effective than no intervention (Abd-alrazaq et al., 2022). Here, I will provide a concise overview of various game-based approaches to support therapy.

Regarding the treatment of *acrophobia* with the support of game-based approaches, there is a growing body of scientific work. Costa et al. (2014) describe the design and implementation of a VR game that can be played in a CAVE environment. In the game, players can climb from lower to higher levels of a virtual building and hereby, increase the intensity level of the anxiety-inducing stimulus (height). In addition to subjective questionnaires, the application allows for the recording of physiological data (e.g. EEG) which is then used as feedback for patients and therapists (Costa et al., 2014). Similarly, work reported by Anton et al. (2020) suggests combining objective and subjective data in a game environment for the treatment of *acrophobia*. For their game, the authors chose an urban setting in which players have to climb various buildings. In the game, players can activate a relaxing modality such as an image of a quote that they chose beforehand. Additionally, the game offers simple tasks like collecting objects or firing at targets (Anton et al., 2020). In collaboration with psychologists and patients, Darooei et al. (2019) developed *BarBam*, a VR game for the treatment of fear of heights. The game offers different scenarios for inducing anxiety in the player in the form of a city level and a bridge level. Gameplay consisted of grabbing, placing, and throwing objects and simply spending time in the environments. In a pilot study that included 13 acrophobic patients and two therapists, the application was evaluated qualitatively and was assessed to be an applicable treatment tool by patients and therapists alike (Darooei et al., 2019).

As a way to treat *accident phobia*, which can occur after being involved in a car accident, Walshe et al. (2003) developed a VRET game that was evaluated with patients who met the criteria for this phobia. Subjects were exposed to digital driving environments in both desktop video games and VR driving simulators. Pre-post tests revealed that for both environments (desktop and VR), participants showed significant reductions in travel distress, travel avoidance, maladaptive driving strategies, and other related measures (Walshe et al., 2003).

Various studies report the applicability of therapeutic games for mental health-related problems for the target group of children and adolescents. One of the earliest examples is a 3D game called *Personal Investigator* (*PI*), which was developed by Coyle et al. (2005) to help adolescents engage with therapy. *PI* is based on a psychotherapeutic model called *Solution Focused Therapy* (*SFT*), which is a goal-oriented approach focused on the strengths of patients. In this game, players take the role of a detective and are tasked to define and solve personal problems in collaboration with the therapist using interactive storytelling techniques (Coyle et al., 2005). As a way to make CBT more approachable for children, Brezinka (2014) designed, implemented, and evaluated the game *Treasure Hunt*. This game aims to support children who suffer from a variety of mental health issues and was evaluated in real-life therapy sessions. Responses from therapists and children suggested that the game helped to engage with therapeutic concepts (Brezinka, 2014).

As an alternative to developing new games, Bouchard et al. (2006) describe the process of altering already existing games like *Half Life* (Valve, 1998) for the purpose of creating a virtual environment for the treatment of *arachnophobia* (fear of spiders). The game took place in a virtual bunker with six different rooms which offered varying levels of intensity regarding the stimulus (as quantified by spider size). Interactivity was limited to walking toward the spiders and simply being in the same room as them. Pre and post-tests revealed a significant reduction in avoidance behavior and self-reported self-efficacy (Bouchard et al., 2006). A mobile serious game for the treatment of cockroach phobia was developed by Botella et al. (2011) and evaluated with a single patient suffering from this phobia. In this study, the patient played the game before being exposed to the stimulus via an augmented reality (AR) exposure. The *Cockroach Game* is a mobile puzzle game in which players have to interact with digital cockroaches to solve the puzzle-matching task. Results showed that playing the game reduced the avoidance behavior of the patient (Botella et al., 2011).

There are game-based approaches that focus on the treatment of impulse-related disorders such as *bulimia*, one of the most common eating disorders. One prominent example is *PlayMancer*, a game that teaches relaxation skills, self-control strategies, and emotion regulation techniques based on biofeedback (Fernández-Aranda et al., 2012). The game features various scenarios, implemented as islands that incorporate CBT-based concepts in an adventure game. The goal is to achieve a higher level of self-control rather than "winning" the game. *PlayMancer* was evaluated with 38 bulimic patients in a follow-up study. Analysis of the data gathered in this study showed that the combination of traditional CBT-techniques and serious games can lead to short-term improvement of eating behavior, anxiety, and anger expression in patients diagnosed with bulimia (Fernandez-Aranda et al., 2015).

## 2.2. Creativity and HCI

This thesis is concerned with the concept of creativity. First, I will give a comprehensive overview of how creativity can be defined and understood from various angles. Following this, I will derive a definition of how creativity is to be understood for the scope of this thesis.

### 2.2.1. Lenses for Viewing Creativity

There have been many attempts to grasp the concept of creativity (Hennessey and Amabile, 2010), coming from various disciplines such as developmental theories, psychometric theories, economics, cognitive theories, systems theories, evolutionary theories, and typological theories. Creativity can also be understood as a stage and componential process, an act of problem-solving based on expertise or an act of problem-finding (Jackson and Games, 2015; Kozbelt et al., 2010). In this section, I will go through these approaches and relate them to current developments in HCI when possible.

Developmental theories of creativity assume that creativity develops over time, turning potential into achievement through the interaction of a person and their environment Kozbelt et al. (2010). These theories have a strong focus on family structures (Goertzel and Goertzel, 1962) and how parents play a key role in fostering their children's creativity through play (Ayman-Nolley, 1999; Pearson et al., 2008; Russ and Schafer, 2006) and independence (Albert and Runco, 1988). Studies suggest that, given the right conditions such as independence and a less restrictive parenting approach, children and young adults may develop creative talent over time (Helson, 1999; Noble et al., 1999; Plucker, 1999; Runco, 1999). In HCI, there is some research regarding developmental theories of creativity. As an example, there are studies that suggest that the use of tangible user interfaces (TUIs) can help children to express themselves creatively (Bevans et al., 2011). Moreover, there are plenty of studies that show how video games such as Minecraft (Studios, 2011) can foster creativity in children (Blanco-Herrera et al., 2019; Karsenti and Bugmann, 2017; Moffat et al., 2017; Sáez-López et al., 2015)

Psychometric theories are concerned with assessing creativity through measurement. They proclaim that creativity can be measured in a reliable and valid way as a construct differing from other related constructs such as intelligence quotient (IQ) (Wallach and Kogan, 1965). One of the earliest examples has been defined by Guilford who describes creativity as a measurable construct as part of the structure of intellect (SOI) theory (Guilford, 1968, 1988). According to the SOI theory, creativity can be measured if the test environment and the test itself allow for *divergent* thinking and production (Guilford, 1968). Based on these theories, various tests have been established that aim to assess specific aspects of creativity. One of the earliest tests of creativity is the Torrance test of creative thinking (TTCT) (Torrance, 1966) which was revised multiple times (Kim, 2006) and stands as the most commonly used test of creativity (Davis, 1997). In its latest version, the TTCT consists of two parts: *figural* and *verbal* forms. In total, five subscales are measured: *Fluency*, *Originality*, *Elaboration*, *Abstractness of Titles*, and *Resistance to Premature Closure* (Torrance, 1998). In the context of HCI, tests are focused on how computer applications can serve as creativity support tools (CSTs) (Gabriel et al., 2016; Greene, 2002; Shneiderman, 2002) and how the extent to which creativity is supported can be measured. A validated questionnaire to measure creativity support is the creativity support index (CSI) which describes creativity support as a combination of six subscales: *Enjoyment*, *Exploration*, *Expressiveness*, *Immersion*, *Results worth Effort* and *Collaboration* (Carroll and Latulipe, 2009; Carroll et al., 2009; Cherry and Latulipe, 2014).

In the context of economics, creativity is often approached as a human trait that is influenced by the supply and demand of the free market. From this perspective, creativity emerges when humans invest in creative ability based on their calculation of personal and temporal cost and potential benefits of intrinsic or extrinsic value (Rubenson and Runco, 1992). The *investment theory of creativity* claims that, in order to make a profit, creative people should "buy low and sell high" in terms of their creative investment (Sternberg and Lubart, 1993). The importance of creativity as an economic factor has been recognized by HCI research as well. Again, prior research suggests that in becoming CSTs, interactive tools can elevate creativity to become a major contributor to economic growth (Candy and Hori, 2003; Frich et al., 2018; Shneiderman, 2009).

Cognitive theories of creativity focus on the mental ideation of creative people based on the assumption that differences in creative abilities between people can, to some extent, be explained by differences in cognition (Kozbelt et al., 2010). These theories explore the underlying cognitive processes that contribute towards creative thinking (Gabora, 2002). For instance, one cognitive theory of creativity assumes that creative ideas are formed by remote associations between already established concepts (Mednick, 1962). In that sense, people are more creative if they have the ability to construct these remote associations. Another noteworthy theory called *Cognitive Cognition* draws from insights of cognitive psychology to investigate how people become creative by generating ideas and considering implications (Finke et al., 1992). HCI research has contributed to this field by identifying cognitive patterns of idea generation and how digital media can support them (Chavula et al., 2022; Kohls, 2015).

Systems theories place a large focus on the interplay of various factors such as societal conditions (Sawyer, 2011) that constitute complex systems in which creativity occurs. One prominent systems theory of creativity has been composed by Csikszentmihalyi (1998, 2014), who emphasized the environment and place where creativity can flourish more than the creative person behind it as prior systems theories did (Gruber and Barrett, 1974). This intellectual approach is particularly interesting for HCI since it poses the question of how digital artifacts can contribute towards creating an environment that fosters creativity. Numerous studies investigate how technology such as VR can help to enable creativity (Graessler and Taplick, 2019; Obeid and Demirkan, 2020; Yang et al., 2018) and how *human-computer co-creativity* can be achieved by including artificial intelligence (AI) technology into the creative workflow (Liapis et al., 2016; Yannakakis et al., 2014).

As mentioned before, there are approaches to defining creativity that do not relate to HCI and are therefore not further scrutinized in the scope of this thesis. Among them are evolutionary theories like the theory of *blind-variation and selective-retention* (Campbell, 1960; Simonton, 1988, 1997), typological theories (Galenson, 2001, 2011; Kozbelt, 2008), stage and componential theories (Hennessey et al., 1999; Runco and Chand, 1995), problem solving (Ericsson, 1999; Simon, 1989, 2019; Weisberg, 1998, 2006) and problem finding theories (Getzels and Csikszentmihalyi, 1978; Runco, 1994).

### 2.2.2. A Working Definition of Creativity

In summary, creativity is a complex concept that can be viewed from a variety of different angles and perspectives, making it impossible to derive a single definition that entails creativity as a whole (Demirkan and Afacan, 2012; Horn and Salvendy, 2006; Obeid and Demirkan, 2020). Therefore, it is imperative to provide a definition of creativity and how it is to be understood in the context of this thesis. For this purpose, I have derived a working definition of creativity based on the *standard definition of creativity* (Runco and Jaeger, 2012). This definition simply states that “creativity requires both originality and effectiveness" and was first formulated in the $20^{th}$ century (Barron, 1955; Stein, 1953). Here, something is *original* when it is uncommon, novel, or unique whereas being *effective* can take on many forms such as being useful, fit, appropriate, or valuable depending on the context. For the scope of this thesis, both of these concepts will be defined more precisely. First, *originality* occurs when people create something novel through the process of play. Play can stimulate creative thinking by presenting challenges for players which have to be overcome in uncommon ways (Bowman et al., 2015; Huizinga, 1949). Second, *effectiveness*, in this context, is achieved if this playful process has value for the player based on their own assessment of the content created. Thus, this definition addresses creativity as a self-report measure of players and focuses on the process of play and the evaluation of the content by the players themselves. This thesis, therefore, conceives creativity as a psychometric measurement and is concerned with the design and evaluation of creativity support tools (Shneiderman, 2002).

### 2.2.3. The Interplay of City-Building Games and Creativity

Based on the definition of creativity given above, this section provides a brief overview of video game research that investigated how playing games impacts players' creativity. More specifically, this section is concerned with playful city-building environments and sandbox games and reports research that was conducted in this field. City-building games are focused here because they provide gameplay mechanics and dynamics that lay the foundation to address RQ2. In general, there are multiple studies indicating that playing games can directly increase or indirectly boost players' creativity in different ways, depending on the game's genre and content (Rahimi and Shute, 2021). One prominent genre that shows great potential in enhancing creativity is *simulation games* which entails games that provide immersive virtual worlds and let players make substantial decisions that impact the world, for instance by creating new environments like cities or landscapes (Rahimi and Shute, 2021; Sitzmann, 2011). As a sub-genre of these games, *city-building games* received much attention in the scope of creativity research lately (Bereitschaft, 2021). These games are open-ended (Juul, 2002) and emergent (Bedau, 1997; Earle et al., 2021; Sweetser, 2008). This means that, in contrast to games that focus on progression, city-building games give players creative freedom in shaping the virtual environment with a fixed set of in-game functionalities and often do not define a distinct end-goal of the game (Juul, 2002; Squire, 2007). In terms of in-game mechanics, city-building games let players create and shape terrains, place city structures on top of these terrains, and populate virtual worlds with characters, foliage, or other scenery decorations (Bereitschaft, 2016). Among city-building games, the *SimCity* series (Maxis, 1989), which originated as an urban dynamics simulation game (Earle et al., 2021; Forrester, 1969) in the late 1980s and has published over ten entries, has been used in many studies examining creativity of players. In addition to *SimCity*, games that have a similar set of mechanics and dynamics such as *City Life* (Cristo, 2006) and *Cities: Skylines* (Order, 2015) are found in some studies concerned with creativity research. In general, multiple studies suggest that city-building games help to arouse or enhance the perceived creativity and imagination of players (Lin and Lin, 2017; Rahimi and Shute, 2021). Often, these studies were conducted in pedagogical settings with students attending school or university. This way, city-building games have shown the potential to let students discover the creative aspect of planning a city (Gaber, 2007) and experience this planning procedure as a fun and creative process (Terzano and Morckel, 2017). Similarly, playing city-building games can increase the perception of *geographic creativity* (Kim and Shin, 2016). There is a multitude of studies investigating the impact of playing on creativity from the genre of *sandbox games* which can contain some city-building elements but also include game mechanics from sports, adventure, action, or strategy games (Ocio and Brugos, 2009; Sweetser, 2008). A game often associated with creativity research is *Minecraft* (Studios, 2011), a sandbox game that lets players explore and shape a procedurally generated world made of cubes that represent objects, equipment, terrain, etc. Studies indicate that self-expression through Minecraft can increase the creativity of students (Blanco-Herrera et al., 2019; Karsenti and Bugmann, 2017; Kim and Shin, 2016; Moffat et al., 2017; Sáez-López et al., 2015).

The games covered in this section all offer a way for players to playfully express themselves in a creative way. Playfulness, as defined for the scope of this thesis, can trigger creativity by providing situations for players to address in novel and interesting ways (Bowman et al., 2015; Caillois, 1961; Huizinga, 1949). The studies reported here suggest that the open and unstructured nature of city-building games and sandbox games can indeed facilitate the perceived creativity of players. Most studies in this field report their findings on creativity research based on self-reports of players (Blanco-Herrera et al., 2019; Gaber, 2007; Karsenti and Bugmann, 2017; Kim and Shin, 2016; Moffat et al., 2017; Sáez-López et al., 2015; Terzano and Morckel, 2017). This is in line with the definition of creativity that was given in the previous section and illustrates that city-building games can make players feel more creative about the process of play and the content they create.

## 2.3. Procedural Content Generation for Cityscapes and Terrains

Procedural content generation (PCG), which is concerned with the algorithmical creation of content (Togelius et al., 2011), has many fields of application within the gaming sphere (Hendrikx et al., 2013; Shaker et al., 2016). One prominent domain for PCG is city generation, a process that describes the generation of cityscapes with urban structures such as streets and buildings that are combined in a reasonable way as to give the impression of a functioning city (Kelly and McCabe, 2006). City generation is often used for video games, but can also be utilized for social simulations (Kim et al., 2018) and urban testbeds (Lechner et al., 2006; Weber et al., 2009). Algorithmically speaking, city generation can be conducted in a variety of ways. To give some prominent examples, the generative process can be based on *Fractals* (Mandelbrot and Mandelbrot, 1982), *Lindenmayer-Systems* (Lindenmayer, 1968; Prusinkiewicz and Lindenmayer, 1990), *Perlin Noise* (Perlin, 1985), *Tiling* (Stam, 1997), *Voronoi Textures* (Worley, 1996), *Grammars* (Wonka et al., 2003) or a combination of these methods (Kelly and McCabe, 2006).

In terms of content, these methods are used to generate terrains, foliage, rivers, road networks, urban structures or entire cities at once (Smelik et al., 2014).

Procedural city generation has been a point of interest in research for more than 20 years. As one of the first approaches, *CityEngine* describes the generative process as a multi-step procedure based on an image map as input (Parish and Müller, 2001). This map provides information regarding the terrain, population, and water levels of the desired landscape. Step by step, *CityEngine* creates a road map, urban buildings, and textures and thus, finalizes a cityscape. Another example for the creation of road networks based on images as input maps is described by Sun et al. (2002) who outline how this method can be integrated into the procedural generation of virtual cities (Sun et al., 2002). Based on these early works, a different algorithmical process was developed in the form of *Citygen* (Kelly and McCabe, 2007). Instead of a singular PCG algorithm, *Citygen* utilizes a variety of methods for different tasks of city generation that are performed one after another. Just as *CityEngine*, the procedure of *Citygen* consists of multiple subsequent steps. First, a road map is generated which is then laid on top of a terrain and ultimately, buildings are placed adjacent to the roads. As a means to generate larger areas, the *Different Manhattan Project* uses a top-down statistical procedure to create a virtual representation of the Manhattan Skyline (Yap et al., 2002). Many of these early methods suffered from a lack of variety in the outcome. As a way to counter this, *'pseudo infinite' cities* is a system capable of generating a large variety of aesthetics based on an integer seed, floor plans, and some location values (Greuter et al., 2003). Some more advanced AI techniques are also used for city generation. One approach divides city generation into different aspects that are each controlled by a different virtual agent. Each agent is responsible for different steps of generation such as defining a road network or placing buildings on top of a terrain (Lechner et al., 2003). Specifically for the creation of buildings, a *CGA shape* constructs architecture with the use of shape grammars that each correspond to a distinct kind of building (e.g office building or industrial factory building) (Müller et al., 2006). A novel approach is described by Kelly (2021) who describes a rule-based procedure for the creation of cities of any size and also coined this method *CityEngine* (Kelly, 2021).

In city-building games, PCG is used to generate initial map layouts for players to build urban structures on. These layouts include a terrain map, with mountains, valleys, rivers, and a variety of biomes (e.g. forest or snowy landscape). Modern city-building games such as *Banished* (Software, 2014), *Civilization VI* (Games, 2016) or *Islanders* (Games, 2019) all make use of some form of PCG to generate content. As stated in the previous section, there is some research that suggests that playing *Mincecraft*, a sandbox game that utilizes PCG for terrain generation, may help to stimulate creativity (Blanco-Herrera et al., 2019; Checa-Romero and Gómez, 2018; Cipollone et al., 2014; Karsenti and Bugmann, 2017; Moffat et al., 2017; Sáez-López et al., 2015).

## 2.4. Summary and Research Directions

In this chapter, I have provided an overview of the theoretical foundations and current relevant works for the various research disciplines that this work is concerned with. What are the main takeaways that help to guide the research of this thesis? In regards to the treatment of phobias with the use of VR technology as realized via VRET, current research shows that VRET is an applicable addition to the therapeutic workflow. Studies indicate that VRET overcomes many challenges posed by *in-vivo* exposure therapy by providing a cost-efficient, ethical alternative that is just as effective as its traditional counterpart (Botella et al., 2017; Coelho et al., 2009; Garcia-Palacios et al., 2007; Gregg and Tarrier, 2007). However, the design of the interaction between the VRET system and its respective users (therapists and patients) is rarely discussed. This is problematic since a badly designed interface may lead to additional technological barriers that prevent VRET systems from being used more frequently. This open question is addressed by this thesis by examining the use of NUIs for this purpose (RQ1). As a way to enhance engagement with VRET systems and thus, increase motivation to seek therapy, many studies have investigated the inclusion of game mechanics into such systems. Games are useful in a therapeutic setting as they lead to higher motivation, accessibility, adaptability, and the alleviation of anxiety (Abd-alrazaq et al., 2022; Griffiths, 2005; Mandryk and Birk, 2017). Studies in this field focus on reporting results from the conducted user studies but rarely discuss the design process of these game-based systems. Therefore, specific requirements that need to be taken into consideration for the design of playful VRET systems are largely ignored by most approaches. This thesis aims to overcome this problem by including active psychotherapy practitioners in the design process. This way, requirements for a game-based approach applicable for the use in VRET are identified and a game design strategy is conceived that focuses on playful creative self-expression (RQ2). Lastly, research shows that games that allow for playful creative self-expression (sandbox games and city-building games), help players to arouse creativity (Lin and Lin, 2017; Rahimi and Shute, 2021). One can argue that these games are primarily played and liked for this purpose - to express the player's ideas by adjusting landscapes and building urban structures in a free, playful, and creative way. In this context, research offers many approaches to pre-generate cities and terrains with the use of PCG (Kelly and McCabe, 2006). Some studies indicate that games that use PCG in this way such as *Minecraft* can trigger creativity (Blanco-Herrera et al., 2019; Checa-Romero and Gómez, 2018; Cipollone et al., 2014; Karsenti and Bugmann, 2017; Moffat et al., 2017; Sáez-López et al., 2015). However, none of the examined studies aims to attribute the enhancement of self-reported creativity to the procedural nature of the game. Moreover, no study has compared procedural versus non-procedural generation of content and how that impacts creativity. Therefore, at this point, there is a lack of research on the effects of PCG on creativity as perceived by players which is addressed by RQ3.

# 3. Research Approach

In this chapter, I will present my approach to addressing the stated research questions. As stated in chapter 1, the overall research theme of this thesis can be summarized as follows:

*How should playful applications be designed in order to be applicable in the context of exposure therapy whilst not interfering with therapeutic success and keeping technical complexity to a minimum?*

To obtain a more structured agenda, I have derived three distinct research questions which cover various aspects of the research theme and are presented here in a condensed form:

**RQ1**: What kind of interaction is suitable to support users who are novices in terms of technical expertise but have high technical demand in their everyday lives?

**RQ2**: What kind of game design strategy can be utilized in the context of psychotherapy without interfering with therapy success?

**RQ3**: In the context of a playful approach to psychotherapy, can PCG be applied to lower the level of technical complexity without notably decreasing creativity as perceived by players?

The following sections will be concerned with addressing these research questions. For each of them, I will present my approach in correspondence with my publications ($P1$ - $P10$) in a brief form. For a more comprehensive overview of my work, please refer to part II where full versions for each publication are appended.

## 3.1. Empowering Novices with Technology

This section examines the use of technology in professional work environments for users with limited technical expertise (RQ1). For this purpose, I will report on the findings that were depicted in publications $P1$ (Volkmar et al., 2020b), $P4$ (Muender et al., 2019) and $P5$ (Malaka et al., 2021).

## Natural Interaction

Medical personnel like therapists often face the challenge of using and maintaining more and more complex systems as technology progresses but have only limited experience in how to do that (Lindner et al., 2017). This is quite similar to the work conditions of content creators from the creative industries of film, animation, and theater where professionals often struggle with the complexity of new technological innovations (Muender et al., 2018). Especially in the previsualization (previs) phase, where creators plan and visualize the final product with limited scope and focus on the essentials, highly complex software like *Maya* [1], *Blender*[2] or *Unity3D* [3] is used (Okun et al., 2020).

To support and empower professionals with low technical expertise but high domain knowledge, one approach has aroused attention in recent years in research and practice - natural user interfaces (NUIs) (Falcao et al., 2015; König et al., 2009; Wesson and Wilkinson, 2013). This term encompasses a collection of interfaces that enable users to interact with computers in a way they interact with the world with a strong focus on *natural* modalities such as speech, touch, and gestures (Jain et al., 2011). This notion of *naturalness* has been subjected to debate among researchers. One core issue with this definition lies in the fact that NUIs rely on modalities that require learning and are not innate or culturally independent (Norman, 2010). Moreover, following this definition of NUIs, these interfaces can never be fully natural since the interface designer imposes the scope of interaction (e.g., number of speech commands, recognizable gestures etc.) (Malizia and Bellucci, 2012). Alternatively, Wigdor and Wixon (2011) define NUIs as interfaces that are designed in a way that makes the user act and feel like a natural. In this sense, *natural* is not a property of the interface itself but is referring to the way users feel and interact with a product (Wigdor and Wixon, 2011). This definition overcomes many of the issues mentioned before since it refrains from defining *naturalness* as an objective attribute of an interface and instead focuses on the context, making an interface potentially natural for a specific user with a specific background.

Following this definition, we designed, implemented, and evaluated an interactive prototype for the context of previs that enables professionals from the domains of film, animation, and theater to fulfill their typical tasks in a way that feels natural to them.

## Requirement Analysis

This segment is based on the work reported in publication *P*4 (Muender et al., 2019). As a first step in the design process, we conducted a requirement analysis with industry experts to identify what features the software should provide and what interaction paradigms feel most natural to the users. For each application area, interviews with professionals from that specific domain were conducted. In total, 16 people participated in this process (animation: $n$=3, film: $n$=5, theater: $n$=8). The interviews focused on specific tasks that users performed in their everyday lives and that the software should

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[1] https://www.autodesk.com/products/maya

[2] https://www.blender.org/

[3] https://unity.com/

enable them to perform as well. In a subsequent workshop, tasks, and requirements for the prototype were discussed. Utilizing the MoSCoW Analysis (Chemuturi, 2013) and card sorting (Spencer and Garrett, 2009), requirements were categorized into *must have*, *should have*, *could have* and *won't have* and a workflow map for the entire previs process was generated. Among the finalized list of 20 core functionalities were many that are three-dimensional in nature such as scene modeling, sketching, layout, camera control, and lighting. Experts stated that for these tasks, traditional software does not feel natural since they rather look around in the scene, control scene props with hand controls, and build assets with their hands. To counter this problem, NUIs that incorporate VR technology might be an applicable solution as previous research suggests (Muender et al., 2018). Therefore, ultimately, these core tasks were directly mapped to natural forms of interaction and the hardware necessary to perform them (see Figure 3.1).

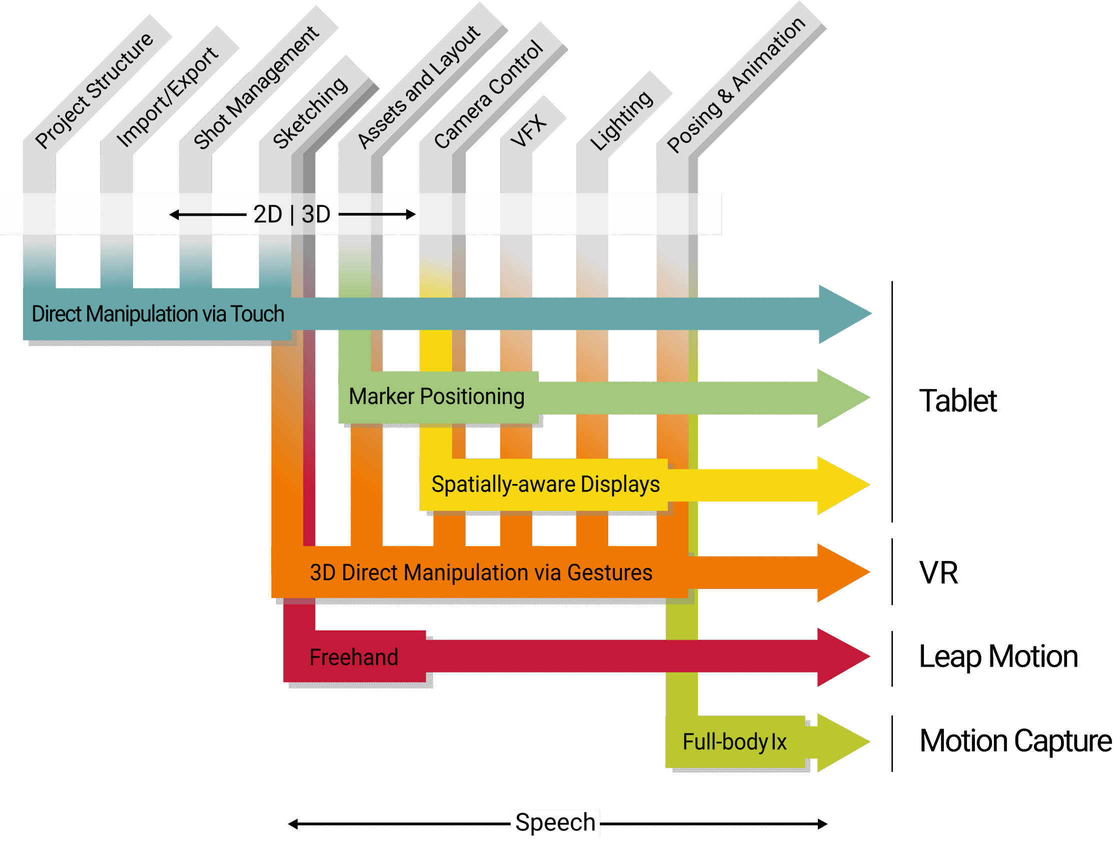


Figure 3.1.: Mapping core previs tasks as identified via requirement analysis to natural forms of interaction and hardware (Publication *P4* (Muender et al., 2019)).

## Implementation

Following the requirement analysis performed in $P4$ (Muender et al., 2019), we constructed a prototype, providing all necessary features for the identified core previs tasks. This prototype was implemented as a VR tool that allows users to move around freely and interact with objects in the scene using hand controllers. Here, they can perform a variety of tasks that are typical for the domain of previs in a fully immersive 3D VR environment. To give an example from the domain of setting up a scene, users can select assets from a hand-mounted menu, place them anywhere in the scene and grab them with the hand controller to relocate, rotate, scale, or measure them (see Figure 3.2). Furthermore, they can sketch and paint 3D objects or create specific poses for virtual characters. This is only a subset of features. For a comprehensive overview of features, please refer to publications $P1$ (Volkmar et al., 2020b) and $P5$ (Malaka et al., 2021).

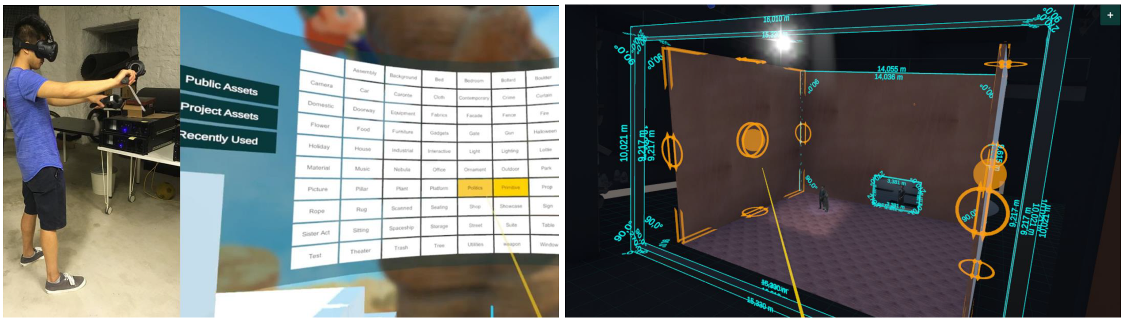


Figure 3.2.: Asset placement and measuring scene elements in the virtual environment (Publication $P1$ (Volkmar et al., 2020b)).

## Project Evaluation

The evaluation process of the prototype is described in more detail in publication $P1$ (Volkmar et al., 2020b). Here, I will provide a short overview of this process. To evaluate the NUI tool in terms of its applicability and user experience in a real work context, we defined a set of previs projects in collaboration with industry experts from film, animation, and theater. These projects resembled actual productions that were common for the respective application domain and were carried out by the experts themselves with the help of the NUI tool (see Figure 3.3).

The animation project was concerned with the production of a previs for an animated series that the experts were working on at the time of this evaluation. They decided to shoot a trailer focused on the story of a girl exploring a semi-fictional world with an animal friend of hers. To accomplish this, the animation experts ($n$=5) placed three animated characters in the virtual scene and shot a variety of scenes with the features provided while moving and animating characters and assets.

For the film production, the experts ($n$=4) created a short commercial video for one of the studio's actual customers. For that purpose, they guided a virtual character through a 3D recreation of their customer's brewery and placed a number of cameras along the way. Using the built-in camera recording and editing tools, they produced a collection of shots of the virtual character showing various distinct locations of the brewery. The result was a previsualization of a commercial video that would later be produced with real actors.

The professionals from the theater project ($n$=7) used the NUI tool to create a previs of their upcoming opera that was to take place in a distinct theater hall with specific requirements for the performance. Among other features, the experts utilized sketching and modeling tools of the software to generate scene props for the stage. In addition to that, painting and texturing the stage layout was also in the focus of this project as well as the placement of lights and virtual actors. Since the real theater had unique properties such as a revolving stage, flybars, and lighting bridges, the previs for the opera performance had to incorporate these mechanisms as well.

For each project team, the procedure of the evaluation was the same. All participants were first informed about the scope of the projects and received a lengthy introduction to the NUI tool and its functionalities. Additionally, they signed a consent form that provided information regarding the study procedure and the data collection. Following this, the teams worked on their respective project autonomously without the interference of the examiners. Upon finishing their projects, a number of questionnaires that addressed the prototype's usability and user experience (UX) were filled out: system usability scale (SUS) (Brooke, 1995), NASA task load index (TLX) (Hart and Staveland, 1988), AttrakDiff (Hassenzahl et al., 2003). Lastly, semi-structured interviews were conducted for additional qualitative feedback.

Figure 3.3.: Impressions from the project evaluations with teams from the domains of (from left to right) animation, film, and theater (Publication $P1$ (Volkmar et al., 2020b)).

## Results

First, I will report on the quantitative findings. The SUS received an average assessment of 66.79 ($SD$=14.92). Overall workload as measured by the TLX received an average rating of 38.59 ($SD$=14.78). Attractiveness, which is the overall score of the AttrakDiff was rated with an average of 1.34 ($SD$=0.84). A comprehensive summary of quantitative results can be found in publication $P1$ (Volkmar et al., 2020b).

In addition to quantitative results, qualitative findings were derived from the interviews and video recordings that were analyzed after project completion. Participants pointed out that the NUI tool provided novel forms for creative expression whilst making the interaction feel intuitive and natural. Furthermore, they stated that the tool required a familiarization and learning phase for the experts to actually use it effectively. However, they also pointed out that standard previs software usually has a steep learning curve and requires weeks or months of learning whereas the NUI tool provided an easy-to-learn environment. Collaboration was mentioned as another positive aspect as well. The experts emphasized that working together on a project went much smoother than with traditional previs software. This is because the NUI tool allowed them to perform certain tasks in VR while another project member could review the work on a desktop PC simultaneously. Multiple participants said that wearing the VR headset all the time could become rather cumbersome after some time. Since most previs tasks take up to several hours of work on end, the experts had to take multiple breaks due to the discomfort of the headset which caused neck pain and fatigue. To review all qualitative feedback, please refer to $P1$ (Volkmar et al., 2020b).

### Discussion

The qualitative data gathered via semi-structured interviews revealed that all participants felt positive towards using the NUI tool for their daily creative tasks in a project context. They stated that the interaction did feel rather natural and intuitive and that navigating the tool and using its various functionalities was easy to learn. Therefore, it can be inferred that the implemented software can indeed be considered a natural user interface. On the other hand, the quantitative results paint a somewhat different picture. The SUS average score of 66.79 lies below the "good usability" threshold of 70 (Bangor et al., 2008). Moreover, the raw TLX value of 38.59 indicates that using the tool was similarly demanding as driving a car or navigating in general (Grier, 2015). How did these values occur even though participants praised working with the software in the interviews? One way to explain this comes from the complexity of the software. As stated in section 3.1, the requirement analysis identified 20 core functionalities that the software should provide and that were indeed implemented in the final prototype. Naturally, this resulted in a highly complex tool that provided a multitude of features, many of which were not used by all project teams. For instance, the theater project was more concerned with placing scene props and lights on a virtual stage than with posing and animating characters which in turn was a core task for the animation team. However, all teams used the same software and were thus overwhelmed by the number of options and functionalities. Another point to consider is the relatively short time that participants had for training and learning. In previs, standard software requires weeks or months of training before it can be used in a professional capacity. However, for the project evaluation, only a couple of hours of training at the maximum were available for the participants. Considering that all projects were nonetheless completed successfully shows that the NUI tool was a big time saver. Similar results would not have been possible with standard software being used by nearly untrained personnel.

### Conclusion

In previs, many experts with varying professional backgrounds work together to visualize a piece of media using highly complex software. Though they are experts in their fields, they do not necessarily have a high level of technical expertise to operate this kind of software. As stated before, in the field of VRET, the situation is quite similar. Therapists are experts in providing treatment procedures for their patients but have to make use of highly complex software if they wish to create and maintain VRET applications. Accordingly, patients who use these applications may be overwhelmed by the level of technical complexity as well. To counter this, I have presented an approach that may serve as a way to make the creation and maintenance of VRET content natural, intuitive, and easy to learn - natural user interfaces. The research described in this section has shown that NUIs can improve the creative process of generating visual content after a short familiarization phase. These insights provide a suitable response to RQ1 which stated: What kind of technology is suitable to support users who are experts in their respective fields but novices in terms of technical expertise? With the help of NUIs that feel natural to the therapists and patients, the creation and maintenance of VRET applications may be supported in eliminating some of the technical hurdles that standard 3D software bears.

## 3.2. Playfulness in the Context of Psychotherapy

In the previous section, I investigated the use of technology that is suitable for game-supported self-expression and creation of virtual environments. Beyond the original application domain of previs, these techniques could also be used for creating virtual environments for psychotherapy. I have concluded, that a natural user interface (NUI) providing an intuitive interaction mode for therapists and patients alike would have the potential to meet this requirement. Now, in this section, I will examine the interplay of game design and psychotherapy. More precisely, I will present a solution that aims to combine the benefits of video games with successful therapy in the context of VRET (RQ2). The work presented in this section is based on the publications $P2$ (Alexandrovsky et al., 2020b) and $P6$ (Volkmar et al., 2020a).

### Requirement Analysis

As outlined before, there are numerous studies that indicate the applicability of serious games (Abt, 1970) and gamification (Deterding et al., 2011) for therapeutic purposes (Fleming et al., 2017; Mandryk and Birk, 2017). However, designing video games for inclusion in therapy settings is a challenging process with many open questions remaining such as how different game elements impact the efficacy of interventions or alter the experience as a whole (Birk et al., 2019). Furthermore, many studies published in this field offer promising results in regard to the applicability of games but lack a direct comparison of game-based and non-game interventions (Fleming et al., 2017). Research suggests that, since games designed for therapy are meant to be used in a setting that includes both the patient and the therapist, both parties should be involved in the design process (Fleming et al., 2016). However, this is not the case for most applications as they are designed without the involvement of therapy practitioners. Therefore, as a first step in exploring game design strategies for the context of ET, this section will illustrate a requirement analysis that has been conducted in collaboration with licensed therapists. Here, I will present only a brief overview of the entire process which can be viewed in greater detail in publication $P2$ (Alexandrovsky et al., 2020b).

### Interview Preparation and Conduct

Based on the standardized method of semi-structured interview preparation from the social sciences domain (Helfferich, 2009), an interview document was compiled that covered four categories of interest: Techniques and Procedures (C1), Setting and Scenarios (C2), Tasks and Motivation (C3) and Supplemental (C4). The aim of this interview was to get insights regarding the standard procedure of traditional CBT as well as give room for discussion on how games may be included in this process. For the interview, two therapists (both self-identifying as female) participated in 30 to 40 minutes sessions. Both were practitioners with expertise in CBT for various cognitive disorders and ET for the treatment of specific phobias. The interviews were conducted in face-to-face sessions in the doctor's office of the respective interviewee. The interviews were recorded as audio files and later fully transcribed manually. For the analysis of the material, a deductive qualitative content analysis (Mayring, 2000) was performed. For the analysis of the material, two examiners processed the transcriptions independently and sorted each coding item into the four categories that were defined at the beginning (C1-C4). A coding item was defined as a statement made by the therapist either consisting of one or more sentences that belonged to a response to one of the questions. After the initial screening of the material, the categories were revised and an inter-coder agreement check was performed.

### Interview Results

The interview provided an overview of the traditional ET procedure. The interviewees emphasized that, during the first stage of therapy (*probatory*), patients and therapists discuss and decide in collaboration how the intervention will be shaped. This notion of collaboration is relevant since it prevents therapy from being perceived as "other-directed". During therapy, the practitioners take over the role of motivators and companions, guiding patients along the way to deal with their phobia. The procedure itself consists of repeated confrontation with the anxiety-inducing stimulus with varying degrees of severity. The end goal of therapy needs to be defined between patients and therapists individually. Usually, therapy is conducted until a state of *habituation* is achieved, meaning that there is a decrease in the physiological response to the stimulus. These responses (e.g., heart rate, sweating, etc.) are measured by the therapist and are taken into account when deciding the next steps of therapy. Scenarios for exposure are discussed between patients and therapists and should come in a rich variety. They should however not be switched between too rapidly before patients become habituated to them. During exposure to these scenarios, the most effective task for the patients is to do nothing and focus on their physical and mental reactions to the stimulus. Exposure should therefore take place in an environment with few distractions, giving patients the opportunity to take control of the situation. To motivate patients to actively seek out exposure, individual goals that represent steps toward the therapy goal can be defined. Reaching these goals invokes a feeling of partial success which in turn motivates patients further. Another aspect to consider when talking about motivation is autonomy. Patients who feel autonomous in undergoing exposure are more motivated to do so than patients who rely too much on the intervention of their therapist. Rewards also play a big part in regard to motivation. They should be defined by patients which again leads to a higher sense of autonomy. The interviewees stated that VRET is an applicable addition to therapy that should not be seen as a replacement but as a tool to accompany the intervention. They furthermore emphasized that any VR content should be based on traditional CBT concepts to ensure that there is a scientific foundation for the content displayed.

### Requirements for Game Design

Here, I will provide a brief overview of the requirements for game design that were derived from the interview results. These represent considerations for game designers and are meant to help start off the design process for playful applications that are to be used in the context of exposure therapy. A more detailed summary of these requirements can be found in publication $P2$ (Alexandrovsky et al., 2020b).

*R1: Motivation.* As the interviewees expressed the importance of motivating patients to seek out therapy, this should be supported by the game design. One crucial aspect is giving patients the feeling of autonomy. This is achieved by involving them in the decision process in regard to the course of therapy and the scenarios for exposure. Furthermore, rewards and sub-goals should not be generalized for all patients but be adaptable to each individual.

*R2: Communication.* In the course of ET, therapists take on the role of motivators and companions for their patients. For a system to be a useful addition to the therapeutic process, it should enable communication between patients and therapists. In the context of VRET applications, this means that both parties should be able to enter the scene. In any way, a direct way of communication should be established in an auditory or visual way.

*R3: Scenario Habituation.* Scenarios for exposure should not be limited to a single scene or aesthetic but be rich in visual variety. They should furthermore offer varying levels of severity of exposure so that the anxiety-inducing stimulus can be altered based on the therapeutic needs. Ultimately, scenarios should give patients the opportunity to reach habituation.

*R4: Non-distracting Tasks.* When exposed to the anxiety-inducing stimulus, patients focus on their physical reaction as well as their cognition of the exposure. By employing therapeutic exercises (e.g., breathing exercises), patients intend to gain control over the situation and thus, get closer to habituation. During this process, they should not be distracted by some other task that demands their attention to shift from focusing on themselves. Common game design elements such as a captivating story or functional challenges (e.g. collecting points) should therefore be excluded as they may be too distracting and thus, interfere with the therapeutic procedure.

*R5: Physiological Symptoms.* Using technology such as a VRET system for treatment should not introduce additional physiological symptoms which are caused by the exposure already. Therefore, a system should have a sound technical implementation that does not cause physical reactions due to stuttering, bugs, or a low framerate.

### Playful User-Generated Treatment (PUT)

As a means to showcase a playful application that incorporates the requirements derived from expert interviews, a game design strategy was composed which will be outlined in this section. As mentioned before, the game design describes an approach to the treatment of acrophobia. I will discuss the generalizability of this approach for other phobias in the discussion section. It is important to note that this section covers the concept of the game design strategy and not the actual implementation. A prototype based on this strategy will be outlined in the next section and is depicted in more detail in publication $P2$ (Alexandrovsky et al., 2020b). The basic idea of this design is to split the therapeutic procedure into two steps: a design phase and an exposure phase (see Figure 3.4). During the design phase, players shape a terrain in a VR environment using an editor that allows them to raise or lower the environment and thus, generate locations for exposure themselves. In addition, they have the option to decorate the scene with a variety of 3D scene props such as trees or houses. This phase takes place in a top-down miniature view that allows players to observe the entire scene and make adjustments according to their liking. In the second phase, the actual exposure happens in first-person view and realistic full-scale. Since players have defined specific locations in the scene in the first phase, they are now exposed to height in these very same locations. This game design strategy was labeled PUT and incorporates all of the requirements that were identified from the expert interviews. PUT is designed to increase engagement with the VRET system in a playful way allowing for creative expression. Additionally, it gives players autonomy by letting them create the environment for later exposure. Both of these features are in line with the first requirement (*R1: Motivation*). In both steps of the intervention (design & exposure), patients and therapists can enter the virtual scene together. Therapists can guide the creation process and act as a companion during exposure. This enables collaboration between both which was defined as the second requirement (*R2: Communication*). PUT allows the creation of and exposure in a variety of scenarios. Players are given a blank slate of a terrain and can adjust the scene to their liking. By adjusting the height of the exposure locations, they can alter the level of severity of the stimulus. This way, the system allows for habituation and thus complies with the third requirement (*R3: Scenario Habituation*). By splitting the experience into two steps, all game-related functionality is limited to the first step (design phase). In the second phase, no game elements are included at all. Here, the only task consists of immersing oneself in the scene and focusing on physical and mental reactions to the exposure. This split allows for a captivating playful experience in the first phase but keeps the actual exposure free of any distractions which satisfies the fourth requirement (*R4: Non-distracting Tasks*). Finally, to ensure that the system does not introduce any additional physical reactions (*R5: Physiological Symptoms*), an implementation of PUT should be delivered on a high-quality VR headset and should not introduce any technical flaws. This way, any symptoms such as sweating or increased heart rate appearing during the experience should be attributable to the anxiety-inducing stimulus and not faulty hardware or software.

Figure 3.4.: Demonstration of the PUT game design strategy, showing the design step (left) in a top-down miniature view and the exposure step (right) in full-scale first person view (Publication $P6$ (Volkmar et al., 2020a)).

### User Study

The game design strategy (PUT) was evaluated in terms of player experience, motivation, and height perception in a laboratory user study. For this purpose, two conditions were defined and compared between subjects: $C_{PUT}$ and $C_{ctrl}$. In the $C_{PUT}$ condition, participants would build, shape and design the VR environment for later exposure themselves. Hence, this condition included the design phase which was described before. In contrast to that, participants assigned to $C_{ctrl}$, had no design phase and would instead view a VR terrain that was pre-generated beforehand. Both groups were balanced for gender but otherwise, assignment to the groups was randomized.

### Participants

Before taking part in the study, all participants were pre-screened via the acrophobia questionnaire (Cohen, 1977) but no one had to be excluded from the study due to critical anxiety or avoidance scores. In total, 31 participants (8 female, 23 male), with an average age of 24.32 years ($SD$=4.32) joined the study. Most participants were students enrolled in a bachelor's or master's study program at a German university. None had any prior experience with VR.

### Material & Apparatus

The prototype was installed on an HTC Vive VR headset allowing participants to move around in a 2x3 meters space in the laboratory. In addition to the terrain editor, the virtual scene included terminal-like apparitions which were used to display questionnaires for subjective data gathering. Questionnaires used for this study included the *Intrinsic Motivation Inventory* (IMI) (Ryan, 1982), the *Positive and Negative Affect Scale* (PANAS) (Crawford and Henry, 2004), the *State-Trait-Anxiety-Inventory (STAI)* (Spielberger, 1983) and the *Subjective Units of Distress-Scale* (SUDS) (Antony et al., 2005; Back et al., 2015).

### Procedure

After giving informed consent regarding the study procedure and data collection, participants were assigned to either $C_{ctrl}$ or $C_{PUT}$. In both groups, participants received a short tutorial in VR in regard to controls, interaction, and movement in the scene. In $C_{PUT}$, the task was to design the terrain in any way, the participants liked. However, their main task was to create three platforms with varying heights (30m, 50m, 70m) for later exposure. In contrast, $C_{ctrl}$ offered no design tools for the participants at all but showed a pre-generated virtual environment. Here, the main task was to get immersed in the scene and try to memorize the layout of the terrain. During this phase, multiple SUDS measurements and one IMI measurement at the end were taken in both conditions. At the end of the first phase, participants entered the exposure scene in first person at the locations they defined in $C_{PUT}$ or were predefined in $C_{ctrl}$. In both conditions, participants had to solve a small task by dropping a ball to the ground and looking down the edge of the platform to read out a series of numbers. After each trial, STAI and SUDS measures were taken via questionnaire terminals in the VR scene (see Figure 3.5). At the end of the procedure (three trials in total), the IMI was filled out a second time and the PANAS was completed. The entire process in VR lasted for an average of 23.07 minutes ($SD$=3.86). At the end of the procedure, a brief semi-structured interview was conducted to gather additional qualitative feedback.

### Results

It is important to note that an in-depth description of all quantitative and qualitative results can be found in publication $P2$ (Alexandrovsky et al., 2020b). Here, I will provide an overview of the most important results. For the analysis of the IMI scores, mixed-factorial ANOVAs were calculated for each of the four subscales of the questionnaire. Here, the subscale was defined as a within factor and the condition ($C_{PUT}$ vs. $C_{ctrl}$) as a between factor (see Figure 3.6). A significant difference was found within-subjects on the Tension-Pressure subscale which was confirmed in a post-hoc t-test after conducting a Bonferroni correction ($t_{29}$=-5.80, $p<0.01$, Cohen's $d$=-1.04). Furthermore, for the Interest-Enjoyment subscale, the ANOVA showed a significant difference between conditions. Again, a Bonferroni-corrected post-hoc t-test confirmed a significant difference ($t_{29}$=2.40, $p$=0.02, Cohen's $d$=0.43).

Place now a multi-story building.

Use a low and evenly leveled area for that.

For each of the following statements, please indicate how true it is for you, using the scale down below.

I am satisfied with my performance at this task.

Figure 3.5.: Left: Instructions displayed for participants of the user study. Right: in-VR questionnaires to assess anxiety-related and motivational measures (Publication *P*2 (Alexandrovsky et al., 2020b)).

To compare positive and negative affect between conditions, we calculated independent t-tests comparing the PANAS scores for each exposure task (three per condition). No significant differences for positive ($t_{29}$=0.75, $p$=0.46) or negative ($t_{29}$=−0.99, $p$=0.33) affect could be found (see Figure 3.7).

To compare anxiety measures, mixed-factorial ANOVAs were calculated for both the SUDS and STAI questionnaires. Here, the three levels of exposure (high, mid, low) were defined as a within factor and the condition ($C_{PUT}$ vs. $C_{ctrl}$) as a between factor. For both questionnaires, the analysis showed no significant main effect nor any interaction effects (see Figure 3.8).

Regarding qualitative feedback, here are some insights derived from the interview that was conducted at the end. 16 people stated that they felt related to the virtual environment in some way. 10 people from the $C_{PUT}$ condition mentioned that the task felt creative. 12 people pointed out that the controls felt intuitive. 15 people acknowledged in some form that the overall experience felt interesting and enjoyable. 13 participants experienced a sort of vertigo effect when looking down the cliff in the exposure phase. Please refer to *P*2 (Alexandrovsky et al., 2020b) for a summary of all statements collected.

### Expert Evaluation

To gather further insights in regards to the proposed PUT game design strategy, an online survey, that was specifically aimed at therapy practitioners, was compiled. The survey consisted of a 3 minutes video that introduced VRET in general and showcased the PUT approach by giving an overview of the idea and functionalities of the prototype. Preliminary results from this survey were reported in publication *P*2 (Alexandrovsky et al., 2020b). An extended investigation of the results was published in publication *P*6 (Volkmar et al., 2020a) which is the basis for this section of the thesis.

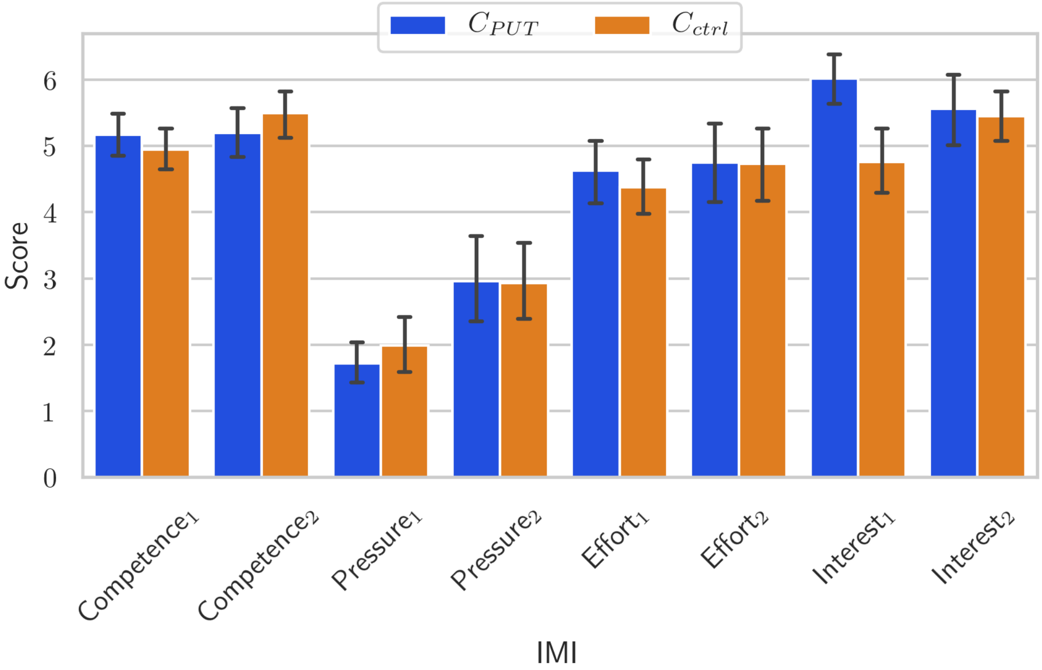


Figure 3.6.: Bar plots for each subscale of both IMI assessments. The numbers represent the time of assessment (1 = after the design/exploration step, 2 = after the exposure step). The whiskers indicate the SD (Publication $P2$ (Alexandrovsky et al., 2020b)).

### Participants

The online survey included psychotherapists with a wide range of expertise in different specialized fields of therapy. In summary, 13 therapists (9 female, 4 male) participated in the study, 12 of which had an approbation and one participant held a master's degree in psychology. Ages ranged between 28 and 67 years ($M$=47.69, $SD$=12.45). Work experience was reported to be between 1 and 40 years ($M$=14.00, $SD$=10.50) with 9 participants specialized in CBT and 4 participants specialized in psychoanalysis.

### Material & Apparatus

The survey was conducted with the use of a Google Form that included twelve questions in regards to the applicability of the PUT game design strategy for therapy. A video was embedded into the document showcasing the PUT approach based on the prototype implementation that was used in the user study. The video was 3 minutes long and introduced the topic of VRET in general and the challenges that are addressed by the

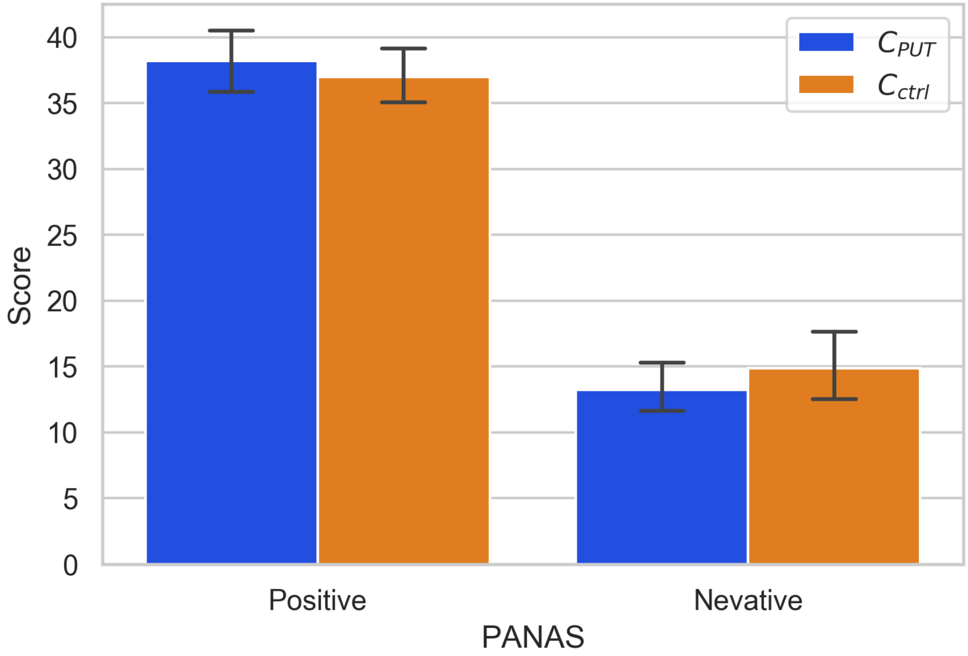


Figure 3.7.: Bar plots of the PANAS. The whiskers indicate the SD (Publication *P*2 (Alexandrovsky et al., 2020b)).

PUT design. It gave an overview of the terrain editor and the overall concept of dividing the experience into two phases.

### Procedure

For participant acquisition, the survey was shared with therapy networks and distributed among therapists via newsletters and mailing lists. Furthermore, the study was advertised on social media. After confirming the terms and conditions of a consent form that laid out the scope of the study, data usage, risks and benefits, and other factors, participants were redirected to the actual survey. The PUT game design strategy was outlined here via descriptive text and a video. In the end, participants filled out the questionnaire items and entered demographic information regarding their background, work experience, and experience with VR.

### Results

The most relevant results will be depicted in this section. For a more comprehensive summary, please refer to publication *P*6 (Volkmar et al., 2020a). Overall, the experts

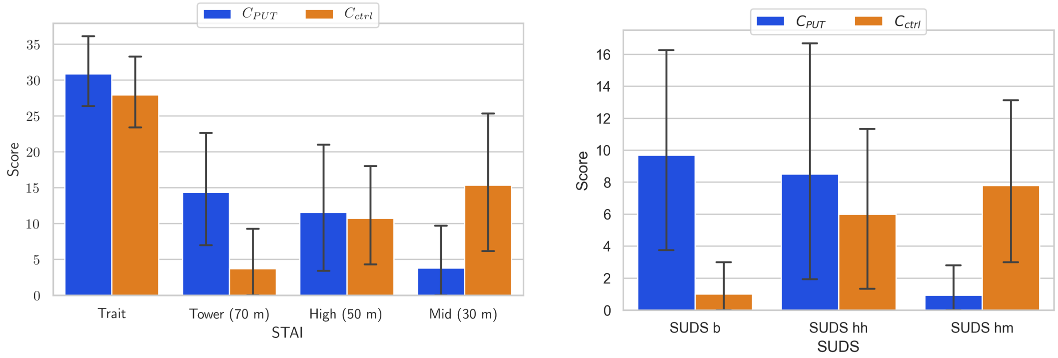


Figure 3.8.: Left: Bar plots of the STAI. Right: Bar plots of the SUDS. The whiskers indicate the SD (Publication *P*2 (Alexandrovsky et al., 2020b)).

rated PUT as a motivational approach to be rather useful for inclusion into therapy. This is confirmed by the average rating of $M$=3.69, $SD$=.91 of the question item "How would you rate the applicability of the software shown in the video in exposure therapy?" which was rated on a 5-point Likert scale from "Not Useful"(1) to "Very Useful"(5). Furthermore, participants ($n$=11) characterized the inclusion of a creative design phase to be a valuable addition to therapy and stated ($n$=10) that the separation into 2 phases may have a positive impact on therapy success.

In addition to analyzing the quantitative questionnaire items, inductive qualitative content analysis with category formation (Mayring, 2000, 2004, 2014) was conducted based on the open qualitative questions. In the course of the analysis, two independent examiners viewed the material and categorized qualitative statements into five *opportunities* (O1-O5) and three *challenges* (C1-C3) that were expressed by the therapists. One opportunity was identified in the way PUT allows for *habituation to anxiety-inducing situations* (O1). Furthermore, the approach was praised for facilitating *perceived control and self-efficacy* (O2). Though the prototype presented to the experts did not include any option for interaction between users, the therapists saw an opportunity for *improved interaction of patients and therapists* (O3). For VRET in general, a core strength was seen in the *economic usage of VR* (O4). Lastly, the prototype was commended for its *realistic environment* (O5). As for challenges, therapists emphasized that any VRET based intervention would be *no replacement for actual communication* (C1) between therapists and their patients. In contrast to O4, some experts stated that the virtual environment suffered from *lacking realism* (C2). Finally, a challenge was identified in the way that the approach may lead to a sort of *pseudo-habituation* (C3), meaning that patients may get accustomed to the virtual environment but remain anxious towards real-life stimuli.

## Discussion

In this section, I will reflect on the findings from both the user study and the online survey. Regarding the setup for the user study, the significant increase of Tension-Pressure (subscale of the IMI) in the second phase indicates that exposing subjects to heights led to some form of stress. However, no difference in both anxiety scales (SUDS and STAI) was found. This is explainable by the fact that convenient subjects that did not suffer from acrophobia participated in the study. Thus, the exposure to height successfully induced a feeling of tension without increasing fear. In regards to the overall experience, the results show that Interest-Enjoyment (subscale of the IMI) was significantly higher in the $C_{PUT}$ condition than it was in $C_{ctrl}$. Since Interest-Enjoyment is the self-report measure for intrinsic motivation overall (Ryan, 1982), this difference shows that the inclusion of a playful design phase increased intrinsic motivation significantly. The qualitative data collected at the end of the study confirms this notion. Participants stated that they felt creative, related to the environment, and that the procedure was enjoyable.

These results are in line with the experts' assessment of PUT as an addition to the traditional therapy procedure. They considered PUT to be useful and valuable with the possibility to impact therapy in a positive way. They expressed opportunities (O1 - O5) and challenges (C1 - C3) that should be considered for implementations of the PUT concept (see Table 3.1).

## Conclusion

In this chapter, I examined the potential of games user research (GUR) in the context of exposure therapy (ET). This was formalized in the second research question (RQ2) that stated: What kind of game design strategy can be utilized in the context of psychotherapy without interfering with therapy success? I have approached this question in multiple subsequent steps. First, a requirement analysis has been conducted in the form of a semi-structured interview with two therapy practitioners. A number of requirements (*R1*-*R5*) were derived from the interviews. Next, a game design strategy was compiled that takes these requirements into consideration. This strategy was coined playful user-generated treatment (PUT) and divides the intervention into two steps: a design phase where playful elements are integrated and an exposure phase where patients experience the anxiety-inducing stimulus without any distractions from other tasks. PUT was implemented as a prototype that included an exposure intervention which is typical in the domain of acrophobia treatment. This prototype was evaluated in a user study with convenient subjects as well as in an online survey with psychotherapists. The PUT condition achieved higher motivational scores than the condition in which no playful element was included. Moreover, PUT did not interfere with the perception of height-related anxiety. Lastly, expert participants of the survey assessed PUT to be an applicable addition to traditional therapy and expresses specific opportunities (O1-O5) and challenges (C1-C3). In conclusion, the conducted studies indicate that PUT is a viable solution for RQ2 by providing a playful approach that makes use of the motivational impact of games whilst

Table 3.1.: Opportunities (O) and challenges (C) identified via therapists (T1-T13) survey. Text excerpts are translated from German. (Publication *P*6 (Volkmar et al., 2020a))

| Coding | Category | Text Example(s) |
|---|---|---|
| O1 | Habituation to anxiety-inducing situations | “Playful (not as threatening), as preparation and habituation for anxiety-inducing thoughts.” (T1)<br>“This allows a graduated approach employing one’s own design elements [...].” (T4)<br>“By employing a playful approach, exposure therapy becomes more accessible for patients, it also facilitates the eventual real exposure in vivo.” (T4)<br>“Deep cognitive processing of anxiety-inducing situations can lead to reassessment and facilitate curiosity/exploratory behavior in vivo.” (T9) |
| O2 | Perceived control and self-efficacy | “[...] which increases one’s own perceived control and with it one’s perceived self-efficacy.” (T4) |
| O3 | Improved interaction of patients and therapists | “Additionally, it enables an easier interaction with the therapist.” (T4) |
| O4 | Economic usage of VR | “In a therapist’s everyday life, the HMD is more practical as it does not require the therapist to go somewhere with the patient but allows them to stay in the facility.” (T5)<br>“In some regions there simply is not enough ‘material’ for exposure.” (T10)<br>“A realistic emotional response in VR can (somewhat) replace a challenging exposure planning/execution outside the therapeutic facility and thus, save time for traveling long distances.” (T11) |
| O5 | Realistic environment | “[...] very realistic and capable of addressing situational anxiety triggers of patients with fear of heights.” (T7)<br>“realistic projection” (T8) |
| C1 | No replacement for actual communication | “It is hard to say to what extent the software is applicable as its own therapeutic approach.” (T1)<br>“[...]the therapeutic relationship would be missing which I think is essential.” (T6)<br>“Direct communication with the therapist is very important.” (T3)<br>“How about the communication between patients and therapists?” (T3) |
| C2 | Lacking realism | “According to the video, the environment (situation) was not displayed in a very realistic way.” (T1)<br>“The expo-scenario showing the mountains was poorly done, too artificial, virtual” (T7)<br>“Buildings and the environment seemed rather unreal.” (T12)<br>“It is fairly obvious that it is not real” (T13) |
| C3 | Pseudo-habituation | “It is rather simple to expose patients to heights in real life which is preferable to a virtual version since certain thoughts such as ‘this is not real’, which may increase the feeling of security, do not appear in a real scenario.” (T5)<br>“There might be a false sense of security which in turn prevents a therapeutic effect when actual exposure happens.” (T5)<br>“In addition, it can become a cognitive avoidance mechanism.” (T13) |

not interfering with the procedure and success of therapy.

## 3.3. Procedural Content Generation and Creativity

As a result of the previous chapter, a game-design strategy (PUT) was derived for the application area of playful VRET. An evaluation with convenient subjects and domain experts of this approach indicated that through the act of playful, creative self-expression, players felt more engaged and motivated to interact with the VRET system. However, the prototype implementation of PUT so far presented the players with a blank terrain for them to shape and build upon. Therefore, players may be overwhelmed with the task of creating an entire environment for the exposure experience since they start out with a flat landscape and nothing on it. Here, pre-generated assets could deliver a solution to this problem. With the use of procedural content generation (PCG), certain elements of the virtual environment can be created without the player's manual inputs. This however poses a new problem. Since the design step in PUT facilitates enjoyment through creative self-expression, it is questionable, if the inclusion of PCG may hinder the notion of self-reported creativity in this step. As a way to address this issue, this chapter is concerned with the investigation of the relationship between PCG and creativity in a playful city-building task as was defined in the design step of the PUT game design strategy (RQ3). For a more comprehensive depiction of this process, please refer to publication $P3$ (Volkmar et al., 2022).

### Requirements for Playful Multi-User PCG Systems

As a way to support practitioners in therapy, the PUT game design strategy was conceived and evaluated. In its first iteration, the PUT prototype is a single-user system specifically designed for the patient to design and experience exposure scenes such as varying levels of height for the treatment of acrophobia. However, as therapists pointed out in the interviews (see publication $P6$ (Volkmar et al., 2020a)), collaboration and communication are vital in any support system for it to be applicable in a real-life therapy scenario. Therefore, ultimately, a therapeutic application based on the principles of PUT should be designed as a multi-user system. Since I am investigating the usage of PCG in the context of playful city-building tasks (as in the design step of PUT) in this chapter, certain requirements need to be met in order to ensure an enjoyable player experience. For this purpose, I will shortly list a number of considerations to make when building a playful multi-user system that incorporates PCG for the layout of virtual worlds in some way. These requirements were derived from a literature review and evaluated with the use of a multiplayer platformer game that utilizes PCG for the creation of map layouts. The process is depicted in detail in publication $P7$ (Volkmar et al., 2019a). This is a condensed overview that summarizes common requirements that are mentioned throughout many games user research (GUR) publications (Costikyan, 2002; Crawford, 1984; Fullerton, 2014; Hunicke et al., 2004; Schell, 2008; Tekinbas and Zimmerman, 2003). The original list (reported in publication $P7$ (Volkmar et al., 2019a))

was shortened to be applicable for the context of terrain and city generation:
**Internal Completeness**: During gameplay, the player should never reach a state of the game that prevents them from continuing the experience. A PCG algorithm should therefore never create in-game content that breaks the game in some way. To give an example for the context of terrain and city generation for a city-building game, the generator should never create a terrain solely consisting of areas that the player cannot build anything on.

**Flow**: This concept describes a mental state of engagement with activity while the challenge to pursue the activity and the skills required to pursue it, are perfectly balanced (Csikszentmihalyi, 1990). Since *flow* is correlated with user engagement and thus, an important factor when facilitating creative self-expression (O'Brien et al., 2018; Slater et al., 1996), any procedurally generated content should not hinder the experience of *flow* for the user. In a city-building game, *flow* would be diminished by a PCG level generator that created chaotic landscapes which require the player to adjust the entire level layout before even starting to build something themselves. Additionally, PCG should not interrupt the game experience and as a result, break players out of their *flow* state.

**Diversity**: The purpose of including PCG in the context of city-building games is to present players with some content that they can use for their own creations. It is therefore paramount to ensure some level of diversity in generated content to prevent boredom and stimulate creativity.

**Performance**: Loading times are crucial in facilitating a positive player experience and can become detrimental to the overall experience when exceeding a threshold of about 9 seconds (Ip and Jacobs, 2004). The terrain and city generator should therefore be efficient enough to not frustrate players due to high loading times.

**Determinism**: Even though procedural methods are employed to generate terrains and cities, the user should have some level of control over the outcome (for instance by adjusting parameters for the algorithm) (Kelly and McCabe, 2007). Therefore, an interface should offer options to give some control to the user regarding the most prominent aspects of the generated content. In the context of city-building games, this could be the density of roads and buildings or the height of hills on the terrain.

For the implementation of the PCG-based process for the creation of a terrain and urban structures, these requirements should be met so as to not compromise the player experience. The following segment describes the implementation process of such a generative system under consideration of these requirements.

### Implementation of a Procedural Terrain and City Generator

In order to address RQ3, a VR city-building tool was developed that allowed for the playful creation of terrains and cityscapes with the integration of procedural methods that create aspects of the scene. One core requirement in the design of this tool was its applicability for non-technical personnel. Therefore, the interaction should feel natural to the users without overwhelming them with features and non-essential functionality. This prototype was conceived as an immersive tool that gives users the opportunity to express themselves creatively by shaping a terrain map, drawing a road network, and placing and decorating urban structures. In addition to a manual input, this tool provided a procedural generation of these scene elements. The outcome of the procedural methods used to generate content was somewhat controllable by the user. As an example, a procedural method was implemented to shape a terrain. For this process, the user was able to define how steep the canyons in the terrain had to be. In the following sections, I will give a short overview of how the procedural generation was conducted and how the overall interaction with the prototype was designed.

### Terrain and Cityscape Generation

The procedural generator was implemented as a multi-step process that divides generation roughly into two parts: terrain generation and cityscape generation. The terrain creation implemented for this prototype was based on the procedure described by Olsen (2004). First, a simple 3D mesh is displaced using a *Voronoi diagram* (Musgrave et al., 1994) which is generated by a *Delaunay triangulation* (Delaunay et al., 1934) and *Lloyd relaxations* (Lloyd, 1982). Following this, the mesh is displaced once more after being processed by a *layered Perlin noise* (Perlin, 1985) algorithm. In order to smooth the resulting mesh, *thermal erosion* (Musgrave et al., 1989) is applied as a final step to the generated terrain mesh (see Figure 3.9).

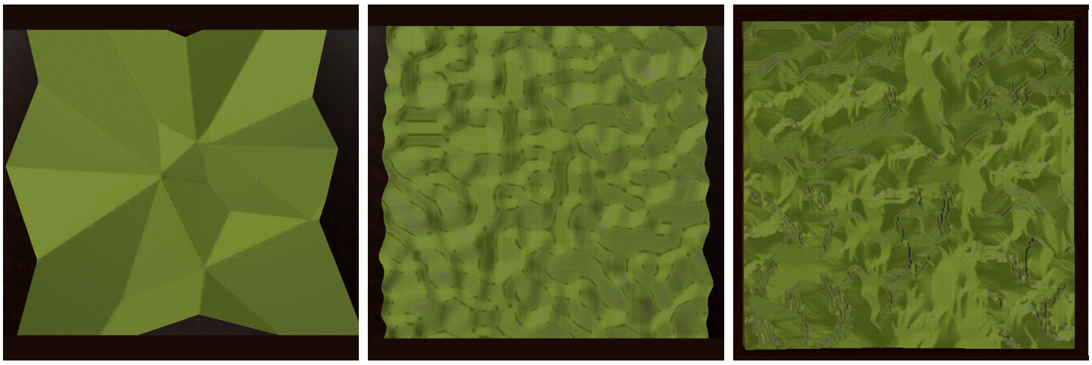


Figure 3.9.: Subsequent steps of terrain generation by Voronoi displacement, layered Perlin noise and thermal erosion (Publication *P*3 (Volkmar et al., 2022)).

After terrain generation is completed, the prototype creates the city and road structures subsequently following the procedure described by Kelly and McCabe (2006) which outlines the generation as a four step process (see Figure 3.10). First, the algorithm takes the generated terrain mesh which was the outcome of the terrain generator, divides it into tiles, and marks certain areas on the tiled mesh. Based on restrictions defined before, areas are marked as *edges* (the outer rim of the terrain mesh), *uninhabitable* (canyons, mountains or steep hills), or *free*. The tiles tagged as *free* indicate areas where buildings and roads can be constructed. On a random selection on *free* tiles, singular road assets are placed which then extend in one of the four cardinal directions. As soon as they hit another road tile, collide with an *edge* or *uninhabitable* tile, or reach their predefined maximum length, the extension stops. When this happens for all placed road tiles, the road network generation is completed. As a next step, the algorithm defines zones in the terrain as either *open* or *enclosed*, meaning, that these areas are confined by roads and/or *uninhabitable* tiles. These enclosed areas are then filled with building blocks that represent urban structures. The 3D assets used for building placement all share the same dimensions but differ in terms of texture, the shape of the roof, and the number of balconies and windows. Their height depends on the maximum building height parameter defined by the user. With the building generation completed, the algorithm concluded and presents the user with a finished terrain and cityscape.

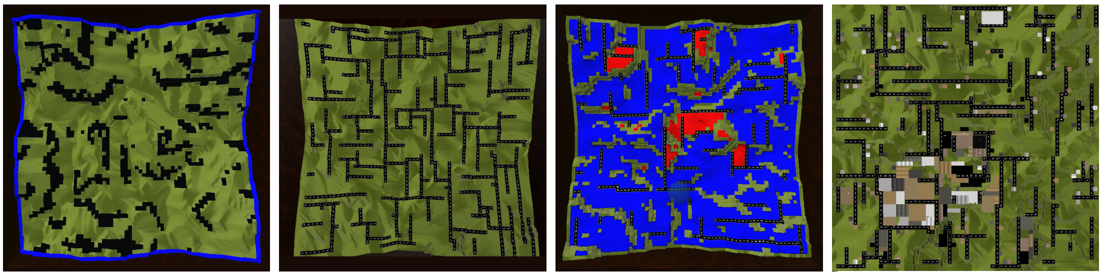
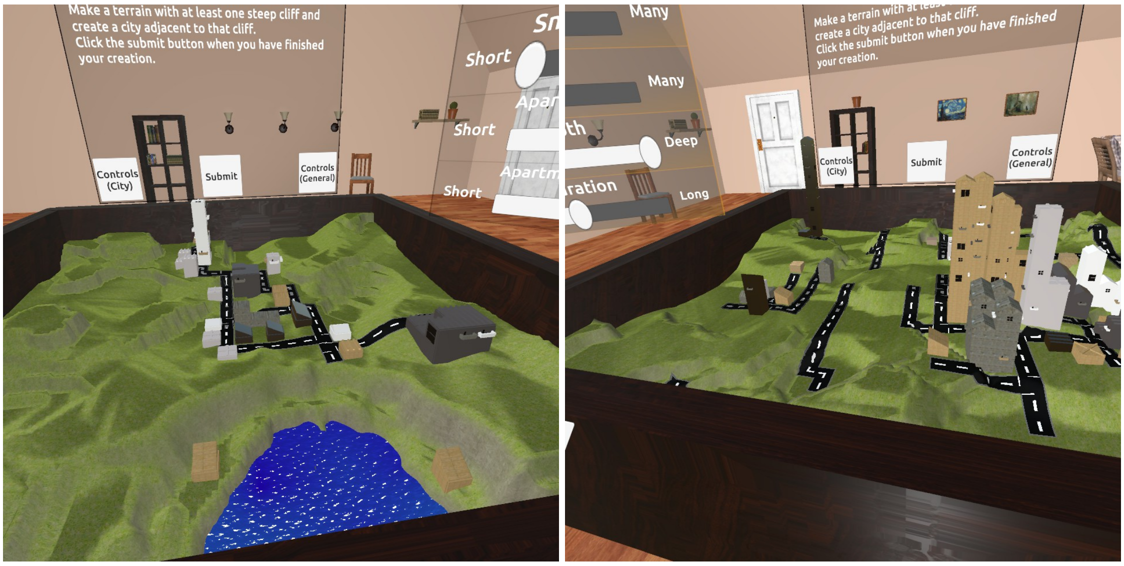


Figure 3.10.: Steps of city generation by marking the terrain, placing roads, defining zones, and placing buildings (Publication *P*3 (Volkmar et al., 2022)).

### Interaction Design

The prototype was designed as a tool that combines procedural methods and manual user input to create a virtual terrain that holds a cityscape on top of it. As a way to achieve this human-computer co-creation, the interface was designed in a way that allows the user to define constraints for the PCG algorithm for various aspects of the scene. For this purpose, inspiration was taken from the works published by Kelly and McCabe (2007) who describe how a PCG-based terrain-and-city generator can be controlled with a set of parameters. Another source of inspiration for the interaction design was taken from *Tanagra*, a level-design tool for 2D platformer games (Smith et al., 2010, 2011). In general, the interface for PCG parameter adjustment is split into two parts, one for terrain and the other for city generation, similarly to the separation into *landscape* and *feature* mode described by Smelik et al. (2010).

In the virtual scene, users are presented with a living room environment and a sandbox located in the center of the room. The parameter adjustment interface for terrain generation is placed as a world-anchored menu (Alexandrovsky et al., 2020a; Rzayev et al., 2019) on the left side of the sandbox (see Figure 3.11). Accordingly, the interface for city generation parameter adjustment is located on the right side. Both interfaces provide sliders for various elements of procedural generation. For terrain generation, users could define the size of hills, the number and depth of canyons, and the smoothness of the terrain as impacted by the duration of the erosion of the mesh. Parameters for city generation entailed the number of streets, the number and height of common houses, and the minimum and maximum height of apartment building complexes. In addition to these static world-anchored interfaces, users were given another menu attached to their non-dominant hand. This menu was designed to offer manual inputs for scene adjustments. One such feature was the direct shaping of the terrain by raising, lowering, or smoothing the terrain mesh in the sandbox with a brush-like circle that is projected onto the terrain, similarly to software like *TiltBrush* (Google, 2016) or *SculptrVR* (Rowe, 2016). Furthermore, with the use of this menu, users could place roads and buildings which could be adorned with roofs, windows, and balconies. All created structures could be erased by the user with a demolition tool.



Make a terrain with at least one steep cliff and create a city adjacent to that cliff. Click the submit button when you have finished your creation.

Figure 3.11.: VR environment of the PCG-based terrain-and city generator with instructional texts in the back and interfaces for parameter adjustment on the left and right (Publication *P*3 (Volkmar et al., 2022)).

For moving around in the virtual environment, users could either walk or use a *teleportation* mechanic. This mechanic allowed users two different perspectives of the scene. Using common teleportation, users would simply change location in the room. In addition, the interface also allowed for teleportation into the created city. Here, users would not perceive the scene as a miniature view from the outside anymore but be fully immersed in the environment on a full scale. All interactions were performed using a ray-cast mechanic that projected a blue ray from the user's dominant hand. This allowed for a typical point-and-click interaction with the system.

### User Study

The aim of the study was to investigate the impact of PCG on the perception of creativity of people that are concerned with a playful city-building task which resembles the second step in the PUT game design strategy. For this purpose, a remote within-subjects study was designed, that would be conducted on VR hardware and hosted on *Prolific*[4], a participant recruitment web service for online studies.

### Participants

The number of required participants for this study was calculated using *G*Power* (Faul et al., 2007) which determined that 69 participants would be sufficient for the study design. Thus, the study on *Prolific* offered a maximum of 80 slots that were filled by people interested in participating. Some participants were filtered out due to missing data, connectivity issues, or if they spent less than 120 seconds in one of the conditions which would indicate that the task was not completed in a meaningful way. After cleaning up the data, 55 participants remained in the sample for further data analysis. Gender distribution was male-dominated (49 male, 5 female, 1 non-binary). Ages ranged between 19 and 50 years $M$=26.16, $SD$=7.55. Participants were pre-screened for fluency in English and ownership of a VR headset.

### Material & Apparatus

To assess creativity as a self-report measure, the CSI (Carroll and Latulipe, 2009; Carroll et al., 2009; Cherry and Latulipe, 2014) was employed. Since focused attention correlates with creativity (Kasof, 1997) and can trigger creative expression (Zabelina, 2018), the user engagement scale - focused attention (UES-FA) subscale of the user engagement scale - short form (UES-SF) (O'Brien et al., 2018) was included in the process.

For the study setup, the prototype was adjusted to provide four different conditions that supported the user with varying degrees of PCG:

1. USER: No PCG was integrated in this condition. Users were presented with an empty scene that contained a flat terrain, where they could adjust the scene using only manual inputs.
2. TERRA: The terrain of the scene was pre-generated in this condition following the procedure described before. No urban structures were generated procedurally.
3. CITY: This condition displayed a flat terrain with pre-generated urban structures (road network and buildings).
4. FULL: Both the terrain and urban structures were procedurally generated in this condition.

Regardless of the condition, the prototype offered functionality for manual adjustment of the scene via the hand-anchored menu. For the conditions in which PCG was utilized, additional menus for parameter adjustment (height of hills, the density of buildings, etc.) were displayed on the left and right side of the sandbox. Questionnaires were included as world-anchored in-VR questionnaires (inVRQs) (Alexandrovsky et al., 2020a; Putze et al., 2020).

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[4] https://prolific.co/

### Procedure

Study details were depicted on **Prolific** informing participants about the requirements and procedure of the study. After accepting participation, they were redirected to *itch*[5] where the prototype was hosted. Here, they confirmed a consent form which included information regarding the study process, the recording and storage of data, risks and benefits, and other details. To start the experiment, participants downloaded the software compatible with their respective VR device and launched the application. At first, a tutorial was presented to the participants, guiding them through the various controls and mechanics of the application. Following this, they started in one of the four conditions, the order of which was counterbalanced using *balanced Latin square* (Bradley, 1958; Gergle and Tan, 2014; Williams, 1949). In each condition, a creative city-building task was chosen from a list of tasks at random. To give an example, a task could be to create a cliff with a town next to it. Participants could freely explore the environment and express themselves creatively without any time restrictions. When they felt like the task had been completed they "submitted" their creation and started the next condition until all four conditions were completed. Focused attention and creativity support were assessed after each condition. At the end of the procedure, participants received a code to enter in *Prolific* to qualify for payment. All participants were paid 6£ for an average of 54.77 minutes ($SD$=26.07) they spent for the experiment. The study flow is depicted in Figure 3.12.

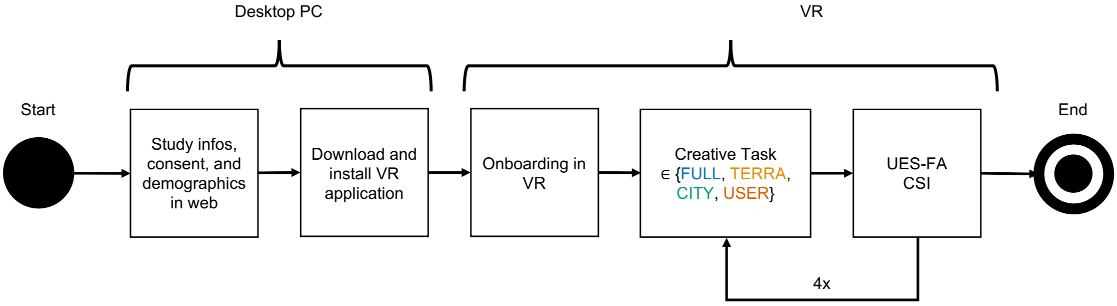

Figure 3.12.: Illustration of the subsequent steps of the study procedure (Publication *P*3 (Volkmar et al., 2022)).

### Results

In terms of user engagement as measured by the UES-FA, a repeated measures ANOVA was calculated. Between the four conditions, no significant differences were found ($F_{3,168}$=0.90, $p$=0.439, $\eta_p^2$=0.016). A Bayesian repeated measures ANOVA on the UES-FA data revealed that the data is 18.15 times more likely under the null hypothesis showing

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[5] https://itch.io/

strong evidence for the equality of the conditions. For creativity support, repeated measures ANOVAs were calculated for each subscale of the CSI. For none of the subscales, a significant difference was found (see Table 3.2). For the CSI total score, no significant differences were found between the four conditions ($F_{3,162}$=0.30, $p$=0.823, $\eta_p^2$=0.006). A Bayesian repeated measures ANOVA indicated that the CSI data is 31.10 times more likely under the null hypothesis.

Table 3.2.: Descriptive statistics and RM-ANOVA results for the CSI subscales (Publication *P*3 (Volkmar et al., 2022)).

| Scale | Mean (SD) | F(3,162) | np2 | p-GG-corr | $BF_{01}$ |
|---|---|---|---|---|---|
| Enjoyment | 5.96 (2.17) | 0.497 | 0.009 | 0.675 | 24.06 |
| Exploration | 5.78 (2.04) | 0.664 | 0.012 | 0.557 | 19.86 |
| Expressiveness | 5.72 (2.03) | 0.098 | 0.002 | 0.960 | 39.93 |
| Immersion | 5.61 (2.03) | 0.487 | 0.009 | 0.683 | 24.67 |
| Effort | 5.65 (2.05) | 1.394 | 0.025 | 0.247 | 8.04 |
| $CSI_{total}$ | 86.17 (26.12) | 0.300 | 0.006 | 0.823 | 31.10 |

## Discussion

Results for both focused attention and creativity support imply that PCG had no noticeable effect on self-reported creativity in a playful city-building task. This is confirmed by repeated measures ANOVAs as well as Bayesian ANOVAs that suggest that the data is more likely under the null hypothesis. These results furthermore demonstrate that the kind of content, be it terrain or urban structures, had no impact on the perception of creativity.

## Conclusion

This chapter was concerned with the effects of PCG on self-reported creativity in a playful city-building task. This was formalized in RQ3 which was addressed by conducting a user study that compared varying degrees of PCG and its effect on creativity support and user engagement. There are implications for the PUT game design strategy that can be derived from the results. The aim of the PUT approach was to investigate ways to harvest the positive motivational effects of video games for the context of exposure therapy without interfering with therapy success. By splitting up the experience into two steps, users achieved a higher sense of motivation by designing the exposure scene and expressing themselves creatively in the process. Taking the results from this user study into consideration, it is clear that PCG can be integrated into this design step without taking away the means for creative self-expression from the user.

# 4. Discussion & Limitations

For the scope of this thesis, an overall research theme (RT) was defined in the introduction. This RT posed the following question:

> *How should playful applications that give the opportunity for creative self-expression be designed in order to be applicable in the context of exposure therapy whilst not interfering with therapeutic success and keeping technical complexity to a minimum?*

In this chapter, I will reflect on the three specific research questions that were defined to address the RT and derive answers for these questions based on the results of the presented publications. Moreover, this chapter aims to embed the presented work into the current state of research. Furthermore, I will examine the limitations of the work that need to be taken into consideration when interpreting any results from this thesis.

The first research question (RQ1) was concerned with the support of users with low technical expertise but high technical demand in their everyday activities. More precisely, RQ1 posed the question of how to support therapists and patients in the conduct of VRET with technology that makes the interaction feel natural to them. This problem was addressed in section 3.1. Based on a requirement analysis that was performed as a workshop with industry experts from the domains of film, animation, and theater, a software prototype was developed to support them in their everyday work activities. This prototype was implemented based on the concepts of natural user interfaces (NUIs) and evaluated in the form of projects that teams from these domains worked on independently. Based on this evaluation, it can be concluded that NUIs served as applicable additions to the experts' workflow. The interaction was assessed to be intuitive and easy to learn after a short period of familiarization. On the other hand, quantitative results showed average scores on system usability and workload due to the high number of functionalities and short learning time. In summary, when dealing with technically demanding tasks, NUIs have proven to be able to alleviate the technical complexity of the task at hand. However, when introducing a system (e.g. to support VRET), a learning phase is necessary so as to not overwhelm users with a magnitude of functionality. These results are in line with the state of research regarding NUIs since they indicate that people greatly benefit from this kind of interaction in their workflows if NUIs are designed with the specific requirements of users in mind (Wigdor and Wixon, 2011). There are some limitations to consider as the project evaluations were performed without the supervision of an independent examiner. This was done by design since the prototype was evaluated in terms of real-life applicability which was best achieved by conducting realistic projects. However, this left the examination without any control over the environment of the evaluation. This in turn could introduce a number of confounding variables from the work environment like noise and other interruptions.

The second research question (RQ2) examined the combination of playfulness and psychotherapy and how motivational benefits that are known from games user research (GUR) can be employed in therapeutic procedures. Thus, in order to address this question, this thesis aimed to define a game design strategy that fulfills the specific needs of virtual reality exposure therapy (VRET) in chapter 3.2. As a first step to a formalization of such a strategy, a requirement analysis was performed with therapists. As a result, the playful user-generated treatment (PUT) game design strategy was defined and evaluated in the form of a user study and an expert evaluation. From both evaluations, it was evident that PUT can be considered an applicable addition to VRET by providing playful elements in a design step of the experience, which is separated from the actual exposure. The PUT-based prototype received higher motivational scores than the control condition without impacting the perception of fear. Results from these studies are in line with previous research from this domain (Coyle et al., 2007; Fleming et al., 2017; Thompson et al., 2010) and indicate that PUT fulfills the requirements of SMART (specific, measurable, achievable, realistic, and time-limited) goals which are part of common treatment techniques in CBT (Fenn and Byrne, 2013). Some limitations constrain this work. Results derived from the user study are based on measures taken from convenient non-phobic subjects. Research showed that non-phobic people react similarly to phobics when exposed to certain anxiety-inducing situations in VR but to a lesser degree (Robillard et al., 2003). Still, it cannot be said conclusively if different results would be achieved if the study was repeated with phobic participants.

The PUT game design strategy derived from the examination of RQ2 includes a playful city-building step in the first half of the experience which motivates players by allowing creative self-expression. In this step, players build and design a terrain and cityscape from scratch using standard tools of 3D VR editing software. Since this process may be too overwhelming and technically complex, a question opened up whether procedural content generation (PCG) could be integrated into this step to support players in their building tasks. However, it remained unclear whether any pre-generated content would have a noticeable effect on players' creativity and therefore, reduce motivation and diminish player experience in some way. This is where the third research question (RQ3) came in and addressed the use of PCG in a playful city-building task and its impact on players' perceived creativity (see section 3.3). This was achieved by conducting a user study that compared four different versions of a playful city-building prototype with varying degrees of PCG, either for the creation of terrain or city structures, or both. The results confirmed that the prototype functioned as a creativity support tool (CST) (Gabriel et al., 2016; Greene, 2002; Shneiderman, 2002), independent of any procedural generation of content, be it terrain-related or city-related. Therefore, as an answer to RQ3, it can be said that PCG can be included in playful city-building environments (as presented in the first half of PUT), without noticeably impacting players' self-reported creativity. Prior research in this field is in line with the results reported in this thesis regarding playful experiences as vehicles for creative self-expression (Blanco-Herrera et al., 2019; Checa-Romero and

Gómez, 2018; Cipollone et al., 2014; Karsenti and Bugmann, 2017; Moffat et al., 2017; Sáez-López et al., 2015). However, a number of limitations need to be addressed as well. First, any results reported in regards to RQ3 stem from a remote VR user study hosted on *Prolific*. There are several implications from this study setup. Participants had to have their own VR equipment at home, meaning that the sample consisted of rather technology-savvy subjects that were used to VR experiences. Moreover, there was no way to control the study environment and thus, to account for confounding variables like noise or interruptions. Lastly, since participants were compensated monetarily, some may have felt inclined to get through the study as fast as possible without taking time and without the opportunity for creativity to flourish. Regardless of these limitations, first insights from the user study indicate that a PUT-based system could benefit from the inclusion of PCG. However, at this point, it remains unclear how this combination would impact patients in a real VRET context.

There are several implications from these results in regard to this thesis' overall research theme. In general, the research reported in this thesis provides novel insights in regard to the design of playful VRET systems. It shows how the inclusion of NUIs can potentially improve the interaction by empowering technical novices to make use of highly technical systems. Though the NUI prototype was evaluated with professionals of a different background than psychotherapy, effects should translate to the therapeutic context due to the low technical expertise of users in both domains which could be examined further in future studies. In any case, this thesis adds to the discussion of technology use and interaction styles for VRET systems and how to make them feel natural and intuitive which is largely ignored by current research in this field. In regards to the design of playful content for a VRET system, this thesis demonstrated that specific requirements need to be taken into consideration that have not been identified by previous research in this sector so far. Specifically, the requirement that playful content should not be distracting from the experience of anxiety in an exposure task is a fact that future works in this direction should emphasize. Here, PUT can be seen as a first step in this direction by splitting the experience into a playful "distracting" design step and a non-distracting exposure step. This way, the motivational pull of games can be exploited whilst the exposure to an anxiety-inducing stimulus is left untouched. Finally, I investigated the effects of PCG when included in the design step of PUT. Since the design step provides mechanics for playful creative self-expression, it was important to investigate if creativity was negatively impacted by PCG which would in turn negate the motivational benefits of including a playful step into the VRET experience in the first place. Our study showed no such effects, either positive or negative suggesting that PCG does not inhibit playful creative self-expression in this context.

This work lays the foundation for the design of playful VRET systems that allow for creative self-expression and are intuitive to use for people with low technical expertise. For the design of such systems, these are some guidelines in a condensed form that should be considered by developers and designers:

- The interaction should be designed in a way that feels natural and intuitive to both therapists and patients. Here, NUIs can serve as a way to decrease the complexity of the interaction, taking off mental workload and thus, minimizing technical barriers.

- For the design of playful VRET systems, requirements should be considered (see $R1$ - $R5$ in section 3.2). Specifically for the design of game content, it should be noted that the exposure experience ought to be non-distracting giving patients the opportunity to reach habituation to the anxiety-inducing stimulus.
- For the treatment of acrophobia with the help of VRET, a VR system that allows for playful creative self-expression helps to increase motivation whilst not interfering with the perception of height. This is formalized in the PUT game design strategy that divides the experience into a design step and an exposure step.
- For the inclusion of PCG into a VRET system, specific requirements for multi-user scenarios need to be considered (see section 3.3).
- PCG can be included into VRET systems without impacting self-perceived creativity of users. This way, map elements such as city structures or terrains can be pre-generated which lowers technical complexity for the users.

# 5. Conclusion & Future Work

In this thesis, I have examined the role of playful creative self-expression in the context of virtual reality exposure therapy (VRET). I have divided this overarching theme into three distinct research questions that addressed different aspects of this problem. As a first step, I examined the use of technology and interaction style for playful VRET systems. For this purpose, I have presented results from a study conducted with creative personnel from the domain of previsualization. This multidisciplinary approach allowed me to derive and generalize findings in regard to technology use for people that have high technical demands in their everyday lives but low technical expertise. By conducting a case study with highly artistically skilled people from different media backgrounds (animation, film, theater), natural user interfaces (NUIs) were identified as a fitting tool for creative self-expression. Following this, a requirement analysis was conducted in the form of interviews with exposure therapy practitioners regarding the integration of playful elements into the therapeutic procedure. A game design strategy was derived, that divided the experience into two steps, a design stage, in which playful elements were included in the form of a city-building game and an exposure stage where patients would focus on their reaction to the anxiety-inducing stimulus alone without any playful elements as distractions. An evaluation in the form of a user study and an expert survey deemed this concept to be applicable in a real-life therapy scenario. Finally, an examination of procedural content generation (PCG) and its impact on self-reported creativity in a city-building task was carried out. Following a requirement analysis, a prototype was designed and evaluated. Regardless of the type of content that was pre-generated, measures of self-reported creativity did not differ significantly, with or without the inclusion of PCG. Therefore, integrating PCG into the design step of PUT does not inhibit creative self-expression or take away its capability to function as a creativity support tool (CST).

For future work, the results from this thesis point in various directions of which I will shortly present the most prominent ideas. In publication *P*6 (Volkmar et al., 2020a), a list of potential challenges was derived from expert interviews in regards to the PUT concept and how to further improve it. One core challenge identified by the practitioners was the facilitation of communication between therapists and patients. In its current state, the implementation of PUT does not provide any way for interaction between these two parties to take place. However, the underlying concept of PUT does not obstruct communication in any way. In a more advanced implementation of the concept, a therapist could easily be included in the procedure, e.g. as an avatar representation which is becoming a common approach in VRET systems (Freeman et al., 2018). A future study could investigate at which stages of the experience a therapist should participate in the process. Another point of concern raised by the experts was the “lack of realism” as they called it. However, the interviewees did not agree on this point and thus, some praised the "realistic environment". A future study could look into the aspects of realism and what role it plays in the VRET procedure or if plausibility (Slater, 2009) might be a more helpful approach. Ultimately, one limitation of the PUT strategy comes from the fact that, so far, it has only been tested in the domain of acrophobia. Subsequent studies should examine the applicability of PUT for the treatment of other phobias as well.

The investigation regarding RQ3 indicates that PCG can be integrated into an application based on the principles of PUT without noticeably decreasing the users' self-reported creativity. However, one open question remains in regard to the type of content that is pre-generated. It may be that differences in personality factors such as the five factor model (FFM) of personality (McCrae and John, 1992) or in *player traits* (Tondello et al., 2019) between users lead to different preferences regarding the content itself or its visual design. A preliminary examination regarding the potential of adaptable content, dependent on *BrainHex* player archetypes (Nacke et al., 2014) was conducted in publication *P*9 (Volkmar et al., 2019b). In this paper, one core insight was that adjusting content in video games to players based on a personality-based categorization can lead to higher intrinsic motivation. This effect could be examined further in future work by seeking correlations between *player traits* and player behavior in playful city-building environments. Based on these correlations, preferences could be derived for certain types of content the PCG terrain and city generator could take into consideration when creating content.

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# Part II.

# Publications

# Publication $P1$

## Evaluation of Natural User Interfaces in the Creative Industries

Georg Volkmar, Thomas Muender, Dirk Wenig, and Rainer Malaka

Published in
Conference on Human Factors in Computing Systems (CHI EA ’20)

Personal contribution:
I contributed a majority to the writing (original draft, review & editing). Thomas Muender and I contributed equally to the idea (conceptualization), conduct (investigation) and analysis (formal analysis).

# Evaluation of Natural User Interfaces in the Creative Industries

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## Abstract

The case study presented in this paper is concerned with the applicability of *natural user interfaces* (NUI) in the context of *previsualization* (previs). For this purpose, we have developed a virtual reality (VR) based tool that includes NUIs as a novel way to perform previs-related tasks. For the application domains of animation, film, and theater, we conducted a quantitative and qualitative assessment of the prototype by realising projects that resembled real life productions in the creative industries. In collaboration with industry experts with different creative backgrounds, we conducted a large-scale evaluation and examined the potential of NUIs in a professional work context. Our results indicate that NUIs can offer a usable alternative to standard 3D design software, requiring only a short familiarization phase instead of extensive training to achieve the intended outcome.

## Author Keywords

Previsualization; Natural User Interfaces; Film; Animation; Theater; Project Evaluation.

## CCS Concepts

**•Human-centered computing** → **Virtual reality; Empirical studies in HCI;** *Usability testing;* **•Applied computing** → *Arts and humanities;*

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**Figure 1:** Possible previs outcome: 3D representation of a theater stage with different lights, props and virtual actors.

**Figure 2:** Character walking animation can be performed by grabbing a node with the handheld controller and drag it across the scene.

**Figure 3:** The timeline tool provides the necessary functionality to record a shot in the scene.

## Introduction

In the creative industries which entail film, animation and theater, it is common to plan and visualize the desired production result before the content is actually generated. This phase is necessary for the creative personnel to get an overall impression of the scene within a limited scope focused on the essential parts. Usually, this stage of production is also referred to as *previsualization* or simply previs [8]. Previs has become an integral part of creative productions since it allows early visualisations that support making creative decisions with much lower cost of changes than at later stages of production. In this day and age, previs is typically conducted with the help of professional digital software packages like *Maya*[1], *Blender*[2] or *Unity3D*[3]. Though these tools provide a multitude of functionalities that can be used in the context of previs, they are overwhelmingly complex, especially for non-technical users such as artists and designers [6]. As a result, most professional 3D design tools become hardly usable due to their complex nature and cluttered menus leading to mental overload for many users.

To overcome this problem and to offer an applicable alternative for the domain of previs, we have designed and implemented a specialized tool that incorporates the concept of *natural user interfaces* (NUI). To give a short definition of the term, NUIs can be described as interfaces that provide an intuitive interaction style and express naturalness “referring to the way users interact with and feel about the product, or more precisely, what they do and how they feel while they are using it” [9]. NUIs have a high potential in the context of previs since they take the innate creative capabilities of practitioners into account. Moreover, they empower users in how they can express themselves in an optimal way depending on the task they want to perform in the previs cycle. This way, NUIs can lower the need and effort to translate user intents and actions through the interface but rather allow for more direct natural expressiveness. Development of the NUI previs tool was based on typical tasks that were identified beforehand to be crucial in the context of previs [7]. More specifically, the software offers functionality for project structuring, import/export, shot management, sketching (modelling), asset selection, camera control, visual effects (VFX), lighting and posing/animation [7].

In the case study presented in this paper, we conducted a large-scale evaluation with industry experts from the fields of film, theater and animation. In the course of this analysis, we gathered quantitative and qualitative data and revealed the potential of NUIs within the previs workflow. The evaluation was conducted in the form of projects, that the experts performed by utilizing the experimental NUI prototype. These projects resembled real-life productions that professionals from the creative industries are dealing with in their daily work routines. By conducting realistic projects with the prototype, we gained insights on how to apply NUIs in the workflow of creative personnel and how NUIs can impact the production process compared to traditional 3D design software. In summary, this paper studies the case of natural user interfaces, specifically interaction in VR, in the context of previsualization for film, animation an theater production. We contribute towards the research domains of natural user interface design and the application of technical solutions for the purpose of supporting creative professionals.

## Previs Tool Features

The NUI tool is a virtual reality (VR) based application that provides a common space for performing previs tasks: the user can move freely within the virtual space and directly

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[1] https://www.autodesk.com/products/maya
[2] https://www.blender.org/
[3] https://unity.com/

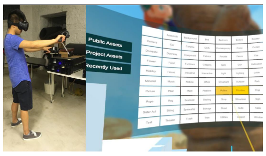

**Figure 4:** To place assets in the scene, the artist can pick an item from the asset library.

**Figure 5:** Collaboration between the artist in the scene and the director who can give instant feedback on the project.

**Figure 6:** Animation project team discussing the outcome of their production.

manipulate objects using the VR hand controllers. This provides the basis for a natural user interface where assets can be grabbed and moved directly, characters can be posed by grabbing and moving parts of their body, paths can be manipulated by grabbing nodes, and special tools can be wielded to perform tasks such as sketching and painting (see Figures 1 to 3). Additional controls are provided by a tablet-like interface on the back of the user's wrist. Touch gestures and speech commands are also used to augment the interface. To support realistic work sessions involving many tasks as part of a larger workflow, the basic platform also provides an online asset repository and a shared repository for saving and reloading stage design and scene scripts along with undo and redo and online collaboration between team members. Scenes are organized into projects and each project has its own team. Theater, animation, film, television, and visual effects each have different requirements for their distinct workflows. This feature-rich prototype provides a common core of functionality across all disciplines as well as functionality targeted at specific disciplines.

In contrast to traditional 3D content creation tools, all interaction with 3D content can be performed in the real 3D space in this prototype rather than with abstract 2D controls, e.g., widgets. This enables the user to interact with the content in a more natural way which resembles how people interact with the real world. In addition, natural gestures like looking at your watch to display additional menus or using the body to pose a character complement this type of interaction to be easy and naturally understandable to the user.

## Project Description

The aim of this case study is to evaluate the NUI prototype in a realistic project scenario regarding the applicability in professional workflows as well as the usability and user experience (UX). For this purpose, we defined three distinct projects in collaboration with industry experts for the domains of animation, film and theater. Each project was based on actual productions that the professionals had worked on previously or were currently developing. Studios from the respective domain were responsible for the actual implementation of the projects. The following sections will provide a brief overview of each project and how they were realized with the help of the NUI prototype.

### *Animation Project*

The aim of the animation project was to create a trailer for an animated series. Content-wise, the trailer should display the adventures of a girl exploring the world with an animal friend. To achieve the desired outcome, the team had to record various video shots with three different animated characters in them. More specifically, the staff had to create the layout for various scenes, place a variety of assets (see Figure 4 & 5) and ultimately animate the characters and record the sequence of actions.

The team consisted of five people with different backgrounds: a director, a production manager, a layout artist, a motion-capture (MoCap) performer and a pipeline supervisor. Over the course of four days, this team intended to create the trailer with the NUI software. Afterwards, they shared their experience with the help of video recordings in which they have detailed feedback on the software and how it compares to traditional workflows (see Figure 6).

### *Film Project*

For the film production, a short commercial video was supposed to be created with the NUI software. The scene took place in a 3D recreation of a brewery from one of the studio's customers. The shot ought to display a tour within the brewery including possible activities. The result of this production could then be used as previs for the actual recording with real actors later on. To generate the sequence as desired, the professional has to load the 3D environment from a database, adjust light settings (see Figure 7), place characters in the scene and create a path through the brewery which is recorded by a set of cameras (see Figure 8). For the final video, the professional has to make use of the built-in editing tools for cutting video sequences and adding effects and filters (see Figure 9). The team for the film production consisted of a light designer, a set designer, a stage designer and a camera operator.

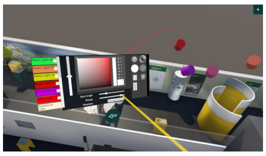

**Figure 7:** Light settings can be adjusted in terms of color, intensity, spot angle and other options.

**Figure 8:** Various cameras can be placed in the scene to record shots in the virtual environment.

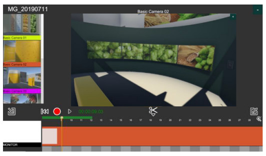

**Figure 9:** After a shot has been recorded, various editing functions can be accessed to produce the final result.

*Theater Project*
The team behind the theater project intended to previsualize a variety of scenes for their upcoming opera performance. Most importantly, tools for sketching, measuring (see Figure 10) and painting/applying texture were in the focus of this evaluation. Sketching was used to generate basic structures for the stage such as walls and simple buildings. These structures were then colored with the paintbrush tool or predefined textures from the asset library (see Figure 11). When the overall layout of the scene had been defined, the designers had to place additional assets like lights and virtual actors on the stage. A special requirement for stage productions which did not apply to the other creative domains was to handle stage machinery. For this project partner in particular, they needed to have control over a virtual representation of a revolving stage, flybars (see Figure 12) and lighting bridges to create useful previs for their plays. The following professionals were involved in the implementation of the project: a stage master, a lighting master, the theater's CTO, a project manager, two stage technicians and an apprentice in event technology.

## Methods

As stated before, the evaluation of the NUI approach was carried out in the form of projects that resembled real productions in the creative industries. These projects were defined and conducted by industry experts with varying backgrounds (see previous section) from the domains of film, animation and theater. The objective of these project evaluations was to examine the prototype regarding the applicability in the work context. In addition, we were interested in standard usability and UX measures to better understand the results and bring them into context with the qualitative findings.

*Material*
In addition to project scripts, we utilized standardized questionnaires established in usability and UX research: System Usability Scale (SUS) [2], NASA Task Load Index (TLX) [4] and the AttrakDiff [5]. Moreover, we prepared questions for a semi-structured interview to be taken out after the procedure (see explanations on the left margin). Additional documents contained a demographic questionnaire and a consent form for usage of personal data for the purpose of anonymous statistical analysis as well as voice and video recording. In terms of hardware, we ran the software prototype on workstations capable of providing a stutter-free and smooth VR experience. For the interaction itself, a HTC Vive basic setup including a head-mounted display and two handheld wireless controllers was used.

*Procedure*
Upon reading and signing the consent form, each participant received a brief introduction regarding the software's functionalities that would be needed while interacting with the prototype. Following the tutorial, subjects took on the headset and the controllers. When they felt confident with the system's controls, they were ready to work on project

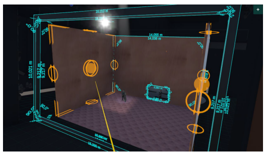

**Figure 10:** To enable accurate planning, designers working in a theater context have to take measurements.

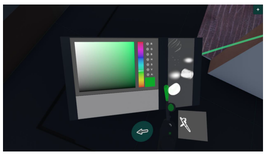

**Figure 11:** Paint can be applied to generated structures.

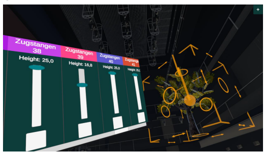

**Figure 12:** Flybars are a common structure in stage machinery which can be raised and lowered while other objects can be attached to them.

related tasks. When the team felt they had completed the project successfully, they filled in a set of questionnaires (SUS, TLX & AttrakDiff). Ultimately, a semi-structured interview was conducted in the end asking for additional qualitative feedback. The following questions were raised during the interviews: What's your overall impression of the software's functions after performing this task? What worked well and what didn't? How natural was the interaction for you? How easy was it for you to complete the task? Are there any functions/features missing that you need to be productive in the task? The entire process was recorded on video for further analysis. These recorded interviews were fully transcribed by the examiners. To derive findings from the data, feedback received from the participants was categorized into positive, negative and neutral statements. After the categorization process had been completed for each application domain individually, we aggregated the results to get an insight on how the introduction of NUI software would be assessed in the creative industries in general.

## Findings

In this section, we will present the findings derived from the project evaluations. These results were identified by conducting interviews and surveys with the professionals involved in the process. Additional data was collected by reviewing video and audio recordings as well as written scripts that participants generated to document their progress throughout their projects. Quantitative results were accumulated for all application areas whereas qualitative results are reported for each domain separately.

### *Animation*

The software arose large interest in the user base as the potential in exploring new forms and methodologies to express visual content is very high according to the participants who were interviewed. Moreover, they pointed out that although the interaction felt natural and intuitive, it took some time to get familiar with the system. However, the learnability of the tool is much higher compared to any other professional software in the market which usually requires weeks to become a skilled user. Moreover, experts stated that being able to animate in real time and reviewing the data immediately allows an approach much faster than in usual previs software. Furthermore, communication was pointed out to be another strength of the software as it allows the director and the artist to communicate directly while the interaction is taking place (see Figure 5). One negative aspect mentioned by the subjects was the cumbersome interaction with VR hardware. As animation previs scenes can take up to several hours, wearing an HMD all the time can become very tiring which leads to the necessity of additional breaks.

### *Film Productions*

Similar to the feedback we received from the animation experts, participants from the area of film productions stated that using the software was easy to learn but needed some kind of familiarization phase and training. The professionals agreed the button layout to be intuitive yet sometimes it was hard for them to remember the mapping from button to function. Overall, the user interface and especially the wrist-pad were rated positively. Team members agreed that the software would be usable to plan the placement and choice of equipment (e.g. cameras & lenses) and that they would benefit from this tool in their actual productions. More precisely, it was mentioned that the planning phase in the film domain often entails large sets and structures. In this context, a specialized previs tool would be extremely helpful to plan camera and light placement. Another advantage pointed out concerned financial savings. Since in film productions, the time spent on set is highly expensive, being able to previsualize a scene digitally is a huge benefit for the team. Moreover, having a database-structure for the previs projects enables professionals from different places to access the scene. This enhances collaboration immensely and again, cuts costs for the producers. As for suggestions for improvement, one participant stated that the work of a camera operator involves haptic feedback as well and that they would like to include that into the software somehow.

### *Stage Productions*

Professionals from the theater project agreed that using the NUI software offered an exciting and usable alternative to their traditional approach to previs which relied on analogue components (e.g. cardboard cutouts & tangible objects that represent actors or scene props). All people involved in the project commented that the software was convincing, very clear and easy to understand. Participants stated that after a short period of getting to know the functionalities, VR proved to be a “great experience”. More precisely, they were impressed by the possibility to immerse themselves in the scene using VR instead of only looking at printed plans like they were used to. Similar to film productions, time spent on stage is rather limited and expensive. Therefore, one important aspect pointed out was that without wasting precious time on stage, the artists were able to identify corridors and areas that were difficult to light up and thus adjust their lighting setup accordingly. Being interviewed about the rather negative aspects of the experience, subjects criticized the lack of some assets they would have wanted to use (e.g. prefabricated walls of different sizes). Besides that, the software received an overall positive assessment.

### *Quantitative Results*

In terms of usability, the software received an average SUS score of 66.79 ($SD{=}14.92$). The general workload caused by the interaction was measured with an overall TLX of 38.59 ($SD{=}14.78$). As for the AttrakDiff sub-scales, the software was rated as follows: *Pragmatic Quality* (PQ) of 0.88 ($SD{=}0.77$), *Hedonic Quality - Identity* (HQ-I) of 0.58 ($SD{=}0.67$), *Hedonic Quality - Stimulation* (HQ-S) of 0.97 ($SD{=}0.54$) and *Attractiveness* (ATT) of 1.34 ($SD{=}0.84$).

## Discussion

In this section, we will discuss the results of the case study in a threefold way. First, we will cover the positive feedback the software received followed by non-positive aspects the professional users pointed out. Ultimately, the third subsection will give an overall assessment of the NUI prototype based on these findings.

### *Positive Feedback*

The feedback collected in the course of the project evaluations was highly positive throughout all examined application areas. In the interviews conducted upon project completion, participants involved in the process gave positive appraisal of the software pointing out how they would benefit from it in their daily workflows. Since they had quite some time to get familiar with menu structures, button mappings and overall functionality, they quickly learned to operate the software and could focus on the tasks at hand. One major aspect expressed by the experts was the ability to collaborate easily with other project members. Animating or sketching in real time and receiving feedback from colleagues instantly was stated to be an enormous advantage compared to traditional 3D software. The collaboration aspect is improved even further by being able to save changes on projects in a database and access the same scene from anywhere in the world since in the modern industry, team members are often located in different places. Moreover, participants identified a huge benefit for planning the placement of lights and superstructures. Usually, this process is very time and money consuming if conducted on actual sets or stages. Creating a previs in VR can help to overcome these financial challenges and give the artists the chance to play around more and try different constellations.

### *Non-positive Feedback*

Qualitative feedback gathered within the project evaluations strongly contrasts the mediocre quantitative results in terms of usability. The usability measures were mostly focused on gathering quantitative data as a way to evaluate the NUI tool on a general level. Looking at the data more closely reveals that participants rated the system to be only moderately usable. After all, a SUS of 66.79 lies below the common threshold of 70 which indicates a “good usability” [1]. This is supported by the results taken from the AttrakDiff questionnaire which showed only slightly positive values for all sub-scales. In addition to these results, a TLX score of 38.59 implies an overall workload comparable to driving a car or navigation tasks [3]. Analysis of the interviews conducted after project completion gave us a rather clear explanation for these values. Subjects stated that despite the interaction feeling natural and intuitive, it was also perceived to be highly complex. Due to the multitude of features, participants who did not have any training beforehand felt overwhelmed to some extent leading to a high mental workload and a medium assessment of usability.

### *Overall Assessment*

It is important to keep in mind that subjects had to complete a rather complex task without knowing the software and some even without being introduced to VR at all. Nevertheless, each one of them was able to get to the desired outcome in a reasonable amount of time. It is highly unlikely that similar results could have been achieved by using professional software like Maya, Blender or Unity3D without lengthy training sessions. Therefore, it can be argued that the NUI prototype has the potential to offer a usable and more intuitive interaction style than common software after a short familiarization period or tutorial has been completed. These findings indicate that NUIs and VR might be applicable to professional workflows and give great advantages to creative work and are not limited to the playful applications they are mostly used in today.

## Conclusion & Future Work

The case study described here presents an attempt to utilize a 3D design software including NUIs in real-life productions for the domains of animation, film and theater. Our findings suggest that NUIs can provide an applicable alternative to traditional design tools requiring only a short familiarization phase instead of lengthy training as professional software demands. For non-technical personnel, this approach might not only offer an alternative, but a more usable and empowering tool than current software solutions.

For future developments, we plan to include other modalities that might improve the naturalness of the interaction. As stated by the professionals, haptic feedback plays a major role in some contexts. For this purpose, we intend to identify where and how to include a more tangible interaction technique. Moreover, our aim is to investigate the usefulness of speech and gesture recognition for specific tasks. Besides the lack of tangibility, the experts involved in this case study also pointed out other negative aspects regarding the interaction as we described in the previous section. This feedback will be utilized in the future to refine the software prototype further. Since the time-consuming nature of software usage was pointed out to be problematic by some animation experts, we intend to include a tutorial-mode, slowly guiding through each functionality of the prototype. This mode could help to educate untrained personnel in the familiarization-phase which would result in a more efficient, less time-consuming usage of the software overall. Since fatigue after long work session was mentioned as another point of criticism, future iterations of the software should address this issue in some way. Especially wearing an HMD for longer periods of time was perceived to be rather cumbersome. Overcoming this problem poses quite the challenge for software developers since the hardware dictates wearing comfort and thus, how physically demanding the interaction can become. However, one potential solution could be to offer desktop-alternatives to some of the functionalities. This way, users could take breaks from VR in between long work sessions while still being able to work on their product. Certainly, this would take away the naturalness of the interaction for these periods. Nevertheless, it could be a way to prevent physical exhaustion and on top of that, empower users further by providing various options to use the software as they see fit.

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# Publication *P*2

## Playful User-Generated Treatment: A Novel Game Design Approach for VR Exposure Therapy

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# Playful User-Generated Treatment: A Novel Game Design Approach for VR Exposure Therapy

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## ABSTRACT

Overcoming a range of challenges that traditional therapy faces, virtual reality exposure therapy (VRET) yields great potential for the treatment of phobias such as acrophobia, the fear of heights. We investigate this potential and present playful user-generated treatment (PUT), a novel game-based approach for VRET. Based on a requirement analysis consisting of a literature review and semi-structured interviews with professional therapists, we designed and implemented the PUT concept as a two-step VR game design. To validate our approach, we conducted two studies. (1) In a study with 31 non-acrophobic subjects, we investigated the effect of content creation on player experience, motivation and height perception, and (2) in an online survey, we collected feedback from professional therapists. Both studies reveal that the PUT approach is well applicable. In particular, the analysis of the user study shows that the design phase leads to increased interest and enjoyment without notably influencing affective measures during the exposure session. Our work can help guiding researchers and practitioners at the intersection of game design and exposure therapy.

## CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Virtual reality**.

## KEYWORDS

virtual reality, exposure therapy, user-generated content, game design

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## 1 INTRODUCTION

Simple phobias such as acrophobia (the fear of heights) or claustrophobia (the fear of closed spaces) cause problems that affect many people. In western countries, 7–9% of the population suffer from simple phobias [7], which can evoke panic [114] and can reduce the quality of life. Commonly, individuals tend to avoid spaces or situations where their phobia could be triggered. Therefore, a therapy is desirable in many cases. The most common therapy for acrophobia (and many other phobias) is exposure therapy [84]. Exposure therapy can follow a paradigm of immediate extreme or of gradual exposure, with the latter being more common. The gradual exposure therapy aims to teach the patients coping strategies when facing situations that may trigger anxiety or panic and also to gradually lower the experienced intensity of the stimulus and the physiological response to it.

Due to relying on physical stimuli, exposure therapy can be difficult to implement and manage. For example, it is often not possible to travel to places with certain heights. However, a considerable and growing body of work is evidencing that exposure therapy can successfully take place in virtual reality (VR). It has been shown that virtual exposure can be as effective as real exposure [32, 42, 43, 85] and that VRET can successively be applied in treatment [43, 86]. In some cases, virtual therapy can even be more effective [28, 66, 68] and enjoyable [28, 50, 51]. In this way, VRET overcomes a range of challenges that traditional therapy faces, e.g. logistics and safety. Moreover, VRET allows for the efficient and scalable design of individually adapted therapy plans [73, 86] and can relieve therapists [28, 54]. Although 7–9% of the population suffers from simple phobias [7], only very few people undergo a therapy [74] and even if they do, many abandon it, often due to a lack of motivation [5, 16, 20, 50].

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Games user research (GUR) established serious games [1] and gamification [39] as effective approaches to foster motivation for learning [22, 31, 38], physical activities [10, 105], work [36, 58] and therapy [50, 77, 103, 104]. While existing literature provides a good understanding of motivational game design (e.g. MDA [62]), it can be argued that common game design strategies for fostering motivation require careful consideration for the context of exposure therapies, as their implementation may interfere with requirements for a successful therapy. Therefore, in this work we investigate the potential of motivational game design elements, including patient-generated content for motivational games, in VRET. Our work was guided by the following research questions:
RQ1: *What are the specific requirements for a game-based virtual reality exposure therapy application?*
RQ2: *How can motivational game design be applied to virtual reality exposure therapy?*
With the more specific follow-up questions for conceptual validation:
RQ3: *For the selected motivational game design strategy: can measurable differences in motivation be achieved?*
RQ4: *For the selected motivational game design strategy: can the resulting exposure experience be expected to be comparable to a non-modified VRET approach?*

To address these research questions, our research is composed of the following parts: (1) To inform the requirements (RQ1) we conducted a literature review that is summarized in Section 2 and two interviews with professional therapists who had a background in traditional exposure therapy that are discussed in Section 3. (2) Based on these results, we developed a two-step concept for motivational games for exposure therapy called PUT which lets users create the anxiety-inducing experience themselves followed by an exposure phase. We built a VR game for exposure therapy (RQ2) that implements the concept in a prototypical fashion (Section 4). (3) To begin answering RQ3 and RQ4, we subsequently conducted a lab-based user study with 31 non-acrophobic subjects to investigate the effect of content creation on player experience, motivation and height perception compared to a baseline condition without the PUT element (Section 5). (4) To provide early-stage ecological validation of our outcomes, we conducted an online survey with 6 professional therapists (Section 6).

Our studies reveal that the PUT approach is well applicable. In particular, the analysis of the user study shows that the design phase leads to increased interest and enjoyment without notably influencing affective measures during the exposure session. Our work provides guidance for game design of computer-mediated exposure therapy.

## 2 BACKGROUND

Our work is informed by conventional and VR-based *exposure therapy*, *motivational game design* and *games for mental health.*

### 2.1 Exposure Therapy

Cognitive behavioral therapy (CBT) is based on a cognitive model of mental illness, which links thoughts, behavior and emotion [45]. The model assumes that one's "emotions, behavior and psychology are influenced by their perception of events. It is not a situation in and of itself that determines what people feel, but rather how they construe a situation" [12]. CBT is problem-oriented focusing on improving the patient's current state with mutually agreed SMART-goals: specific, measurable, achievable, realistic and time-limited [45]. CBT-based mental treatment methods such as exposure therapy (ET) are recognized as the most effective therapy methods [43, 84]. "Exposure therapy is a psychological treatment that was developed to help people confront their fears. [...] In this form of therapy, psychologists create a safe environment in which to 'expose' individuals to the things they fear and avoid. The exposure to the feared objects, activities or situations in a safe environment helps reduce fear and decrease avoidance"[4]. ET is based on two main mechanisms: (1) *Natural habituation* describes a natural decay in physiological response after frequent exposure to the anxiety stimulus. (2) *Cognitive revaluation* is a mechanism that comprises the patients' reflection on the exposure and their fear reaction [84]. The therapy procedure consists of three main phases: preparation, exposure, and reflection. Over time, ET typically varies between gradual and concentrated increase in the stimulus strength (e.g. increases in height). Scharfenberger discriminates three types of exposure therapy: *in-sensu* where the participants only image the exposition to the stimulus, *in-vivo* – an exposure to real stimuli and *in-virtuo* [110] an exposure to virtual stimuli (i.e. VR) [95]. *In-virtuo* exposure, as realized by VRET, offers several advantages over the exposure in-vivo, since the treatment can be conducted in the therapist's office or in remote settings and on patients who are too anxious to undergo an in-vivo exposure [43]. Furthermore, VRET allows for flexible adjustments to individual needs [86]. VRET uses immersive displays – most commonly head-mounted displays (HMDs) –, spatial audio and frequently reality-based user interfaces [63] for interaction to create strong immersion [19, 100, 102] and a sense of presence [41, 98, 99, 115]. A substantial body of research has applied psycho-physiological measures in the process of VRET and reported on studies that showed effectiveness of exposure in VR and VRET as viable options for treatment of claustrophobia [18, 75], fear of heights [40, 48, 61, 69], fear of flying [71], anxiety disorder [54, 70], and public speaking [67] among others. Emmelkamp et al. showed that exposure to heights in VR can achieve the same effect as in-vivo therapy [42]; a result that has been reproduced multiple times [28, 66, 83, 86]. Further meta-analyses on VRET studies provide strong arguments for applying VRET in clinical contexts [17, 28, 50, 56, 86].

We add to this body of research by developing a new approach for VRET that applies a two-step game design. Insights from previous work on motivational game design and game design for mental health further informed the design of these 2 phases.

### 2.2 Motivational Game Design

Literature on game experience often aims to understand features of games that shape player engagement (c.f., [96, 116]) and to transfer this knowledge into recommendations, guidelines, or principles for the design of more appealing games and engaging interactive systems with a purpose [21, 39]. An array of theoretical frameworks has been developed that helps to structure engaging characteristics of games [21, 111]. These theories are adjacent to flow theory [35] as well as self-determination theory (SDT) [92] which remain the most commonly applied theories to inform and validate game design and metrics of player experience [21, 111].

In his early work in the field, Malone identified challenge, fantasy, and curiosity as 3 key elements of engaging design [76]. For individual game mechanics, a broad array of frameworks exists [2, 52, 82, 89] that identified common structures in game design and linked them with experimentally-focused empirical research. While a large portion of the literature builds on *functional challenges*, which address physical or cognitive skills of the players [30], games with *emotional challenges* received much attention recently. These games confront players with emotionally salient material through narratives, frightening scenarios, strong characters or difficult choices players have to make [30, 37]. In such settings, the players' gratifications can result from resolutions of tensions within the narratives and overcoming negative emotions [15, 30, 44, 55]. However, emotional challenges require a careful design as they can also lead to frustration and disengagement with the game [55]. In relation to ETs, facing and overcoming negative emotions have been recognized as capable elements for shaping engagement and motivation in game design. Accordingly, Ilinx [11, 25] or vertigo games [23, 24] are built around core experiences of vertigo that can become enjoyable in the context of play. As fear tends to be avoided by individuals, games that provide enjoyment from an inherently negative experience could positively contribute to engagement in exposure therapy. In our work, we found that emotional challenges rather than functional challenges in the game should play an important role during an exposure phase in VRET. We also present suggestions how these emotional challenges could be designed.

## 2.3 Game Design For Mental Health

Games for health offer considerable potential for a broad range of application areas and enable not only fostering engagement and motivation, but also guidance (e.g. on treatment protocols in the absence of health professionals) and analysis (through tracing behaviour and/or engagement) [103]. According to Fleming et al. [46], game design offers 3 potentials for health interventions: (1) *appealing potential* by reaching out to target groups without access to treatment otherwise [13, 46, 77], (2) *engaging potential* [17, 93] due to games' enjoyable nature, and (3) *effectiveness potential* since they allow for sensory rich interactive learning experiences. Coyle et al. [33] identified mental health as a key challenge that faces society and argue towards technology-facilitated intervention methods. The authors provide development guidelines for mental-health interventions (MHIs) and suggest that HCI experts and therapists should work in conjunction in a two-phase development cycle [33].

Most literature agrees upon the fact that serious game design for health is a multidisciplinary field where different stakeholders from game design and behavioral change should team up [26, 47, 109]. There is a shared consent that the role of the therapists is essential for a successful and effective intervention [26, 47]. *Clear goals*, *feedback*, *engagement*, *enjoyment* and *challenge* are recurrently reported as game elements that support motivation in serious games [45, 46, 57, 109]. However, there has been little research that systematically analyzed effects of game elements on mental health [13]. Johnson et al. reviewed literature that reports empirical evidence on the effect of gamification on health. The authors identified 10 gamification elements and pointed out that "not a single study captured game design elements on intrinsic motivation (e.g. motivation to exercise)" [65] but rather gamification around rewards which address Cole et al.'s *functional challenges* [30]. In this paper, we analyze effects of game elements for mental health games, e.g., on motivation, and thus add a novel contribution to game design for mental health.

# 3 REQUIREMENT ANALYSIS

Designing VRET games is challenging since concepts of traditional exposure therapy and game design elements need to be combined to achieve the desired therapeutic objectives [13, 77]. Additionally, therapists should be involved in the design process as these applications are to be used in a collaborative therapy setting [47]. However, as of now there are few tested game design patterns and no generalizable guidelines for the design of therapeutic games in the domain of VRET that were derived based on the expertise of therapy practitioners. To fill this gap, we conducted and analyzed semi-structured interviews with professional therapists who have a background in treating patients using traditional exposure therapy.

## 3.1 Interview Design & Structure

In preparation of the interviews, a semi-structured document was composed, consisting of bullet points from various themes that were of interest to us to address RQ1. As we aimed for unexpected input by the therapists to arise, the structure of each interview was kept rather flexible, allowing the examiner to adapt to the situation by adding or rephrasing certain questions. The preparation process of the interview followed Helfferich's method of qualitative analysis from the social sciences domain [59] and included the following 4 steps: (1) Collection, (2) Inspection, (3) Sorting and (4) Subsuming.

Following this approach, the interview document was divided into 4 categories: Techniques and Procedures (C1), Setting and Scenarios (C2), Tasks and Motivation (C3) and Supplemental (C4). C4 carried all items that could not be categorized into one of the identified clusters but still remained relevant to address RQ1.

## 3.2 Interview Participants

In total, 2 experts, both self-identifying as female, agreed to participate in the inquiry. Both could draw on substantial expertise in traditional ET. One expert held a master's degree in clinical psychology, had finished clinical training in CBT and was currently working as psychotherapist specialized in posttraumatic stress disorder (PTSD), depression and the influence of childhood maltreatment. The other interviewee held a diploma in psychology and was also working as a psychological therapist offering a variety of therapeutic methods in individual or group sessions. Both had experience in using ET to treat specific phobias on a regular basis.

## 3.3 Conduct of Interview

The interviews were conducted as 30 to 40 minutes long face-to-face conversations in a location of the respective therapist's choosing. Following an introductory conversation, the experts signed a consent form. This detailed the usage of audio recordings and anonymized further processing of data gathered throughout the interview. As a next step, the examiner began to work through the semi-structured interview.

### 3.4 Interview Analysis

We fully transcribed the audio recordings and conducted a deductive qualitative content analysis [78] using the categorization approach described above. The content analysis was conducted deductively since a basic categorisation had been carried out already in preparation of the interviews. We refrained from deploying an inductive approach as our overall objective was to derive requirements that a technical VRET implementation should account for. As C1 - C4 were created with the aim for a technical solution to ET, they served as a meaningful foundation for the analysis process. In the first step of the analysis, each statement given by the therapists was coded into these four basic categories (C1-C4). A single coding item could be one or multiple sentences belonging to one response. After the material was processed for a first screening, the basic categorization was revised. To ensure validity of the re-categorization and overall coding process, we conducted an inter-coder agreement check [78]. For that purpose, two examiners processed the material independently, created their own categories and coded the data accordingly. As a result of discussion between both coders, 9 final sub-categories emerged. Techniques and Procedures (C1) was divided into: Therapy Procedure (C1.1), Role of Therapist (C1.2), Motivation of Patients (C1.3) and Possible Symptoms (C1.4). Setting and Scenarios (C2) was split into: Impact of Environment (C2.1) and Environment Characteristics (C2.2). Tasks and Motivation (C3) was divided into: Rewards (C3.1) and Possible Tasks (C3.2). Lastly, the additional category Supplemental (C4) was replaced by: Practical Applicability (C4). The categories along with the coding scheme are provided as supplementary materials: https://osf.io/4cq3k.

### 3.5 Interview Results

We provide an overview of summarized insights derived from the interviews and link them to game design considerations.

Regarding therapy procedure, the first step in ET is referred to as *probatory*, which serves to discuss and collaboratively decide the steps of ET between patients and therapists. This is necessary in preventing therapy from being experienced to be "other-directed" or imposed upon oneself from the patient's perspective. In the following course of therapy, patients are confronted with their phobia multiple times until a state of habituation is achieved. In game design, this can be linked to gradual, possibly customized or adaptive increases in challenge relative to one's own skills. Such patterns are closely linked to flow and the *competence* dimension of SDT.

During therapy, therapists educate patients regarding the effectiveness of the therapeutic approach as well as potential challenges and difficulties. On top of that, therapists have the role of motivators and companions, especially in the first sessions while they gradually recede from directly intervening with the process. In game design, this can be linked to the *relatedness* dimension in SDT, but should be considered in interplay with *autonomy*. It also relates to a range of social and multiplayer game design patterns.

A vital factor determining the outcome of therapy is the patient's motivation. In line with CBT's SMART goals [45], motivation is achieved by introducing moments of partial success that are linked to the patient's small objectives. Motivation is greatly increased by making the patients feel autonomous, e.g. when they finally take the step to seek out phobia-triggering situations on their own. Rewards are a common component of ET and should be used to facilitate motivation. They should be defined by the patients themselves and come in a variety of forms. Both interviewees emphasized the importance of social support and its role as a reward system. In game design terms, this outcome provides clear motivation to explore the potential of games to foster motivation and engagement. More specifically, it invites the consideration of traditional game design elements, such as points, badges or leaderboards, and more complex patterns around personal development (e.g. from RPGs).

During exposure, certain physiological symptoms (e.g. extensive sweating, accelerated heart rate and shaking legs) are expected to appear. Therapists can make use of heart rate measurements and anxiety meters to observe these symptoms. In relation to games, this outcome is important, as traditional game design patterns would overlook this element. It can however, as detailed below, be considered through patterns that emphasize the role of an involved therapist. This can also be linked to promising potential around using modern interaction devices that can record physiological signals, such as wearables, camera-based analysis, etc.

Based on the probatory phase, therapists determine a variety of scenarios for their patients to be exposed to. These scenarios address visual and tactile senses and have some relation to the patient's daily life. The scenarios usually come in rich variety while not switching between settings too rapidly before reaching habituation. The patients autonomously define which environments they prefer and what level of intensity they choose to confront in a session. In general game design terms, this links to generative / customizable / personalized content and – as further detailed below – this also offers an opportunity to consider user-generated content.

The interviews indicate that one of the simplest and yet most useful tasks in ET is doing nothing at all while focusing on the environment (e.g. the edge of a cliff) and the symptoms it evokes. In relation to games, this constitutes another "unusual" element. When relating to game design patterns, "atmospheric" games and the associated patterns are relevant. This also marks the crucial consideration that the exposure phase may not be easily compatible with the majority of established game design patterns, which typically focus on functional challenges [30] (skill-based tasks) and narrative [9], which are both designed to be captivating.

In summary, the experts agreed that a VRET system could generally be used effectively in ET. They pointed out that the application's content should not be random but scientifically sound and thus, incorporate traditional therapy concepts. The interviewees stated that VRET can become a vital part of therapy but should not replace real exposure. This calls for the consideration of possible game design patterns that can serve a dual-flow purpose in the sense of seeking alignment between (serious) therapy aims with game-oriented motivation mechanics [103].

Place now a multi-story building.

Use a low and evenly leveled area for that.

For each of the following statements, please indicate how true it is for you, using the scale down below.

I am satisfied with my performance at this task.

(a) Lobby scene with terrain editor controls.

(b) On-body UI instructions in the lobby scene.

(c) Exposure scene with view from a tower building.

(d) Questionnaire terminal.

Figure 1: Screenshots of the VRET application.

## 3.6 Requirements & Design Implications

Based on the insights from the expert interviews, we discuss how game design patterns can be combined to build a VRET system that is tailored to support therapists who conduct traditional ET in treatment of acrophobia. We derive a variety of requirements (*R1-R5*) that should be taken into account when designing a VRET system:

*R1: Motivation.* From the interviews, we gathered that one key aspect of motivation in the context of ET is autonomy. Patients are motivated by pro-actively determining the course of therapy. More precisely, by defining sub-goals and deciding which situations to expose themselves to, they are more engaged in the process which helps them to eventually reach habituation. In summary, a VRET application should emphasize the sense of autonomy. This can, for example, be achieved by giving users the opportunity to choose or shape a scenario and the respective tasks.

*R2: Communication.* In line with requirements frequently stated in the literature [26, 47], the communication between therapists and patients was identified to be another crucial element of ET. Since therapists function as motivators, educators and companions during therapy, a VRET system should enable direct communication between them and their patients. This can be achieved by either placing both in the virtual scene (e.g. as avatars [48, 67]) or at least allowing audio feedback to guide patients through the experience.

*R3: Scenario habituation.* Scenarios should give patients a chance to reach habituation. Therefore, users should have enough time to become familiar with their surroundings. Scenes should come in a variety of different aesthetics in dependence of the respective phobia but are not allowed to be switched too quickly.

*R4: Non-distracting tasks.* Regarding tasks that provide a meaningful occupation in the virtual scene, the experts proposed some additional requirements. The typical activity during traditional ET involves exposing oneself to the situation in absence of any other specific activities. As a result, tasks in a virtual environment (VE) should not be distracting, to avoid shifting the focus from the situation to completing some arbitrary task. Notably, this excludes the majority of common game design patterns, which are often built around particular functional challenges and narratives. To enhance motivation, the activities in the VE have to be designed with care and should be linked to real-life rewards.

*R5: Physiological symptoms.* Physiological symptoms are direct results of phobia exposure and help the therapists to monitor the situation and react accordingly. A VRET system should be designed in a way that prevents additional symptoms due to technical flaws. Visual stuttering, an unstable frame rate or other visual glitches have to be eliminated. Otherwise, physiological symptoms might be wrongly attributed to the virtual exposure although they emerged on account of technical defects.

## 4 GAME DESIGN FOR PLAYFUL USER-GENERATED TREATMENT

Our approach splits the VRET experience into 2 distinct phases (Fig. 1): (1) The design phase, where participants use a terrain editor in VR to create their exposure (Fig. 1a and 1b); (2) The actual exposure phase, in which the participants enter their (self-designed) terrain at full scale (Fig. 1c).

The key of the concept is to allow users to design their exposure in a simulation (top-down view of a miniature map) before they experience it in the exposure at full-scale from a first-person perspective. This approach is in line with recommendations by Mine who found that user-generated content motivates creativity and self-expression as well as that world-in-miniature models can help conceptualizing the VE [80]. This "sandbox" approach is designed to foster intrinsic motivation by creating an engagement with – and a degree of personal relevance of – the exposure through playful creative action (*R1 Motivation*). Further, the approach empowers patients to adjust the degree of exposure to their specific needs, assess their limits and reflect on the progress, all in collaboration with the therapists. The terrain editor can also be included in the preparatory talks between the therapists and the patients in VR (*R2 Communication*) and help visualize the anxiety-producing stimuli. Since a self-paced *scenario habituation (R3)* was regarded as an important aspect, both phases needed to be designed in a way that gives users enough time and the right interaction options to either shape and customize (design phase) or explore and experience (exposure phase) the virtual scenario. Moreover, for the exposure phase, the interaction needs to be kept simple and focus on allowing the attentive perception of the exposure, explicitly avoiding any potentially *distracting tasks (R4)*. Finally, we opted for a proven consumer-grade VR setup (HTC Vive), as the technical setup itself should not cause any additional *physiological symptoms (R5)*.

### 4.1 Design Phase

For the design phase, we created a terrain editor that employed game elements from sandbox games [49, 90, 108] (e.g. Minecraft [81]) and interaction techniques from applications for 3D content creation (e.g. Tilt Brush [53], Blender [14]), which allow designing own worlds and offer great platforms for customization [112]. In the terrain editor, users interact with the VE in tabletop mode using the VR controllers and a commonly used laser pointer metaphor [64, 72]. The terrain is displayed in miniature form situated in a lobby room. To shape the terrain, users press the up and down buttons on the touch pad to raise or lower the terrain respectively. We attached a body-anchored [3, 94] UI at the controller of the non-dominant hand. From there, users get help or instructions and can select assets (e.g. buildings, nature or characters) to place in the terrain for decoration and personal customization. The asset library consists of 6 exemplary decoration objects: trees, rocks, grass, bushes, stumps, and wooden cottages. The spawn points can be placed as viewing platforms at different points of height (e.g. on buildings or mountains), which then become entry points in the exposure phase. Therapists can pre-select specific assets for the patients that are convenient for the individual cases. They also have control over the minimum and maximum heights and slopes for the VRET as these parameters are most significant for shaping the intensity of the stimulus.

### 4.2 Exposure Phase

The exposure phase resembles examples from existing literature (cf. [43, 86]). To further support a clear focus on the experience, context menus, teleportation and terrain editing tools are disabled. As a general safety precaution, we implemented a panic button: when pressing all four grip-buttons simultaneously, the screen fades out and users immediately teleport back to the lobby.

We implemented our concept using Unity3D and a HTC Vive with the bundled hand-held controllers as the VR platform. This described approach presents an exemplary instance of an implementation that adheres to the requirements and illustrates a specific response to RQ2 in addition to the general requirements discussed above.

## 5 LAB-BASED USER STUDY

To validate the viability of the requirements and the specific approach described in response to RQ2 above and to provide empirical evidence with respect to RQ3 and RQ4, we designed and conducted a user study with non-acrophobic subjects, which investigates the effect of content creation on player experience and height perception. The study employed the acrophobia VRET setup with a playful terrain editor and an exposure to heights in VR as described above. The study took place in a lab, in which users wore an HTC Vive head-mounted display and could move around in a tracking space of approx. 2×3 m. The overall size of the virtual landscape at full scale simulates a world of approximately 40×60 m with heights up to 70 m. However, the surrounding skybox indicates a much larger space and allows for the perception of real-world scale exposure.

Our study included 2 conditions in a mixed between-subjects setup with repeated-measures. In the first condition ($C_{PUT}$), the participants were asked to shape and decorate the terrain with the built-in VR terrain editor. In the control condition ($C_{ctrl}$), the subjects could only view a pre-defined terrain they were about to enter. Both groups were informed that they would enter the terrain they were viewing or shaping in the second scene. We employed subjective self-reports as measures of intrinsic motivation, affect and anxiety. The assignment to the groups was randomized after balancing for gender. The study received an ethical approval.

To examine how the playful sandbox-style shaping of the exposure environment affects motivation (RQ3) and the perception of height (RQ4), we derived the following hypotheses:

**Hypothesis H1:** The activity of shaping terrains provides a measurably higher motivation than viewing a predefined terrain.

**Hypothesis H2**: There is a measurable difference on subjective ratings of anxiety induced by exposure to height between a self-created terrain and a predefined terrain.

### 5.1 Participants

We advertised the study on campus, via university mailing lists and through word-of-mouth. During acquisition, all subjects were pre-screened using the acrophobia questionnaire (AQ) [29] to exclude participants showing tendencies for acrophobia. An Anxiety Score of >45.45 and an Avoidance Score of >8.67 were determined as thresholds to exclude subjects from the experiment as it is one standard deviation below the score averages of clinical acrophobics [6, 29]. 31 participants (25% self-identifying as female) volunteered for our study. The mean age was 24.32 years ($SD$=4.32). None of the participants showed clinical tendencies for acrophobia (anxiety: $M$=18.87, $SD$=11.67, avoidance: $M$=3, 55, $SD$=2.36). 20 participants experienced VR once; the others had no prior experience with VR. The groups were balanced for gender ($U$=133.5, $p$=0.49), age ($t_{29}$=1.159, $p$=0.25), avoidance ($t_{29}$=-1.03, $p$=0.31) and anxiety ($t_{29}$=-0.73, $p$=0.47).

### 5.2 Apparatus

In our study, we used the prototype as described in Section 4 with the following adjustments. To only allow valid viewpoints in the scene, we restricted the placement of the spawn points to specific plausible regions (e.g. viewing platform or rooftops of a building). Additionally, after completion of the design phase, the following adjustments were applied to the terrain: a) a straight abyss down to the ground level was cut at the view point and b) the surface of each mountaintop was flattened (without notably changing the total height). For the final spawn points, we calculated the position on the spawn platform that was furthest away from the abyss. The rotation was set to look away from the ledge. To avoid users watching down the “end of the world”, we restricted the rotation of the buildings so that the viewing platform would always face towards the center of the terrain. For consistency between the trials in the design phase, we provided only one single circular shaped terraforming brush with a medium strength.

As we aimed to assess repeated self-reports in VR, to avoid breaks in presence [101] we added questionnaire terminals (see Fig. 1d) as world-anchored in-VR questionnaires (inVRQs) [3, 87]. In the terrain scene, we positioned the questionnaires on the opposite side of the ledge to minimize interference with the exposure when responding.

## 5.3 Measurements

We assessed intrinsic motivation using the *Intrinsic Motivation Inventory* (IMI) [91] on the 4 sub-scales *Interest-Enjoyment*, *Competence*, *Effort-Importance*, and *Tension-Pressure* with 7-point Likert scales. To get an impression of the participants' emotional state, we applied the *Positive and Negative Affect Scale* (PANAS) [34]. PANAS consists of 2 sub-scales (10-items each) that assess positive and negative affect respectively on 5-item Likert-scales.

Cleworth et al. [27] showed that non-phobic subjects rate the exposure to different heights with different ratings. Therefore, we included subjective measures of anxiety as to validate the effectiveness of the VE. To measure levels of anxiety induced by the exposure to heights, we used the 20-item *State-Trait-Anxiety-Inventory (STAI)* [106]. STAI contains 2 sub-scales (10 items each) that access the propensity to be anxious (*trait anxiety*) and a temporary anxiety with fluctuating intensity (*state anxiety*). As an additional measure of affliction, we used the *Subjective Units of Distress-Scale* (SUDS) [6, 8] – a single-item visual analog scale ranging from 0 (no anxiety) to 100 (highest anxiety).

## 5.4 Procedure and Tasks

We first informed the participants about the study procedure and gained their consent for participation. Next, the subjects stated basic demographics and were randomly assigned to one of the conditions ($C_{PUT}$ or $C_{ctrl}$). Subsequently, the participants entered the lobby scene. Depending on the conditions, we instructed the subjects differently. In both conditions, they initially entered an empty lobby where we explained the panic switch, navigation and interaction with the inVRQs. After the tutorial, the participants rated their anxiety on the SUDS and we activated the terrain. For $C_{PUT}$, we explained the controls of the terrain editor and asked the participants to shape and decorate the landscape to their liking, but with the constraint that the terrain should contain 3 viewing platforms with different heights each (mid high hill 30 m, high hill 50 m and a tower building 70 m). We chose these heights because all exposures should evoke a sense of notable height at different intensities for convenient subjects (explicitly not suffering from acrophobia). For $C_{ctrl}$, we pre-designed a terrain that contained the same types of elements available for placement and modification in the other condition. To create a meaningful duration for the pre-exposure phase, the subjects were instructed to inspect and memorize the scene. In both conditions, the participants thereby engaged with the terrain for 3–5 min. After 2 min in, the participants gave a second SUDS rating. After finishing the editing or memorizing task respectively, the participants completed the IMI as well as a third SUDS and were further instructed to proceed to the next scene (teleport to the next location).

In random order, the participants teleported to all 3 spawn points and underwent an exposure to heights from each platform. To ensure that the participants were exposed to the heights and did not have their eyes shut, we implemented a secondary task. The participants should throw down a ball and read a series of numbers displayed on the ground when they looked down the pit. Although the secondary tasks can potentially facilitate an unintended playful experience or a distraction, this or similar tasks have been applied in the experimental setups to encourage participants engaging with the exposure task [40, 79, 97]. Each trial consisted of the following steps: (1) Participants pick up a ball and approach the ledge; (2) They extend their arm over the ledge so the ball is above the abyss; (3) They let the ball fall and follow it with their sight; (4) Participants read out numbers shown on the ground floor when the ball hits the ground; (5) They approach the terminal and rate their anxiety on STAI and SUDS. We assessed trait anxiety after the first trial. State anxiety was rated after every exposure. After all 3 trials, the participants filled out a second IMI and a PANAS and left VR. We then conducted a semi-structured interview with the participants to gain additional insights about their player experience. On average, participants spent 23.07 min (*SD*=3.86) in VR ($C_{PUT}$: *M*=24.2, *SD*=4.02; $C_{ctrl}$: *M*=21.63, *SD*=3.24; $t_{28.38}$=2.14, *p*=0.02, Cohen's *d*=0.76), with the difference resulting from a varying duration in the first phase. A detailed analysis showed the difference was only significant in the lobby scene ($t_{11.65}$=11.65, *p*<0.01, Cohen's *d*=0.76)) with 2.07 min (*SD*=2.00) in $C_{PUT}$ and 3.99 min (*SD*=0.36) in $C_{ctrl}$. The total study duration was about 30 min.

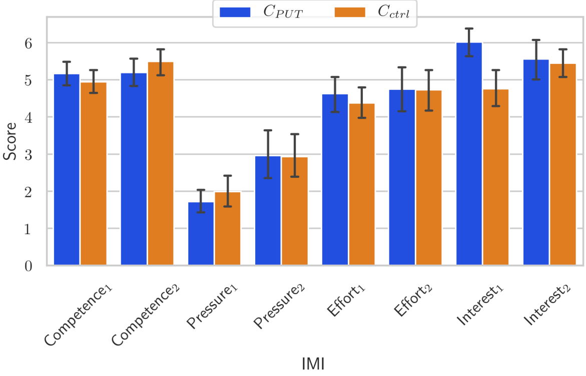

**Figure 2: Bar plots of both IMI assessments. The whiskers indicate the SD.**

## 5.5 Results

*Intrinsic Motivation.* For all IMI subscales, we conducted mixed-factorial ANOVAs with the respective subscale as a within (repeat-measures) factor and condition as between factor (Fig. 2). The analysis showed significant differences within subjects only on Tension-Pressure. A Bonferroni-corrected post-hoc t-test confirmed this difference ($t_{29}$=-5.80, *p*<0.01, Cohen's *d*=-1.04). The MF-ANOVA revealed a significant difference between the conditions and an interaction effect on the Interest-Enjoyment subscale. A post-hoc comparison of Interest-Enjoyment with Bonferroni-correction between the $C_{PUT}$ and $C_{ctrl}$ was significant ($t_{29}$=2.40, *p*=0.02, Cohen's *d*=0.43). There was a significant interaction of CONDITION × INTEREST-ENJOYMENT between $C_{PUT}$ and $C_{ctrl}$ of the first assessment ($t_{29}$=3.90, *p*<0.01, Cohen's *d*=0.70) as well as between first and second assessment in $C_{ctrl}$ ($t_{29}$=-3.17, *p*=0.02, Cohen's *d*=-0.57). The results of the MF-ANOVAs are summarized in Table 1. This indicates that significantly higher motivation potential can be achieved on the Interest-Enjoyment dimension (H1, RQ3), while the more

**Table 1: Mixed-factorial ANOVA for both IMI assesses.**

| | $C_{PUT}$ | $C_{ctrl}$ | IMI | | | Condition | | | IMI × Condition | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M (SD) | M (SD) | $F_{1,29}$ | p | $\eta_p^2$ | $F_{1,29}$ | p | $\eta_p^2$ | $F_{1,29}$ | p | $\eta_p^2$ |
| Competence | 5.18 (0.72) | 5.22 (0.71) | 4.12 | 0.05 | 0.12 | 0.04 | 0.85 | < 0.01 | 3.29 | 0.08 | 0.10 |
| Tension-Pressure | 2.34 (1.22) | 2.46 (1.12) | 32.87 | < 0.01 | 0.53 | 0.14 | 0.71 | < 0.01 | 0.63 | 0.43 | 0.02 |
| Effort-Importance | 4.69 (1.12) | 4.55 (1.01) | 2.25 | 0.14 | 0.07 | 0.15 | 0.70 | 0.01 | 0.53 | 0.47 | 0.02 |
| Interest-Enjoyment | 5.79 (0.97) | 5.10 (0.89) | 0.59 | 0.45 | 0.02 | 5.78 | 0.02 | 0.17 | 14.37 | < 0.01 | 0.33 |

**Table 2: One-sample t-tests against a neutral response (4.0) for both IMIs. Top: IMI$_1$ assessment directly after terrain editing. Bottom: IMI$_1$ assessment after all 3 exposures.**

| IMI$_1$ | $t_{30}$ | p | mean diff. |
|---|---|---|---|
| Competence | 9.14 | < .001 | 1.06 |
| Tension-Pressure | -15.40 | < .001 | -2.15 |
| Effort-Importance | 3.09 | < .001 | 0.50 |
| Interest-Enjoyment | 7.45 | < .001 | 1.41 |
| **IMI$_2$** | **$t_{30}$** | **p** | **mean diff.** |
| Competence | 9.88 | < .001 | 1.34 |
| Tension-Pressure | -4.73 | < .001 | -1.05 |
| Effort-Importance | 3.46 | < .001 | 0.74 |
| Interest-Enjoyment | 9.07 | < .001 | 1.51 |

**Table 3: Mixed-factorial ANOVA of anxiety measures SUDS and STAI for all 3 exposures.**

| | | SUDS | STAI |
|---|---|---|---|
| Anxiety | $F_{2,58}$ | 0.46 | 0.11 |
| | p | 0.63 | 0.89 |
| | $\eta_p^2$ | 0.02 | < 0.01 |
| Condition | $F_{1,29}$ | 0.82 | < 0.01 |
| | p | 0.37 | 0.99 |
| | $\eta_p^2$ | 0.03 | < 0.01 |
| Anxiety × Condition | $F_{2,58}$ | 3.27 | 2.91 |
| | p | 0.05 | 0.06 |
| | $\eta_p^2$ | 0.10 | 0.09 |

functional (competence / effort) and potentially negatively associated (with respect to the application scenario) Tension-Pressure dimension is not likely to differ dramatically (RQ4). The lack of differences in the exposure phase and increased Tension-Pressure after the exposure indicate some functioning of the phase as intended (RQ2, RQ4).

To determine if the IMI measures deviate from neutral, we performed one-sample t-tests against a neutral score of 4 (see Table 2). The results (all $p<0.001$) show a positive difference from neutral for Competence, Effort-Importance and Interest-Enjoyment, suggesting that the experience was perceived as challenging, enjoyable and that the participants are willing to invest effort. Tension-Pressure showed a significant negative difference from midpoint, which can be linked to the exposures not resulting in notable anxiety (as expected with non-acrophobic convenient subjects).

*Affect and Anxiety.* We measured affect using PANAS after each exposure task. We conducted independent t-tests to compare the participants' affect between the conditions. Both positive affect ($M$=37.61, $SD$=4.39, $t_{29}$=0.75, $p$=0.46) and negative affect ($M$=14.03, $SD$=4.55, $t_{29}=-0.99$, $p$=0.33) did not differ significantly. This arguably provides further corroborative evidence to comparable exposures (RQ4). For STAI (see Fig. 3) and SUDS as measures of anxiety, we conducted MF-ANOVAs with the 3 exposures (tower, high, and mid) as within factors and condition as between factor. The results show no significant differences and no interaction effects for both measurements (see Table 3). To investigate how the anxiety evolved over the course of the study, we conducted MF-ANONVAs with anxiety and assessment number (STAI and SUDS) as within factors and condition as between factor. For SUDS, we used the assessment at the end of the first phase as baseline for anxiety. Both analyses showed significant main effects (SUDS: $F_{3.34,67.95}$=17.69, $p$<0.01, $\eta_p^2$=0.38, Greenhouse-Geisser corrected $\epsilon$=0.78; STAI: $F_{2,58}$=4.90, $p$=0.01, $\eta_p^2$=0.02) but no significant differences between conditions nor interaction effects. Subsequent post-hoc tests revealed significant differences between platform$_1$ and platform$_3$ on both anxiety measures (SUDS: $t_{30}$=2.73, $p$=0.03 mean diff.=3.32, see Fig. 4; STAI: $t_{30}$=2.82, $p$=0.03 mean diff.=3.58). For SUDS, all platforms were significantly more anxiety-inducing than the baseline (platform$_1$: $t_{30}$=-5.46, $p$<0.01, Cohen's $d=-0.98$; platform$_2$: $t_{30}$=-4.99, $p$<0.01, Cohen's $d=-0.90$; platform$_3$: $t_{30}$=-5.54, $p$<0.01, Cohen's $d=-1.00$). These results indicate that there were perceivable differences between the different levels of exposures in-line with the intended effects (RQ2), while there are no strongly notable differences in the resulting exposure phases between conditions, as intended (RQ4, H2$_0$). There was a strong correlation of STAI and Tension-Pressure (Pearson's $r_{29}$=0.72, $p$<0.01) and a medium correlation with Effort-Importance (Pearson's $r_{29}$=0.43, $p$=0.02). This underlines a positive applicability for ET (RQ2, RQ4).

*Qualitative Feedback.* At the end of each session, we asked the participants to comment on their experience and their relationship with the VE. We list paraphrased statements ordered by their frequency: "I felt related to the VE" ($C_{PUT}$ 15×, $C_{ctrl}$ 1×), "The terrain shaping was creative" ($C_{PUT}$ 10×), "The controls were intuitive" ($C_{PUT}$ 10×,$C_{ctrl}$ 2×), "The experience was interesting or enjoyable" ($C_{PUT}$ 9×, $C_{ctrl}$ 6×), "I had a vertigo experience when I was looking down" ($C_{PUT}$ 6×, $C_{ctrl}$ 7×), "The environment felt realistic" ($C_{PUT}$ 6×,$C_{ctrl}$ 0×), "I had difficulties with the pointer or teleporter" ($C_{PUT}$ 5×, $C_{ctrl}$ 1×), "Reading the UI was difficult" ($C_{PUT}$ 4×), "I would like to have more assets/controls" ($C_{PUT}$ 4×), "Looking down did not make me anxious" ($C_{PUT}$ 1×, $C_{ctrl}$ 7×),

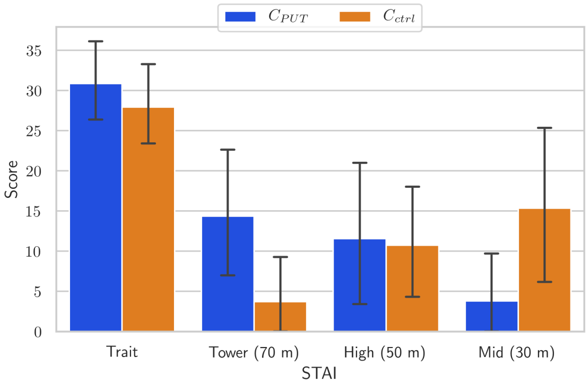

Figure 3: Bar plots of STAI. The whiskers indicate the SD.

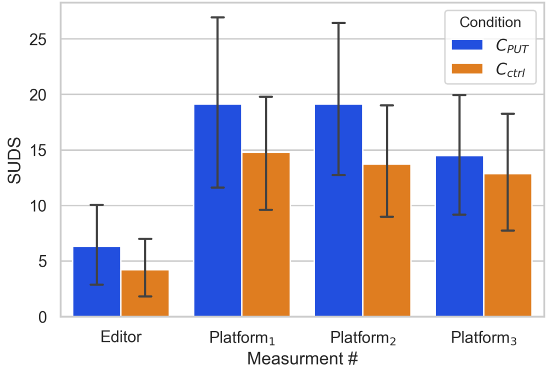

Figure 4: Bar plots of SUDS by order of exposure. The whiskers indicate the SD.

“There were too many questionnaires” ($C_{PUT}$ 1×, $C_{ctrl}$ 0×), “I learned something about myself” ($C_{PUT}$ 1×, $C_{ctrl}$ 0×), “The experience was not interesting or enjoyable” ($C_{PUT}$ 0×, $C_{ctrl}$ 6×), “I did not feel related to the VE” ($C_{PUT}$ 0×, $C_{ctrl}$ 4×), “The environment felt unrealistic” ($C_{PUT}$ 0×, $C_{ctrl}$ 2×).

### 5.6 Outcomes

The results show that the VR experience created some sense of anxiety (RQ2), although not to the point of resulting in strong perceived tension or negative affect. This is supported by the raised SUDSs of all platforms compared to baseline and relatively raised Tension-Pressure of $IMI_2$ after the exposure. Also, the significant decay in anxiety both on SUDS and STAI from first to third exposure indicates a habituation which is normal for people without acrophobia. The strong correlation of Tension-Pressure and Effort and the anxiety measurements further corroborates these outcomes. Low negative and high positive PANAS scores as well as positive ratings of IMI show that the experience was generally engaging and positively accepted by the participants (RQ2).

Regarding H1, the higher interest and enjoyment in $C_{PUT}$ shows that user-generated content can bring up interest. This is further underlined by the qualitative comments which indicate that the process is perceived as creative and supports the forming of a personal VE. This is a positive indication for the concept of playful user-generated therapy (RQ3). Moreover, only in $C_{PUT}$ the subjects stated that the environment felt realistic. Contrary, only in $C_{ctrl}$ the participants stated they felt not related, had a low sense of vertigo or lack of realism. These results show evidence in favor of H1, that user-generated content facilitates aspects of intrinsic motivation. We observed a significant increase of Interest-Enjoyment in $C_{ctrl}$ between $IMI_1$ and $IMI_2$. This results most likely from the non-interactive experience in the lobby. Conversely, we observed a drop in Interest-Enjoyment for $C_{PUT}$ between $IMI_1$ and $IMI_2$ to a level comparable with $IMI_2$ in $C_{ctrl}$. This can be explained by the simplicity of the experience in the exposure phase and by the participants' low anxiety towards heights.

We could not find conclusive evidence to support H2. For anxiety, we only observed differences between the height levels but not between the conditions. These results, together with the qualitative comments, indicate that the exposure felt realistic and anxiety-inducing without a notable effect of the game elements on the perception of heights. We therefore reject H2 and count this as positive evidence towards the requirement that the game elements should not notably interfere with the exposure (RQ4). However, the results show fluctuations with small effect sizes and a marginal significance. Therefore, it is undue to conclude that there are no effects and these indications require further validation.

With regard to RQ2, we found that the probatory is a suitable phase of the therapy session to include game elements that do not interfere with the therapy. The self-creation of the phobic stimuli is a welcomed approach for the therapists and allows them to adjust the exposure to the patients' individual needs; a feature that is crucial for effective computer-mediated therapy [60]. This is in line with the SMART goals [45] and with Thompson et al.'s guidelines and offers opportunities to address the *Goal Setting*, *Problem Solving*, *Motivational Statements* and *Feedback* in game design for therapy [109]. Empowering self-creation mechanics can facilitate creativity [113, 117] and interest for the therapy and address Malone's curiosity dimension of educative game design [76] in contrast to frequently applied elements such as rewards or challenges.

## 6 ONLINE SURVEY EXPERT EVALUATION

To validate our approach regarding its potential applicability in a real-life therapy scenario, we conducted an online study with practicing therapists. For further validation, we included therapists with a wider range of expertise than in the initial interviews. This online survey was not meant to be a final evaluation of a fully functional system but a way to obtain an additional expert perspective on the PUT concept. The survey consisted of a consent form, 12 questions concerning the proposed game design and 13 items targeting the respondents' professional background, technical expertise and other demographic data. To illustrate the design approach, the survey contained an introductory text with corresponding images and an embedded video explaining VRET in general and demonstrating the

PUT concept. The 3 min long video was compiled from several documentaries from public media on VRET and demo clips of VR games and VRET applications which corroborate the feasibility of VRET as well as a demo of the terrain editor and the exposure phase accompanied by an explanation of PUT. For copyright reasons, the video cannot be published. After perceiving the material, the therapists filled out the forms which took between 15 and 20 minutes.

## 6.1 Participants

6 therapists (5 female) filled out the online survey. The group of interviewees included 3 therapists specialized in depth psychology, 2 behavioral therapists and 1 expert in ET. Their ages ranged from 28 to 64 years (*M*=49.33, *SD*=13.51). 5 experts held an approbation and 1 a master's degree in psychology. Work experience as a professional therapist was reported to be between 1 and 31 years (*M*=11.17, *SD*=9.91). All therapists were asked to rate their experience regarding VR on a 5-point Likert-scale ranging from "No Experience (1)" to "Expert (5)". On that scale, responses lay between 1 and 2 (*M*=1.17, *SD*=.37). None of the experts used VR in a professional capacity or for entertainment. Responses on frequency of utilizing CBT methods in therapy included "never" (*n*=1), "once a year" (*n*=1), "multiple times a year" (*n*=1), "once a week" (*n*=1) and "multiple times a week (*n*=2). The frequency of treating acrophobia ranged from "never" (*n*=1) to "once a year" (*n*=1) and "multiple times a year" (*n*=4).

## 6.2 Results

*Quantitative Results.* Regarding applicability in a real-life therapy scenario, the therapists rated the PUT design approach on a 5-point Likert-scale ranging from "Not Useful" (1) to "Very Useful" (5). On average, the design received a score of *M*=3.67 (*SD*=.75) (RQ2). All experts agreed that giving the patients the opportunity to create the environment for later exposure is a valuable approach. The majority of participants (*n*=5) stated that separating therapy into 2 steps (design and exposure phase) may have a positive impact on the course of therapy. The remaining expert expressed it would not affect the therapy. Regarding the influence of the patient's contact with the scaled-down miniature terrain (RQ4), the experts reported that it may lead to positive effects (*n*=4) or no effects (*n*=2). Since non-distracting tasks were identified to be one core requirement of VRET design, we asked the experts if the design phase may distract from the actual exposure (scale ranging from "No Distraction" (1) to "Full Distraction" (5). This item received an assessment of *M*=2.00 (*SD*=1.15) (RQ4). Regarding communication between therapists and patients, 4 therapists would like to accompany their patients during the design phase, whereas the remaining 2 experts stated this would not be necessary.

*Qualitative Feedback.* 2 experts stated that a playful approach would be beneficial in preparation to real-life exposure as the situation itself would not be perceived to be as terrifying as in the real world. However, since the virtual representation of phobia-inducing stimuli lacks in realism, 3 experts explicitly stated that it should not replace real exposure. Additionally, 2 experts pointed out that communication should be enabled by the system whereas 1 therapist wished to enter the virtual world along with the patient. 1 expert reported that PUT may lead to a higher sense of control (RQ3) and perceived self-efficacy. Another therapist reinforced this assessment by stating that PUT design could give patients a sense of security. As a suggestion for future development, 1 therapist proposed the idea of exposing patients to virtual scenes that were not created by them in later stages of therapy.

## 7 DISCUSSION

With regard to RQ1, we identified 5 considerations for VRET game design. For an auspicious computer-mediated ET, patients should have control over the course of therapy by defining tasks, goals and situations themselves (R1). VRET should allow for direct communication between therapists and their patients during exposure (R2). Scenarios should come in rich variety but leave patients enough time to get accustomed to and reach habituation (R3). As for potential in-game tasks, they should be linked to real-life rewards but not be too distracting from the exposure or be perceived as tests of courage (R4). The system itself should not cause any additional physiological symptoms that might be wrongly attributed to exposure (R5). Most of these requirements are in line with the SMART goals [45] and existing frameworks on game design for interventions (cf. [33, 46, 109]). However, we found the combination of motivating (R1) and non-distracting game design (R4) a specific requirement for VRET that is rarely discussed in the literature on games for change. The outcomes of the user study show evidence that self-generated anxiety stimuli can raise the intrinsic motivation for a simple task (RQ3, H1) while not interfering with the sense of anxiety (RQ4, $H2_0$) and thus, our design approach fulfills R1 and R4 explicitly. The experts involved in the online survey gave an overall positive assessment of PUT design in terms of applicability in a real therapy scenario (RQ2). A minority of the therapists was concerned that the patients would avoid challenging themselves. Most therapists acknowledged the PUT concept to be applicable, to have a positive effect on the motivation (RQ3) and not being too distracting (RQ4). Moreover, the survey identified potential for improvements for future iterations such as a communication interface between the therapists and the patients. The experts emphasized that communication between therapists and patients is crucial and should be anchored deeply in the design. They highlighted that VRET should be considered as an addition but not as a replacement for conventional ET. These triangulated results corroborate that PUT appears to be a viable concept that warrants further development and study.

## 7.1 Limitations and Future Work

Empirical user studies with phobics are ethically problematic, since they require experienced support in case of a panic. Therefore, this early-stage research evaluated the approach with convenient subjects. However, Robillard et al. [88] compared emotional reactions of phobics and non-phobics to different phobias in VR and showed that both groups react to phobic stimuli similarly but to a different degree; with phobics being affected by the VE stronger. Interestingly, the authors found no differences in the perception of game elements. This shows evidence that evaluation of game design for exposure-based VR with non-phobics should generalize to phobics as well and may be transferred to other phobias. According to Coyle et al. [33], this work is situated in the first phase of the development cycle. In future work, we aim to investigate PUT with afflicted subjects under the supervision of therapists. In the study, we did not assess autonomy since the study was conducted with convenient subjects and therefore, we did not expect a raise on autonomy, as no deregulation compared to traditional ET would be notable to the subjects. However, literature on motivation shows that user-generated content can raise the sense of autonomy and competence [92, 113, 117] and that creativity is linked to self-empowerment [107]. As the study was mainly concerned with the interference of game design, height perception and intrinsic motivation, assessment of autonomy was beyond scope. This should, however, be addressed explicitly in future work with phobic patients and SDT. Further, the subjective ratings on anxiety (SUDS and STAI) show high variances that are likely attributed to low sensitivity towards heights. Although this work is based on validated measurements, future work should consider physiological measures of anxiety such as heart rate or galvanic skin response for clearer and more reliable data.

As fear generally embodies avoidance, it is difficult to create an intrinsic motivation to coping with one's phobias. Thus, presenting anxiety inducing stimuli in an enjoyable way is a challenging demand for game design. Our research shows that game design for non-intrusive playful experiences is rarely explored in the literature and requires further attention. Likewise, further traditional game elements could be employed, especially in the design phase, as well as game mechanics that may contribute positively to the therapeutic potential of the exposure phase, e.g. around vertigo experiences or emotional challenges associated with phobias. Both are underexplored in the literature and should be considered in future research on VRET games.

## 8 CONCLUSION

We presented a novel game design approach for VR exposure therapy: playful user-generated treatment (PUT). We investigated this concept with a multi-angled approach: a requirement analysis, the implementation of a VR-based game, a user study with convenient subjects, and an online survey with a distinct group of therapists. The requirement analysis revealed that VRET is considered to be a useful addition to conventional therapy and that VRET game design demands specific considerations, which are rarely addressed in the literature. The requirements led to the PUT design approach that separates ET in VR into design and exposure phases. Our two validation studies with the VR game show that PUT is well applicable. In particular, the user study reveals that the users' content creation leads to increased interest and enjoyment without notably influencing affective measures during the exposure session. The positive indications with convenient subjects also suggest that further study and validation in an applied therapeutic context appear warranted.

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# Publication $P3$

## Effects of PCG on Creativity in Playful City-Building Environments in VR

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# Effects of PCG on Creativity in Playful City-Building Environments in VR

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The use of procedural content generation (PCG) in the context of video games has increased over the years as it provides an economical way to generate game content whilst enhancing their variety and replayability. For city-building games, this approach is often utilized to predefine map layouts, terrains, or cityscapes for the player. One core aspect of facilitating enjoyment in these games comes from creative expressivity. PCG, in this context, may support creativity by lowering the technical complexity for content creation, or it may hinder creativity by taking away control and freedom from the user. To examine these potential effects, this paper investigates if PCG has an impact on players' creativity in the context of VR city-building games. We present a VR prototype that provides varying degrees of procedural content: No PCG, terrain generation, city generation, and full (city + terrain) generation. In a remote user study, these conditions were compared regarding their capability to support creativity. Statistical tests for equivalence revealed that the presence of PCG did not affect creativity in any way. Our work suggests that PCG can be a useful integration into city-building games without notably decreasing players' ability to express themselves creatively.

CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**; *Virtual reality*; • **Applied computing** → *Computer games.*

Additional Key Words and Phrases: procedural content generation, creativity, city-building games, virtual reality

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## 1 INTRODUCTION

Creating content for video games has become an increasingly costly and time-consuming process [86, 108] as the technical capabilities of modern gaming systems are steadily advancing just as the demands and expectations of game consumers [119]. At the same time, video games have become larger in scope, providing vast virtual worlds filled with non-player characters (NPCs), quests,

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and all kinds of activities that offer players rich and diverse gameplay experiences. Especially in the Triple-A (AAA) market, where games can have vast budgets of up to hundreds of millions of dollars, this trend becomes more and more apparent. One approach to providing developers with tools to create game content economically whilst maintaining or even increasing the variability of that content lies in PCG. PCG is commonly defined as "algorithmical creation of game content with limited or indirect user input" [114]. In recent years, procedurally generated content has been used in all kinds of games and in various ways [100]. For instance, commercial games like *Minecraft* [110] or *No Man's Sky* [36] make use of PCG algorithms to create large 3D worlds with different biomes, flora, and fauna for players to explore. However, PCG is not restricted to creating only maps, levels, and visuals but can also be used for procedural storytelling [57] in games like *Wildermyth* [37] or the creation of in-game items [95] as depicted in games like *Borderlands 2* [103]. In the genre of *city-building games*, PCG is mostly used to generate or rearrange parts of the map that players use as a starting point for city creation [34, 35, 104].

However, although an extensive body of work investigating the interconnection between creativity and PCG-supported sandbox games exists[8, 16, 18, 48, 70, 91], it is still not clear how PCG affects human creativity from a player's perspective in the context of city-building games. It can be argued that the inclusion of PCG may violate the fundamental design principle of control as described by Shneiderman [93] or Nielsen's [74] understanding of user control and freedom and, therefore, impair the overall user experience (UX). This way, PCG could diminish human creativity by taking away the means from players to express themselves creatively. On the contrary, previous research suggests that *human-machine co-creativity* as facilitated by PCG in the context of games cannot only enable but actively foster human creativity [3, 61, 125]. Moreover, procedural tools are helpful to support the creative workflow (especially for mundane and repetitive tasks [52]) as long as they respect designer control, the creative process, and existing work processes [58]. From this perspective, PCG could serve as an alternative to traditional content generation for certain tasks, not as a replacement, but an addition to creative workflows.

City-building games are focused on letting players express themselves creatively by allowing them to create, shape, and design terrains and cities in an *emergent* way of playing [5, 6]. Since enjoyment in city-building games is (among other factors) strongly facilitated through creative expression, it is important to investigate if the inclusion of PCG has any effect on the creativity of players. This question remains relevant in other domains besides entertainment-focused city-building games. A significant and growing body of work has examined the use of open-ended and creative games in different contexts beyond entertainment, such as education[27, 65, 69, 75], human computation [53, 84], or virtual reality exposure therapy (VRET) [2, 117] among others. Arguably, many of these applications would benefit from procedurally augmented support of creative creation tasks to decrease the technical complexity of these systems for non-professional players.

It is yet unknown if the integration of procedurally generated elements would have any effect on players expressing themselves creatively or undermine the motivational effects of self-expression in this context. Furthermore, the process of city-building is usually split between shaping a terrain and building the city [98] and the literature is silent about how creativity differs among these different types of content being hand-crafted or computationally generated. To fill this gap, the present research investigates how manual and procedural content generation affects users' sense of creativity. Our work is guided by the following research questions:
RQ1: *Does procedurally generated and user-generated content yield a different sense of creativity?*
RQ2: *Does the sense of creativity differ for different types of content created manually or with PCG?*

With the recent advancement and dissemination of virtual reality (VR), creators can produce content in immersive environments using spatial and direct interaction that closely mirrors content creation in physical reality. VR tools like *TiltBrush* [39] and *SculptrVR* [88] gained much popularity and have become valuable tools for prototyping as well as content creation [87]. Recent research has shown that immersion yielded through VR facilitates creativity, imagination, the state of flow and yields higher quality creative products [15, 31, 75, 116, 118, 124]. Therefore, to amplify the creativity support, we opted for VR as our platform of investigation.

To investigate the research questions, we conducted an online VR user study ($n$=55) where the participants were tasked to design terrain and/or a city using either manual brushing, PCG, or a combination of both. In total, 4 conditions were compared to each other in a within-subjects study, each providing a different degree of procedurally generated content: No PCG (nothing is pre-generated, the scene is blank), terrain generation (terrain is pre-generated), city generation (cityscape and road network are pre-generated) and full generation (terrain, city, and road network are pre-generated). Users could use manual input to design the scene in every condition with the same direct manipulation tools. Our results indicate that there are no noticeable differences of supported creativity between manual and procedural content creation while PCG significantly lightens the users' work. Our findings show that PCG is a viable method to support users in achieving their creative goals independent of the type of content the users are creating. We conclude that procedural content can be included in creative, playful activities such as shaping a terrain and designing a cityscape without interfering with players' creativity.

## 2 RELATED WORK

Our research is strongly related to the concept of creativity in the context of gaming. There are numerous ways to define creativity coming from different directions of research like (among others) cognitive science, social science, economics, evolutionary theories, and system theories [43, 46, 56]. Creativity is a complex construct, and it is virtually impossible to find a definition that entails creativity in its entirety [24, 44, 75]. Runco and Jaeger provide a historical overview on how the *standard definition of creativity* was derived based on previous works that date back to the $20^{th}$ century [4, 109]. The standard definition states that "Creativity requires both originality and effectiveness" [89]. Here, *originality* describes something to be novel, unique, or uncommon, whereas *effectiveness* is heavily dependent on the context and can mean usefulness, fit, appropriateness, or value [89]. In the context of video games, *play* is frequently described as a creative process as it stimulates creative thinking by providing players with situations that can be approached in novel and uncommon ways [9, 45]. The unstructured and spontaneous nature of play can be an enabler of creative thought processes [11]. Within the scope of this paper, we are adopting the standard definition of creativity [89]. In this context, an *effective* city-building game would allow players to shape a terrain and populate it with urban structures such as buildings and streets and thus, create an *original* virtual environment. It would function as a kind of *creativity support tool* [33, 40, 94] that provides a platform for letting players explore their internal mental imagery and externalize it [23] in the act of city-building in a playful way. It is important to note that for this paper, we refer to creativity as it is expressed by players based on self-reporting. Thus, creativity here is not based on an external examination and assessment of player creations regarding their creative value. This paper contributes to the domain of creativity research by investigating how playful applications with a focus on city-building tasks may stimulate creativity.

### 2.1 City-Building Games and how they foster Creativity

City-building games received much attention in recent years [7, 85]. They are frequently described as open-ended games [47] that offer *emergent* gameplay [5, 26, 112], meaning that these games provide a distinct set of mechanics and rules and allow players to express themselves creatively while not defining a set goal as strictly as in games focused on *progression* [47, 106]. City-building games are *simulation* games that allow players to explore an open-ended world while giving them the tools to design, adjust, and rearrange the world to their liking by shaping the terrain and placing urban structures [6].

One of the earliest and most popular games of this genre is *SimCity* which was designed by Will Wright and published in 1989 [67]. *SimCity* was inspired by the theory of urban dynamics [26, 30] and let players build cityscapes divided into specific zones (industrial, commercial, residential) while having to manage costs and the overall economics of building and maintaining a city. This game was followed up by many sequels [6] and inspired other game series providing similar features and mechanics such as *City Life* [20] and *Cities: Skylines*[79]. There is evidence that city-building games have the potential to enable and enhance players' creativity [85]. By self-creating content in a simulated reality, these games can help to cultivate imagination and creativity [62]. Gaber states that using city-building games in the classroom can help students develop a sense of the creative side of planning a city [32]. Similarly, Terzano and Morckel used the 2013 version of *SimCity* [28] in a large-scale comparative study in a classroom setting. Students' responses from a survey indicated that playing the game increased their perception of planning out a city as a fun and creative process [113]. In a pedagogical study with University students, Kim and Shin [55] investigated how playing *SimCity 4* [68] may help students develop *geographic creativity*. They found that, based on self-reports, most students (83%) stated that playing the game facilitated creativity.

An adjacent genre to city-building games is known as *sandbox games*, which also offer emergent gameplay. However, sandbox games are not constrained to building a city but come in a variety of settings such as adventure, shooter, sports, or strategy games [77, 112]. Popular games representing this genre are for example the *Grand Theft Auto* (*GTA*) series [25] or *Minecraft* [110]. Especially *Minecraft* has been in the focus of researching creativity facilitated by video games [85]. Studies indicate that *Minecraft* can help students express their creativity in the form of in-game short films (*Machinima*) [16, 18] and enhance their creativity in general [8, 48, 70, 91]. Systems that offer functionality similar to *Minecraft* but enriched with VR and augmented reality (AR) technology have also shown great potential in supporting users' creativity [31, 118].

## 2.2 Procedural Virtual Environments, Cities, and Terrains

Procedural content generation (PCG) describes a family of methods that employ algorithms to generate data in contrast to manually created content. Most common approaches for procedural generation of virtual environments (e.g., cities, terrains, dungeons) are based on *Fractals* [66], Lindenmayer systems (L-Systems) [63, 82], *Perlin Noise* [81], *Tiling* [107], *Voronoi Textures* [123], *Grammars* [122] or a combination of these methods [50, 92]. The Procedural Content Generation Wiki [1] has an extensive collection of PCG algorithms and discusses their implementation in games.

Many games have employed PCG as a means to assist designers in creating compelling and diverse virtual worlds that players would enjoy revisiting. In recent years, many modern commercial city-building games have incorporated PCG algorithms to generate map layouts that serve as blank slates for players to build urban structures on. Examples can be found in games like *Banished* [104], *Civilization VI* [34] or *Islanders* [35]. A significant body of work has investigated and developed procedural methods and algorithms for the generation of cityscapes in the context of games (cf. [52, 99]). Furthermore, Kim et al. [54] argue that PCG has the potential to reach out to other areas beyond gaming, such as social simulations or urban testbeds [59, 120].

Dating back to 2001, Parish and Müller describe *CityEngine*, an approach on how to create a virtual city with the help of image maps that contain information about population density, differences in strato types of the terrain, water levels, among other parameters [80]. The generative

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[1] http://pcg.wikidot.com

process consists of multiple stages that are performed subsequently (roadmap creation, division into lots, building generation, geometry & textures). This approach of generating a cityscape in a series of singular steps was further advanced by Kelly and McCabe. They developed a system called *Citygen*, an interactive tool that combines different PCG methods that are performed in succession (road creation, road mapping to terrain, building generation) [51]. A method for road creation is depicted by Sun et al., who use images as input maps for the creation of road networks which in turn can be applied in procedural city generation [111]. Yap et al. describe the computational creation of large geographical regions like the Manhattan Skyline as a top-down process based on statistical parameters [126]. With the intention of creating a larger variety in the aesthetics of virtual cities, Greuter et al. describe a system for the creation of *'pseudo infinite' cities*. Based on the input of an integer seed, location values, and a collection of floor plans, these cities can be created in real-time [41]. An agent-based approach to city creation is described by Lechner et al.. Their system implements a variety of virtual agents, each concerned with different aspects of building a city, such as road planning and building houses [60]. An alternative approach for the creation of city structures is provided by *CGA shape*, which describes a method of creating computer graphics architecture based on shape grammars that define models for various kinds of buildings (e.g., family houses, office buildings, etc.) [71]. A number of survey papers have been published that give a more comprehensive overview of PCG techniques that are used in the context of city generation [12, 42, 50, 99].

### 2.3 Summary

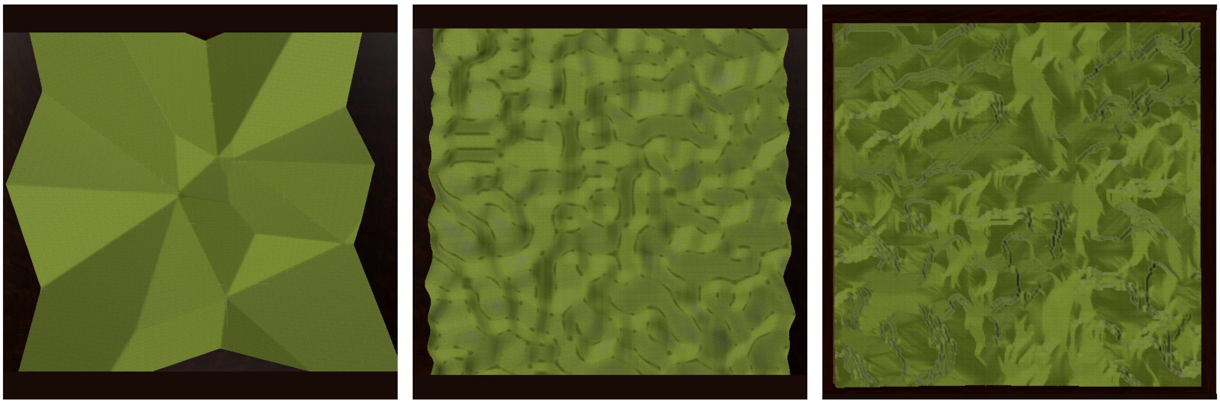
Playfulness has been identified as a facilitator of creativity as it can be open and unstructured in nature and lets players explore novel and interesting solutions for situations presented by games [9, 11, 45]. A game genre that is especially open in its structure is city-building games as it offers a blank terrain for players to fill with streets, buildings, and other environmental details in a creative way [7, 85]. We have covered a variety of previous works that investigated if the use of city-building games can enable and support players' creativity. Most of these studies rely on self-reports and are conducted as pedagogical studies with school or university students [32, 55, 62, 113]. These studies indicate that city-building games indeed bear the potential to act as creativity support tools [94] that stimulate imagination and let players experience the planning process of building a city as something creative. Some games from this genre have incorporated procedural methods to generate landscapes and cities and thus create map layouts rich in variety for players to design and reshape at their will [34, 35, 104]. There exists research that suggests that PCG-supported games from the adjacent genre of sandbox games such as *Minecraft* [110] may help to stimulate creativity[8, 16, 18, 48, 70, 91]. However, to the best of our knowledge, there is a lack of research investigating the effects of PCG on creativity, in particular in the domain of city-building games. We approach this gap by implementing a playful city-building application capable of creating various elements using PCG and examining its effect on creativity.

## 3 PROTOTYPE IMPLEMENTATION

We designed and implemented an application that incorporated functionality typically found in city-building games based on the following criteria. The tool was designed as a playful VR experience. As stated before, we chose VR as it allows creators to be fully immersed in a virtual environment and lets them express themselves creatively in a more natural way. Moreover, there is great potential for PCG to be used in a creative VR setting as it may remove technical hurdles that might be present in a 2D Desktop environment which is especially useful for artists and designers. The application should allow users to generate terrain and a simple cityscape by adjusting a variety of parameters for a PCG algorithm in a fashion similar to existing procedural city generators [51] but inside a VR scene. In addition to parameter adjustment, the application should provide direct manipulation tools that allow the design and shaping of the scene and thus, stimulate players' creativity. We chose *Unity3D*[2] as the development environment and set up our own FTP server for data recording.

### 3.1 Procedural Terrain and City Generation

Our approach for procedural terrain generation was based on the work of Olsen who describes the process as a displacement of a 3D mesh by using a *Voronoi diagram* [73]. Our system creates a *Voronoi diagram* using *Delaunay triangulation* [22] and 2 *Lloyd relaxations* [64]. The resulting mesh then undergoes another displacement via *Layered Perlin noise* [81] and an algorithm for *Thermal erosion* [72] to smooth surfaces (see Figure 1).



(a) Voronoi texture (b) Layered Perlin noise (c) Thermal erosion

Fig. 1. Steps of terrain mesh manipulation.

For the cityscape generation, we implemented an algorithm inspired by the works of Kelly and McCabe. In total, the entire process consists of 4 steps (see Figure 2). First, each tile of the terrain on which the city shall be built is marked as either an edge, an uninhabitable tile (steep hill or canyon), or free (buildings and streets can be placed here). As a second step, streets are placed on some of the free tiles and extended in one of the four cardinal directions until they collide with another street, hit an edge, or reach their maximum length. In step 3, zones are defined as either enclosed by a street network (or steep hills/canyons) or open. Finally, in step 4, houses are placed in the enclosed areas. The models of the houses are randomly picked from a collection of 3D house assets. Models used for house creation consist of blocks that come in 7 basic types, all having the same cuboid shape but different textures. Each house is composed of a collection of these blocks, depending on the maximum and minimum height parameters specified by the user. On top of each generated house, a roof is placed which has 1 of 8 different shapes and a matching texture to the house. For more variety, some houses have balconies added to singular building blocks or windows cut into them (see Figure 3).

### 3.2 Mechanics and Controls

The prototype provides functionality that combines procedural methods and direct user input for the manipulation of a 3D terrain, placement of roads, and creation of urban buildings. The application is inspired by previous advances in PCG. Similar to *Tanagra*, a co-creative 2D platformer level design tool, our prototype allows a human designer to define constraints that are taken into

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[2] https://unity.com/

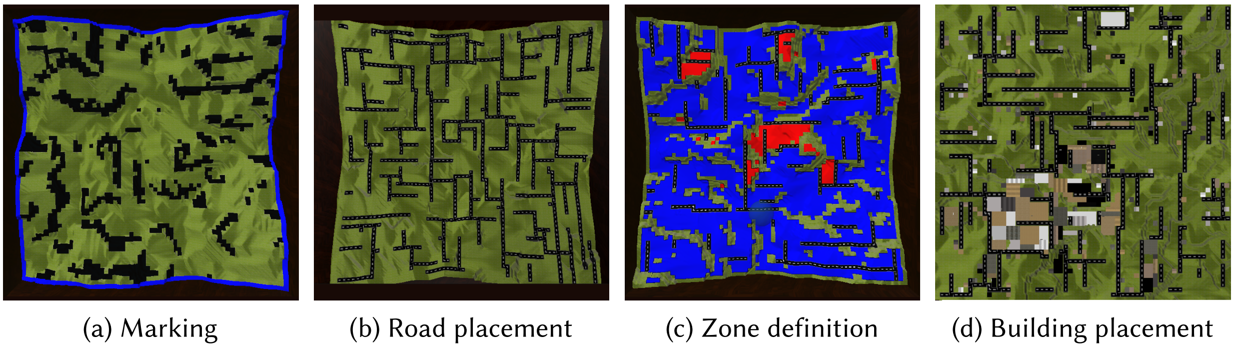
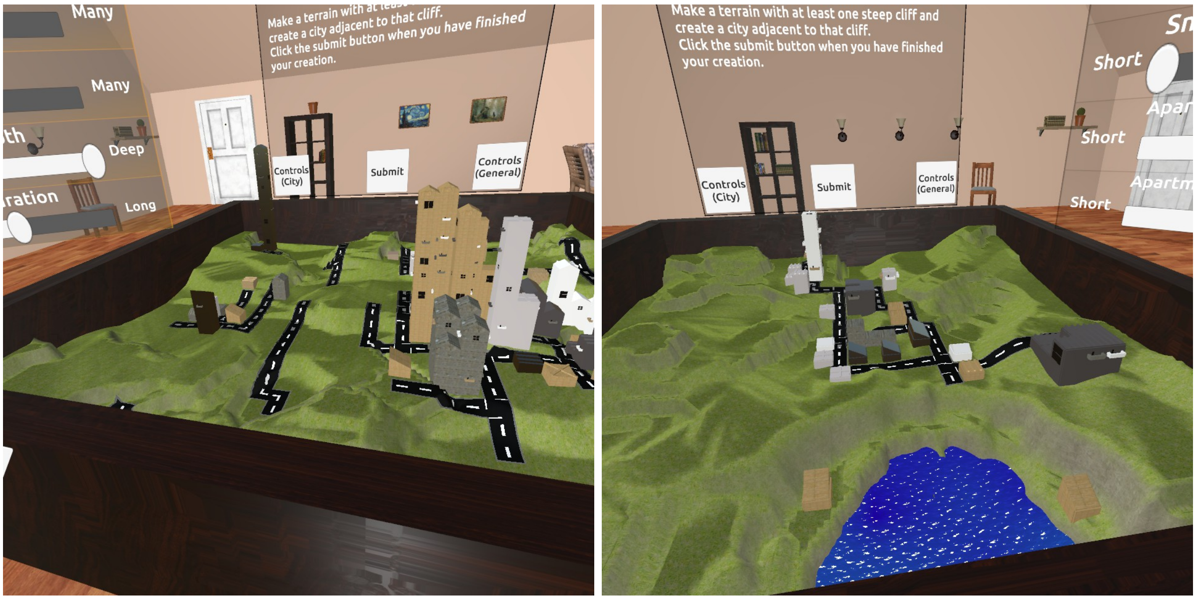

(a) Marking (b) Road placement (c) Zone definition (d) Building placement

Fig. 2. Steps of city generation. (a) marking of the terrain (edges are blue, black tiles are uninhabitable) (b) creation of road network (c) zone definition (red tiles are enclosed, blue ones are open) (d) building placement in enclosed areas.


Fig. 3. Exemplary scenes showing varying kinds of house and roof blocks with different textures and sizes.

account by a level generator [101, 102]. The world creation is split into 2 distinct areas: terrain manipulation and city creation. This resembles work by Smelik et al., who describe the generation of a virtual world with the use of *procedural sketching*, including a *landscape mode* and a *feature mode* [98].

When launching the application, users are positioned in a living room environment with a large sandbox-like structure in the center of the room (see Figure 4). A tutorial screen is displayed in front of their view, outlining the system's controls and mechanics. On their non-dominant hand, a user interface is attached to the in-game representation of the controller. This interface provides functionality for various direct manipulation actions of the scene (see Figure 5). Users can enable terrain shaping tools (raising, lowering, smoothing), adjust the brush type or size, pick objects to place in the scene (streets, house blocks, roofs), or activate a tool to remove built structures. On the left and ride side of the sandbox, world-anchored [1, 90] 3D menus with controls the PCG algorithms. For city generation (menu on the right), parameters include the density of buildings and streets as well as the minimum and maximum height of buildings. For terrain generation (menu on the left), players are able to control the height of hills, occurrence of canyons, and their respective depth, as well as the erosion duration for smoothing the terrain. Adjustments can be confirmed by clicking a button below those menus (either "Generate Terrain" or "Generate City"). All interactions are performed by pointing, which casts a blue ray in the direction of the pointer and clicking with the trigger of the controller of the dominant hand. This ray-casting point and click approach is a common interaction technique for VR software prominently shown in *TiltBrush* [39] or *SculptrVR* [88]. For movement in the virtual environment, players can either move around by walking or activate a teleportation mode allowing them to quickly move around the scene. Teleportation comes in 2 modes: The standard teleportation allows users to quickly change locations in the room whilst preserving the top-down view (unscaled teleportation). As an alternative, the application features scaled teleportation, where users can enter the self-created environment and perceive their surroundings in a more realistic, lifelike size. In this mode, they can walk around in the city they created and get a different perspective of the scene. At any time, users can switch back to standard teleportation and enter the living room scene again.



Make a terrain with at least one steep cliff and create a city adjacent to that cliff. Click the submit button when you have finished your creation.

Fig. 4. A virtual environment in which the study took place from different perspectives. Instructional texts are displayed in the back, interfaces for parameter adjustment are on the left and right sides.

## 4 METHODS

To address RQ1 and RQ2, we designed a user study using our VR prototype with varying degrees of manual and procedural content generation. The study could be conducted remotely on any *SteamVR* compatible device or on an *Oculus Quest* or *Oculus Rift*.

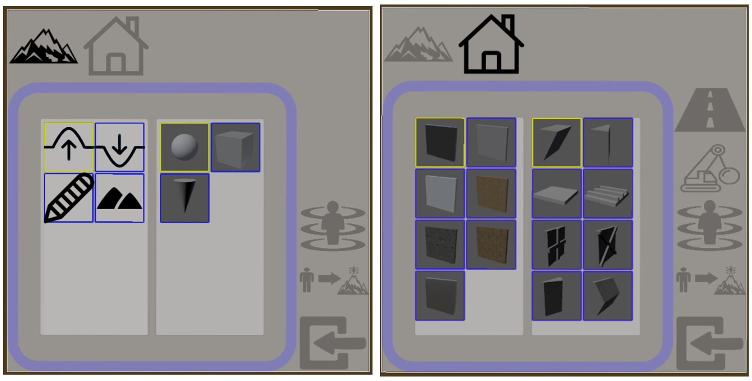


Fig. 5. Menu attached to non-dominant hand for direct terrain manipulation (left) and city placement (right).

### 4.1 Participants

One aim of the study was to identify whether PCG yields comparable creativity support as manual creation. Therefore, to capture little differences between the variants, we considered small effect sizes for our sample size estimation. To calculate the number of required participants for the study, we performed an a priori power analysis for a within-subjects Repeated Measures Analysis of Variance (RM-ANOVA) with four conditions using G*Power 3.1 [29]. With an expected small effect size of $\eta_p^2$=0.02 with $\alpha$=0.05 and $1-\beta$=0.8, we determined a required sample size of $n$=69. The expected partial $\eta_p^2$ corresponds to Cohen's d of 0.09≈0.1 considered a small effect size [19].

Coming from Prolific 299 people signed up for the study, of which 62 participants started the experiment in VR. 8 participants signed up for our study from Reddit. We filtered participants that had missing data due to connection errors who did not complete the study or stayed in at least one of the conditions for less than 120 seconds. After cleaning, our sample consisted of $n$=55 complete data sets, which were used for all subsequent analyses. The following user demographics are taken from this cleaned-up data. The gender (options for responding based on [105]) distribution was strongly male-dominated, with 49 participants describing themselves as male, 5 as female, and 1 as non-binary. On average, the participants were $M$=26.16, $SD$=7.55 years old, ranging between 19 and 50 years. On Prolific, the participants were pre-screened for fluency in the English language and ownership of a VR device which was required for study participation. To assure our results are not affected by verdant VR usage, we inquired about the participants' prior experience with VR devices. Most participants were rather VR-savvy, stating that they used VR "daily" ($n$=9), "a few times per week" ($n$=22) or "weekly" ($n$=9). Others used VR "a few times per month" ($n$=11), "monthly" ($n$=3) or "a few times per year" ($n$=4). No participant stated to use VR "annually" or "never". To ensure that the participants are generally familiar with creative activities, we asked how often they perform creativity-demanding tasks. Generally, the sample was familiar with creative tasks in some capacity and most participants exerted creative tasks on a regular basis (5: "daily", 14: "a few times per week", 5: "weekly", 9: "a few times per month", 4: "monthly", 6: "a few times per year", 4: "annually" 2: "never"). According to the accumulated user data retrieved from *Prolific* after the study was concluded, we found that participants took an average of $M$=54.77, $SD$=26.07 minutes for successful completion of the procedure.

### 4.2 Apparatus

The prototype described in section 3 was adjusted for the user study as follows. Four different conditions were defined, representing varying levels of procedurally generated content. In the USER condition, the game presented a blank scene with flat terrain and no environmental details pre-generated. For the TERRA condition, only the terrain was predefined for the players. By adjusting the parameters on the menu to the left, players could adjust the parameters and re-generate the terrain to their liking. In contrast to that, the CITY condition offered a flat terrain with a typical cityscape (houses and streets) generated on top. A menu on the right side allowed for parameter adjustment. Finally, the FULL condition displayed a scene with both terrain and a cityscape generated procedurally. Here, both menus on the left and the right side could be used by the players for parameter adjustment. Throughout all conditions, players could use the same direct manipulation tools for adjusting the terrain (e.g., raising and lowering) as well as adding details to the scene (e.g., placing houses and streets manually). For subjective data collection, questionnaires were implemented as part of the VR experience. To avoid breaks in presence [97], those were presented as world-anchored in-VR questionnaires (inVRQs) [1, 83].

## 4.3 Procedure

We provided our tool on *itch*[3] – an online platform for indie games. The study was hosted and advertised on *Prolific*[4], a participant recruitment service for online studies. Subjects were paid 6£ for participation in the study, which was estimated to take 45-60 minutes in total. In addition, we posted the study on the *SampleSize*[5] subreddit – a thread specifically to advertise user studies. For participants who signed up for the study on Reddit, no reimbursement was paid. Participants were directed to the webpage either coming from *Prolific* or *Reddit*. On the instruction page, participants were informed about the study procedure, the general purpose of the study (no details that could give away the actual research question), potential risks and benefits, the confidentiality of recorded data, and their right to withdraw from participation at any time. Participants had to give consent to these terms before downloading the software. In addition to the consent form, we provided instructions on how to install and run the application on the VR headset. Upon downloading and launching the application on their device, subjects would be greeted with an information and instruction panel in VR. Here, they would be guided through the controls and various mechanics of the software. When they confirmed that instructions were understood, the study began, and the participants executed all four conditions in succession. The order of the conditions was counterbalanced using a *balanced Latin square* [10, 38, 121]. In each condition, participants were given one of the 4 open creative tasks that were described as follows: 1: Create a cliff with a town adjacent to it. 2: Create two mountains and a skyscraper on each of them. 3: Create any terrain with three separate towns on it. 4: Create terrain with at least two canyons and completely surround them with houses or streets. For each condition, one of these tasks was picked at random. Each task was assigned only once. Whenever participants felt they had finished a task successfully, they would click the submit button on the main panel. After each task was completed, an instruction panel popped up, asking participants to turn around and to self-report their focused attention (User Engagement Scale - Focused Attention (UES-FA) [76]) and perceived creativity support (Creativity Support Index (CSI) [13, 14, 17]). After all 4 tasks at the end of the experiment, the app displayed a completion code required for *Prolific* and gave participants the option to register for a 15€ voucher for *Amazon*[6]. The study flow is depicted in Figure 6.

## 4.4 Experimental Design

The study was conducted as a remote 1×4 within-subjects user study using subjective self-reported measures of focused attention and creativity support. We assessed focused attention on a specific task as attention, in general, correlates with creativity [49] and focused attention can be beneficial for creativity to occur when performing specific tasks [127]. Furthermore, focused attention is associated with user engagement [21, 76, 96] For that purpose, we deployed the UES-FA subscale of the User Engagement Scale - Short Form (UES-SF) [76]. To measure how the tools may support creativity, we used the CSI [13, 14, 17]. As objective measures of engagement and to capture the participants' behavior, we logged all interaction events during the study from which we derived higher-level metrics of time spent in each condition, number and duration of actions (terrain shaping, object placing, object deletion), PCG parameter adjustments, and number PCG re-generations.

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[3] https://itch.io/

[4] https://prolific.co/

[5] https://www.reddit.com/r/SampleSize/

[6] https://www.amazon.com/

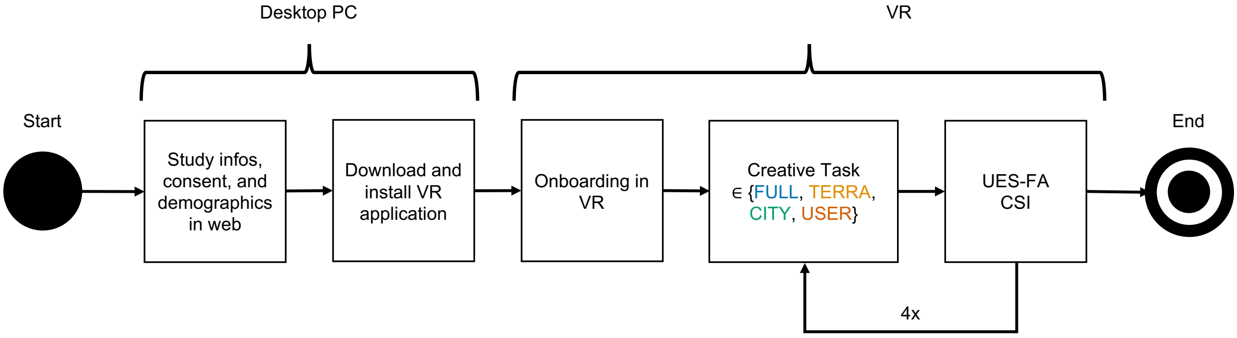


Fig. 6. Study procedure. The participants registered for the study on a desktop PC. Next, the participants installed the VR application and entered the scene. In VR, the participants first read instructions regarding the interface. Then, in counterbalanced order, the participants performed open creative tasks (creating a landscape with a city) in all 4 conditions (within-subjects). After each condition, the participants rated their focused attention and creativity support of the current interface. The study ended upon completion of all four tasks.

# 5 RESULTS

## 5.1 Subjective Measures

As subjective measures of user engagement and creativity, we assessed focused attention on the UES-FA and CSI, respectively. All subjective ratings were collected on 10−point Likert-scales (1 lowest) after each condition.

*UES-FA.* All conditions were rated with moderate attention. USER: $M$=4.92, $SD$=2.04; TERRA: $M$=5.35, $SD$=1.92; CITY: $M$=4.96, $SD$=2.00; FULL: $M$=4.89, $SD$=1.86. To determine if the focused attention differed between conditions we performed a RM-ANOVA with the UES-FA as dependent variable and the conditions as within-subjects factor. The analysis showed no significant differences between the conditions ($F_{3,168}$=0.90, $p$=0.439, $\eta_p^2$=0.016). To provide support for the assumption that the tools are equivalent, we conducted a Bayesian RM-ANOVA with a prior of 0.5, which showed that the data 18.15 times more likely under the null hypothesis.

*CSI.* To assess creativity support of condition, we employed five subscales *Enjoyment*, *Exploration*, *Expressiveness*, *Immersion*, *Results worth Effort* from CSI. The *Collaboration* subscale was discarded since collaborative tasks were beyond the scope of this study. The administration of the questionnaire contains two modules. The first module contains questions regarding the creativity support on each of the subscales and is presented to the participants after each tool. The second module is administered at the end of the study. It contains paired questions for all combinations of the subscales where the participants are required to select the more relevant of the two subscales. For each subscale, the choices are summed up and used as weights to calculate the total CSI score. The overall experience was rated with a medium creativity support ($M$=86.17, $SD$=26.12).Each condition received the following CSI scores: USER: $M$=85.61, $SD$=27.67; TERRA: $M$=86.70, $SD$=25.41; CITY: $M$=84.85, $SD$=25.33; FULL: $M$=87.53, $SD$=26.65. To determine if the tools yielded different perceived creativity support, we performed RM-ANOVAs on the total CSI score as well as on each subscale with the condition as the within-subjects factor. The descriptive statistics of the CSI subscales and the ANOVA results are shown in Table 1. The RM-ANOVAs showed no significant differences between the conditions on any scale. To further corroborate if the tools were equivalent in their effect on creativity, we performed a Bayesian RM-ANOVA with a prior of 0.5. The Bayesian ANOVA revealed that the data is 31.10 ($BF_{01}$) times more likely under the null hypothesis.

Table 1. Descriptive statistics and RM-ANOVA results for the CSI subscales

| Scale | Mean (SD) | F(3,162) | np2 | p-GG-corr | $BF_{01}$ |
|---|---|---|---|---|---|
| Enjoyment | 5.96 (2.17) | 0.497 | 0.009 | 0.675 | 24.06 |
| Exploration | 5.78 (2.04) | 0.664 | 0.012 | 0.557 | 19.86 |
| Expressiveness | 5.72 (2.03) | 0.098 | 0.002 | 0.960 | 39.93 |
| Immersion | 5.61 (2.03) | 0.487 | 0.009 | 0.683 | 24.67 |
| Effort | 5.65 (2.05) | 1.394 | 0.025 | 0.247 | 8.04 |
| $CSI_{total}$ | 86.17 (26.12) | 0.300 | 0.006 | 0.823 | 31.10 |

Table 2. Descriptive statistics and results of the RM-ANOVAs on the behavioral measures.

| | Mean (SD) | F | $df_1$ | $df_2$ | $\eta_p^2$ | p-GG-corr | $BF_{01}$ |
|---|---|---|---|---|---|---|---|
| Time (sec.) | 796.71 (5686.35) | 1.04 | 3 | 162 | 0.019 | 0.313 | 10.69 |
| # Scaled Teleportations | 0.845 (2.29) | 2.56 | 3 | 162 | 0.045 | 0.088 | 1.27 |
| # Modeling Actions | 4160.45 (4043.60) | 3.67 | 3 | 162 | 0.063 | 0.019 | 0.48 |
| # PCG Generation Actions | 1.99 (2.92) | 4.96 | 2 | 114 | 0.080 | 0.011 | 0.20 |

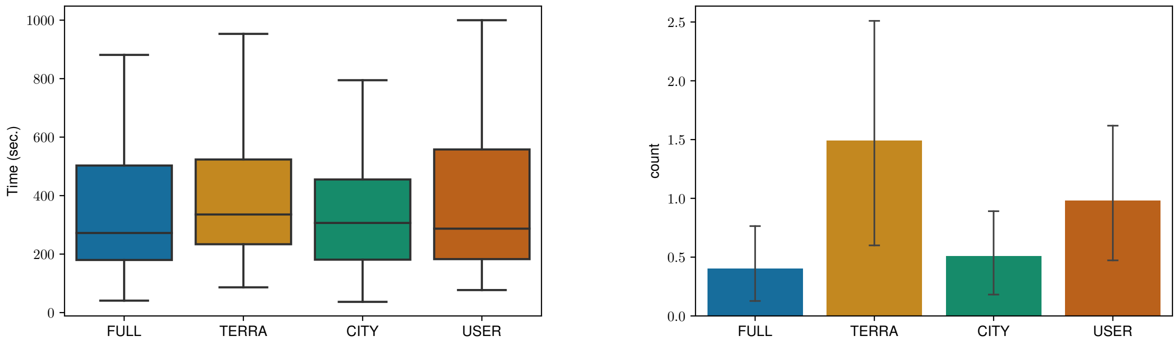
### 5.2 Behavioral Logs

As an objective measure of engagement and to better understand the participants' activities, we logged all actions during the VR experience. Our main measurements were the TIME spent in each condition, # SCALED TELEPORTATIONS, # MODELLING ACTIONS, and # PCG GENERATION ACTIONS. We performed RM-ANOVAs on each variable to investigate differences between the conditions. To further confirm the equivalence or the differences between the conditions, we conducted Bayesian RM-ANOVAs with a prior of 0.5. As shown in Table 2 and Figure 7, the conditions were comparable for TIME and # SCALED TELEPORTATIONS. However, # MODELLING ACTIONS and # PCG GENERATION ACTIONS differed significantly.

## 6 DISCUSSION

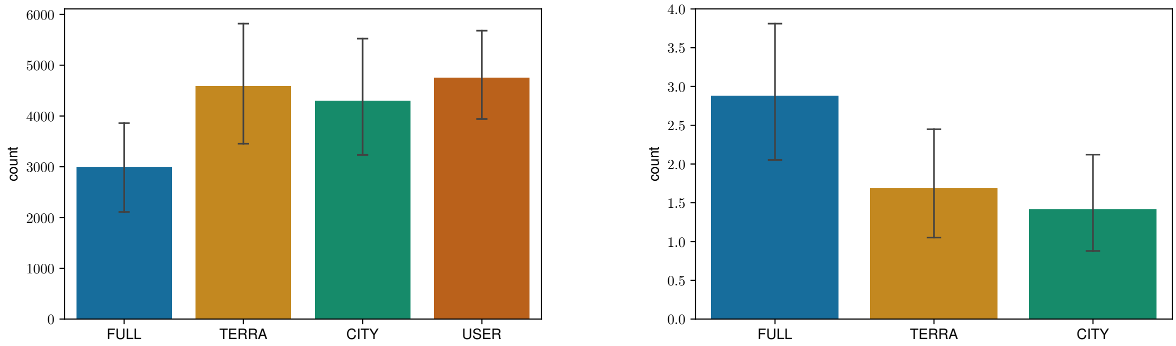
The objective and subjective measures of engagement and creativity indicate that the study was representative and effective in investigating the effects of PCG on creativity. All tool variants received moderate scores for focused attention and creativity support. This confirms that our apparatus yielded a sufficient UX that does not inhibit creative content creation. Furthermore, the comparable TIME spent in each condition underlines that the study proceeded as intended, and the participants invested comparable effort in exploring each tool. Moreover, the different number of modeling and generation actions between the tools indicate that the tasks were performed as intended. The lower # MODELING ACTIONS and highest # GENERATION ACTIONS in FULL compared to tools with no or partial generation allows us to infer that the PCG supported users in achieving the task goal.

Regarding RQ1, the subjective results show that PCG has no noticeable differences in creativity when creating content manually or through a PCG algorithm. This is supported by the insignificant results of the RM-ANOVAs as well as the high likelihood ratios in support for H0 from the Bayesian ANOVAs on UES-FA and CSI. Our data suggest that the prototype functioned as a *creativity support tool* [33, 40, 94] which stimulated the same level of creativity regardless of the inclusion of PCG. Therefore, we conclude that PCG has no effect on engagement and creativity as subjectively perceived by players. In response to RQ2, we did not find differences in focused attention, creativity support,



(a) Time spent in condition

(b) # Scaled Teleportations



(c) # Modeling Actions

(d) # PCG Generation Actions

Fig. 7. Behavioral Metrics

nor in participants' behavior for the conditions with partial PCG (CITY, TERRA). These results indicate that the type of content the users are creating does not impact the creativity support, nor the overall interaction with sandbox environments. Contrary, # Scaled Teleportations shows a slight trend that participants in the TERRA and USER teleported into the terrain more often and, therefore, might be more engaged with their creation. However, this result failed to reach significance and thus, does not allow for a conclusive response of RQ2. Comprising the study results, our findings indicate that PCG can be integrated into playful city-building systems without compromising the players' creativity. These results are in line with previous research that identified PCG-supported games as a platform for creative expression[8, 16, 18, 48, 70, 91].

## 7 LIMITATIONS

In the user study, we did not find any impact of PCG on players' self-reported creativity as measured by the CSI regardless of whether terrain or urban structures were procedurally generated. It is possible that these results would have been different if we had only compared both extremes - no PCG (USER) and City + Terrain Generation (FULL) before running a more fine-grained examination of 4 conditions with varying degrees of PCG.

The study was conducted remotely with the use of *Prolific* as a recruitment platform. Though remote studies are a valid method to be employed in Human-Computer Interaction (HCI), there are a number of concerns that should be taken into account when interpreting the collected data. Firstly, our study relied on the usage of VR equipment that participants had to have at their homes. The implication here is, that all participants had some basic level of technical expertise since they not only had to have the hardware but also know how to enable developer mode on their devices or at least be able to follow our instructions on how to enable it. Demographic data reported in section 4 confirms this assessment. Concerning participation, our study had a rather high dropout rate as only 70 people completed the experiment out of 299 initial sign-ups. This may be due to a multitude of reasons, for instance, a lack of understanding of the instructions or simply because some people claimed the study on Prolific without reading the requirements section. It is important to note that in this context, a dropout can have different meanings. For one, some participants canceled their participation mid-study. Others however never started the application in the first place after realizing that they did not meet the necessary requirements (e.g. equipment) for participation. Both would be considered a dropout which may explain the high high dropout rate in our study.

Another point of concern comes from the rather short time that participants spent in each condition on average (a little more than 3.3 minutes), which may have been too short to stimulate creativity. Furthermore, it should be noted that yielding creativity in a user study, in general, is challenging since the participants might not have a personal relationship with the generated content. Moreover, it cannot be excluded that some participants, since there was monetary compensation for their participation, did not feel inclined to express themselves creatively but simply finished the task at hand. Although we designed the tasks for the study to be open and non-restrictive, some participants might have interpreted them as explicit missions or quests to be completed.

Regarding the measurement of creativity, we relied solely on self-reports assessed via the CSI. Therefore, we cannot evaluate whether the city and terrain designs were created in a creative way. This would necessitate an expert's examination of these designs which was outside the scope of this study.

Also, there are potential environmental factors we cannot account for. As with all field studies, there is a lack of control over the setting in which the study took place. However, the current pandemic situation caused by the spread of the COVID-19 virus motivated us to conduct the study in a safe place while keeping the threat of infection for our study participants at bare minimum. Another limitation comes from the gender distribution in our sample, which is heavily dominated by participants that identified as male (89%). Lastly, we need to mention that, since we did not assess collaboration as part of the CSI, our reported scores cannot be contrasted with related research that employed the CSI.

## 8 CONCLUSION AND FUTURE WORK

In this work, we investigated the interplay of PCG and user creativity in the context of playful city-building environments. Specifically, we designed a VR PCG co-creation city-building tool, which allows enabling PCG on different degrees of interaction for city and terrain generation in conjunction with manual environment shaping. We conducted an online user study (*n*=55) where the participants were required to perform different city-building tasks with the tool and to state their perceived level of creativity. Our results show strong evidence that PCG and manual creation yield a comparable level of creativity and that the type of objects being created does not affect the sense of creativity while at the same time, PCG reduces the amount of work the users are required to take in order to achieve their creative goals. These results substantiate that PCG is a valuable method for city-building environments that supports the users without undermining their creative flow. This work only concerned the creativity of city and terrain creation. However, future work should investigate other types of content with PCG, such as virtual agents or more elaborated Artificial Intelligence (AI) approaches. Regarding the users' influence of PCG algorithms, the participants had only five control sliders to determine the outcome of the algorithm. In future work, we aim to investigate more granular degrees of user control and its influence on users' creativity. Additionally, we intend to examine what users may wish to control in an open creative task manually or which aspects they prefer to be handled by a PCG algorithm. Furthermore, in future work, we aim to build on these findings and investigate the role of personality factors such as player traits [115] in the context of PCG-supported city-building games.

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# Publication *P*4

## Analysis of Previsualization Tasks for Animation, Film and Theater

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# Analysis of Previsualization Tasks for Animation, Film and Theater

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## ABSTRACT

Previsualization (previs) is an essential phase in the visual design process of narrative media such as film, animation, and stage plays. In digital previs complex 3D tools are used that are not specifically designed for the previs process making it hard to use for creative persons without much technical knowledge. To enable building dedicated previs software, we analyze the tasks performed in digital previs based on interviews with domain experts. In order to support creative persons in their previs work we propose the use of natural user interfaces and discuss which are suited for the specific previs tasks.

## KEYWORDS

previsualization; user requirements; natural user interface; animation; film; theater; interview; workshop

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## INTRODUCTION

Narrative media disciplines such as film, animation, and theater use a profound planning phase for the visual outcome of a production to explore ideas, plan technical solutions, and communicate a shared vision. This planning phase is referred to as previsualization (previs) [6]. Previs gains increasing popularity through the steady advancement of technology and most of today's previs work is done digitally. Digital previs brings the advantage of precise planning, producing high-quality visual output and the ability to use the results of the previs phase in the production process later on.

Typically, complex 3D tools such as Maya[1], AutoCAD[2] are used for previs. However, the use of complex 3D tools requires skilled technical users excluding creative, non-technical users such as artists, designers, directors from the previs production process. Therefore, many iterations of designs and communication between creative personnel and technical staff is required [4]. The 3D tools used in the application domains are not designed for the previs process but rather are general 3D tools for high quality 3D modeling, design and animation. They offer a wide range of functionality and options, many of them focusing on very specific tasks which are not necessary in the previs production. Offering all these functions in a standard 2D interface makes the use in the previs context unnecessarily complex. In addition some of the functions required in previs are not supported by standard tools and workarounds have to be used resulting in complex workflows or the implementation of custom functionality.

In order to enable the development of previs software that is tailored to the previs process and offers the specific functions that are required, we investigate the specific tasks performed in digital previs. Furthermore, to enable creative persons without much technical knowledge to use digital previs software we discuss the use of natural user interfaces (NUI) for previs tasks. The interaction with NUIs is described as intuitive [5] and makes use of the humans inherent capabilities to express themselves by their body, gestures and speech [2, 3, 9]. Such interaction can be suited for the interface of previs software that speaks the language of artists instead of technicians.

In interviews with domain experts from the application domain of film, animation and theater we collect the tasks and workflows performed in digital previs. We aggregate and analyze these tasks to present a consistent set of previs tasks that should be supported by a dedicated previs software. We identified 20 core tasks presented in an overall workflow. We discuss possible natural user interfaces to support easy and intuitive interfaces for the presented tasks. We contribute a detailed analysis of

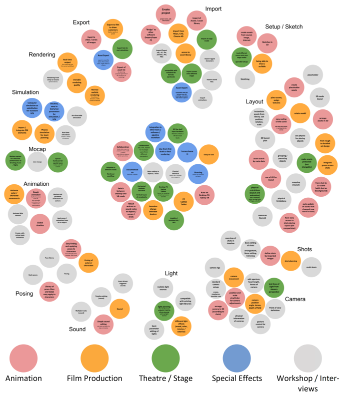

**Figure 1: Circular arrangement of all requirements assigned to workflow steps. For details see supplementary files**

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[1] https://www.autodesk.com/products/maya

[2] https://www.autodesk.de/products/autocad

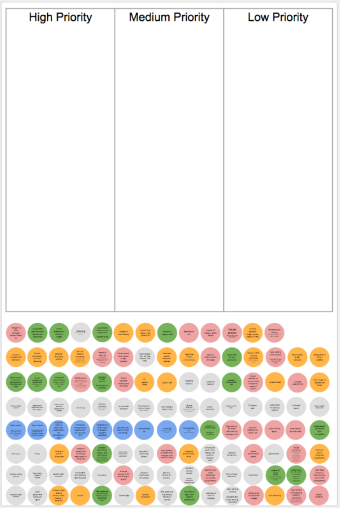

**Figure 2: Prioritization template showing color-coded requirements at the bottom and three priority categories.**

the digital previs process in three application domains and suggestions for supporting these tasks with NUIs.

## IDENTIFICATION OF PREVIS TASKS

We aim to provide a set of core functionalities, that a previs software would have to offer in order to be sufficient and usable. We employed a structured methodology consisting of the following steps: 1. *Extraction of user requirements from interviews using personas, use cases and scenarios* - 2. *Workflow Generation* - 3. *Prioritization* - 4. *Categorization*.

### Tasks in Animation

To get an insight in the daily routines and tasks that are typical for the professional animation domain, we conducted interviews with three different experts: an animation supervisor, a layout supervisor and an editing supervisor. One key requirement derived from the interviews was the capability of creating and working on projects containing information regarding scenes, shots, layout, animations, cameras and effects that can be shared with coworkers. Moreover, the experts identified the option to import different kinds of media such as texts, images, videos and 3D models as essential. Additionally, scenes and shots, the fundamental building blocks of any animation project, should be integrated into a timeline interface. For the purpose of communicating and sharing ideas with team members, it was required to attach annotations in the form of voice and text to objects in the scene. On top of that, the interviewees emphasized the need for exchange of content between the software and other standard industry applications. Final requirements expressed by the experts were export of asset lists, integration of motion capture technology and the use of VR for sketching and lay-outing.

### Tasks in Film & Commercial Productions

For the application area of film and commercial productions, we conducted interviews with five domain experts including a professional producer, a set designer, a cinematographer and two directors. Sketching ideas was identified as one of the core tasks and starting point in previs for the film domain. Besides supporting the sketching process itself it was also required to allow users to import data sets from CAD software. To enrich the scene with objects and props, designers have to have access to a library of various assets. Another crucial task identified during the interviews was planning for character actions that would later be performed by real actors. To achieve this, animation experts have to able to select different character models and visualize their motions subsequently (e.g. by drawing a path for the characters to follow). In addition to that, it should be possible to design different light and camera setups with a variety of light colors, themes and lenses. Since modern film productions are concerned with the generation and integration of computer generated images (CGI), the incorporation of these elements was identified as another substantial requirement for the software. Further software requirements that were extracted from the interviews were exact physics simulation for stunt planning, high rendering quality for movie exports, hardware flexibility and clean UI design.

**Figure 3: Prioritization of requirements by the domain experts. For details see supplementary files**

### Tasks in Theater & Stage Productions

Eight domain experts were interviewed in the process of identifying tasks typical in theater previs. The main difference in theater productions compared to film is the fact that staff members are working on a single immobile asset - the stage. Naturally, import and export of accurate 3D models in industry standard formats is a crucial requirement for the software. Besides importing and working on a stage model, the technical and physical limitations of the stage should be represented as well. This way, set designers can guarantee visibility for the audience from all seats and make sure that it's impossible to peek behind the stage drawing the attention to set props. Generally, the interviews revealed that theater productions share many common tasks with the film domain. In both application areas, substantial requirements involve the light setup, integration of CGI, communication between coworkers and intuitive UI design.

### Workflow Generation

Once the definition of user requirements based on expert interviews had been concluded, we organized a workshop including domain experts. For the purpose of obtaining functional requirements that could not be identified during the interviews, we made use of the MoSCoW Analysis [1], which provides a categorization into *must have*, *should have*, *could have* and *won't have*. Ultimately, we summarized a set consisting of requirements that originated from the interviews as well as the ones that were specified in the workshop. For reasons of organization and comprehensibility, we generated index cards and used color-coding as a means of indicating the origin of each requirement, see figure 1. With the help of a card sorting approach [8], the team assigned each card to a specific workflow step. This way, we compiled a circular workflow map including the steps: import, setup/sketch, layout, shots, camera, light, sound, posing, animation, motion capture, simulation, rendering, and export. Requirements that couldn't be associated with a single individual step were placed in the center, see figure 1.

### Prioritization and Categorization of User Requirements

In total, we identified a collection of 118 different user requirements in the interview and workshop phase. Since the overall objective is to build a software based on these requirements, a thorough prioritization was obligatory. For the rating process, each domain expert received an empty template, containing all 118 requirements as well as three columns labeled *high priority*, *medium priority* and *low priority*, see figure 2. Ranking scores were assigned to each requirement: three points for high, two points for medium and one point for low priority. Upon completion, average scores for each requirement were calculated and summarized in an overview table. To give an example, requirements that received the highest possible rating involved import/export, arrangement of 3D assets, compatibility with industry standard formats, project management (creation, information, editing) and an overall high usability.

The requirement acquisition process was carried out by each project member independently. As a result, various items were identified that were relevant in multiple application areas, overlapping entirely or at least in terms of content. To erase redundancies, some requirements had to be merged or reorganized. Ultimately, we accumulated lists of common, overlapping and application-specific requirements.

## DERIVATION OF CRUCIAL PREVIS FUNCTIONALITIES

In accordance with the collection of requirements, we derived a set of 20 functionalities that previs software should provide to be a usable tool for domain experts. However, not all of the core functionalities can be directly translated into previs tasks. Some of them relate to general functions like multi-user capability or seamless changes between devices. Therefore, we reduced the set of 20 core functionalities to crucial previs tasks that apply to all application areas, resulting in a list of 9 core previs tasks: *Project Structure*, *Import/Export*, *Shot Management*, *Sketching (Modelling)*, *Assets and Layout*, *Camera Control*, *Visual Effects*, *Lighting* and *Posing and Animation*. See table 1 for definitions.

**Table 1: Definition of the core previs tasks**

**Project Structure:** Organization of previs work in projects, including all resources like 3D models or textures, that comprise of scenes (scene graph) and shots (2D views on a scene).

**Import/Export:** For the integration of previs into production pipelines, different input and output options in the form of file format support are offered. For ex-ample, OBJ, FBX, or STL files are supported at both ends.

**Shot Management:** Creation and overview of shots on a 3D scene.

**Sketching (Modelling):** Creation and modelling of 2D and 3D objects for outlining and dressing scenes.

**Assets and Layout:** Creation of 3D scenes as virtual worlds, sets, or places using assets, models, animations, effects, etc. Import, selection, and interaction with pre-made 3D objects and animations from a database.

**Camera Control:** Adding and interaction with virtual cameras in a scene for shot creation with different camera parameters, lenses, and camera path animations.

**Visual Effects (VFX):** Create, edit, and arrange visual effects in a scene by selection from a database or by direct gesture control to the simulation.

**Lighting:** Adding and interaction with virtual light sources, creating different moods and scene styles.

**Posing and Animation:** Creation and application of animations onto characters and objects using pre-recorded animations, physics animation, and motion capture. Posing on rigged characters and pose selection from library.

## DISCUSSION

As previs is a creative process led by the vision of directors, artists or designers it is important to support the creative persons in using a previs software. A dedicated software which supports the exact tasks we identified will improve the accessibility for these people over standard software. However, these tasks still have to be controlled in an easy and intuitive fashion in order to be usable by creative people who often have not much technical knowledge. NUIs are described with these attributes [9]. Therefore, we discuss the use of different NUIs for the identified previs tasks.

The identified previs tasks show quite distinct features in the nature of their media types. Some of them are inherently one- or two-dimensional e.g., import/export, project structure, shot management, structuring some flat data content. Direct manipulation on touch devices offers a 2D interfaces that is intuitive, easy to learn and offer a high degree of precision and overview. Others previs tasks are by nature three-dimensional such as 3D scene modelling, layout, camera, or lighting. We argue that direct manipulation and gestures in 3D used in current VR systems offers the most intuitive and powerful type of interaction for these tasks. In previous research [4] we could show that VR is well suited for previs, especially for non-technical persons as they do not have to struggle with complex controls for navigation in 3D space but rather can look around naturally and build the space by using their hands. Interaction in VR utilizes the spacial nature of our interaction in the real world and therefore makes it intuitive and easy to learn [9]. VR is mostly limited to one user at a time, making it not suited for every situation - previs is a collaborative process often including multiple persons. Tangible interaction can be used for a intuitive and collaborative interface that builds on the natural interaction with real world objects [7]. Spatially-aware displays and mobile augmented reality can provide the hand-held feeling of operating a camera while offering a view into the virtual world. This can resemble the natural way how creatives interact in their professional workflow. Motion-tracking solutions like motion-suits or camera-based tracking offer the capabilities of recording human motion. This technology can be used as full-body interaction and embodiment for intuitive and easy animation. This would offer creatives the possibility to perform the actions themselves instead of using abstract animation software. Finally, speech can provide an additional layer of interaction that could be combined with all other forms of interactions which were presented in order to give easy access to common actions, e.g. undo.

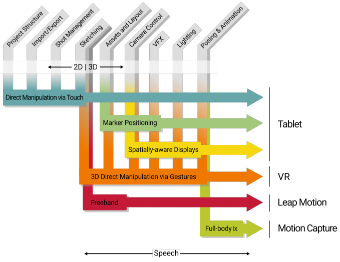

**Figure 4: Mapping the core tasks in previs with natural forms of interaction and the related hardware.**

## CONCLUSION

In this work we analyze the digital previs process and identify core functionalities for dedicated previs software. We aggregate the results form interviews with 16 domain experts. Further, we discuss the use of natural user interfaces for the specific previs tasks to support creative people in doing digital previs themselves. In future work we aim to evaluate natural user interfaces with domain experts for the previs tasks presented in this work.

## ACKNOWLEDGMENTS

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# Publication $\boldsymbol{P}5$

Using Natural User Interfaces for Previsualization.

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# Using Natural User Interfaces for Previsualization

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## Abstract

INTRODUCTION: An important phase in the process of visual design for the narrative media is previsualization (previs). Professionals use complicated 3D software applications that are not especially designed for the purpose of previs which makes it difficult for the artists and non-technical users to create previs content.
OBJECTIVES: The aim is to empower artists to express and visualize their ideas and creative capabilities in an optimal way.
METHODS: We suggest using natural user interfaces (NUIs) and discuss suitable interactions for different previs tasks. We developed and evaluated a series of individual prototypes as well as a central overarching prototype following our NUI concepts.
RESULTS: The results show that our NUI-based interaction methods were perceived highly positive and experts found it valuable for their work.
CONCLUSION: With only a brief familiarization phase, NUIs can provide a convenient substitute to traditional design tools that require long training sessions.

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**Keywords:** Previsualization, Natural User Interface, Virtual Reality, Animation, Film, Theatre, Visual Effects

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## 1. Introduction

Previs is known as an indispensable and critical process that could increase the production value of a project [1, 2]. It has been adopted for decades in disciplines such as film, product design, and architecture and is growing in popularity because of technological improvements [3]. Most of today's previs task is handled digitally and despite all the potential advantages for production, it is time consuming and requires trained personnel. The tools used for the purpose of previs are frequently complex 3D tools such as Maya[1], Auto CAD[2], Blender[3] and recently game engines such as Unity[4] and Unreal[5] [4]. The use of such tools is time consuming and requires proficient technical experts excluding the non-technical, imaginative users namely artists, designers, and directors from the previs process. This requires various design iterations and constant communication between the technical experts and the creative staff [5]. This could be problematic due to the fact that most creatives are used to be in control of the design process by drawing, writing, or sketching.

Current 3D software programs used by experts for previs purposes provide an extensive set of features and functionalities, many of which are for highly specific use cases that are not really essential for previs. The collection of all these features within a 2D interface makes these tools complex and could frustrate users that intend to use them only for the purpose previs. Furthermore, several specific functions required for previs may not be supported by standard tools and a great deal of extra effort might be needed to find workarounds.

In order to design a previs software that particularly provides the necessary functions for the previs process,

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*Authors are listed alphabetically
[1] https://www.autodesk.com/products/maya
[2] https://www.autodesk.com/products/autocad
[3] https://www.blender.org/
[4] https://unity3d.com/
[5] https://www.unrealengine.com

investigating the tasks that are specifically carried out in digital previs is crucial. In a survey study amongst practitioners [5], we identified and analyzed a persistent collection of previs tasks and the main functionalities that a reliable previs software should support. Previs applications user base also comprises of a broad range of users in different roles who have different workflows and stories: what is wanted for animation is not necessarily what is wanted for theatre [5].

We believe that users should have the possibility to choose their interaction method to use for different previs tasks and select the one best fitted for their creative needs. This way, the artist can express their creativity and be more focused on their previs task without having to face an inflexible interface that does not specifically consider the needs of an artist. To involve non-technical people more into the previs cycle and empower artists to use a digital previs software, we propose using natural user interfaces (NUIs) for previs tasks to empower users in how they can express themselves in an optimal way depending on the task they want to perform in the previs cycle. NUIs have the potential to minimize the effort needed to translate user's actions and provide increased direct natural expressiveness [6].

In the pages that follow, we examine the potential NUIs to support intuitive interfaces for the purpose of previs. Moreover, we provide a comprehensive analysis of digital previs in practice within the application domains of film, animation and theatre. We then propose recommendations to support such tasks with NUIs and create the natural interaction concept by mapping both users' needs and the previs task characteristics to meaningful and natural interaction techniques. In order to examine our interaction concept, we developed and evaluated a series of individual prototypes which we refer to as 'vertical prototypes', as well as a central overarching prototype which we call the 'horizontal prototype'. The prototypes were designed within the framework of the EU-project "first.stage". First.stage is a previsualization project that researches and designs natural user interfaces and tools for previs in order to make it accessible to non-technical users.

Using these prototypes, we aim to find how to integrate NUIs in the previs process of the creative personnel and how NUIs affect the production process in comparison to common 3D software.

The main contribution of this work is to provide a natural user interface concept that is built around a set of interaction methods which are chosen specifically to the nature of the diverse previs tasks. The concept is based on the requirements of the application areas and incorporates a detailed review of the literature.

## 2. Related Work

### 2.1. Natural User Interfaces

The term natural user interfaces refers to a broad collection of interactive technologies that offers rich ways for interacting with the digital world using existing human capabilities for communication and human capacity to manipulate the physical world [7]. Although it still lacks a common definition since the understanding of this term is subjective to the constant development of the technology [8]. However, in the literature, there are recurring aspects of NUIs that appear to establish a shared view on natural user interfaces. NUIs utilize the capabilities of human beings to express themselves with their body movement, voice and gestures, thus described as intuitive [9] [10]. The term NUI encapsulates any technology that allows users to interact in a more natural or humanistic way with computer systems [11].

Early research on NUIs roots back to the 1980s, where they introduced the "Put that There" system, an interface controlled by voice and gesture [12]. In the beginning, the term NUI was mainly used for (multi-)touch gestural interaction. Eventually, researchers and designers worked with different modalities such as speech, gesture3D, manipulation, and virtual and augmented reality (AR), expanding the terminology. Some popular consumer products that have been mentioned a lot with reference to natural user interfaces are the Wii[6] and the Kinect for Microsoft Xbox[7], both vision-based devices that indirectly or directly support full-body movements for system input [13]. The premise of NUIs is to let computers understand the innate human means of interaction and not induce humans to train to the language of computers [14]. They aim to provide a smooth user experience where the technology is almost invisible [15] and make users learn the interactions as quickly as possible. Liu describes the characteristics of NUIs as being user-centred, multi-channel, inexact, high bandwidth, voice-based, image based, and behaviour based [16].

A very similar concept to natural user interfaces is Reality-based Interaction (RBI) by Jacob et al. [17]. They proposed RBI as a unifying concept that ties together a large subset of the evolving human-computer interaction techniques. The RBI framework allows to discuss aspects of the multitude of current user interfaces "beyond the desktop" in a structured way by identifying and analyzing aspects of reality and computational power that are useful for interaction. The authors argue that the new interaction styles make use of users' pre-existing knowledge of the everyday,

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[6] http://wii.com/

[7] https://www.xbox.com

non-digital world. Their assumption is that "basing interaction on pre-existing real world knowledge and skills may reduce the mental effort required to operate a system because users already possess the skills needed" [17].

Although you can see the use of humans' experiences from the physical world to a stronger degree in most recent user interfaces, computer tools and applications would not be as powerful, if systems were based purely on reality-based themes. The "computational powers" of computers such as Expressive Power, Efficiency, Versatility, Ergonomics, Accessibility and Practicality are undoubtedly advantageous [17]. That makes it challenging for the current user interface design to combine and find a balance between the computational power and reality. Jacob et al. propose that "the goal is to give up reality only explicitly and only in return for other desired qualities" [17].

### 2.2. NUIs for Performance Animation and Modelling

The common animation systems are too complex for the high demand in animated content today. To improve the accessibility and efficiency of such systems, researchers suggest an HCI perspective on computer animation [18]. An interaction perspective on computer animation can help to construct a design space of user interfaces for spatiotemporal media. Many researchers have investigated the use of NUIs for performance animation and modelling. Lee et al. presented the implementations of full-body input as a natural interface to character animation by extracting user silhouettes from camera images [19]. Chai & Hodgins [20] introduced an approach for performance animation based on optical marker tracking.

An affordable approach to performance animation is presented by Walther-Franks et al. [21] with the "Animation Loop Station", allowing users to create character animations layer by layer by capturing users' movements with Kinect sensors. In their proposed system, a speech interface is included so that users can fluently work on their animation without the need for a graphical interface. In another work by Walther-Franks et al. [22], authors introduce the Dragimation technique which allows users to control timing in performance-based animation on 2D touch interfaces where they can directly interact on the characters instead of a timeline. The authors found that Dragimation performs better with regard to learnability, ease of use, mental load, and overall preference compared to timeline scrubbing and a sketch-based approach. This system was inspired by the work of Moscovich et al. who introduced a rigid body deformation algorithm for multi-touch character animation [23].

An interesting approach to augment the own character animations with rich secondary animations is the combination of performance animation with physics simulation. However, the combination of both technologies is not trivial. An approach is presented in a natural user interface that combines motion capture using the Kinect sensor and physics simulation for character animation by Liu et al [24]. They introduce a framework that combines both technologies to prevent conflicting inputs from users' movements and physics engine. Their approach and framework has been extended by Shum and Ho (2012) who present a more flexible solution to the problem of combining physical and motion capture information [25].

Another area of complex 3D interaction is the field of digital modelling and sculpting. There is a strong need for tools that allow for natural expression in digital content creation, especially for previs, as many productions start with zero assets. This means, that assets, objects, and props have to be created from scratch most of the times. For instance, Herrlich et al. investigated interface metaphors for 3D modelling and virtual sculpting [26]. The first implementation of virtual sculpting was presented by Galyean and Hughes (1991) [27]. They used a custom force-feedback system that would translate the absolute positions of the input device into a 3D mesh. The approach was further extended by Chen and Sun (2002) and Galoppo et al.

by implementing virtual sculpting using a stylus device and a polygonal mesh instead of a voxel approach [28] [29]. Wesson and Wilkinson implement a more natural approach by using a Kinect sensor for deformation of a virtual mesh, while also integrating speech commands for a more fluent user experience [30]. Natural animation can also be approached by using Virtual Reality (VR) technology. For instance, Vogel et al. designed a VR system for animation where users work with a puppeteering metaphor for character animation [31]. They evaluated their tools with animation experts and found that it improves the speed of the workflow and fast idea implementation.

## 3. Previs Task Analysis

Typical previs tasks include scene layout, camera work, animation, and special effects [32]. To better develop a software that is specifically suitable for the purpose of previs and covering the fundamental functions needed for this process, we examined the tasks that are specifically operated in digital previs [5]. In order to do this, we first collected user requirements by interviewing experts from the domains of film ($n$=5), animation ($n$=3) and theater ($n$=8), using scenarios, personas, workflow generation, prioritization, and categorization, and extracted the everyday tasks and work-flows carried out in digital previs. After we gathered the requirements from the experts in the interviews, we arranged a workshop with the experts of the domain. We used the MoSCoW Analysis [33] to obtain the functional requirements which were not identified during the interview. We outlined a set consisting of the requirements which were collected within the interviews and the workshop. We produced index cards and employed color coding to mark the origin of every collected requirement for the reasons of clarity and organization.

Overall, we identified a set of 118 requirements. Based on the collected information, we identified 20 functionalities as core features that an efficient previs software should support. Although, one can not directly translate all these core features into previs tasks, since a few of these are general functions such as the ability to support multi-user and visual effects (VFX). Hence, we reduce the number of core functionalities to those that are essential for previs and can be applied to all application areas.

Result of this reduction presented the 9 core previs tasks: Sketching (Modelling), Project Structure, Shot Management, Import/Export, Camera Control, Assets and Layout, Animation, Lighting and Posing, and Visual Effects.

For further information regarding this procedure, please refer to Muender et. al [5].

## 4. Natural Interaction Concept

In this section, we present our Natural Interaction concept that builds the foundation for the implementation of our vertical and horizontal prototypes. We designed our core interaction techniques based on the core previs tasks that we identified, each one considering the natural aspects of the task and their context of use.

In Figure 1 we provide a graphical overview of our overall interaction approach based on the previs tasks mentioned earlier. We open up a 2D/3D space where we fit the task affordances to 2D and 3D interaction techniques and select the hardware correspondingly. Our ideas and concept development are driven by the variety of feedback on naturalness during the requirements elicitation that has been performed and our first-hand experiences with users that tested our prototypes. We further present additional interaction methods that complement our concept generation.

### 4.1. Interaction Techniques

It is crucial for a previs software to include the core functionalities of a previs task, “those functionalities of the product without which, the product is not useful for the users” [33]. Based on the requirement analysis, we suggest direct manipulation via touch on 2D interfaces, 3D direct manipulation, object-oriented user interfaces, spatially-aware displays, tangible interaction, AR, full body and embodied interaction, hand-based interaction, and speech as interaction techniques that would fit for a NUI based previs software. Here we discuss these techniques in more detail and show how they fit to the respective tasks.

**Direct Manipulation via Touch.** 2D interfaces that offer direct manipulation are intuitive and provide high accuracy. As with the high penetration of iOS and Android touch devices, these interfaces prove to be very intuitive for a large user base and naturally capture user intent on 2D screens via direct manipulation metaphors and 2D gestures. For tasks such as import/export, shot management, and project structure, a 2D touch interface is suitable and natural as it benefits from current mental model of users which they employ for 2D content manipulation.

**3D Direct Manipulation.** Direct manipulation is well suited for the interaction with 3D content as it is presented in a model-world interface which reflects to the real world. Having real-world metaphors for objects and actions can make it easier for a user to learn and use an interface. On top of that, rapid, incremental feedback allows a user to make fewer errors and complete tasks in less time, as they can see the results of an action before completing it. The user of a well-designed model-world interface can wilfully suspend belief that the objects depicted are artifacts of some program and can thereby directly engage with the world of the objects. This is the essence of the “first-person feeling” of direct engagement. This interaction technique is natural and well suited for all tasks that require object manipulation in 3D space using stereoscopic view, such as modelling, assets and layout, camera control and motion, animation and posing, and lighting. In practise, there can be situations when it is not possible for users to interact with certain objects directly. This is especially relevant for groups of objects which can be spread across the scene, objects that are far away from the user or are too small for direct interaction, and objects that are completely or partially occluded by other objects. In order to overcome such issues, we implement an addition to the direct manipulation concept: *surrogate objects*.

A surrogate object is a reification of one or more domain objects that the user intends to interact with [34]. Other than the object within the scene, a surrogate object can always be presented in the field of view of the user and within the interaction space, reachable by touch or VR controllers. The idea of surrogate objects shows that by extending the direct manipulation concept in such way, the limitations of direct manipulation can be overcome [34].

**Object-oriented User Interfaces .** State-of-the-art 3D tools often come with overloaded Windows, Icons, Menus and Pointer (WIMP) interfaces. Such interfaces are not suitable for typical users of previs software.

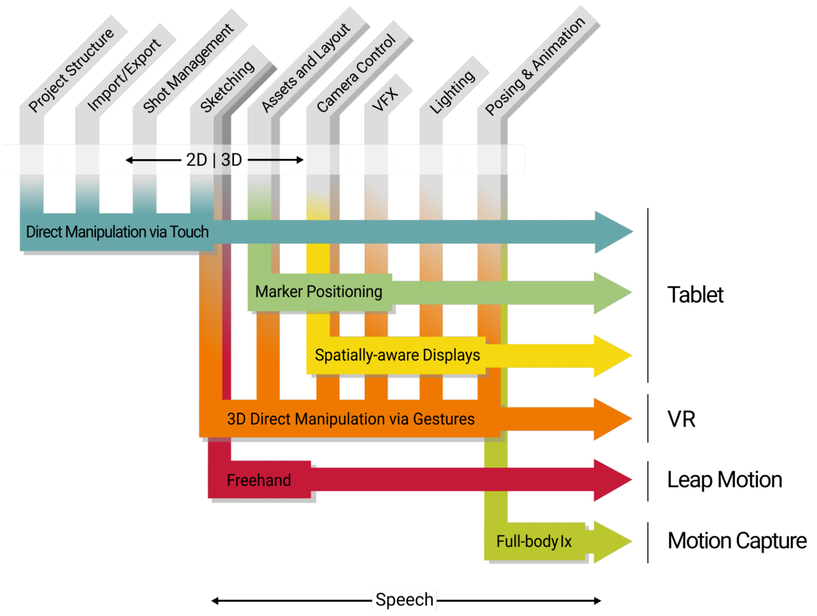

**Figure 1.** From previs tasks over interaction techniques to technologies

Previs tasks require specialized training and are often time consuming. As different input and output devices often require an entirely different interface, it may be required for the user to learn three different interface variants. These arguments contradict the requirement that the software is suitable for non-technical persons and can be learned quickly. A common practice in standard WIMP interfaces is to use buttons for all possible actions. If an object is selected, the actions that are not supported for this object are deactivated (in grey colour) but still presented to the user. This leads to cluttered interfaces, which can easily overwhelm users. In addition, buttons are commonly spread across the interface leading to a loss of association with the intended object that user wants to manipulate. Based on these observations, we implement object-oriented user interfaces (OOUI). These are types of user interfaces in which the user interacts explicitly with objects that represent entities in the domain of the application. They can be seen as the counter approach for function-oriented interfaces that are normally used in 3D applications. We propose a system in which objects have a dedicated interface only displaying the actions available for this specific object.

The interface is positioned relative to the object it is corresponding to, rather than fixed button positions in a static WIMP interface. Object oriented user interfaces are proven more user friendly compared to other interface paradigms and provide several advantages in terms of usability [35] . In addition, the relation to the object which will be affected by an action is better understandable. Users can also classify objects based on how they are presented and behave. In the context of what users are trying to do, all the user interface objects fit together into a coherent overall representation. OOUI can reduce the learning curve for new users as only relevant actions and options are displayed. It is possible to display an object related interface with a similar visual representation on different output devices such as tablet or VR. This can be rendered as part of the application and does not need a WIMP GUI. Furthermore, the interaction with such an interface can be designed to be similar with different input devices.

**Spatially-aware Displays .** These are displays that have information about their position and orientation in the room either by relative differences (gyroscope and compass data) or access to absolute position and rotation data using tracking devices. Using such displays, which are mainly tablet devices, one can create a direct access to a virtual scene by putting the control over the virtual camera directly in the hands of the users. They can then move this device across the room in order to change position and orientation of the virtual camera. This approach can be complemented with basic 2D gestures in order to extend the interaction space. Previs tasks that make the most out of this interaction technique are camera work and camera motion. Using spatially-aware displays, users can position cameras in a virtual scene and navigate in 3D while at the same time having the resulting shot visible through the display at all times for high efficiency. Thus, it is very natural to frame a shot in a virtual scene using real-world references by walking in a real room and orienting the device as needed.

**Marker Positioning (Mobile AR) .** With augmented reality, real images and projections of real scenes on screens such as mobile and tablet devices can be augmented with digital information. This bridges the real world with the virtual world, allowing for an immersive experience. Marker-based AR could be used for layout related tasks that require multiple users to work together in a virtual scene. The markers connect physical objects with digital media and enable interaction with the data via interaction with the objects. These interfaces are intuitive and easy to learn since users can directly observe the actions on the digital data which have direct mapping to their actions.

**Full-body Interaction and Embodiment .** Embodied interaction relies on the integration of interaction between humans and computers into the material and social environment. The recording of motion capture data allows for full body interaction and embodied performance animation through inertial sensors that can be worn in the form of a suit. This makes it easy and natural to record character animations since users can benefit from using their own body as input, directly transferring their motion data to virtual characters. In several previs cases and especially for character animation, this can make complex and expensive keyframe animation techniques superfluous. Such interaction techniques are natural as they do not rely on a translation between user intent and action. This approach has a low learning curve regarding the animation and almost no graphical interface is needed.

**Hand-based Interaction .** With hand-based interaction users can perform manipulations to digital objects using their own hands without using digital tools by tracking the hand and finger motion and applying the data for the manipulation of the virtual object. We employ hand-based interaction for rapid prototyping and modelling of 3D content and objects in the modelling and layout tasks. Here we focus on the workflow of modelling and layout where we support users in “getting their ideas quickly out of their head” by removing a graphical user interface (noUI), allowing them to concentrate on implementing their vision in either a 3D model or scene layout.

**Speech .** Speech commands are used as a supportive layer that can be integrated as a secondary interaction to complement a primary interaction. For instance, in layout, users can filter and select the asset library using speech commands. Generic commands include deletion, menu interaction, and basic manipulation tasks that are expressive by speech but hard to express through manual interaction, such as flipping an object, switching to a specific camera view, or switching between different views and zoom factors.

## 4.2. Interaction Principles

Having introduced our core interaction techniques, we now present interaction principles that enhance the interaction by implementing the notion of “how” the interaction in our tools should be. We organize these into general principles that should apply to all prototypes and specific principles that will only apply to certain, focused prototypes presented in this paper.

**General Interaction Principles.**

***Task Context*** Depending on what users are doing, it is important to find natural interaction for each specific scenario. An interaction is natural depending on its context of use. Organizing a digital project such as files on Windows Explorer or Finder is more natural on a 2D interface as it stems from the digital domain of graphical user interfaces that most computer users are familiar with. As Jakob Nielson suggests, It may be difficult to control a 3D space with the interaction techniques that are currently in common use for 2D manipulation [8]. It would be very different when trying to organize, copying, duplicating or moving files in VR using other than 2D metaphors. An example for this is the “minority report vision” that has often been used to exemplify the use of gesture and 3D interfaces for desktop tasks. Studies have shown that these kinds of tasks are slower to perform in 3D and are cognitively more complex to achieve than with 2D GUIs [36]. We pick up on this notion and motivate a natural use depending on the context. For instance, arranging 3D objects in space as well as exploring spaces, getting sense of scale, and picking shots for cameras are most natural done in VR. On the other hand, project organization is best done on 2D interfaces. Transforming and working with digital content for organization is, as previously stated, most natural using GUIs. Another example is motion capture. Animating humanoid characters can be done in different ways. It can be done by key-framing a 3D character or by drawing frame by frame. Both has advantages and disadvantages, but looking for a natural way of interaction, using the own body is the only way of having a direct 1-to-1 relationship between user intend and desired outcome. Using the motion suit, users can work with their own body without having to understand complex key-framing or drawing techniques, making it more natural to create animation content and providing a low learning curve.

***Easy to Use*** In order to make a previs software accessible to users with little technical knowledge,

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[8] https://www.nngroup.com/articles/2d-is-better-than-3d/

special aspects should be considered to make the software easy to use. Interactions should not be designed to be as fast as possible but plausible and intuitive to the user. The system should provide feedback for the actions and help users to follow the intent. This is especially important when an action involves multiple sequential interactions. In order to not overwhelm the user with options, only a minimal amount of possible options should be shown which can be achieved by using interaction scaffolding and nested interactions.

***Consistency*** The interactions should be consistent within the application. Ideally, users only have to learn a minimal set of interactions. It should be avoided to use different interaction schemes for the same tasks in a different context. For example, positioning an object by "grab and place" should work the same way in layout mode and in animation mode. The interaction should be as consistent as possible across different input devices. This will help the user to seamlessly switch between devices and not have to learn or remember special interactions for this input method. In some cases, this will not be possible as the different input devices provide different input modalities and degrees of freedom. But a primary interaction (left click, tap or trigger button) should perform the same action on all devices. Furthermore, the interaction should be consistent with other applications from the field, so that the user who has learned to interact with another tool does not get confused by a completely different interaction scheme. This means the application should not break with interaction standards from the field, e.g. support drag and drop.

***Feedback*** The system should provide feedback for every action performed by the user. Visual feedback should be provided on all hardware platforms. If the object the user is interacting with is currently not in the field of view, and visual feedback is not visible, assisting indicators at the edges should indicate where the interaction is happening. Haptic feedback should be utilized when interacting in virtual reality using the vibration functions of the controllers. Audio feedback is also helpful in certain situations especially when something is happening outside the field of view.

***Nested Interaction*** Rather than putting all actions onto different buttons, the system should utilize nested interactions which chains the selection of an action, parameter finding and performing the action into a series of small lightweight interactions. Sequenced actions should be designed so that experienced users can perform them very quickly and do not perceive them as impairing. The buttons in a sequenced action should be positioned in close distance, following the direction of motion.

### Specific Interaction Principles.

***Reality-based*** The interaction in 3D should orient towards the interaction with objects in the real world. As the interaction in 3D space is still novel and is not a known for many users, it should utilize their everyday knowledge [17]. This applies to positioning and rotating objects: Small objects like a bottle can be grabbed, rotated and placed with one hand. Bigger objects like a table or houses on the other hand have to be pushed and rotated using two hands. Falling objects stop when in contact with the ground or other objects. This behaviour should be supported as it is perceived as natural to the user. Another aspect that should be reality-based is the interaction with buttons, knobs and slider elements from the object-oriented interface. A clear 3D representation of the intractable object should be provided comparable to real life light switches, volume knobs and radio controls. The visual representation should present feedback of the current state of the control.

***Playful and Fun*** Playing is intrinsically motivated and autotelic[37]. When users are provided with a user interface that supports playful expression, they can explore, be creative, try different solutions, and find joy and amusement even in productive contexts. This increases long-term motivation and lowers the frustration barrier [38] which is achieved by more pleasurable interaction rather than optimizing for speed and being goal oriented. Playful interaction invites users to discover features rather than frustrating them with an overloaded interface. Therefore, it is suitable to support novice users and users with little technical knowledge.

***Creativity Support*** In order to support the creative process of the user creating a virtual set, animation or camera shot, the interaction with the software can be designed accordingly. The system should invite users to interact with objects in a natural manner rather than telling them what to do. This can be achieved using affordances [39]. Designing subtle affordances invites the user to discover through exploration. Presenting users with different viewpoints on a scene or with the sequence of their actions can support them in their iterative and evaluative process.

***Rapidness, Accuracy and Precision*** The interaction used should be rapid, avoiding time-based interaction and large motions. Time based interaction disrupts the workflow, especially for experienced users. For instance, "look and hold" or "point and hold" interactions could easily frustrate users. In contrast to the general schema of rapid interaction, it should be possible to improve precision with additional effort. For instance, scaling up in order to work on detailed structures.

***Multi-User*** Handing over a project to others is complicated and requires a lot of management.

However, working together in the same physical context where a common understanding is shared in the physical space through observation and communication of intentions and tasks is natural. This natural interaction could be achieved by providing input to the system that is not bound to one device. For instance, in a multi-user scenario, different devices can be used in a shared context in order to achieve a common goal.

## 5. Concept Implementation and Evaluation

In this section, we present research prototypes developed and evaluated during the project. These prototypes were built to evaluate individual interaction concepts and principals.

### 5.1. Virtual Reality for Previsualization

In order to support the non-technical professionals to work with 3D content and allow for more expressive interaction, we suggest using virtual reality for previs. In contrast to traditional 2D interfaces, VR offers immersion, illusion of *embodiment*, and illusion of physical interaction for a more natural interaction (*reality-based*). We developed two prototypes in VR and conducted a user study with non-technical domain experts to investigate how they experience VR use for the purpose of previs.

Our first prototype was a tool that focused on camera work for taking shots. The second one was meant for exploring stage designs and experimenting with stage equipment in a theater. These two scenarios were chosen as they interest professionals from all relevant domains such as film, animation, and theater by covering important aspects of previs such as exploring a virtual scene, layout, and shot finding.

Our results showed that the participants were predominantly positive towards VR for previs and rated it as a useful technology. All users could perform typical 3D previs tasks even after a very short learning time. Using the prototypes also convinced participants of the practical use of VR for previs and removed certain doubts [3].

### 5.2. Tangible Scene Design

Using physical objects and models to visualize scenes is a common practice among professionals. Technologies such as VR have the ability to provide immersive experiences with an accurate dept and scale perception. Nonetheless, such technologies usually lack the tangibility aspect. In this work, we combined the VR technology with tangibles to utilize the immersive experience with the intuitive controls of miniature models, following the concepts of *3D direct manipulation* and *full-body interaction and embodiment*. We aimed at providing an interface where the non-technical users can intuitively create previs content (*creativity support*) using natural forms of interactions to create and delve into the 3D scenes. The prototype was used to evaluate how the tangibles with distinct haptic fidelity can effect the performance, immersion, and intuitive interaction for creating a 3D scene in VR. In a user study ($N = 24$), as well as an interview with eight experts in previs, tangibles with distinct production processes were compared (uniform objects without resemblance to digital object, 3D-printed and Lego-build tangibles similar to the digital object).

**Figure 2.** Camera prototype with yellow virtual camera (right). View finder is attached to left controller (left).

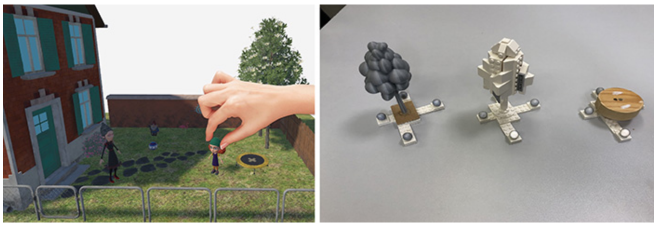

**Figure 3.** Left: The tangible scene design concept. Right: The 3D-printed tangibles with the highest fidelity

Our results showed that Lego was preferred as it provided *fast* assembly and adequate fidelity. No significant differences were observed in terms of haptics, grasping precision and the perceived performance. Professionals pointed out that digitally planning and adopting scenes is major benefit that could save a lot of time (*rapidness*) [40].

### 5.3. Collaborative Scene Design across Virtual Reality and Tablet Devices

Through the use of head-mounted displays (HMD's) users can perceive 3D content with believable depth sensation, being able to walk around and look around virtual objects. Further, room-scale tracking allows for natural movement (in a restricted area) and object manipulation in a natural and direct way.

VR controllers are used as extensions of the own body, employing easy and intuitive ways interaction by grabbing, holding, rotating and placing objects in VR. However, there are aspects in VR that limits the usefulness of the approach. Specifically in collaborative design, where several users work together in achieving a common design task, VR may restrict the collaboration. For instance, in VR users are often isolated and are not at the same location with other users. To share a common working space and work together, they are commonly connected with other users in VR. This interaction is usually done remotely rather than a shared office space as most places do not host more than one or two VR sets. This may have effects on the collaboration and work distribution between users.

In order to address these concerns, we aimed at combining the advantages of VR and tablet interaction to build a system where users can collaborate using both devices in a shared environment utilizing *direct manipulation via touch* and *3D direct manipulation*. We built a prototype where two users can work together simultaneously (*multi-user*) using VR and a tablet device in an attempt to improve work efficiency and *rapidness* (see fig 4). In a lab-study with 18 participants (9 teams) we investigated the impact of the device-dependent interactions on user behavior. Results showed that there are device-dependent differences in the interaction style that also influence user behavior. For instance, tablets were primarily used for overview and rough positioning, while VR was mainly used for smaller object manipulation. However, we did not observe a device-dependent “lead” role as the tasks were mainly distributed and worked on in parallel [41].

**Figure 4.** Witch house scene from the tale Hansel and Gretel created during the study

## 5.4. Tablet Camera Prototype

Following the concept of *spatially aware displays*, the tablet camera prototype provides the view through a virtual camera into a scene. The camera can be controlled by physically moving and turning the tablet. In addition, the camera can be moved forward and backward in view-direction by a slider. The camera motion can be recorded and replayed. This prototype is intended to give a more natural feeling (*reality-based*) while controlling virtual cameras by giving the user the tablet a physical device as a viewfinder for the camera. The prototype was evaluated by three experts in the context of film productions. The participants got an introduction to the tool and afterwards got a task to record a defined camera motion. In the end they were free to continue using the tool on their own. Semi-structured interviews were conducted with the participants to find out about their experience using the tool.

The results showed that the tool was perceived highly positive by the experts and they found it intuitive as they are used to having something physical in their hands as a viewfinder. All participants were able to record the defined camera motion in under five minutes.

**Figure 5.** The tablet camera prototype

## 5.5. Embodied Interaction for Animation Capture

Another important part of previs is character animation. Only by providing believable and interesting animations, previs becomes a convincing tool for production planning. However, the creation of character animation is a task for expert animators using complex tools that requires years of experience. Motion capturing could be a possible solution for such problems. However, there are still several issues with motion capture. One of the biggest is that individuals who work alone have problems with animating a scene completely without context. When wanting to create a scene with multiple people interacting with each other, different animations from each character has to be recorded with the other movements in mind so that the complete scene makes sense after editing. In order to overcome this issue, we developed a VR user interface for capturing embodied animations. *Embodied interactions* resemble bodily experiences that every human is familiar with (*easy to use*, *reality-beased*). In contrast to traditional interfaces for motion capture, this system enables users to record animations from the perspective of their own body, to slip in any other body (human or not) and perform animations from their perspective (see fig 6).

We performed a preliminary user study with 16 participants. Most users quickly became familiar with the VR user interface and interaction styles. We observed that even older participants could sufficiently work in VR after having a short familiarization phase. Nonetheless, we observed the need for another interface when it comes to integrating the tools in a larger working context.

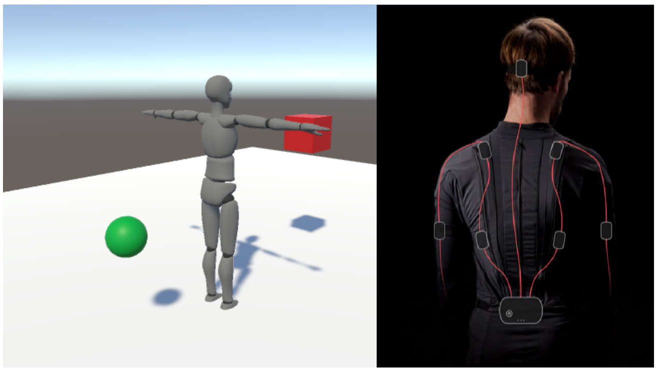

**Figure 6.** Users had to perform two basic and two advanced tasks using a motion capture suit. Basic tasks included interaction with the two objects, a green sphere and a red box.

## 5.6. Anticipation Cues for Motion Capture

To further develop the *embodied interaction* for animation capture, we integrated anticipation cues in the form of target indicators, progress bars, and audio feedback to help the user to record animations in sync with previously recorded animations or other animations in the scene. To design a prototype integrated with the anticipation cues, we interviewed three experts from the animation domain. These cues offer multi-sensory indicators for where and when to start the next animation. In a first step, the anticipation cues can be set by the user at the desired time and location. When going into the record mode, the cues are displayed in the field of view of the user, at the target location and are audible as sounds with increasing frequency as well as through the vibration of the controller.

The prototype was evaluated with 20 students to identify differences between multi-sensory anticipation cues and only visual cues. The results showed a clear preference for multi-sensory anticipation cues. Participants stated that they would not have been able to record the more complex animations without the cues.

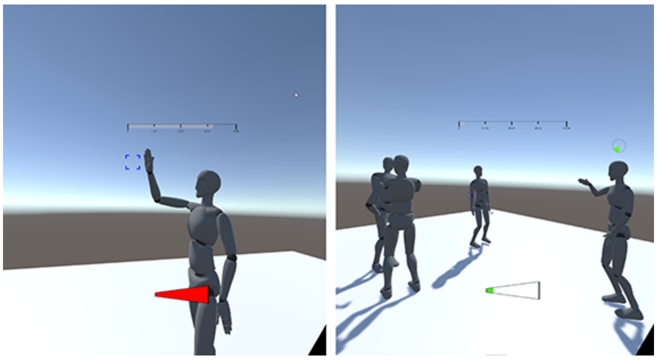

**Figure 7.** Anticipation cues: When recording an animation, the cues are displayed in the field of view of the user at the target location.

## 5.7. Playful Shooter for Fast and Easy Scene Design

Generating self-made content, e.g. for video games, allows players to creatively extend their gaming experience with additional maps or mods. Besides the player enjoyment of the additional content, production studios can benefit from user generated content since long-term motivation and playability is supported, at the same time production costs for studios are minimal. For this, games that support user content are often accompanied with tools for map or mod making like Valve's Hammer Editor [9]. However, these world or map builders can be cumbersome to use because of complex user interfaces with a high learning curve and limited UX.

In order to overcome this, we introduce a world builder game where the process of creating a 3D scene is play itself. Users of are able to navigate directly in the 3D scene, placing objects in a *playful* manner by shooting them in the scene for placement and manipulation. We implemented four weapons: A gun for physics enabled placement, a laser gun for more precise positioning and manipulation, a sniper rifle for far distance interaction, and a hand grenade for spawning multiple objects at the same time using an explosion, all allowing for playful interaction with the 3D content. We assumed that users would find the design of 3D scenes *easier* and more *fun*, feel more *creative*, have less difficulty positioning objects in 3D, and have a lower learning curve compared to standard editors.

We conducted an experiment with 17 participants where we compared our game to a simplified version of

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[9] https://developer.valvesoftware.com/wiki/Valve_Hammer_Editor

the Unity editor, representing usability and workflow of standard 3D tools like Hammer. We were interested in how users perform both in a free building task and in a replication task where they had to rebuild a 3D scene from a printed template. Results show that users would like to use the game more frequently, found it less complex, would not need technical support and appreciate the learnability and ease of use. Additionally, we found that hedonistic and, interestingly, also the pragmatic quality of the game is rated higher than for the editor. This came as a surprise since the editor is highly task oriented and pragmatic in its design, functionality, and user experience [42].

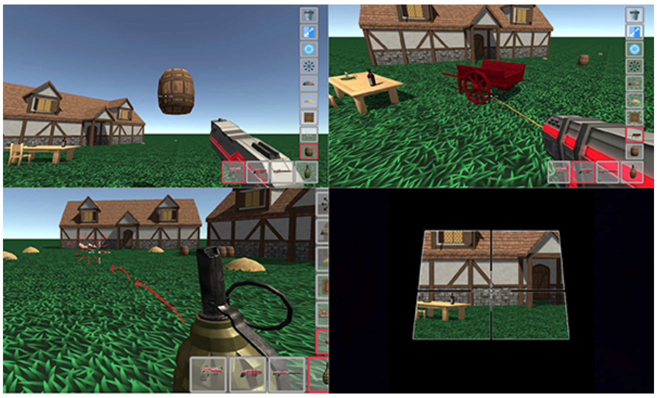

**Figure 8.** Overview of the implemented guns (clockwise): pistol, laser, sniper, grenade.

## 5.8. Rapid No-UI Modeling in VR

Creating 3D content, especially the aspect of modeling in 3D can be a challenging task for novice users. Available applications such as Blender or Maya are complex tools that have a high learning curve for beginners. As much as these applications are ideal for their purpose, that is the creation of complex models including shaders, lighting, animation, etc., beginners can feel overwhelmed by the user interface and the manifold options.

To address these problems, we looked into how to make the creation of 3D models and prototypes more natural and approachable for novice users in order to create a pleasurable experience that motivates diving deeper into the world of 3D modeling. Rather than creating detailed and complex models, the focus was on creating 3D models that represent a rough version of models that users have in mind through offering *rapid prototyping* with natural ways of interaction. Therefore we explored the use of *hand-based interaction* in combination with drawing gestures. Different mid-air gestures can be used to create primitive objects, e.g. cubes, spheres, pyramids. These objects can be grabbed through *direct manipulation* and assembled to more complex structures.

The prototype was evaluated by eight participants through structured interviews. The results show that the prototype was successfully used to create a variety of scenes in short time. However, we could also show that gestures that are too similar quite negatively influenced the mental workload and the users experience in general due to higher rates of miss-detection. However, this was mainly due to inaccurate and unstable tracking and the qualitative feedback was promising.

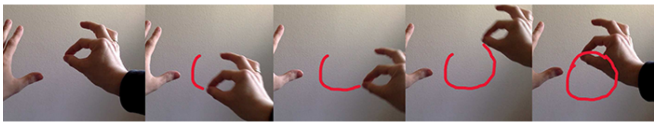

**Figure 9.** Demonstration of drawing a sphere gesture in mid-air using the starting gesture

## 5.9. Playful VR Sandbox for Creativity and Exploration

Sand playing is a nostalgic activity that reminds one about the childhood days where it opened possibilities for observations, creativity and cooperation. Sand play provides different developmental benefits such as proprioceptive sensing, body awareness, space awareness, and social skills. Such pleasant activity is not only limited to children, but many adults also enjoy sand playing and rediscovering the sensations of this activity. Interactive and augmented sandboxes take this experience to a new level by adding another interactive element to it, increasing the interaction and application possibilities. Simultaneously, people can play with the sand and experience projected interactive visual feedback onto it. We developed VRBox which is an interactive sandbox for *playful* and immersive terraforming. Our prototype combines the approach of augmented sandboxes with modern Virtual Reality technology and mid-air gestures. By exploiting *3D direct manipulation* and *embodiement*, this system extends the current approaches by adding a new interaction and visualization layer to interact with the sand and virtual objects. Furthermore, to provide better *creativity support*, users have the possibility to switch between two perspectives, a tabletop mode for the creation phase, and a first person mode by teleporting directly into their own creation which allows for a more immerse experience of the landscape in full-size. To evaluate the VRBox, a qualitative user study was conducted with nine experts from the domains of education, computer graphics, and game design. Our focus was on the user experience, as well as the technical aspects and the possible use cases. Our results indicated highly positive attitudes towards the VRBox which highlights the immersive and creative experience the system offers [43].

**Figure 10.** The landscape can be shaped by interacting with real sand (Right). VRBox from first person perspective (Left).

## 5.10. Grasping Objects in VR

With this prototype, we propose emulating human grip abilities for virtual reality to enable an interaction with virtual objects (*3D Direct Manipulation*) that corresponds better to object manipulation in *reality*. We devised different interaction designs to allow the user to dynamically set the firmness of the grip and thus be able to hold an object firmly and loosely using conventional controllers.

A qualitative pilot study and a quantitative main study have been conducted to evaluate the various interaction modes and to compare it to the current status quo of invariable grip. Pivotal design properties were identified and evaluated in a qualitative pilot study. Many test persons appreciated the suggested interaction's similarity to real object handling. The study participants especially used and valued the variability of their grip in vertical tasks in which the angle between object and hand typically needs to be altered. Two revised interaction designs with variable grip were compared to the status quo of invariable grip in a quantitative study. The users performed placing actions with all interaction modes.

Results showed that the variable grip has the potential to *enhance usability*, improve *realism*, reduce frustration, and better approximate real life behavior depending on tasks, goals, and user preference. The research conducted within the scope of this work contributed valuable insights regarding the manipulation of objects in a VR environment. To be precise, we gained an understanding of how to enrich objects with realistic rotational features in order to enhance overall usability and decrease mental effort as much as possible [44].

## 5.11. Drawing for Asset Selection

This prototype examines the feasibility of novel 3D object retrieval user interfaces in the context of VR and previs. Three prototypes were developed: sketch interaction, virtual keyboard interaction and *speech* interaction. All prototypes shared a common back-end in which assets were stored and associated with tags in a one-to-many configuration. Every retrieval type maps user input to asset tags.

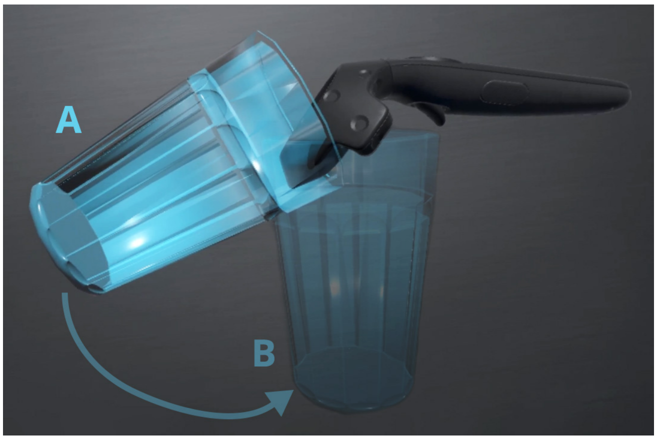

**Figure 11.** Illustration of grip adjustment. The glass is held with firm grip (a). Then, the user loosens the grip by releasing the trigger half-way: The glass swings downwards according to gravity (b). The position of the controller does not change.

In a within-subjects design user study ($n$=15), we examined the usability of each prototype. The results showed that applications of multimodal queries in an asset retrieval environment are promising. Overall, exploring the design space in a more natural direction proved more successful with the Voice interface. Though not in all cases statistically significant, its usability metrics fell within closer reach of the Keyboard interface. Moreover, the Keyboard interface exhibited significantly less task load. A rudimentary object placement system was devised in order to enable testing with complete tasks found in previs workflows.

## 5.12. Natural Language for Scene Interaction

This prototype investigates the possibility to arrange objects in a virtual scene using *speech* in an attempt to provide *fast* and *easy to use* interaction. It focuses on understanding relative spatial relations and ambiguous spatial descriptions, e.g., “next to”. The prototype was developed using the speech API Wit.ai [10] to process the audio and to identify spatial keywords. A model of people common understanding of ambiguous spatial descriptions was developed for to translate the words into executable actions for the system. This model was developed based on a user study where participants had to place object according to ambiguous spatial

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[10] https://wit.ai/

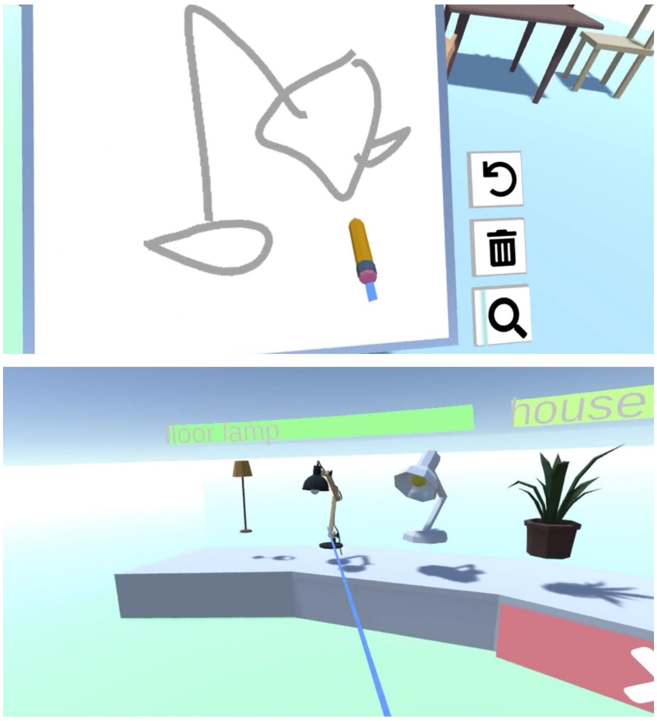

**Figure 12.** Top: The user draws a sketch of the lamp. Bottom: Based on the sketch the user can choose between different 3D objects.

descriptions. The data of this study was used to mathematically define most probable interpretations of the descriptions. The resulting model is used to translate spatial keywords from user input into positional data which can be used to position the objects.

The developed prototype was evaluated in a final user study with ten participants. The results showed that the task-load of the system is relatively low and in the same range as other input modalities such as mouse or touch. The participants could successfully position the objects of a scene according to the tasks they were given. Nevertheless, applying this approach to general scenes is challenging as all objects have to be annotated in order to define their up, front, etc.

## 5.13. Cognitively Enabled Scene Design

This prototype investigates a way to combine the power of modern Artificial Intelligence (AI) with the demands of professional designers to fine-tune their content. It incorporates a novel concept called Cognitively Enabled User Interfaces (CUI). These interfaces provide an innovative and *easy to use* interaction to *support creatives* by taking the user's cognitive world into account. To give an example, instead of adjusting the appearance of a 3D scene by tinkering with various menus and options, a scene designer might simply want to make the environment look more "exciting". A CUI would be capable of understanding this intention and have an underlying AI that knows what parameters need to be changed in order to get the desired outcome. For this purpose, we imitated an AI with the option to adjust a scene between the states of "cozy" and "scary" and integrated this approach into a simple slider interface. As a first evaluation of this approach, we implemented a prototype and conducted a comparative user study ($n$=31). We found that CUIs can offer a significantly higher usability and better user experience than traditional interfaces from the domain of virtual content creation.

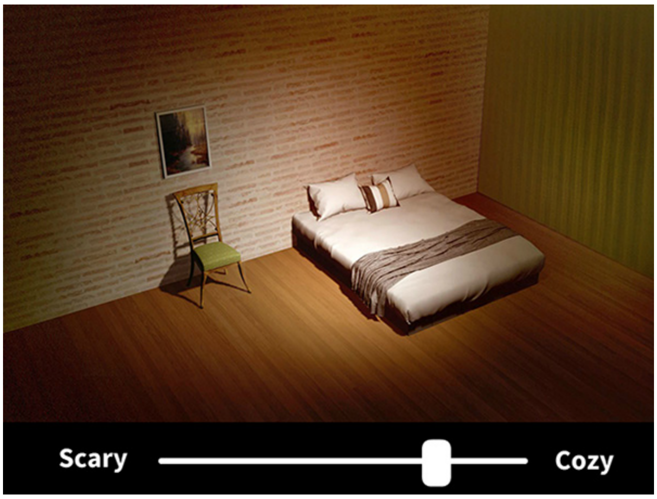

**Figure 13.** Example of a CUI capable of switching the scene between the states "cozy" and "scary"

## 5.14. ScenARy: Augmented Reality Scene Design

This *mobile AR* prototype is an application which can be used to layout scene by augmenting a table or room with the virtual objects of the scene. Virtual objects can be chosen from an asset library or created by the user drawing on the screen. In this *marker-based* prototype, regular playing cards are recognised by the application and virtual objects can be assigned to the cards. This enables the user to arrange the virtual objects by interacting with the tangible cards instead of the screen that displays the scene. The prototype was evaluated with professionals from the theater domain. After an introduction to the application, each participant had to perform a defined task using the app.

The professionals rated the prototype with a high usability score. The interview results demonstrate that this prototype can be a valuable tool for the initial planning phase of stage productions. The participants mentioned that they liked being able to physically layout the scene using the playing cards and did not have to work with complicated on screen controls.

The selection of objects to assign to the cards was perceived as textiteasy. All participants mentioned that is valuable that the tool encourages collaboration and *multiple persons* can use it together as the layout phase is a collaborative process. The professionals also mentioned that they miss some features such as lighting in order to use it for their professional workflow.

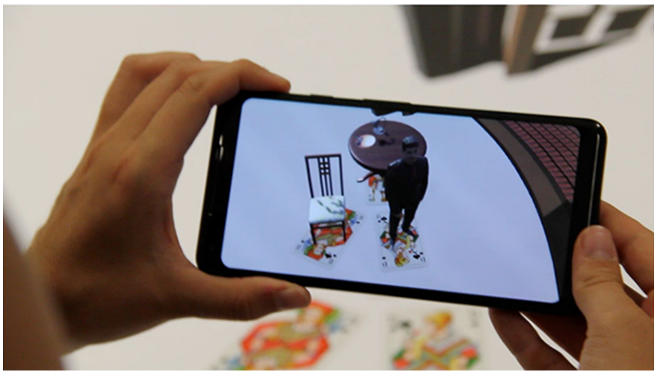

**Figure 14.** The AR scene design prototype running on a smartphone. The cards presents assets.

## 6. Main Prototype

Based on different interaction metaphors which are derived from our NUI Concept, in order to best support the various tasks and diverse users of a previs software, We developed a fully integrated software prototype which provides functionality for all relevant previs tasks defined earlier, e.g. import, sketching/modelling, set layout, lighting, animation, camerawork, motion capture and visual effects. We integrated the individual research prototypes or parts of them into the main prototype based on positive evaluation, technical feasibility and positive review by the application partners, in order to create a direct impact of the research results.

This prototype is a VR based application that provides a common space for performing previs tasks: the user can move freely within the virtual space and *directly manipulate objects in 3D* using the VR hand controllers. It provides the basis for a natural user interface where assets can be grabbed and moved directly, characters can be posed by grabbing and moving parts of their body, paths can be manipulated by grabbing nodes, and special tools can be wielded to perform tasks such as sketching and painting. Additional controls are provided by a tablet-like interface on the back of the user's wrist. *Touch gestures* and *speech* commands are also used to augment the interface. To support realistic work sessions involving many tasks as part of a larger workflow, the basic platform also provides an online asset repository and a shared repository for saving and reloading stage design and scene scripts along with undo and redo and *multi-user online collaboration* between team members. Scenes are organized into projects and each project has its own team. Theatre, animation, film, and visual effects each have different requirements from their respective user stories. This prototype provides a common core of functionality across all disciplines as well as specifically targeted functionalities for individual domains.

**Figure 15.** Possible previs outcome: 3D representation of a theater stage with different lights, props and virtual actors.

### 6.1. Scene Design

A fundamental part of previs is set design and asset layout. One can start with an empty stage and start building on it or simply import a model of an environment. The core functions for dressing the set and laying out assets are searching the repository for assets and placing them within the scene, precisely translate, rotate or scale the asset, selecting multiple objects to be moved or deleted as a group and attaching objects to others as parent/child such as cups on a table or lights on a rig. For the selection of the assets, on top of the primary mode of selecting an asset using the VR controllers, a *speech* interface is developed to retrieve the spoken objects. The object placement is carried out using *direct manipulation*.

In addition to regular static assets like a table, special assets that provide some functionality are contained in the repository and can be placed like any other object. These special objects are lights, visual effects, characters and cameras.

For **lighting**, several different styles of light are included such as a light with visible beams. Once placed in the set, users can adjust the color, brightness, range, and opening angle of the lighting.

**Visual Effects** provide dynamic objects which can represent fire, water, smoke and more. They are based on particle systems which can be activated and looped by the user.

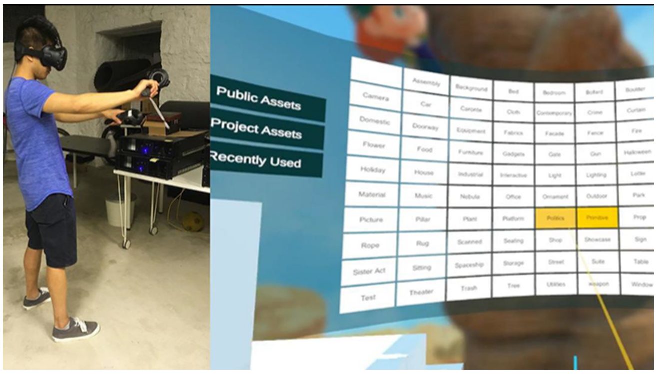

**Figure 16.** To place assets in the scene, the artist can pick an item from the asset library.

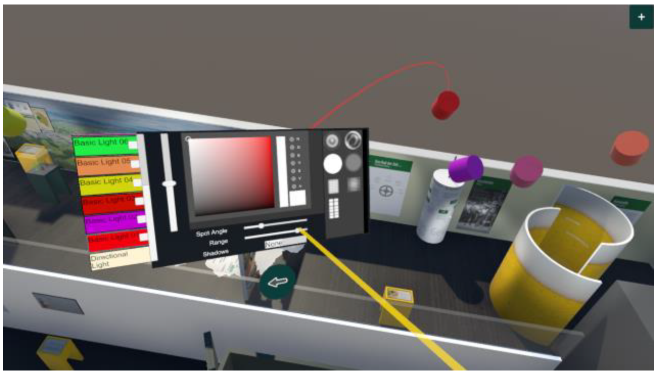

**Figure 17.** Light settings can be adjusted in terms of color, intensity, spot angle and other options.

**Figure 18.** Humanoid puppets which fall into the 'Characters' category.

**Characters** are most typically humanoid puppets but also include vehicles. These assets can be animated in detail and are the foreground of previs and storytelling.

In addition to the assets from the repository, users can create their own objects through **Digital Crafting**. Using the a Sketch Tool, one can create a shape by drawing an outline of it and modify the shape by grabbing and moving faces, edges or vertices of the shape. Once a shape has been created, it can be painted with an airbrush tool.

### 6.2. Animation

A major part of the previs process is animating characters and other objects according to a storyboard. The main prototype provides different animation possibilities for characters and objects to enable this. All animations are recorded on a timeline which holds every activity that is happening in the scene.

**Character Animation.** One of the most common needs in animation is to have a walking animation. In this prototype, one can simply sweep out the desired path for the character to follow from one mark to another. This path can then be modified by grabbing and moving it. Humanoid characters will have automatic behaviors such as walk, run, jump, fall, get up etc. Vehicles will also follow paths automatically applying steering, acceleration and braking as required.

Humanoid characters can also be animated in more detail through **posing**. Each character has handles attached to their body parts, e.g., shoulders, elbows and hands, allowing the puppet to be posed through *direct manipulation* (see figure 19). Poses set keyframes on the timeline and produce a path in space that allows the pose to adjust over time.

One of the easiest and most intuitive form of animating a character is through **Motion Capture**. The prototype supports the use of the Rokoko Smartsuit [11], allowing the user to directly take over the control of a character. Through the *embodiment* of the character the user can perform an animation in a natural way and is not restricted by complex controls(see figure 20).

**Object Animation.** Objects of a scene that do not fall in the category of characters can be animated through **rigid animation**. This provides a simple and intuitive way to animate by acting out the motion. A user can grab and move an object while recording the performed motion. This form of animation also refers to the concept of *embodiment* and *reality-based interaction* as it follows the idea of how kids play out scenes with toys. Once an animation path has been created, the path can be further manipulated by grabbing it at points and moving it as desired.

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[11] https://www.rokoko.com/

**Figure 19.** Puppets can be posed by adjusting the attached handles to their body parts.

**Figure 20.** A performer directly animating the character using the Rokoko Smartsuit.

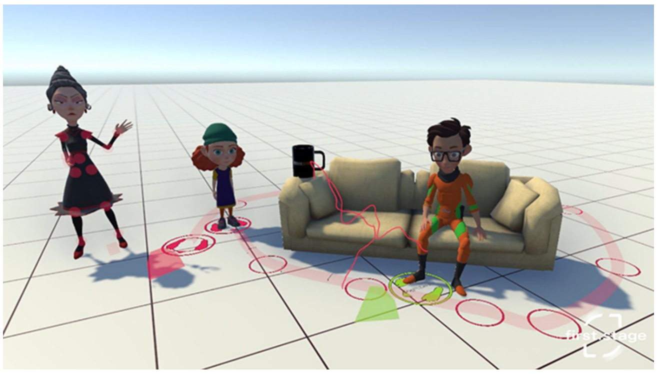

**Figure 21.** Rigid animation of a mug which can be manipulated by grabbing it at points and moving it as desired.

Objects in the scene can also be animated through **physics interaction**. This can be used as a quick and easy way to add natural secondary motions to assets. For instance, a chair might be knocked over as a character walks past it, or a character might kick a ball that then bounces off. For each object physics behaviors can be enabled individually and recorded together with all other forms of animation.

### 6.3. Camerawork

Cameras can be placed on set as an asset or a special tool. The Viewfinder can be used to frame a shot and create a new camera. Camera views can be previewed from the Wrist Pad. By clicking on a camera, the user can enter the "Through the Lens" mode which effectively puts them in the position of a camera operator. Camera motion is animated to move between keyframes. This emulates dolly tracks, cranes and other staples of camerawork.

**Figure 22.** View from the "Through the Len" mode.

### 6.4. Shot Sequencer

One of the key outputs of the main prototype are the shot sequences. The shot sequencer is a desktop tool to assemble recorded shots. After recording a shot, one can select and preview cameras, cut to the chosen camera on the master track, trim/reveal camera clips, and export the final project as video file.

### 6.5. Collaboration

While many tasks only directly involve one practitioner, one of the main purposes of previs is to communicate ideas amongst the team and manage any issues and risks that arise. The prototype supports *multiple users* working on a scene at the same time, each in their own location. Team members can see avatars of each other and speak to one another. When a team member makes an edit to the scene, other team members see the effect of that edit as the objects are synced within the members.

### 6.6. Evaluation of the Main Prototype

We aimed to evaluate the main NUI prototype in terms of applicability for the usage in realistic projects

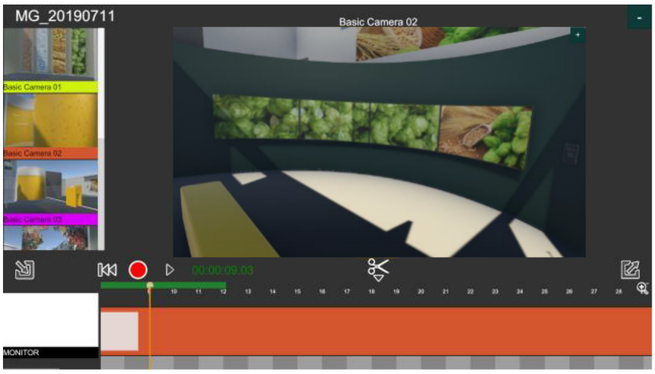

**Figure 23.** After a shot has been recorded, various editing functions can be accessed to produce the final result.

from the creative industries of film, animation and theater. For that purpose, three project scenarios were defined with professionals from the respective creative domains. For each project, the scope and overall objective were defined based on actual finished or ongoing projects that were developed in the experts' companies. For the realization of these projects, the studios used the NUI prototype and conducted the development process autonomously. Once the projects were completed successfully, we evaluated the procedure with the help of semi-structured interviews. Here, we focused on collecting qualitative data to get an insight into the overall user experience of using NUIs for previs. In total, we presented nine questions to the professionals, for instance asking if they were able to achieve their goals using the prototype or how the workflow compared to their traditional previs procedure. Across all examined application domains, we gathered highly positive feedback. The industry experts involved in the interviews emphasized that they would benefit greatly by using a software based on NUIs in their working routines. As the feedback expressed by the experts differed quite substantially dependent on the respective domain, we will now provide a short overview for each project individually. For detailed information regarding the responses of the interviews, please refer to the corresponding case study [6].

**Animation.** For the animation project, the studio in charge assembled a team of five people with varying backgrounds: a director, a production manager, a layout artist, a motion-capture (MoCap) performer and a pipeline supervisor. Their objective was to shoot a trailer for an animated movie by using the NUI prototype. In the interviews conducted after project completion, the experts pointed out that the software gave them new ways to express themselves visually while offering an intuitive and natural form of interaction. On the downside, interviewees stated that they were not familiar with the prototype and thus, needed some time to adjust to the new working environment. In contrast to that however, they also rated the overall learnability to be higher compared to any traditional software alternative available on the market. Being asked about the reasoning for this assessment, the experts stated that it normally takes a vast amount of time to become a professional with any standard 3D content creation software. With the NUI software however, they were able to internalize all necessary functions within hours. In addition to learnability, another advantage of NUIs was found in the option to create animations in real time and review the results on the spot instead of separating these two steps. By using the NUI software, artists and directors could communicate more directly exchanging ideas and feedback right there in the animation phase. In contrast to these benefits, the interviewees also mentioned that wearing the head-mounted display for the duration of the project was rather tiring and exhausted them after a couple of hours. Even for a small-scale project, previs is a lengthy process and thus, the professionals had to take additional breaks due to the cumbersome nature of the hardware.

**Film.** The film team included a lighting artist, a set designer, a stage designer and a camera operator who worked together to create previs for a short commercial video for one of the studio's customers. A large variety of positive feedback was expressed by the experts. First off, in accordance with the animation team, learnability of the software was emphasized to be one of its major advantages. Instead of lengthy training, the NUI software only required some familiarization and was rather easy to use. Being asked about specific use cases where the experts would benefit most from using NUIs, they mentioned the planning phase of placing props and choosing the right equipment for the production. Furthermore, they pointed out that previs in the film domain usually requires large sets being built and moved around. Making use of VR however allowed them to freely try out different settings, camera placements and light setups. On top of that, financial advantages were mentioned as well since time spent on a film set is rather costly and thus, digital previs would reduce costs immensely. As a final note, the interviewees concluded that the database-structure of the prototype would greatly enhance collaboration among team members. This new approach allowed people involved in the production to work from different places around the globe simultaneously. A suggestion for improvement was expressed by the camera operator who suggested to have a physical replica of an actual camera in the virtual scene for better haptic feedback.

**Theater.** For this project, the theater involved a stage master, a lighting artist, a CTO, a project manager, two stage technicians and an event technology trainee. Their objective was to create a collection of scenes to previsualize an opera performance. Previs in theater productions is usually based on analogue elements such as cardboard props. Therefore, using VR and NUIs to work on a production felt new and exciting from the team's perspective. Although the experts were unfamiliar with this approach to previs, they found the software to be usable, clearly structured, easy to learn and overall a convincing alternative to traditional methods, offering a "great experience". One major feature they found particularly engaging was the ability for be fully immersed in a virtual scene instead of working with real props in the outside world. Just like in the film production team, the experts pointed out financial advantages of using such a software since time on stage is rather expensive. Additionally, they benefited strongly from using VR to plan out the lighting setup for corridors and areas on stage that were difficult to illuminate. As a suggestion for further development, some interviewees expressed the need for more assets to be used in the stage preparation.

## 7. Discussion

In this work, we developed and evaluated prototypes based on our proposed concept of using natural user interfaces (NUIs) built around a set of interaction techniques and concepts. Overall, The feedback collected in the course of the project evaluations was highly positive and supporting. The professionals from the creative industries stated affirmative appraisal of the prototypes pointing out how they would benefit from it in their daily workflows.

To develop a previs software that supports the need of individual creative personnel, we identified the necessary functionalities needed for a dedicated previs software. The accessibility of a previs software can be improved if the identified tasks are supported. Moreover, in order to have high usability, these tasks need to have intuitive controls and not highly rely on prior technical knowledge.

The individual prototypes provided us with valuable insights regarding our NUI concept. For each prototype, we scientifically evaluated individual interaction concepts and principals. These prototypes showed great potential to support creatives in different stages of the previs process. We used the feedback from these studies and integrated them partially or entirely into the main prototype.

Regarding the evaluation of the main prototype, a major aspect expressed by the experts was the ability to collaborate easily with other project members. Participants stated that animating or sketching in real-time and receiving feedback from colleagues instantly is an advantage in comparison to the traditional 3D software. The collaboration aspect is further improved by having the ability to save projects in a database and access the same scene from anywhere in the world. In the modern industry, it is often the case that team members are located in different places. Having such collaborative features can be extremely practical and helpful. Furthermore, participants found the planning for placement of lights and superstructures highly beneficial for their workflow. As this process is usually cumbersome and expensive when conducted in a physical set or stage, the VR previs tool helps to overcome these challenges and provides artists with an opportunity to try different constellations without worrying about the costs.

All participants were able to get to the desired outcome in a reasonable amount of time, even though they had to complete a rather complex task without having prior knowledge about the prototype and some even without being introduced to VR at all. Obtaining similar results using a professional software without long training sessions is very unlikely. We can therefore argue that our NUI-based prototype has the potential to offer a usable and more intuitive interaction style than the common software after a short familiarization period or tutorial has been completed. NUIs and VR are not just limited to the playful applications they are mostly used in today. Our findings indicate that they are applicable to professional workflows and can provide great advantages to creative work.

Taking these results into account, we will address some of our interaction principles that were presented in the early stages of the project. Within the course of the project evaluations, we could demonstrate that professional users from the creative industries were able to create digital previs in a fast and easy way having generated accurate and precise end results. The artists and creatives were able to directly interact with the software and exhibit their ideas. In our main prototype evaluations, all participants were capable of completing the test cases they were given and thus, generate convincing previs in the course of mere minutes. Additionally, expert users stated the potential of the software and pointed out its ease of use. Participants also addressed the entertaining factor of using the prototype and how they enjoyed the time they spent interacting with the software. Therefore, we conclude that the "Easy to Use", "Rapidness, Accuracy and Precision", "Playful and Fun" and "Creativity Support" interaction principles have been successfully integrated into the prototype. The main prototype also supports a "Multi-User" environment by providing the possibility to collaborate easily with other project members from various places around the world. Multiple users being able to access the same scene from different locations and make changes on a project at the same time was expressed by the experts.

### 7.1. Limitations

Due to the large amount of features presented in the main prototype, some participants felt overwhelmed to an extent which led to a high mental workload and a medium assessment of usability. However, we should keep in mind that the subjects had to perform a set of complex tasks without knowing the software and without having any prior experience in VR. For the future iterations of the software, we intend to include a tutorial-mode, slowly guiding through each functionality of the prototype. This mode could help to educate untrained personnel which would result in a more efficient, less time-consuming usage of the software overall.

Fatigue after long sessions was mentioned as another point of criticism. Especially wearing an HMD for longer periods of time was perceived to be rather cumbersome. Overcoming this problem poses quite the challenge for software developers since the hardware dictates wearing comfort and thus, how physically demanding the interaction can become. However, one potential solution could be to offer desktop-alternatives to some of the functionalities. This way, users could take breaks from VR in between long work sessions while still being able to work on their product. Certainly, this would take away the naturalness of the interaction for these periods. Nevertheless, it could be a way to prevent physical exhaustion and on top of that, empower users further by providing different options to use the software.

## 8. Conclusion

In this article, we introduced a NUI concept for previsualization in an attempt to empower artists and practitioners to intuitively visualize their ideas and show their capabilities depending on the task they want to perform in the previs cycle. Initially, requirements for a previs software were collected from experts in the application areas and the core functionalities were defined based on those requirements. In addition, a concept for the interaction with the system based on natural user interfaces was introduced to guide the development of the user interface for the main prototype as well as exploratory research prototypes. Our findings suggest that NUIs can provide an applicable alternative to traditional design tools and only needs a brief familiarization phase instead of lengthy training as professional software demands. For non-technical personnel, this approach might not only offer an alternative, but a more usable and empowering tool than current software solutions. Overall, the application of VR for previs seems to be beneficial for creative personnel with little technical knowledge due to its easy and intuitive use.

For future developments, we plan to include other modalities that might improve the naturalness of the interaction and further utilize the feedback from the experts to refine the software prototype. As stated by the professionals, haptic feedback plays a major role in certain contexts. For this purpose, we intend to identify where and how to include a more tangible interaction technique. Moreover, we plan to investigate the usefulness of speech and gesture recognition for specific tasks.

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# Publication *P*6

## Playful User-Generated Treatment: Expert Perspectives on Opportunities and Design Challenges

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# Playful User-Generated Treatment: Expert Perspectives on Opportunities and Design Challenges

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## ABSTRACT

Virtual reality exposure therapy (VRET) is a promising approach in treating phobias such as fear of heights (acrophobia). VRET provides an effective, cost-efficient, scalable and individually adaptable alternative to traditional exposure therapy. To further foster the potential of VRET, a novel concept called *Playful User-generated Treatment* (PUT) was derived from expert interviews and literature review. In this paper, we provide additional insights regarding the applicability of PUT in real therapy scenarios. For that purpose, practicing psychotherapists ($n$=13) participated in an online survey and shared their assessments regarding PUT. By conducting qualitative content analysis (inductive category formation), we identified opportunities and challenges that should be considered for the design of playful VRET systems. Opportunities were seen for preparatory habituation, increased control and self-efficacy, improved interaction, economic usage and a realistic display of anxiety-inducing environments. Challenges included lack of direct communication and realism as well as pseudo-habituation to virtual environments.

## CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Virtual reality**.

## KEYWORDS

virtual reality; exposure therapy; user-generated content; game design

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## 1 INTRODUCTION

The immersive characteristics of reality-altering technologies such as virtual reality (VR) open avenues for novel modes of treatment and facilitate the democratization of therapy [6, 18, 22, 28]. For mental health – e.g. treating phobias –, a growing body of work has shown VRET to be valuable [8, 10, 11, 27], enjoyable [6, 16, 17] and sometimes even more effective [6, 20, 21] than traditional therapies. As with many other uncomfortable activities, undergoing and adhering to a therapy is difficult and many patients avoid treatment [2, 4, 5, 16]. To this end, motivational strategies from game design are frequently recommended. While a large portion of the literature on game design builds on *functional challenges*, which address physical or cognitive skills of the players [7], these insights may not be applicable for therapy games. Therefore our approach leans on *emotional challenges* where the gratification results from resolutions of tension or overcoming negative emotions [3, 7, 12, 19].

For acrophobia therapy in VR, Alexandrovsky et al. [1] developed *Playful User-generated Treatment* (PUT) – a two-step approach, where users first engage with a *design phase*, in which they can shape and design a terrain in table-top mode with top-down view and then enter an *exposure phase*, in which they experience the very same terrain at realistic scale from a first-person perspective (see Figure 1). Enabling users to design their exposure in a simulation (top-down view of a miniature map) before they undergo the exposure with the terrain at full-scale is the key concept of PUT, as it enables playful interaction in the first phase without impacting any desired characteristics of the second phase. The approach of Alexandrovsky et al. [1] was based on related literature on game design for mental health [13, 14], motivation [29], behavioral theories [30] and informed by interviews with practicing therapists. The concept was evaluated in a user study and showed positive effects on player experience. After showing that the game design principle can be effective, we conducted a second round of interviews with expert therapists to begin to further consider ecological validity. The outcomes confirmed the value of the approach and also pointed towards valuable design recommendation for VRET games.

This work augments the previously reported evaluation of the PUT concept and discusses the design approach from the perspective of a larger group of therapists based on outcome-oriented qualitative content analysis [23]. The analysis is guided by two main areas

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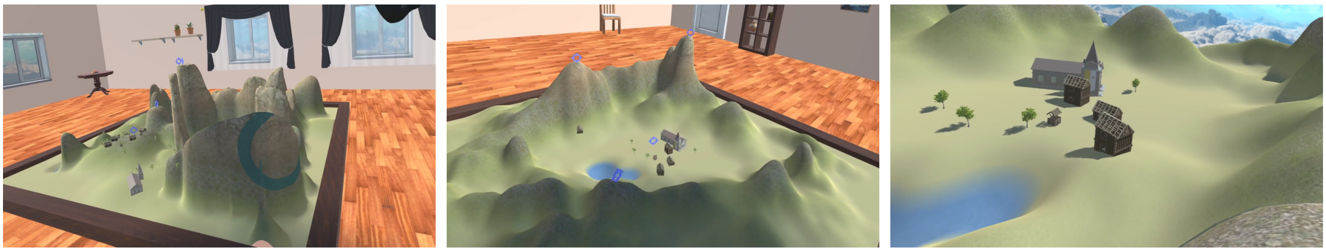

(a) Terrain editor in top-down view. (b) Asset placement in top-down view. (c) In-vivo exposure in first-person view.

**Figure 1: Subsequent steps of a VRET application incorporating the PUT concept.**

of consideration:
*Opportunities*: Where do professional therapists see potential in using PUT for VRET?
*Challenges*: What concerns need to be considered when employing PUT in VRET?
We build on – and extend – the results from the initial interview study and provide additional guiding insights for the playful design of VRET.

## 2 METHODS

In order to address the challenges and opportunities, a survey targeting professional psychotherapists was implemented as an online study. This survey extends the expert evaluation reported in [1] and therefore followed the same structure and procedure. However, whereas the previous evaluation served only to gain insight regarding technology acceptance and the general applicability of PUT [1], this survey was aimed at deriving specific strengths and weaknesses regarding the concept. Therefore, it included a larger group of therapists ($n$=13) together with a deeper analysis procedure.

### 2.1 Material

The survey was delivered using a Google Form consisting of an introductory page, a consent form, an extensive description of the concept (composed of a text, images and a 3 minute explanatory video) and 12 questionnaire items. The embedded video provided a short explanation of the possibilities of VR in the context of exposure therapy and it illustrated the core functionalities of PUT by displaying short clips of the terrain editor application. Next to structured and free-form responses to the questionnaire items, demographic data on the therapists' age, gender and professional background (13 additional question items) was collected as well.

### 2.2 Characterizing the Expert Interviewees

In total, 13 professional psychotherapists (9 self-identified as female, 4 as male) took part in the evaluation. The reported age ranged between 28 and 67 years ($M$=47.69, $SD$=12.45). 12 participants held a professional approbation whereas the remaining participant held a master's degree in psychology as highest qualification. In terms of work experience, participants stated to have performed their occupation as psychotherapists for a period between 1 and 40 years ($M$=14.00, $SD$=10.50). Being asked about their job specialization, 9 therapists reported to use methods from the domain of cognitive behavioral therapy (CBT) [26] most frequently, whereas the other 4 primarily used psychoanalytic methods from the domain of depth analysis / depth psychology [9]. The frequency of engaging with acrophobia therapy was assessed with "Once a Week" ($n$=1), "Multiple Times a Year" ($n$=5), "Once a Year" ($n$=5) and "Never" ($n$=2). Regarding experience with VR in general, participants responded on a 5-point Likert-scale ranging from "No Experience (1)" to "Expert (5)" resulting in a minimum score of 1 and a maximum of 3 ($M$=1.46, $SD$=0.63). None of the therapists indicated that they had ever used VR in a therapy setting before.

### 2.3 Procedure

The link to the survey was distributed via social media and several networks of therapists that shared it in their newsletters and mailing lists. The first part of the survey gathered informed consent. Upon agreeing to the terms, the concept of PUT was laid out with a descriptive text accompanied by images and the 3-minute explanatory video. After the experts were informed about the concept, they responded to the items of the survey (consisting of qualitative and quantitative measures) and a demographic questionnaire. The entire procedure took between 15 and 20 minutes.

## 3 OUTCOMES

As part of the online survey, quantitative and qualitative measures were collected that will be reported separately.

### 3.1 Expert Ratings

For the first three questions, participants were asked to respond on 5-point Likert-scales ranging from "Not Useful"(1) to "Very Useful"(5). Question one asked how the therapists would rate VR in general in terms of applicability in exposure therapy. On average, this item received a score of $M$=4.15 ($SD$=.77). Question two was concerned with the applicability of playful software in exposure therapy and was assessed with an average rating of $M$=3.85 ($SD$=.86). Finally, the third question addressed the applicability of the PUT design approach specifically which received an average score of $M$=3.69 ($SD$=.91).

The majority of therapists ($n$=11) stated that giving patients the ability to create (or take an active part in designing) the anxiety-inducing environment themselves would be a valuable approach. Accordingly, most therapists ($n$=10) agreed that separating therapy into two phases of creation and actual exposure may have a positive

**Table 1: Codes and text passages of the inductive qualitative content analysis. Categories O1-O5 are concerned with opportunities of PUT whereas C1-C3 cover challenges. T1-T13 represent respective therapists. Text excerpts are translated from German.**

| Coding | Category | Text Example(s) |
|---|---|---|
| O1 | Habituation to anxiety-inducing situations | “Playful (not as threatening), as a preparation and habituation for anxiety-inducing thoughts.” (T1)<br>“This allows a graduated approach employing one’s own design elements [...].” (T4)<br>“By employing a playful approach, exposure therapy becomes more accessible for patients, it also facilitates the eventual real exposure in vivo.” (T4)<br>“Deep cognitive processing of anxiety-inducing situations can lead to reassessment and facilitate curiosity/exploratory behavior in vivo.” (T9) |
| O2 | Perceived control and self-efficacy | “[...] which increases one’s own perceived control and with it one’s perceived self-efficacy.” (T4) |
| O3 | Improved interaction of patients and therapists | “Additionally, it enables an easier interaction with the therapist.” (T4) |
| O4 | Economic usage of VR | “In a therapist’s everyday life, the HMD is more practical as it does not require the therapist to go somewhere with the patient but allows them to stay in the facility.” (T5)<br>“In some regions there simply is not enough ‘material’ for exposure.” (T10)<br>“A realistic emotional response in VR can (somewhat) replace a challenging exposure planning/execution outside the therapeutic facility and thus, save time for travelling long distances.” (T11) |
| O5 | Realistic environment | “[...] very realistic and capable of addressing situational anxiety triggers of patients with fear of heights.” (T7)<br>“realistic projection” (T8) |
| C1 | No replacement for actual communication | “It is hard to say to what extent the software is applicable as its own therapeutic approach.” (T1)<br>“[...]the therapeutic relationship would be missing which I think is essential.” (T6)<br>“Direct communication with the therapist is very important.” (T3)<br>“How about the communication between patients and therapists?” (T3) |
| C2 | Lacking realism | “According to the video, the environment (situation) was not displayed in a very realistic way.” (T1)<br>“The expo-scenario showing the mountains was poorly done, too artificial, virtual” (T7)<br>“Buildings and the environment seemed rather unreal.” (T12)<br>“It is fairly obvious that it is not real” (T13) |
| C3 | Pseudo-habituation | “It is rather simple to expose patients to heights in real life which is preferable to a virtual version since certain thoughts such as ‘this is not real’, which may increase the feeling of security, do not appear in a real scenario.” (T5)<br>“There might be a false sense of security which in turn prevents a therapeutic effect when actual exposure happens.” (T5)<br>“In addition, it can become a cognitive avoidance-mechanism.” (T13) |

impact on the course of therapy. The remaining ($n$=3) therapists stated that the approach may have no effect at all.

In the design phase, patients view the terrain they are editing from a top-down perspective and at miniature scale. We asked the therapists if this may have an impact on reducing the patient’s anxiety level. Responses included “Yes, a Positive Impact” ($n$=8), “No Impact” ($n$=4) and “Yes, a Negative Impact” ($n$=1).

We asked the participants whether the design phase of the PUT concept may form too much of a distraction from the actual therapy. On a 5-point Likert-scale ranging from “No Distraction”(1) to “Full Distraction”(5) the mean response was a rating of $M$=2.31 ($SD$=1.20).

## 3.2 Opportunities and Challenges

Accompanying the quantitative items, the survey contained open-ended qualitative questions that were phrased to address the two areas of investigation. As described in the previous section, the survey participants were asked to rate the applicability of PUT on a 5-point Likert-scale. In the following question we asked the therapists to explain their reasoning for this rating in a free-text field. Additionally, another item of the survey asked for any further remarks regarding the PUT concept. Responses to these two items were subjected to a structured qualitative content analysis performed by two independent researchers. More precisely, we employed inductive category formation [23, 24] to work out specific opportunities and challenges of the concept that were expressed by the experts. The steps reported in this section are in line with the standard procedure of inductive qualitative content analysis [25]. The content-analytical units were defined as follows: A coding unit was defined as distinct semantic elements in the text. This could be a sentence or a bullet point that was entered into the online form. The context unit was composed of two open-ended questions of the online survey which specifically targeted opportunities and challenges of the playful user-generated treatment PUT design concept. The recording unit entailed the summarized data of the online survey from all 13 participants. For the analysis, a category was defined as a property of PUT design which was emphasized by the therapists to be an opportunity or a challenge in a real therapy setting. Hereby, the level of abstraction was specified to be concrete properties of PUT design that impact its applicability for actual usage in therapy. With the preparations for a structured content analysis finished, we worked through the material and derived 5 categories of opportunities (O) and 3 categories of challenges (C) which are depicted in Table 1.

### 3.3 Suggestions for Improvements

In the survey, one item asked for particular suggestions that the experts may have for future implementations of PUT. One expert proposed to "enter the virtual world together"(T3) to enhance the interaction between patients and therapists. Another therapist expressed the wish to mirror the patient's view on their device. This way, they could "encourage the patient to look around, stand still, face the anxiety-trigger consciously, to really look at it without evading the situation" (T7). One suggestion included the option to "integrate real buildings that relate to the patient's [personal experience] as a first step to exposure" (T13). Other suggestions included the "option to enter unknown terrain" (T5) and a way to "create potentially phobic stimuli while being able to adjust the level of difficulty" (T9).

## 4 DISCUSSION

The quantitative ratings confirm preliminary findings of the previous study in which PUT was assessed to be well applicable in therapy and deemed capable of raising interest and enjoyment [1]. Accordingly, in this study we found that therapists were rather fond of VR and playful applications in terms of applicability in a real therapy setting. Similar responses were recorded for the PUT concept which received high ratings regarding applicability and was attributed potential positive effects on the patients' health according to the experts. Although most participants assessed PUT to be a valuable approach, it received mixed results regarding the scaled-down miniature view and possible distraction from the actual therapy. To obtain more nuanced findings on the experts' reasoning for their assessment, we included open-ended questions and employed qualitative content analysis to categorize distinct opportunities and challenges of the concept.

The therapists stated that PUT allows for a graduated habituation to anxiety-inducing situations (O1) and identified this property to be a core feature of the concept. They stated that by using PUT as an element of therapy, it can serve as a preparation for actual exposure in-vivo and ease the early stages of therapeutic procedure. Additionally, according to the therapists, PUT may also increase the level of perceived control and self-efficacy (O2), which can be relevant mediators of motivation and adherence. In terms of patient-therapist communication, the approach may improve the interaction between both (O3) but should not be seen as a replacement for real communication or in-vivo exposure therapy as a whole (C1), since the relationship between patients and therapists is clearly seen as an essential element of therapy. Another opportunity that therapists noted is the relatively low cost of VR when used in a therapy setting (O4). Especially for treating certain phobias that require seeking extraordinary anxiety-triggers (e.g. treating fear of flying), VR may serve as an economic and efficient alternative. However, the experts also pointed out that VR exposure alone might lead to a kind of pseudo-habituation (C3) which means that patients could become accustomed to the virtual scene but remain anxious regarding real exposure. This concern is in line with the lack of realism (C2) that was expressed to be a potential weakness that could lead to pseudo-habituation. As some therapists rated the virtual environment to be realistic (O5), there seems to be disagreement between the experts regarding this point. This is understandable since the therapists had only sparse prior experience with VR and thus different, highly subjective standards in rating a scene to be realistic or not. Nonetheless, realism is considered to be a relevant factor in allowing a graduated preparation to real exposure while preventing pseudo-habituation to the virtual scene.

## 5 CONCLUSION & FUTURE WORK

This work provides an extended expert-perspective on the the applicability of a novel VRET concept - PUT (*Playful User-generated Treatment*). This research provides an extension of previous findings [1] with a more nuanced view regarding the potential of the concept as well as concerns from professional therapists. The therapist considerations indicate that VR applications in general and the PUT concept specifically, bear great potential to be used as effective treatments in exposure therapy. Additionally, we identified points of concern that should be considered for future implementations of the concept. From the responses reported in the previous section, we can already derive expert suggestions for improving the PUT application. As therapists pointed out, communication between patients and therapists is vital for a successful treatment and should be incorporated into the concept. Entering the virtual scene together could be implemented through avatar-based projection, which is a promising trend in VRET [15]. On top of improving the interaction between patients and therapists, the participants of the survey suggested that there may be value in increasing the level of visual realism and thus, potentially prevent pseudo-habituation. These propositions can be seen as design implications to inform future developments of the PUT concept. Future work will need to investigate the applicability of PUT in a long-term study including phobic patients and CBT therapists in a real therapy setting. Moreover, we will consider other use cases in addition to acrophobia where PUT may form a valuable addition to traditional exposure therapy and assess the impact on motivation as a potential mediator.

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# Publication *P7*

## Procedural Content Generation in Competitive Multiplayer Platform Games

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# Procedural Content Generation in Competitive Multiplayer Platform Games

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**Abstract.** Procedural content generation (PCG) techniques have become increasingly established over the years in the context of video games. In terms of generating level layouts, PCG has proven to be a cost-efficient alternative to handcrafted design processes. However, previous research is mostly concerned with singleplayer experiences only. Since multiplayer games differ strongly in regards to the requirements that have to be met by map layouts, we addressed the following question: Which PCG approaches are suited best to ensure qualities relevant in the area of level creation for competitive multiplayer platform games? We conclude that a combination of constructive and grammar-based methods serves as a viable solution. We developed a PCG prototype which was integrated into a competitive platform game. Results of a user study indicate that a constructive-grammar PCG algorithm can be used to generate map layouts that are perceived to be fun and compelling.

**Keywords:** Game Design · Procedural Content Generation · Multiplayer Platform Games.

## 1 Introduction

In recent years, the use of procedural content generation (PCG)[1] has risen in popularity, especially in the context of video game content generation [7]. PCG has become highly attractive for game development studios in terms of cost-efficiency since it offers a more time- and money-saving alternative [5]. Various elements of video games are suited to be generated procedurally. One established application domain in the field of video game related PCG is the construction of levels for platform games such as *Super Mario Bros.* [19, 15]. However, previous research heavily focused on the utilization of such methods for singleplayer experiences. Since multiplayer games differ immensely in terms of structure and gameplay, it is questionable whether these established methods can be applied

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[1] In the domain of games, procedural content generation can be defined as “the algorithmical creation of game content with limited or indirect user input.” [20]

without alteration. Thus, the first problem addressed in this paper is concerned with the identification of quality requirements for procedurally generated multiplayer platform maps. Additionally, we review a number of various commonly used PCG techniques in terms of suitability to satisfy these demands. Aside from covering the technical aspects of PCG-based level generation, we have to bear in mind, that games are ultimately developed to be enjoyable forms of entertainment. Though it has been shown that PCG can lead to higher replayability and new forms of gameplay [18], it remains unclear if an entertaining experience can be provided in the context of competitive multiplayer platform games. Therefore, we evaluate whether procedurally generated maps provide a satisfying player experience. This paper is a contribution to the research domain of procedural content generation and the empiric validation of PCG methods.

## 2 Identification of Quality Requirements

In this section, we compile a list of quality requirements that have to be met for the generator to be a viable solution. How to evaluate the quality of video games in a standardized way is a topic of debate as the consumption of games is highly subjective leading to different preferences based on personality and experience [10]. However, literature in the domain of video game design has brought up a variety of quality criteria that can be considered when evaluating games [6, 14, 2, 1, 8, 13]. For the purpose of evaluating the quality of the procedurally generated maps used in a multiplayer platform game, we have derived a number of criteria from the mentioned literature:

**Internal Completeness**: In an internally complete game, the player never reaches a point that leads to compromising gameplay or functionality [6]. For that purpose, unreachable areas and dead ends [2] should be avoided in any case. This property is especially relevant in a multiplayer scenario since dead ends might lead to the feeling of unfair level design. Reaching a dead end as one player might give the opponent a competitive edge and the opportunity to strike the other player down.

**Flow**: Traditionally, the concept of *Flow* describes a mental state of being fully involved in an activity while the proportion of the task's challenge to the operator's skills is perfectly balanced [3]. In video games, *Flow* strongly correlates with immersion and player enjoyment [6, 14]. In the context of multiplayer games, an applicable level generator shouldn't create obstacles that act as hindrances for the players and reduce *Flow*. Therefore, lethal gaps, spikes, traps and the likes should be used scarcely and gaps should be designed smaller than the maximum jumping range of players.

**Risks and Rewards**: Having meaningful and impactful choices spread throughout a game can increase player enjoyment immensely [6]. To have a positive effect, choices need to be designed in proportion to *Risks and Rewards*. In competitive

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[2] "A dead end occurs when a player gets stranded in the game and cannot continue toward the game objective [...]" [6]

platform games, risks can be designed as gaps or spikes whereas rewards typically take the form of power-ups. Both should be spread over the map in a way that gives meaning to player choices (e.g. placing a power-up in an area that's hard to reach). For multiplayer games, *Risks and Rewards* face the challenge of providing a fair distribution of items such as power-ups.

**Diversity**: As mentioned before, increasing the level of replayability is one core motivational factor to utilize PCG methods. For this purpose, generated map layouts should provide a certain *Diversity* in level structure. For multiplayer games, this factor gains even more relevance as playing the same or similar map over and over again would lead to boredom and players using the same tactics that have proven to work on the map layout.

**Performance**: According to a recent survey conducted by *Electronic Entertainment Design and Research (EEDAR)*, 72% of the interviewed PC players stated that reasonable loading times are a key factor when it comes to enjoyment in playing video games [4]. In multiplayer games, players already spend many seconds or even minutes before the actual game starts by waiting for other players in a lobby or contents to be downloaded [11]. For the *Performance* requirement to be fulfilled, we define a threshold of 15 seconds, as loading times below that time span are generally considered “good” [9].

**Determinism**: Modern games such as *Minecraft* [12] allow players to share randomly generated maps with others by providing a seed. For competitive multiplayer games, *Determinism* plays a vital role as it allows to repeat a match on a specific map multiple times, ensuring fairness among all players for tournament-like game modes.

## 3 Review of PCG Methods for Level Generation

PCG techniques can be divided into the following categories: optimization, constraint satisfaction, grammars, content selection and constructive [18]. Algorithms based on optimization generate content iteratively based on quality evaluation. The generative process endures until a sufficient result is achieved [16]. The evaluation can be conducted by humans or the algorithm itself. If conducted by the algorithm, optimization is computationally expensive, especially if the generated content ought to be playable [21]. Since we have identified *Performance* as a vital requirement, optimization-based approaches might not be the perfect solution. Constraint satisfaction requires a level designer to formulate properties that a generated map should provide which in turn are fed into a constraint solver algorithm. This method of content generation has been utilized before to create solvable tile-based mazes [17] and might proof suitable for multiplayer platformers as well. Content selection describes a method of generating content by assembling smaller pieces into larger segments. Despite fulfilling the *Performance* requirement, it is rather questionable if generated maps will entail the needed level of *Diversity* as players might notice repeating patterns [18]. Grammars can be used in the context of PCG with the help of production rules. If these rules are well defined, content does not require additional evaluation leading to an increased *Performance* [18]. Constructive generators combine building blocks that represent small pieces of content to create levels. Often, they are tailored to fit a specific game and do not need any additional evaluation, similar to grammars [18].

## 4 Prototype Implementation

From reviewing existing literature, we conclude that constraint satisfaction, grammars and constructive approaches may provide the qualities we identified as vital in multiplayer platformer levels. For a first prototype, we developed a constructive-grammar algorithm combining the advantages of both techniques in Haskell. As a basic principle, the approach described here fills up an empty map by combining pre-authored building blocks until the area is occupied entirely. As a starting point, we have defined the following set of building blocks or tiles, commonly used in platform games: *air* - players can move freely, *border* - define the frame of each level, *spike* - kill players upon contact, *surface* - provide platforms for players to stand on and finally *any* - tiles in an unfinished map that need to be filled by other types of tiles. With the help of these building blocks, we have created a standard empty map, consisting of a large area of *any* tiles, confined by *border* tiles. At the bottom, *spike* tiles are placed to kill players that fall off the screen. This basic layout served as an initial input for our PCG algorithm to build a level from. Next up, as the map shall be filled with sets of tiles, we had to define a collection of building blocks for the generator to choose from and combine. For this purpose, we have grouped standard tiles into larger segments that served as building blocks. Combining these blocks randomly can lead to malformed level structure which is clearly a violation of the *Internal Completeness* requirement we identified before. This is where grammars and production rules come into play. A single rule could be described as follows: "Building blocks are only to be inserted if they do not overwrite existing tiles in the process." While making sure that all rules are respected, the algorithm integrates building blocks into the map until no insertions can be performed anymore. As a final step in level generation, power-ups and player-spawns were spread over the map. Ultimately, the level generator was integrated into a competitive multiplayer game. The structure of the game was kept rather simple, two players spawn at dedicated positions and aim to hit each other with flying disks that have to be thrown in the other player's direction (see Figure 1).

## 5 Evaluation

After the development of the constructive-grammar prototype had been concluded, we conducted an evaluation based on quality requirements that were defined beforehand.

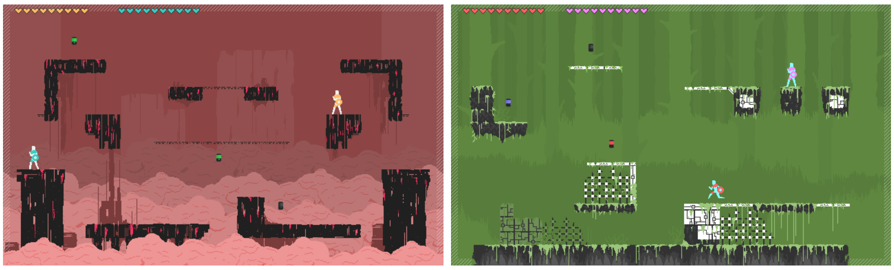

**Fig. 1.** Screenshots taken from *Diskophoros*, which was played in the study.

### 5.1 Performance Assessment

To get quantitative measures rating performance, we ran the algorithm 1000 times and noted the time individually for each round. Execution times varied between 0.43 and 6.47 seconds ($M = 0.43$) while about 99% of recorded times lie below 3 seconds. Since we had defined the threshold of operation time as a maximum of 15 seconds, we argue that our approach fulfills the *Performance* requirement sufficiently.

### 5.2 Explorative Pre-Study

To get a first insight regarding the remaining requirements *Flow*, *Risk and Rewards* and *Diversity*, we conducted a small-scale user study. For this purpose, we integrated the constructive-grammar PCG algorithm into the existing multiplayer platform game *Diskophoros.*

**Participants** The experiment consisted of two trials in which two subjects competed against each other. In the first group, two male software developers, aged 39 and 30 years participated. The second group contained two male students, both aged 22 years studying computer science and teaching.

**Procedure** Before being exposed to procedurally generated maps, subjects were playing a test run on handcrafted levels. When they felt comfortable with the game's controls and overall gameplay, participants were asked to play on random maps, created by the constructive-grammar algorithm, for 20 minutes. During the procedure, the examiner took notes of observations and feedback given by the players. Ultimately, all subjects filled in a short questionnaire.

**Material** The study was conducted using a PC with Windows 10 and standard game controllers. For data collection, a questionnaire was compiled that contained questions aimed to examine certain qualities of the game such as *Diversity*, *Flow*, overall impression and wishes for improvements.

**Results** Three participants explicitly stated that they liked the game in terms of *Diversity*. No subjects mentioned monotony or repetition to be a problem. All players agreed that the game felt enjoyable and playable. As for suggestions for improvement, some pointed out that gaps between platforms were sometimes too large and that maps felt a little empty. Moreover, players criticized cavities that emerged in some maps leading to unescapable death traps and a distortion of *Flow*. Being asked regarding the collection of power-ups, all subjects agreed that they didn't feel like they had to pay extra attention to them and just picked them up. Hence, *Risks and Rewards* felt like they were balanced properly.

**Discussion** We need to address some limitations of the study and its reliability in general. It is important to note that this user study served as a first evaluation of the constructive-grammar approach in terms of playability. The objective of this study was to gather qualitative data in order to collect user insights that shall help to improve the map generator. It should be taken into consideration that our study involved a very small sample which is sufficient to obtain qualitative data but shouldn't be misinterpreted as a representative group. Additionally, since only male subjects took part in the study, results are gender-biased, potentially leading to skewed effects.

## 6 Conclusion & Future Work

The aim of this paper was to examine the applicability of PCG techniques in the context of multiplayer platform games under consideration of quality criteria that are required in this genre. For the purpose of addressing this topic, we identified a set of quality requirements (*Internal Completeness*, *Flow*, *Risks and Rewards*, *Diversity*, *Performance* and *Determinism*) and concluded that a combination of constructive and grammar-based methods have the potential to satisfy those needs. Furthermore, we investigated if PCG-based levels offer a satisfying player experience in a competitive multiplayer platform game. To analyze this problem, we conducted an explorative user study and came to realize that procedurally generated map layouts can indeed provide a fun and engaging experience for the players involved.

Concerning future developments, we plan to address the following remaining issues. Regarding the empiric validation of our approach, we rely on a few heavily gender-biased samples, limiting the reliability of the user study immensely. On top of that, only qualitative data has been gathered so far. Therefore, we will conduct another study involving more participants and standardized questionnaires to compare PCG-based levels with hand-crafted ones.

## 7 Acknowledgements

We would like to thank all participants of the study for their time and effort. This work was partially funded by the EU-project *first.stage*.

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# Publication *P*8

## Memorial Quest - A Location-based Serious Game for Cultural Heritage Preservation

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Personal contribution:
I contributed a majority to the writing (original draft, review & editing), conduct (investigation), analysis (formal analysis), idea (conceptualization) and programming (software).

# Memorial Quest - A Location-based Serious Game for Cultural Heritage Preservation

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## Abstract

This paper describes the design and evaluation process of a location-based serious game in a *heritage awareness* context. Conveying knowledge regarding tangible cultural heritage with the help of video games is a well-established concept. Though many applications in this domain have proven to be effective, they always rely on restrictions regarding time, place and usage of specific hardware. In contrast to previous approaches, we have developed *Memorial Quest*, a serious game with the objective to convey knowledge regarding cultural heritage objects accessible without aforementioned constraints. We examined educational effects by conducting a user study ($n = 40$) in which we compared our game to a common learning method in cultural heritage. Statistical analysis of the results revealed that learning effects were significantly larger when playing the game instead of perceiving the same contents in a traditional way. With the help of questionnaires and qualitative data, we identified possible flaws and elaborated potential improvements for future iterations.

## CCS Concepts

**•Applied computing → Computer games;**

## Author Keywords

Serious Games; Cultural Heritage Awareness; Game Design; Location-based Services; Embodiment

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## Introduction

*Tangible cultural heritage (TCH)*, a concept first established by the *International Council on Monuments and Sites (ICOMOS)* [12], incorporates structures such as landscapes, historic places, sites and built environments [13]. Those objects, spread across a cityscape determine a city's unique character and thus, play a significant role in shaping a society's identity [25].

As Anderson et al. have summarized in an overview paper [1], serious games have been utilized to preserve and enhance knowledge regarding *TCH* by reconstructing ancient historical sites, virtual museums and commercial historical games. However, games that were developed within this context were bound to a specific place and in some cases custom-built hardware. Therefore, those applications were naturally limited in scope and required special circumstances to be played leading to a decreased accessibility. In contrast to this approach, we wanted to empower people all around the globe to learn about the historical background of their environment in a playful way. With this intention in mind, we developed *Memorial Quest (MQ)* - a mobile location-based *TCH* serious game that can be played anywhere only requiring internet access.

Since the learning effectiveness of this new approach hasn't been evaluated yet, we conducted a user study, in which the game was compared to a common learning approach in cultural heritage. Results show that *MQ* led to a significantly higher learning effect than its traditional counterpart while keeping mental workload to a similar level. Moreover, we collected qualitative and quantitative data on how to improve the game even further and implemented additional features based on subjects' feedback.

With this work, we contribute to the preservation and expansion of knowledge concerning *TCH* by presenting a functional gameful approach of tackling this objective with the help of embodied interaction.

## Related Work

Serious games developed in the application area of cultural heritage fall into three different categories based on their specific learning objective: *cultural awareness* [1], *historical reconstruction* [2] and *heritage awareness* [3] [18]. For each of those categories, previous projects have contributed substantial work.

The *GEIST* project provides a historic sightseeing tour through the old town of Heidelberg, enhanced by mobile, augmented reality technology [15, 17]. *VeGame* is a location-based application that aims to facilitate historical knowledge regarding the Italian city of Venice [3]. In *Frequency 1550* [24], a team of four players has to solve tasks that are spread over the city of Amsterdam. Playing *Virtual Egyptian Temple* [14], players learn about ancient Egyptian culture in a CAVE-like environment. *Revolution* [10] covers the everyday lives of citizens in Williamsburg during the $18^{th}$ century. The *Ancient Pompeii Project* [16] and *Roma Nova* [21] are concerned with displaying avatar behavior as realistic as possible to immerse players and increase learning effects. In the *Media EVO Project* [7], players visit a recreation of the Italian city Otranto using a Nintendo Balance Board for navigation and a Wiimote for interaction. As for the *Priory Undercroft Game* [8], a treasure-hunt setting was utilized to motivate people to learn about the eponymous crypt in Coventry.

What all of the discussed previous projects share is that content is tied to a specific place or event. These games work fine for players who are particularly interested in the history of a city or a certain time period. However, for peo-

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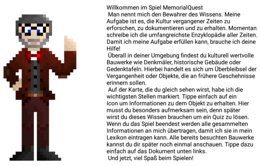
[1] Games that cover intangible cultural heritage aspects such as norms, values, rites, beliefs and the overall society.

[2] Games that were developed with the intention to portray a specific period of time, event or place.

[3] Games that provide representations of current real structures and aim to motivate players to engage with their environment.



Willkommen im Spiel MemorialQuest
Man nennt mich den Bewahrer des Wissens. Meine Aufgabe ist es, die Kultur vergangener Zeiten zu erforschen, zu dokumentieren und zu erhalten. Momentan schreibe ich die umfangreichste Enzyklopädie aller Zeiten. Damit ich meine Aufgabe erfüllen kann, brauche ich deine Hilfe!
Überall in deiner Umgebung findest du kulturell wertvolle Bauwerke wie Denkmäler, historische Gebäude oder Gedenktafeln. Hierbei handelt es sich um Überbleibsel der Vergangenheit oder Objekte, die an frühere Geschehnisse erinnern sollen.
Auf der Karte, die du gleich sehen wirst, habe ich die wichtigsten Stellen markiert. Tippe einfach auf ein Icon um Informationen zu dem Objekt zu erhalten. Hier musst du besonders aufmerksam sein, denn später wirst du dieses Wissen brauchen um ein Quiz zu lösen. Wenn du das Spiel beendest werden alle gesammelten Informationen an mich übertragen, damit ich sie in mein Lexikon eintragen kann. Alle bereits besuchten Bauwerke kannst du dir später noch einmal anschauen. Tippe dazu einfach auf das Dokument unten links.
Und jetzt, viel Spaß beim Spielen!

**Figure 1:** Welcome screen that is presented after launching the game with the historian on the left and an introductory text on the right.

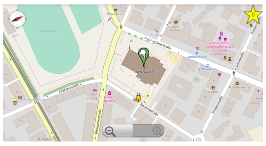
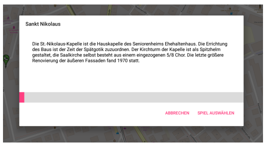


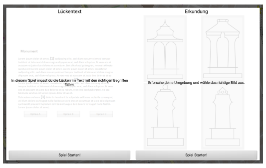
**Figure 2:** Standard view showing map layout, player, compass, points, zoom options and *POI* in the vicinity.



Sankt Nikolaus

Die St.-Nikolaus-Kapelle ist die Hauskapelle des Seniorenheims Ehehaltenhaus. Die Errichtung des Baus ist der Zeit der Spätgotik zuzuordnen. Der Kirchturm der Kapelle ist als Spitzhelm gestaltet, die Saalkirche selbst besteht aus einem eingezogenen 5/8 Chor. Die letzte größere Renovierung der äußeren Fassaden fand 1970 statt.

**Figure 3:** Learning set of a single *POI* (text retrieved from *Wikipedia*).



In diesem Spiel musst du die Lücken im Text mit den richtigen Begriffen füllen.

Erforsche deine Umgebung und wähle das richtige Bild aus.

**Figure 4:** Menu showing minigame choices: *Fill-in-the-blanks* (left) & *Exploration* (right)

ple who would like to gain knowledge regarding cultural heritage of their surroundings, these applications don't provide a viable solution.

In the following section, we will depict the design of the location-based serious game *Memorial Quest* which tackles this problem.

## Game Design

As stated above, *MQ* is constructed as a location-based game that can be played anywhere as long as an internet connection is available. The overall objective of *MQ* is to convey historical data by providing a playful interaction technique. The game can be played on a mobile device such as smartphones or tablets. The user's position is tracked via GPS or, if not available, a position-estimation algorithm based on the network connection. Information regarding culturally relevant objects is obtained with the help of *OpenStreetMap (OSM)* [19]. Since *OSM* only includes very basic information in regards to these structures (object's position & type), we used *Wikipedia* [26] which provided more detailed information. Data from *OSM* and *Wikipedia* is merged and integrated into *MQ*.

In terms of what gameplay elements should be integrated into the game, this work relied on the *Serious Game Model for Cultural Heritage* [2]. This model offers various *task templates* based on different gameplay mechanics. For *MQ* the *Manuscript* template, which lets players insert missing words in a text document was implemented. For a second minigame, we made use of another template called *VisualQuiz*, that requires players to choose the correct image representing a specific object. Furthermore, the game is set in a treasure-hunt scenario in which the player has to collect *TCH* objects to proceed.

As a method to increase motivation, a story-context has been implemented in the game. The approach of having a fictional character introduce the story has been used in other serious games from the domain on cultural heritage with promising results [4, 5, 11]. In *MQ*, this idea was adopted by having a virtual historian tell the player that they need to collect historical data.

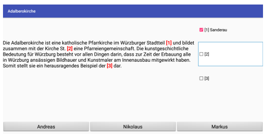
### *Technical Basics*

Information regarding location and object type are obtained with the use of *OSM*. The application reads the player's position which is then transmitted to *OSM*. Within a specific bounding box (radius of about 50 meters around the player) objects of cultural relevance are retrieved. A query contains key-value pairs which determine what kind of point of interest (*POI*) is requested. For *MQ*, the query consists of a *historic* key and *values* such as *memorial*, *monument* or *archaeological_site*. Based on the object's kind, a specific marker icon is displayed on the map (e.g. an abstract statue for memorials).

After selecting a *POI*, the game sends another request to *Wikipedia* using the name that was retrieved via *OSM* before. If an entry could be found, the application obtains the general descriptive text that is used as a learning set and material for the *Fill-in-the-blanks* minigame later on. An image of the object is also stored for the *Exploration* game. In case no entry was found on *Wikipedia*, a small dialog appears telling the player that there is no information at the moment.

### *Gameplay*

When launching the game for the first time, a virtual historian greets new players explaining their task and thus, the story-context of the game (see figure 1). He introduces himself as the *Preserver of Knowledge* and states that his task is to explore and document cultures of the past, summarizing information for an encyclopedia that he's currently writing. In the introductory text, the historian assigns the role of



Adalberokirche

Die Adalberokirche ist eine katholische Pfarrkirche im Würzburger Stadtteil [1] und bildet zusammen mit der Kirche St. [2] eine Pfarreiengemeinschaft. Die kunstgeschichtliche Bedeutung für Würzburg besteht vor allen Dingen darin, dass zur Zeit der Erbauung alle in Würzburg ansässigen Bildhauer und Kunstmaler am Innenausbau mitgewirkt haben. Somit stellt sie ein herausragendes Beispiel der [3] dar.

☑ [1] Sanderau
☐ [2]
☐ [3]

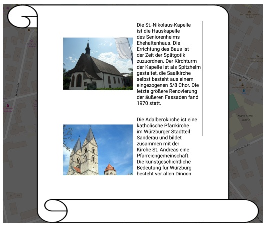
**Figure 5:** *Fill-in-the-blanks* minigame: incomplete text on top and 3 options for each blank below.

Punktestand für: Sankt Nikolaus
Richtige Antworten:
[1] Spätgotik
[2] 5/8
[3] 1970

**Figure 6:** Feedback dialog after *Fill-in-the-blanks* showing received score & correct answers.

Welches Bild gehört zu diesem Objekt?

**Figure 7:** Layout of the *Exploration* game displaying four images including the correct picture.



Die St.-Nikolaus-Kapelle ist die Hauskapelle des Seniorenheims Ehehaltenhaus. Die Errichtung des Baus ist der Zeit der Spätgotik zuzuordnen. Der Kirchturm der Kapelle ist als Spitzhelm gestaltet, die Saalkirche selbst besteht aus einem eingezogenen 5/8 Chor. Die letzte größere Renovierung der äußeren Fassaden fand 1970 statt.

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**Figure 8:** Page of the virtual encyclopedia that holds information for collected *POI*.

a collector of knowledge to the player who in turn embodies this role physically by aggregating the desired information in the real world.

After the introduction has been given, the standard view of *MQ* is displayed. This screen contains the user's position (visualized with a distinct icon), a compass, a map showing basic information such as streets or buildings and certain *POI* that carry cultural relevance (see figure 2).

By pressing a *POI* via touch, a learning text is presented on screen (see figure 3). When they are finished reading the text, players can press the *Choose Game* button which gives them the opportunity to select either the *Fill-in-the-blanks* or *Exploration* minigame (see figure 4).

For *Fill-in-the-blanks*, players have to assign specific expressions to blanks in the text by applying the information they learned while reading the text (see figure 5). For each blank, two false alternatives are presented. After all three blanks have been filled, *MQ* gives a feedback dialog showing how many answers were correct (see figure 6). Points are assigned for each right answer.

When playing *Exploration*, the correct image representing the object has to be selected (see figure 7). Tho solve this task, players have to engage with their environment, exploring and thus learning cultural heritage in their vicinity. Just as in the other minigame, points are rewarded if the task was completed successfully.

The encyclopedia was integrated in the game as a treasure-hunt scenario to foster motivation. For each visited *POI*, a new entry is created that can be perceived later on (see figure 8).

To enrich the score that can be increased by collecting *POI* with meaning for the player, we implemented badges that are unlocked for a number of points (see figure 9). As of now, the first badge unlocks *Exploration* whereas *Fill-in-the-blanks* is available from the start.

## Comparative Study

The application's educational effectiveness was evaluated by conducting a study in which the game was compared to a traditional learning approach in cultural heritage (e.g. information on brochures in the tourism sector). This traditional counterpart is based on mere texts and images, a method that common cultural heritage education used to rely on [20]. The evaluation was performed in the form of a between-subjects design consisting of two conditions. In the experimental condition participants played the game whereas in the control group they perceived the learning set in the form of text and images.

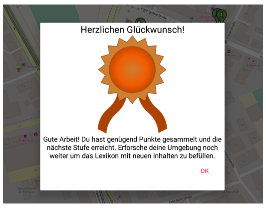
### *Material*

The experiment was conducted using a mobile device (10.1 inches Android tablet). For evaluation purposes, a prototype that only included basic functionality was developed. This version didn't contain a story-driven introduction, badges or treasure-hunt mechanics. Moreover, since the study was conducted in a laboratory setting, *Exploration* couldn't be played sufficiently. Therefore, we focused solely on the *Fill-in-the-blanks* minigame.

For the study, five specific *POI* were created with simulated historical data (no linkage to *Wikipedia* for reasons of robustness during the experiment). Additional materials used in the study were instructional documents, a multiple-choice quiz for the examination of learning effects and questionnaires (SEA-Scale for mental exhaustion [9], ISONORM 9241/10 for overall software quality [23]).

### *Procedure*

Before the actual session began, participants signed a statement of agreement (collection and use of personal data) and read the instruction paper. In the experimental condition, subjects played the game "visiting" five *POI* in random order (see figure 10). Afterwards, they filled out the



Herzlichen Glückwunsch!

Gute Arbeit! Du hast genügend Punkte gesammelt und die nächste Stufe erreicht. Erforsche deine Umgebung noch weiter um das Lexikon mit neuen Inhalten zu befüllen.

**Figure 9:** Dialog showing a medal as an achievement (bronze in the example) after reaching a specific score.

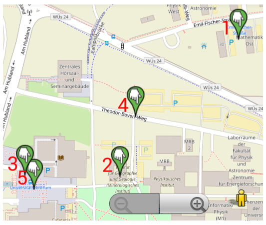


**Figure 10:** Adjustments for the evaluation study: random order of *POI* determined by a red number.

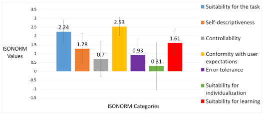


**Figure 11:** Values for each category of the ISONORM 9241/10 questionnaire with one standard deviation as error bars.

SEA-Scale, self-reporting their mental exhaustion. Finally, the ISONORM 9241/10 was completed and demographic as well as qualitative data was gathered. In the control group, a PowerPoint presentation covering the same *POI* as in the experimental one was presented in random order as well. The rest of the procedure was the same with the only exception that no ISONORM 9241/10 questionnaire had to be completed.

*Participants*

Overall, 40 subjects (18 female, 22 male) took part in the study. Their ages ranged between 19 and 31 years ($M$ = 22.23, $SD$ = 2.83). Most participants (97.5%) stated to be students of either Media and Communication (B.A.), Human-Computer-Systems (B.Sc.) or Human-Computer Interaction (M.Sc.).

## Results

For learning effects and mental workload, t-tests for independent samples ($\alpha$ = .05) between control and experimental condition were conducted. Effect sizes were calculated according to the formulas reported by Cohen [6].

*Learning Effect*

Overall, the amount of achievable points ranged between 0 and 15. Subjects who played the game answered significantly more questions correctly ($M$ = 13.50, $SD$ = 1.43) than subjects in the control group ($M$ = 12.20, $SD$ = 2.38), $t(38)$ = 2.10, $p$ = .043, $d$ = .68.

*Mental Exhaustion*

Values for self-reported mental workload measured by the SEA-Scale could vary between 0 and 220. No significant differences could be identified between subjects playing the game ($M$ = 59.60, $SD$ = 31.60) and subjects who were part of the control condition ($M$ = 60.40, $SD$ = 31.69), $t(38)$ = -.08, $p$ = .937.

*Software Quality*

In the study, the German version of the ISONORM 9241/10 was used. For this paper, we refer to its scales by the translation provided in the international version [22]. Values for each scale can vary between -3 and 3. Excellent results were received for *Suitability for the task* (2.24), and *Conformity with user expectations* (2.53). Promising ratings were also received for *Suitability for learning* (1.61) and *Self-descriptiveness* (1.28). In terms of *Controllability* (0.7) and *Suitability for individualization* (0.31), there is still room for improvement (see figure 11).
For the experimental condition, subjects were given the opportunity to express their opinions concerning the game's quality and content. Many participants stated that they missed context information on why they would play the game in the first place and keep playing over a prolonged period. Moreover, players criticized that awarded points didn't carry any meaning at all.

## Discussion & Future Work

As the results indicate, *MQ* has proven to be an effective tool for conveying cultural heritage knowledge in a playful manner. In comparison to traditional learning methods, *MQ* achieved a significantly higher educational effect. Considering mental workload, both the serious game and the common approach caused a similar level of exhaustion. Taking data from the ISONORM 9241/10 questionnaire into account, the game was seen fit for the task at hand, it was capable of describing its own functionality rather well and it behaved according to players' expectations.
Since *Controllability* received such low scores, we want to address this issue in the future. Certainly, low ratings for *Controllability* can be attributed to the nature of our study. Subjects were given a distinct task and were not able to use *MQ* in its entirety, features such as collecting *POI* or exploring were not integrated in the study prototype after all.

Nevertheless, we want to increase the feeling of *Controllability* further by providing players more options and thus freedom when interacting with the software. For instance, allowing them to pause or abort a game session would be imaginable. Generally, options for playing the game are quite limited since there are basically only two minigames provided so far. Giving people the feeling of more control could be enhanced even further by adding more mechanics in various ways. *MQ* offers stages that can be unlocked by playing the game and collecting points. However, only the first level-up (= bronze badge) actually impacts the gameplay by unlocking the new minigame *Exploration*. For future iterations of the software it would be advisable to provide additional game fragments which become available when the player has reached a new stage.

*Suitability for individualization* obtained the lowest ratings since it wasn't in the focus of development up to this point. In the future, we want to enhance this quality by implementing ways for customization. Potential changes would be the integration of a personal avatar for the player, different tile sets for the map screen and color schemes.

Based on qualitative data, participants of the study have criticized the lack of purpose and motivational factors. These problems have already been tackled by the full version of *MQ* that wasn't playable in the evaluation study. We embedded the game in a story-context with the use of a virtual agent to give meaning to gameplay mechanics and added a treasure-hunt setting while giving players the feeling of contributing something to the problem established in the story-introduction.

With the current version of *MQ*, we have delivered an effective serious game that isn't restricted to a specific location as previous projects have been.

However, in our first experiment, we only investigated short-term effects regarding motivation and learning progress.

It is still unknown whether these effects will prevail over a longer period of time. Thus, we can't say if *MQ* will motivate players to stay engaged in the long run and hence achieve a long-term learning effect. In the future, we would like to conduct an experiment over an extended time span to examine this issue.

Furthermore, we have evaluated the game in a laboratory setting so far. Since *MQ* is meant to be played in a mobile context, we will conduct a study in the wild in the future. It is worth noting that all subjects of the first study presented here had a media and/or computer science background. As a consequence, it can be assumed that most of them had prior knowledge in terms of using mobile devices and interacting with touch-based applications similar to *MQ*. None of the participants were in need of an extensive introduction on how to operate the tablet device or how touch inputs worked. Being able to interact with the game intuitively for reasons of familiarity may have impacted the results regarding mental exhaustion and software quality. In the future, we aim to address a more heterogeneous audience with our game. Therefore, we plan to include a larger variety of subjects regarding age and educational background in the proposed field study.

## Acknowledgements

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# Publication *P*9

## Player Types and Achievements – Using Adaptive Game Design to Foster Intrinsic Motivation

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# Player Types and Achievements - Using Adaptive Game Design to Foster Intrinsic Motivation

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## Abstract

Intrinsic motivation is a key factor in facilitating enjoyment and engagement in video games. In recent years, various approaches have been introduced by the industry to raise motivation of players. One of the most prominent methods in modern games comes in the form of *Achievements* which are defined as optional meta-objectives that players can obtain by fulfilling tasks in the game. However, *Achievements* are designed uniformly regardless of the player's personality, play style or general preferences. Therefore, individual differences between players are ignored which can diminish the motivational impact of *Achievements*. To tackle this problem, this paper proposes the design of adaptive *Achievements* based on specific archetypes extracted from the *BrainHex* player typology. For the validation of this approach, we developed a simple Action-RPG which included adaptive *Achievements*. In a comparative study ($n{=}28$) we found that adaptation of *Achievements* leads to an increase of motivational aspects such as perceived effort/importance and sense of reward & individualization.

## Author Keywords

Player Types; BrainHex; Achievements; Adaptive Games; Intrinsic Motivation.

## CCS Concepts

**•Applied computing → Computer games;**

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## Introduction

In modern video games, *Achievements* or *Trophies* serve as symbols of accomplishment which can be unlocked by displaying a specific set of skills of the player and are defined by the game itself, the player/community or the game platform [1]. Introduced in 2005 by Microsoft for their XBox 360 system, *Achievements* have established themselves as small rewards aimed to raise player motivation and engagement as well as a way of socializing with other players [12]. However, in terms of motivation, *Achievements* can provide extrinsic rewards for players [10] which in turn may lead to a decrease of intrinsic motivation [7, 20]. Since intrinsic motivation is strongly related to engagement and enjoyment in any activity [25] including playing video games [22], extrinsically rewarding *Achievements* have the potential to act as a hindrance to a compelling player experience. To tackle this problem and enable *Achievements* to raise intrinsic motivation, we propose an approach to design them in an adaptive way. More precisely, this paper presents a game prototype which adapts *Achievements* according to specific player types. The idea of adapting game content to player types is based on previous research showing that this solution has the potential to create an adequate level of challenge and an overall improved player experience [5]. By displaying a way to implement adaptive *Achievements* based on player types to raise intrinsic motivation successfully, this paper contributes to the research domains of adaptive game design and player typologies.

## Player Types and Adaptive Game Design

Categorizing players into types and play styles has been a research topic in the HCI community for years as it helps game designers to understand their target audiences and tailor content to individual players [28]. For this reason, many different models have been developed and evaluated over the years, based on geographic, demographic, psychographic or behavioral characteristics of players [11, 8].

The earliest approach to define a coherent player typology is known as the *Bartle Taxononmy of Player Types* [2]. This model categorizes players based on two axes (Acting - Interacting & World - Players) resulting in four types - *Achievers, Explorers, Socialisers, Killers.* In a refined version, another axis (Implicit - Explicit) was added and thus, eight sub-types emerged - *Planners, Opportunists, Scientists, Hackers, Networkers, Friends, Politicians* and *Griefers* [3].

Based on this fundamental approach and additional long-term data collection, Yee developed an advanced player typology [29]. Instead of categorizing players into distinct types, this model consists of motivational components that reflect player behavior and preferences. Overall, three overarching groups containing ten sub-elements were defined - *Achievement* (*Advancement, Mechanics, Competition*), *Social* (*Socializing, Relationship, Teamwork*) and *Immersion* (*Discovery, Role-Playing, Customization, Escapism*).

By clustering players into groups based on intensity, sociability and the actual games played, the *InSoGa* model defines three *Gamer Mentalities - Social Mentalities* (*Gaming with Kids, Gaming with Mates, Gaming for Company*), *Casual Mentalities* (*Killing Time, Filling Gaps, Relaxing*) and *Committed Mentalities* (*Having Fun, Entertaining, Immersing*) [13].

The *BrainHex* model was developed with the intention to combine previous research regarding player types and neurobiological insights in terms of player satisfaction [17]. In total, *BrainHex* describes seven archetypes - *Seeker* (curious to explore the game world), *Survivor* (enjoys game experiences associated with terror or fear), *Daredevil* (likes to take risks, seeking thrill), *Mastermind* (solving puzzles, identifying efficient decisions & strategies), *Conqueror* (overcoming challenging opponents including other play-

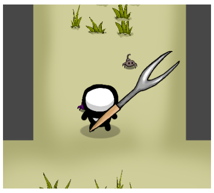

**Figure 1:** Player character carrying standard equipment at the start of the game.

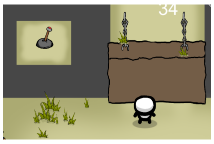

**Figure 2:** Progressing the level requires players to overcome obstacles such as lever-driven gates.

**Figure 3:** Hidden passageways can be found by moving across the level edges.

ers), *Socialiser* (talking, helping and spending time with people they trust) and *Achiever* (is focused on finishing objectives). In contrast to most other typologies, *BrainHex* doesn't assign a single exclusive type but categorizes players as combinations of these archetypes. More precisely, after undergoing a *BrainHex* test, the model assigns a *primary* and a *secondary* class.

In the domain of gamified learning environments, *BrainHex* was utilized to design and implement game elements according to player types, leading to a significantly higher level of engagement [16]. Moreover, adaptation based on *BrainHex* archetypes was applied in the context of persuasive health games in order to improve eating behavior [19, 18]. To this day, the empirical validation of *BrainHex* is still lacking [28]. However, this model shows great potential regarding the increase of motivation based on player type specific adaptation [4]. Therefore, it will serve as a foundation for the design of adaptive *Achievements* in this paper.

## Game Description

For the *Achievements* to be included, we developed a simple Action-RPG with 2D graphics and a top-down perspective called *Forkknight*. Playing the game, players take control of a generic character equipped with a fork-like weapon trying to overcome various challenges included in the levels (see Figure 1).

### *Mechanics*

The main objective of the game is to fight groups of rather weak enemies that appear in the form of hostile tomato-creatures and reach the end of the game where a boss has to be defeated. At the top of the screen, the game displays a health bar which is reduced by stepping on traps spread throughout the level or being hit by an enemy.

Health can be refilled by picking up specific items. If however, the player's health drops to zero, the level is restarted.

Progressing levels is not only achieved by killing off enemies but also by solving simple puzzles like finding switches that need to be activated to open a gate (see Figure 2).

While traversing the game, players can find items to upgrade their abilities and properties. These power-ups are hidden behind illusory walls (see Figure 3) and can increase the character's speed, enhance the health bar or enlarge the weapon which helps to keep enemies at a distance (see Figure 4).

The character is controlled via mouse and keyboard inputs. Using arrow keys or WASD alternatively, players can move in four directions. By moving the mouse in all directions, the fork-weapon results in a circular movement around the character.

In total, 14 levels have to be completed to finish the game. Each mechanic is introduced slowly in tutorial levels giving players the chance to get accustomed to each game element.

### *Adaptive Achievement Design*

As *BrainHex* subdivides its archetypes into a *primary class* and a *secondary class*, the game displays *Achievements* for both categories. Overall, three *Achievements* are available for one playthrough, two of them represent the *primary class*, whereas the last one is based on the *secondary class*. Throughout the entire play session, they are displayed in the upper right corner of the screen (see Figure 5). Multiple *Achievements* have been developed for each type for the game to pick. For each type, one example will be presented in this section.

*Seekers* are asked to find a way to set the fork on fire by locating a bonfire (see Figure 6). The respective fire can be found behind an illusory wall and requires players to explore each level thoroughly. *Survivors* have to complete a specific challenge run in a level where spikes are moving towards the player who has to evade a number of traps to survive (see Figure 7). This section is a part of the game regardless of player types. However, for *Survivors* to unlock the *Achievement*, they have to finish a second, more dangerous iteration of this challenge. *Daredevils* have to complete ten levels in under 45 seconds which requires them to take many risks and should provide a thrilling experience. For the *Mastermind* to be rewarded with the *Achievement* and upgrades, a number of word-based puzzles have to be completed. To solve a single puzzle, three letters have to be entered in the correct order. Hints regarding which letters are to be pressed on the keyboard at which time are distributed at the level edges (see Figure 8). The mechanics of these puzzles are not directly explained but have to be figured out by the player hence providing a challenge for the *Mastermind*.

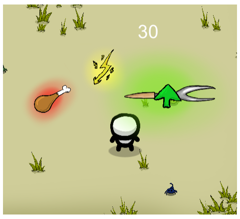

**Figure 4:** Power-ups to enhance health, speed or weapon size.


Find a way to ignite your weapon 0/1
Find 5 secrets 0/5
Smash 50 vases 0/50

**Figure 5:** Example showing how *Achievements* were displayed.

**Figure 6:** By finding a bonfire, players can light the weapon.

Since *Conquerors* enjoy the process of overcoming difficult enemies, one of their *Achievements* involves killing the final boss using an alternative method instead of simply attacking with the fork. In order to fulfill the *Achievement* successfully, they need to identify various traps that are placed around its arena as a way of damaging the boss (see Figure 9). As *Achievers* are motivated to complete tasks simply for the sake of completing them, their *Achievements* entail hitting certain objects a couple of times or destroying scene props such as vases scattered all over the game. For the research presented in this paper, we solely focused on singleplayer experiences. Therefore, no adaptations for the *Socialiser* class were implemented in the prototype. For the study depicted in the next section, data obtained from primary class *Socialisers* was planned to be assigned to the control group. However, this reassignment wasn't necessary in the actual experiment.

## Evaluation

To examine the impact of player type-specific *Achievements* on players' intrinsic motivation, a between-subjects laboratory study was conducted. In the experimental group, subjects were exposed to adaptive *Achievements* whereas control group members were given random *Achievements* that didn't match their type.

### *Material*

To play the game and answer the set of questionnaires, a standard gaming laptop with built-in keyboard and an external mouse were provided in both groups.
Items for the subsequent questionnaire were extracted from the *Intrinsic Motivation Inventory (IMI)* as it has been deployed successfully in previous studies related to intrinsic motivation [23, 27, 21, 15, 24, 26, 6]. Participants could respond to these questions with a 5-point Likert scale [14].
Additionally, another questionnaire was constructed asking for qualitative feedback and ways to improve the experience.

### *Participants*

Subjects for the study were recruited with the help of social media posts and printed hangouts that were distributed around the university's campus. Therefore, most participants were undergraduate students aged between 20 and 30 years. Of all recruited subjects, three people were asked to conduct a small pilot-test to identify potential flaws in the study design or game-related bugs. The other 29 subjects conducted the actual experiment. No additional demographic data was recorded. Data gathered from one participant had to be excluded from the analysis due to a game-breaking error in the software. Therefore, results reported in this paper are based on the measurements from the remaining subjects ($n{=}28$), 15 in the control group and 13 in the experimental condition.

### *Procedure*

Upon giving informed consent by signing an according document, participants were asked to conduct a person-

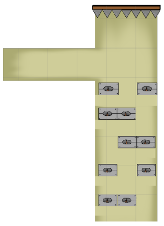

**Figure 7:** Spike-challenge requiring players to move downwards while evading traps.

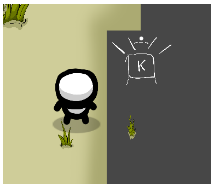

**Figure 8:** Hint for word puzzles that are spread around the level.

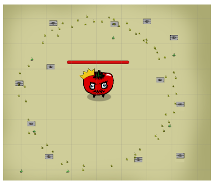

**Figure 9:** Final boss of the game that can be defeated by attacks or traps.

ality test based on the *BrainHex* questionnaire which can be found online [1]. Following this procedure, the examiner transferred the resulting values from the test to the game prototype. It is important to note that this process was conducted identically for both groups and without notifying participants which type was calculated for them from the test. This prevented people from guessing which group they might belong to and from priming them in terms of their player type which otherwise might have had an impact on their in-game behavior. Before subjects were exposed to the game itself, the examiner briefly introduced them to the game mechanics and gave the opportunity to ask any remaining questions. It was made clear that the objective of playing was to get to the end of the game while the *Achievements* were to be treated as optional sub-goals and not as mandatory end-states.

As the game was started, *Achievements* were automatically assigned to the player dependent on their group. For the experimental group, fitting *Achievements* were displayed whereas for the control group, unfitting ones were chosen randomly. Altogether, three *Achievements* were shown in the upper right corner of the screen, two of them representing the *primary class* and one taken from the *secondary class*. Each *Achievement* was designed as a plain descriptive text carrying a simple progress indication. Participants played the game for a maximum time span of 30 minutes. In case they beat the final boss prior to this limit, they were given the choice to play again (e.g. to complete any remaining *Achievements*) or to finish the test-phase. Ultimately, all subjects were asked to fill out a final questionnaire containing items from the *IMI* and additional questions aimed at qualitative feedback.

## Results

For each category of the *IMI* questionnaire, a Student's t-test for independent samples was calculated to analyze differences between the control group and the experimental condition. Regarding *interest-enjoyment*, no significant differences between the control group ($M$=3.61, $SD$=0.45) and the experimental group ($M$=3.52, $SD$=0.52) could be identified, $t(26)$=1.01, $p$=0.32. For *perceived competence*, no significant differences between the control group ($M$=3.28, $SD$=0.95) and the experimental group ($M$=3.42, $SD$=0.84) were found, $t(26)$=0.95, $p$=0.35.
In terms of *tension-pressure*, the control group ($M$=3.03, $SD$=0.86) and the experimental group ($M$=2.75, $SD$=0.63) showed no significant differences either, $t(26)$=1.39, $p$=0.18. However, concerning *effort-importance*, the experimental group ($M$=3.87, $SD$=0.51) was rated higher than the control group ($M$=3.37, $SD$=0.88), showing a statistically significant difference, $t(26)$=2.98, $p$=0.047, $d$=0.68.
With respect to the questions specifically constructed for this evaluation, Student's t-tests for independent samples were calculated as well. We found significant effects asking for *"It feels like the achievements matched my personal preferences"* ($t(26)$=2.09, $p$=0.046, $d$=0.66) and *"I tried hard to fulfill the achievements"* ($t(26)$=2.45, $p$=0.02, $d$=0.81), as well as a highly significant difference for *"Fulfilling the achievements felt rewarding"* ($t(26)$=3.05, $p$=0.005, $d$=1.06), all in favor for the experimental group. Within a structuring qualitative content analysis, we asked participants what kind of *Achievements* they would have liked to see in the game, without providing information that other *Achievements* could have been in their play-through. Most of the proposed *Achievements* were among or similar to the remaining ones. Seven of the participants stated to want *Achievements* that could be attributed to one of their assigned player types and another seven mentioned *Achievements* that did not fit their *BrainHex* estimate.

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[1] http://survey.ihobo.com/BrainHex/

## Discussion & Future Work

Results of the *IMI* indicate that *Achievements* adapted to the individual player type do not necessarily render game experiences more enjoyable or exciting, but evidently more engaging, increasing the resulting motivation. More precisely, we have identified a significant difference in *effort-importance* in favor of the experimental condition. This is supported by the strong effects that were measured assessing the impact of the adapted *Achievements* on perceived reward and effort spent solely on completing these, even though their introduced importance within the game was secondary. However, regarding *interest-enjoyment*, we couldn't find any significant differences dependent on the adaptability of *Achievements*. Since *interest-enjoyment* is a strong predictor for intrinsic motivation overall [9], our results indicate that only specific motivational aspects (related to *effort-importance*) could be fostered via the adaptation of *Achievements*.

*BrainHex* proved to be able to supply suitable classifications of player types to which a multitude of *Achievements* were successfully ascribable. Yet, when it comes to the qualitative assessment of desired *Achievements*, participants were equally likely to request *Achievements* that did not fit their assigned player types as they were to fitting ones. This might stem from the two-stage problem: Firstly, the mapping of *BrainHex* to player types still needs empirical validation and secondly, the translation of particular *Achievements* to player types is also imprecise and one-dimensional. To tackle this problem, we plan to extend our research in the future by investigating current *Achievement* types that are established in the video game industry. Based on our findings, we aim to compile an *Achievement* classification system and examine how certain player types match with specific types of *Achievements.* Above that, we plan to extend this study in order to capture the effects of *Achievement* adaptation between particular player types and investigate if the type itself has an influence on the motivation-increasing potential.

Understanding the effects of matching certain *Achievements* with specific player types can bear great potential for the video game industry. Instead of defining uniform *Achievements* for everyone, developers can address players more individually by conducting a simple and brief typology test beforehand. For this purpose, another topic for future research would be to analyze player behavior and extract their *primary* and *secondary* classes automatically, making a test outside of the game obsolete.

## Conclusion

Unlockable *Achievements* have proven to be a major motivator in video games. Yet, the public and often bragging-focused nature of these accomplishments facilitates rather extrinsic instead of intrinsic motivation, while the latter is known to be a substantially better instrument for actual engagement and enjoyment in games. In order to harness the motivational potential while offering more intrinsic appeal, we introduce the adaptation of *Achievements* on the basis of individual player types. Within a comparative user study, we were able to provide evidence for a positive impact regarding certain motivational aspects such as perceived effort and importance as well as sense of reward and individualization.

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# Publication *P*10

## Make my phone secure! Using gamification for mobile security settings.

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# Make my Phone Secure!
# Using Gamification for Mobile Security Settings

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## ABSTRACT

Granting permissions in different contexts to applications on mobile devices might pose a direct threat to the users' security and privacy by granting access to sensitive information. Although, Android permission dialogues already provide information about possible dangerous permissions, users might still not be aware of the consequences. Therefore, appropriate solutions for empowering users and raising awareness should be examined. As gamified applications can motivate players to learn more about rather uninteresting areas, we investigate the potential in the context of mobile security. We developed the gameful application *Make my phone secure!* for learning how to grant and change permissions. The game presents the Android menu in a playful and explanatory environment. To analyze possible learning effects of the application, we conducted an empirical study, comparing the game and two more basic variants (one with a simple Android menu and one menu enriched with hints concerning the permissions). The lab study ($n = 18$) showed that all three variants could increase the participants' awareness significantly. However, the game was perceived as the most fun variant and provided more informative content than the common menu structures.

## CCS CONCEPTS

• **Security and privacy → Usability in security and privacy**; **Software and application security**.

## KEYWORDS

Android, Permission, Gamification, User Awareness, Usable Security

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## 1 INTRODUCTION

Mobile devices such as smartphones and tablets are increasingly powerful gadgets that are replacing personal computers due to advanced features[1]. Today, a large amount of data is stored and processed on mobile devices, including sensitive information like contacts, emails, photos and videos. In general, it is difficult for an operating system like Android to determine if an application uses the sensors or data legitimately or in an inappropriate way. As a way to protect users against malicious applications, Android uses a permission system to inform the user what kind of permissions are needed and what data could be accessed by a particular application. Several studies have been conducted in association with Android permissions to inform users about the risk of installing the applications (e.g., [9, 22, 31]). Prior research studies have also focused on identifying malicious behavior, without considering how to help users make informed security decisions [23, 33].

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[1] https://www.statista.com/statistics/245501/multiple-mobile-device-ownership-worldwide/

While users can provide feedback through reviews and comments in the Google Play Store, there are no feedback or ratings available for various security configurations of the application and granting permissions [15]. Users do not consider security risks meaningfully in their reviews [20]. This could have different reasons, for example, because users do not care much about security, or that the typical user cannot assess the security risk of the apps that are used daily [11]. Also, this is compounded by the fact that security is a secondary task for most people [30]. Therefore, there have been several cases in which application permissions have been misused by application developers and users' privacy has been compromised.

An example of such an abusing behaviour is the official application of the Spanish soccer league *La Liga - Spanish Soccer League Official* [2]. This application used the microphone's data of its users to search for unlicensed television broadcasts. *La Liga* denied any wrongdoing but confirmed that the application, installed by around ten million people, could access the microphone and the location of the smartphone after granting permissions [5].

*Flashlight LED Widget* is another example that abused permissions to an even higher level (pulled from the Google store based on the article by the ESET security community website[3] in April 2017). For running the application, the user had to give it device administrator privileges. The user was also asked to grant permissions to draw over other applications (SYSTEM_ALERT_WINDOW) and to access usage statistics (PACKAGE_USAGE_STATS). The application was able to hide the menu icon and appears like a normal widget. However, its main goal was not to give the users the functionality of a flashlight, instead it was able to steal their banking credentials[3].

Such examples show that the consequences from granting permissions might be hard to understand. Novel approaches are needed to improve and achieve a greater depth of understanding what the consequences are. Gamification, "the use of game design elements in non-game contexts" [7], has been applied across a number of domains, to increase motivation and influence human behavior in education [17]. Therefore, we developed an application which applies gamification in the Android security domain to raise awareness regarding the security settings of mobile devices.

*Make my phone secure!* is a gamified app that helps users to understand the consequences of granting permissions to the applications. Following the definition of Deterding et al. [7, 8], *Make my phone secure!* is classified as a gamified app, since it constitutes an informational app with added low-level gamification features.

Through a laboratory study with 18 participants, we evaluated our idea based on the question: "How can a gamified application help to raise awareness regarding mobile security settings?". In order to analyze possible learning effects, a comparison was made between the game and two other basic variants. One variant represented a generic Android menu, while the other one contained hints and explanations about the consequences of granting Android permissions. Our study showed that players of *Make my phone secure!* achieved a higher awareness of the consequences that might follow after granting permissions to an application significantly.

With this paper, we provide a contribution to the domain of gamified solutions in the context of mobile security settings.

## 2 RELATED WORK

In this section we focus on the research studies that are technically related to our work. First, we present work related to security and permission issues and afterwards we discuss studies related to gamification in the security area.

### Privacy in Mobile Devices

Several studies demonstrated a lack of user attention to privacy and security associated with installing mobile applications [1, 11, 16]. They also showed that this lack of awareness hinders users in making an informed decision while granting permissions to applications when they are requested [32]. Therefore, Android privacy and security researchers have developed several approaches that help users to avoid privacy breaches [10, 11, 13, 28]. Kelley et al. [18] reported that it was difficult for Android users to understand the terms and wording of Android permissions. They also argued in another study [19] that privacy should be a part of the app decision-making process. They included an overview page to the Google Play Store which represented the sensitive information an app can access. Their results showed that they could influence the decisions of the users compared to the existing permission display. Their goal was to integrate privacy into the decision-making process by summarizing permissions into a table. To specify privacy settings for installed apps at any time, Zhou et al. [34] developed an application for Android with a privacy mode. With this application, which requires changes to the Android framework, the user can adjust whether an application can access real, fake, anonymous, or empty data. In contrast, we attempt to empower users' awareness by making permission risks concrete and understandable by using gamification. We want to enable users to make a decision if they trust a certain application and its developer to access their personal information.

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[2] https://play.google.com/store/apps/details?id=es.lfp.gi.main&hl=en

[3] https://www.welivesecurity.com/2017/04/19/turn-light-give-passwords

### Gamification and Security

Although serious games and gamified interactions have become popular in the last years, including use in computer security education [6], social media and websites [35], there are still many challenges related to the privacy and security of the Android operating system. Harbach et al. [14] customized the permission dialogues with personalized examples (such as viewing a personal photo for accessing the gallery) to make the risks more prominent. Permission visualization could help the authors to raise the attention to relevant information and to improve users' decisions. The feedback of participants suggested that the visualized personalized examples reflect the consequences of the application's permissions. In addition, they found that participants learned which permission sets are appropriate for the purpose of the application. Rather than focusing on visualization of permission dialogues, in this paper we concentrate on gamification learning effects to analyze the behavior of users in order to increase the awareness of unexpected behavior in granting permissions.

A number of user studies were conducted to evaluate the effectiveness of serious games incorporating cyber-security concepts to protect smartphones and digital systems from information leaks [2, 3, 25]. For example, a game-based anti-phishing educational approach was used by Wen et al. [29]. They developed a serious game with the goal of educating employees on how to better handle phishing emails. Their purpose was to improve the player's ability to distinguish between phishing emails and safe emails before and after the game.

Suknot et al. [27] proposed to enhance the educational experience through gamification in order to teach users security more consciously in different types of Internet related threats. Their game encountered privacy topics such as smartphone, social networking, email and general Internet use. However, their work did not cover any special settings of mobile operating system.

In related work, Rader et al. [24] showed that many users learn about security from informal stories told by family and friends. Hence, in terms of their work, we try to visualize small stories about how sensitive information may be at risk when a user grants permissions without enough knowledge.

## 3 MAKE MY PHONE SECURE!

The playful application *Make my phone secure!* was designed to answer our research question "How can a gamified application help to raise awareness regarding mobile security settings?". Therefore, it was important to cover functionalities necessary in this context. In this section, the game's concept, design and content shall be depicted in detail. With the development of a gamified application, we aim to achieve a twofold educational objective. First off, players shall acquire knowledge regarding the Android permission system in general. Most importantly, the app is designed to teach users what granting a permission to any application can entail and what consequences this might involve. Secondary, we want to improve how users interact with the permission system itself. By letting them explore the menu structure of a typical Android device in a playful way, we intend to teach players how to enable and disable certain permissions for applications installed on the device.

### Concept

The game is set in an IT customer service context. Players take control of a specialist whose task is to deal with security issues that are put forward by virtual customers. A typical situation would involve a client asking the player to alter the behavior of certain applications on their phone, for instance in order to turn off personalized advertisements. To solve this problem, players have to find and change permissions for the respective apps. After handing over the device back to the customer, the consequences of the player's actions become apparent. In case they have identified and changed the appropriate permission correctly, clients will react accordingly, expressing their satisfaction by telling the player that the problem was eliminated. However, if the player was not able to perform the task successfully, customers will tell them that they are not satisfied while the problem still persists. For instance, not being able to turn off the microphone permission might lead to advertisements still being personalized which the customer will complain about at the end of a level.

### Course of Events

Each level of *Make my phone secure!* follows a predefined pattern:

1. Problem statement: The customer illustrates the problem at hand to the player.
2. Finding a solution: The player navigates through various menu structures trying to find and adjust the right setting.
3. Customer feedback: The customer expresses their satisfaction or disappointment depending on the player's actions.

For each state, a number of user interfaces has been developed using Unity3D[4].

*Level Introduction.* After launching a level, the game displays a screen showing an avatar representation of the customer and the text explaining the issue (see Figure 1). By clicking

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[4] https://unity3d.com/unity/

*Let's start* in the bottom right corner, the game reaches the next state in which players are to find a solution.

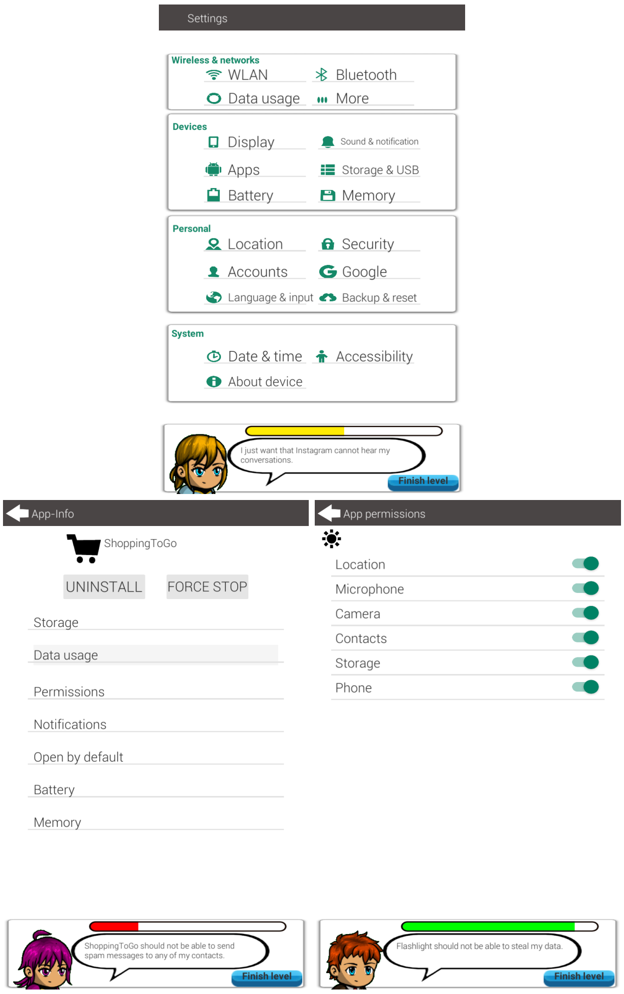
Hi, Julia here. Recently I am getting advertisements that appear creepy to me, because I just spoke about those products before. Can you stop Instagram from using my microphone?

Hi, I'm Tom. Can you help me with my phone? I heard of a flashlight widget stealing data from mobile phones. Can you avoid that my flashlight widget does that?

Hello, I'm Maria. A friend of mine has the same application as me, it's called ShoppingToGo. Most of her contacts, like me, now receive a lot of spam messages from ShoppingToGo. I don't want that my contacts get those too.

**Figure 1: Introductory texts for each level: *Instagram hears my conversations* (top middle), *Flashlight could steal my data* (left) and *ShoppingToGo sends spam messages* (right).**

*Level Progression.* By navigating through the menu structures (mimicking Android 6), players should attempt to find and disable the permission. While doing so, the game provides constant feedback on whether players' actions are leading to the desired outcome or not. Feedback is conveyed by dialogue windows and a progress bar at the bottom of the screen. Performing correct actions fills the bar while false decisions empty it. Additionally, customers comment on every step taken by the player with positive or negative remarks. Since we did not want to punish the player for simply navigating through sub-menus, we had to clearly define what a *wrong* action entails. Ultimately, we decided that false actions only involve altering wrong permissions or adjusting settings for other apps that are irrelevant in the context of the level. On the other hand, correct actions include finding the app in the settings menu and turning off the appropriate permission (see Figure 2).



I just want that Instagram cannot hear my conversations.

ShoppingToGo should not be able to send spam messages to any of my contacts.

Flashlight should not be able to steal my data.

**Figure 2: Menus that are displayed during the game including settings (top middle), app information (left) and permissions for each app (right). At the bottom, feedback regarding the player's progress is located.**

*Level Completion.* At any time during the game, players have the opportunity to press the *Finish level* button located in the lower right corner. Following this, another window pops up telling the player whether their actions led to the desired outcome or not. In addition to customer's feedback, the game prompts a rating based on the progress bar from the previous step (see Figure 3). If players wish to gather more information regarding the rating, they can press the *Explain* button which gives a more detailed explanation.

Hey, again. Thank you! Instagram seems to have stopped listening to me. I just got normal advertisements.

Hey. I see advertisements, about things I recently talked about, again.

**Figure 3: Final ratings displayed at the end of one playthrough, depending on success (left) or failure (right) of the player.**

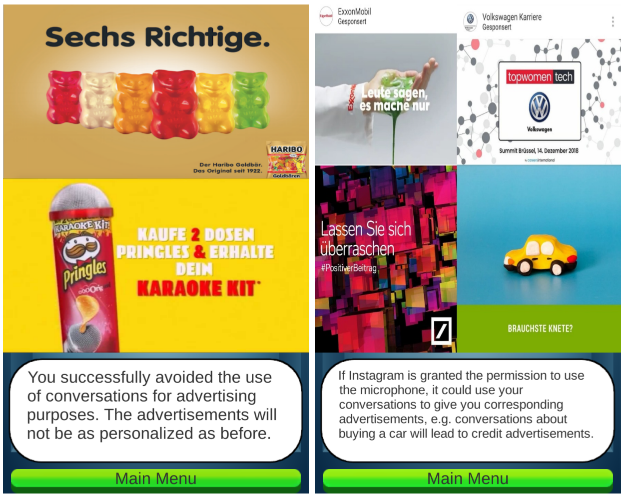
### Stages

To embrace the role of a specialist working in IT support, we intended to design realistic scenarios that players could relate to. Therefore, we developed three levels that deal with the behavior of modern and popular applications available for Android devices. Applications depicted in this section (*Instagram*, *Flashlight*, *ShoppingToGo*) were not actually implemented. They are, however, based on real apps and mimic their behavior in order to provide a context for the game *Make my phone secure!*. The following segments shall provide an overview of each level with its own story and objectives.

*Instagram Hears my Conversations.* With more than one billion users, *Instagram*[5] can be considered to be one of the most popular applications available on the Google Play Store. As the application is free to use, it is financed by advertisements that are displayed in the user’s feed.

Among other permissions, *Instagram* asks the users to enable and allow the usage of the microphone. The first level has the fictional scenario, that the client complains that *Instagram* displays personalized advertisements based on conversations he/she had before. To complete the level successfully, players have to find the permission to use the microphone and turn it off. Afterwards, the customer informs the player that the application cannot send personalized advertisements any longer. However, if the player does not change the permission, the client states that *Instagram* has not changed its behavior, leaving them disappointed (see Figure 4).

whether Instagram listening to conversations is controversially debated and not necessarily proven, but we give this example to show the players that such security and privacy concerns might arise with popular mobile apps. Although this example could lead to misconceptions about *Instagram*, this fictional scenario aims to investigate whether users of mobile devices with a permission-based application actually do understand these access rights and the implications they have.



You successfully avoided the use of conversations for advertising purposes. The advertisements will not be as personalized as before.

If Instagram is granted the permission to use the microphone, it could use your conversations to give you corresponding advertisements, e.g. conversations about buying a car will lead to credit advertisements.

**Figure 4: Positive or negative message that is displayed after the level *Instagram hears my conversations* has been finished. If the level was completed successfully, the text on the left is revealed, otherwise the one on the right.**

*Flashlight Could Steal my Data.* For the second level, we conceived a simple widget called *Flashlight*, which enables the camera’s flash as a permanent light. However, this application requires users to permit access to the device’s storage. Taking into account that a number of flashlight apps can and do request access to permissions and data on users’ mobile devices that seemingly have nothing to do with the ordinary functioning of the app and that such permissions could theoretically enable hackers to obtain sensitive information from users. In order to improve user’s awareness of privacy leakage on a mobile device, this scenario provides an appropriate example for the players. At the beginning of the level the virtual client states that he/she worries, the app might conduct data theft and that the client is puzzled why the *Flashlight* application requires storage permission. It is the player’s task to find the correct settings and change them

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[5] https://www.instagram.com/

accordingly. If the player succeeds in disabling the permission, the game presents a text ensuring that no data has been stolen. If the player fails, the game states that personal data has been leaked to the Internet.

*ShoppingToGo Sends Spam Messages. ShoppingToGo* simulates the properties of a common shopping application that allows its users to choose and purchase products from a variety of items. For reasons unknown to the user, it asks for the permission to retrieve contact information from the device. This simulated app can exploit the Contact permission for its personal gain. It can help a hacker to steal user's contacts and sell them to advertising networks. This scenario aims to raise user's privacy concerns with granting the Contact permission. In this fictional scenario, the client has noticed that people from their contact list have received spam messages since the app was installed. On top of that, the customer has heard from the news that this is a typical behavior of this application. Therefore, the client assumes a correlation between installing *ShoppingToGo* and spam messages sent to the contacts. Players should turn off the permission to access contact information. Upon completion, the game presents a text and images displaying the consequences of the player's actions. Just as all levels, the outcome depends on whether players were successful or not. In case they were, the text ensures that people from the contact list no longer receive any *ShoppingToGo*-related spam. On the other hand, if the permission could not be located and revoked, the text states that the app still keeps on sending out messages to the customer's contacts.

## 4 EVALUATION

With this paper, we aimed to evaluate a gamified application in terms of the educational impact regarding mobile security settings and in particular the permission system. To answer the research question "How can a gamified application help to raise awareness regarding mobile security settings?" we designed a user study. In this study, the application *Make my phone secure!* was compared to a traditional menu system displaying the information in a direct way through simple text-based user interfaces.

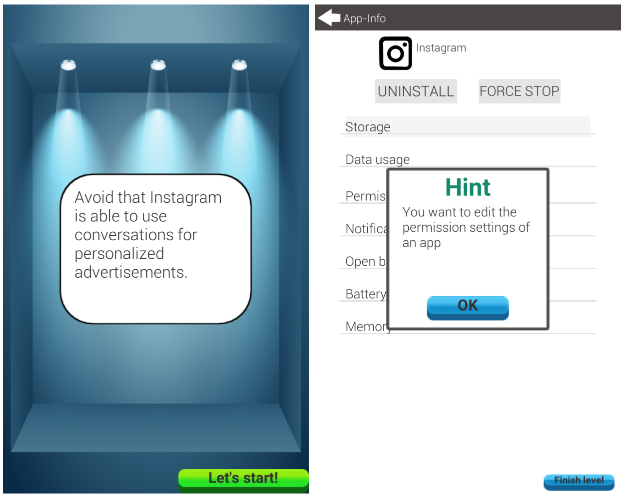
### Study Design

The experiment was conducted as a within-subjects design with three conditions. Each condition represented a different approach of conveying information about the application permission system. The following variants were developed for the purpose of comparing their educational impact:

(1) *Menu* variant: This prototype mimics the look, feel and functionality of a traditional Android system. It displays the task as text and offers the same menu structure as the full game for the user to navigate through. After finishing the task, the prototype prompts a message showing whether the player was successful or not.

(2) *Menu + Hints* variant: This version equals the first variant with minor modifications. In addition to the menus displayed in the first variant, this one provides hints that pop up as small dialogue windows (see Figure 5). These hints support players to achieve their objectives. To give an example, a hint would tell the user to adjust the settings for each installed application individually.

(3) *Gamified App* variant: This variant represents the game *Make my phone secure!* with full functionality illustrated in a previous section.



Avoid that Instagram is able to use conversations for personalized advertisements.

Hint

You want to edit the permission settings of an app

**Figure 5: Start screen of the *Menu* variant (Left) and an exemplary hint from the *Menu + Hints* variant (Right) developed for the study.**

For the *Menu* and *Menu + Hints* variants, scenarios based on the mini games *Instagram hears my conversations*, *Flashlight could steal my data* and *ShoppingToGo sends spam messages* were developed. To eliminate confounding errors, we used a Latin square design [4] to generate different orders for the variants and scenarios.

### Material

For data collection, we setup a number of questionnaires containing various items intending to reveal possible educational effects of each variant. The first questionnaire was presented before the treatment, containing general questions regarding demographic information (e.g. age and gender). Additionally, we asked for previous knowledge of the subjects by asking how they handle Android permissions and whether they know what kind of permissions their favorite application needs.

In addition, for checking the participants' previous knowledge, we compiled a set of questions targeted to examine the awareness of the applications' permissions. These questions involved asking participants how likely it is that applications use permissions for undesired actions (e.g. recording audio without notifying or sending spam messages to people from the contact list).

It is important to note that we only asked for the level-specific permission that was relevant in the context of the variant that participants were using or about to use. Therefore, if the microphone permission was not part of the level they were playing, these questions asked for a different permission (e.g. storage or contacts). Each item of the questionnaire could be answered by filling in a seven point Likert-scale [21] reaching from "Very unlikely" to "Very likely". For statistical analysis, questions from this section were combined into a single variable representing subjects' awareness by calculating their mean value. For the upcoming statistical analysis, we calculated the difference between the values before and after the treatment. We call this combined variable *Awareness Progression.*

Ultimately, the last section of the questionnaire contained two simple questions, "How much fun did you have with this version?" (*Perceived Fun*) and "How informative was this version?" (*Perceived Informative Content*). Responses could be given on a seven point Likert-scale reaching from "Very boring" to "Very exciting" (and "I learned nothing" to "I feel enlightened" accordingly).

As a mobile device we used a Lenovo Tab2 A10-30 with Android 6.0.1 to run the variants for each condition.

### Participants

The study consisted of 20 participants, all of them had a college degree. Since we initially planned to include 21 participants in the study but could only recruit 20, we had to exclude the last two participants for reasons of counterbalancing. Therefore, data presented in this section is based on 18 subjects. Among the subjects, 13 people identified themselves as male and 5 as female. In terms of age, participants ranged between 21 and 36 years ($M$=25.27, $SD$=4.77).

### Procedure

We invited participants to take part in the study via an email distributor and printed notices that were spread across the university where the study took place. No information regarding the context of the game or the overall aim of the research was revealed. The experiment itself was conducted as a laboratory study. Before the examination, all participants signed a consent form, to store personal data for an anonymous statistical analysis. Before being exposed to the treatment, all subjects conducted a pre-test by answering all relevant questions regarding to *Awareness Progression.*

Subsequently, the following steps were carried out for all three variants and each interview took 30-45 minutes: Upon testing their previous knowledge, participants were exposed to the treatment which consisted of one of the variants (*Menu*, *Menu + Hints* or *Gamified App*) and a level context concerned with a distinct permission (microphone, storage or contact).

Following the treatment, participants answered all questionnaires concerned with *Awareness Progression*, *Perceived Fun* and *Perceived Informative Content.* The entire process was reiterated until all variants were featured.

### Limitations

The study is limited in terms of representative validity. For the purpose of evaluating potential learning effects, we employed a self-designed questionnaire. This document consisted of rather specific questions targeted to examine if participants gathered any knowledge concerning the permission system. As there are no established questionnaires for this particular task, we had to come up with an individual solution. However, this questionnaire is not standardized which should be taken into consideration when interpreting the results.

The nature of the study conducted as a within-subjects design may have led to the occurrence of sequence effects. While we aimed to reduce this effect to a minimum by counterbalancing all conditions, it cannot be excluded that some kind of learning took place from one treatment to another. This might have had an impact on the awareness ratings we derived from the questionnaires.

## 5 RESULTS

For each variable, statistical analysis was applied to identify possible differences between the prototypes. *Awareness Progression* refers to the difference between all awareness-related questions before and after participants were exposed to one condition. For each variant a pre-post comparison was conducted by calculating dependent t-tests for paired samples [26].

For the *Menu* variant, the average progression ($M$=0.78, $SD$=0.99) showed significant differences, $t(17)$=3.23, $p$<0.01. Similar results could be achieved for the *Menu + Hints* variant ($M$=0.65, $SD$=0.97), $t(17)$=2.77, $p$<0.05 and the *Gamified App* variant ($M$=0.61, $SD$=0.76), $t(17)$=3.33, $p$<0.01 (see Figure 6). When comparing *Awareness Progression* between all variants by calculating a one-way ANOVA for repeated measures [12], no significant differences could be found.

Ratings for *Perceived Fun* are not based on pre-post tests but on the final questionnaire. A one-way ANOVA for repeated measures was calculated and found statistically relevant differences between the variants, $F(2)$=5.21, $p$<0.05. Post-hoc tests revealed that participants rated the *Gamified App* condition ($M$=5.78, $SD$=1.13) to be significantly more

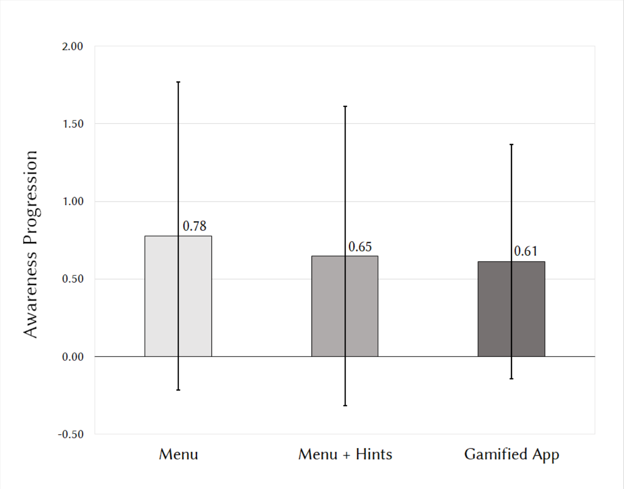


**Figure 6: Bar plot showing the average *Awareness Progression* for each variant with one standard deviation as error bars.**

fun than the *Menu* ($M$=5.06, $SD$=0.91) variant, $t(17)$=3.42, $p<0.01$. Similar results were found for the comparison between the *Gamified App* and *Menu + Hints* ($M$=5.06, $SD$=1.39), $t(17)$=2.85, $p<0.05$ (see Figure 7). No significant differences in terms of *Perceived Fun* were found between the *Menu* and *Menu + Hints* conditions.

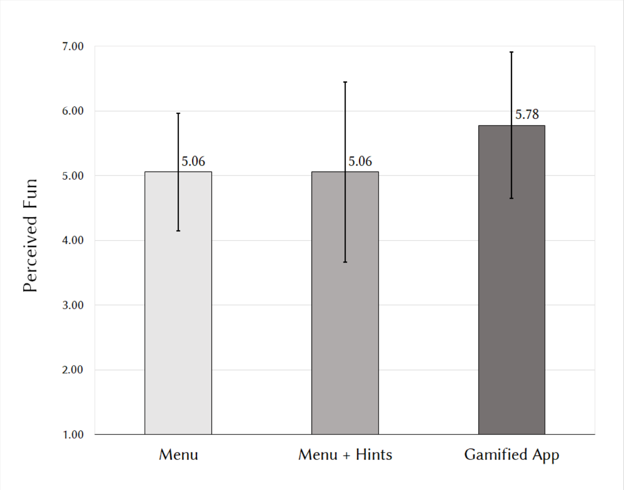


**Figure 7: Bar plot showing the average *Perceived Fun* (Likert scale from 1 - "Very Boring" to 7 - "Very Exciting") for each variant with one standard deviation as error bars.**

*Perceived Informative Content* is also based on the questionnaire which was filled out at the end of the experiment. A one-way ANOVA for repeated measures was calculated and found statistically relevant differences between the variants, $F(2)$=4.32, $p<0.05$. Post-hoc tests showed that participants rated the *Gamified App* condition ($M$=5.33, $SD$=1.91) significantly more informative than the *Menu* ($M$=4.39, $SD$=2.06) variant, $t(17)$=3.45, $p<0.01$. Comparing the *Gamified App* and the *Menu + Hints* ($M$=4.78, $SD$=2.10) conditions could not prove any significant differences. The same applies to the difference between the *Menu* and *Menu + Hints* conditions (see Figure 8).

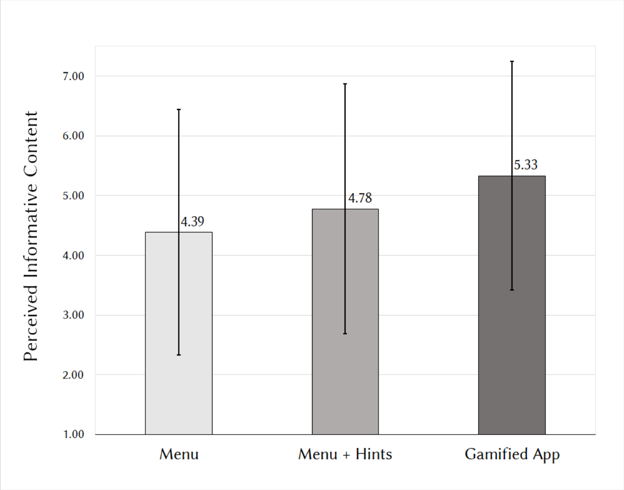


**Figure 8: Bar plot showing the average *Perceived Informative Content* (Likert scale from 1 - "I learned nothing" to 7 - "I feel enlightened") for each variant with one standard deviation as error bars.**

## 6 DISCUSSION

Results from the user study indicate that participants who played *Make my phone secure!* could achieve a short-term learning effect regarding the functionality of mobile security settings and the permission system. More precisely, by applying pre-post comparisons, we could demonstrate that participants obtained significantly higher awareness in a questionnaire designed for educational effects by playing the game. However, it is important to mention that participants' awareness could be also raised by the standard menu and the menu system that additionally provided hints. The results showed that the participants were already aware of the importance and consequences of mobile security settings.

The user study also showed that among all tested conditions, the game variant was perceived as the most fun compared to common menu structures or systems that provide help in the form of hints. Furthermore, compared to traditional menus, the gamified application was rated to be more informative.

Taking these results into consideration, we conclude that gamified applications can serve as an appropriate mean for raising the awareness of the users when it comes to granting applications permissions (e.g. to access their contacts, microphone or storage). Although, common menu structures were able to raise users’ awareness as well, gameful approaches can provide a more fun alternative. Thus, to support users to engage themselves with mobile security concerns, gamification can provide a more motivating approach.

## 7 CONCLUSION & FUTURE WORK

In this paper, a novel approach to mobile security has been presented, using gamification and game-based learning. *Make my phone secure!* is a gamified application that raises users’ awareness regarding mobile security settings. Our study shows that playing the application provided a more fun experience than the Android permissions menu. Besides, the results show that our application was perceived to be more informative than common menu structures that do not include any additional information such as hints. Since the mobile operating system developers have moved towards usable security in the last years, it is important to note that the users have found better awareness.

During the study we found that the knowledge of participants was higher than expected. In most cases they had a good understanding about their privacy settings and possible threats. Since the average age of participants of our study was rather low (about 25 years), we could assume a minimum awareness specially for young users in future studies. In order to expand our work in the future, we will work on proactive and context-aware menus for different age groups. We will consider a larger sample and also try to investigate long-term effects. Furthermore, we want to develop gamified application specifically for older adults. Also, use of Android security experts in a multiplayer gamified scenario can help to empower not only users’ security awareness but also help developers familiarize with users’ concerns.

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