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Perceived Empowerment and Empowering Behaviors with Augmented and Virtual Reality in Transdisciplinary Research

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Abstract. In transdisciplinary research, relevant stakeholders from science, government, society and economy work together to create innovative solutions to societal-relevant problems. One crucial part of transdisciplinary research is the utilization of participatory methods. Participation has the potential to empower people, a concept that encompasses on an individual level perceived empowerment and empowering behaviors amongst others. Due to the diverse context, stakeholders and outcome various participatory methods exist, including with and without the utilization of technology. AR and VR are more and more part of participatory methods in transdisciplinary research. This opens up the discussion what potential and challenges AR and VR as part of participatory methods in transdisciplinary research have regarding perceived empowerment and empowering behaviors. Results of a theoretical overview have shown that participatory methods with AR and VR may enhance perceived empowerment, particularly through participatory creation rather than just offering choices. However, challenges arise in utilizing results further in the transdisciplinary research process and addressing knowledge gaps. Regarding empowering behaviors, similar possibilities may arise since perceived empowerment and empowering behaviors are connected with each other. However, examples are limited. Based on the presented potential and challenges an exemplary implementation of a transdisciplinary research process supported by AR and VR is depicted. Future research empirically testing participatory methods with AR and VR will reveal their positive and negative impact.

Keywords: Augmented Reality, Virtual Reality, Transdisciplinary Research, Participatory Methods, Individual Empowerment.

1 Introduction

In transdisciplinary research, relevant stakeholders from different scientific disciplines and practitioners work together to solve societal-relevant issues [1–3]. This requires integration and collaboration of relevant stakeholders to increase the acceptance [4], ownership [5] and empowerment [6] of involved stakeholder groups. Participatory methods, such as transdisciplinary workshops [7] with or without Augmented (AR) and Virtual Reality (AR) technology [8, 9], have already been used to support such research processes. However, there is a gap regarding an overview of the current research on possibilities and issues of AR and VR concerning individual empowerment. Hence, the following theoretical overview investigates potential and challenges of AR and VR regarding individual empowerment in context of transdisciplinary research.

Within transdisciplinary research, scientists from relevant disciplines collaborate with practitioners, such as citizens, municipalities and local businesses [3, 10]. Here, participation can be used to integrate people into transdisciplinary processes and involve them in decision-making by taking their needs and wishes into account [11–13], conducted with participatory methods. A participatory method is defined here as any kind of technique or practice that enables relevant stakeholders to participate, similar to co-design methods [14] or co-creation tools [15]. Dependent on the context, stakeholder and goal of the participation, the participatory method varies, e.g. prototyping workshops [15] or Delphi surveys [16]. Also, continuously evolving technologies such as AR and

VR, are finding their way into transdisciplinary processes [17, 18], e.g., visualization in participatory decision [8] or virtually creating one's own world [9].

By integrating stakeholders into research processes people can get empowered [6, 19], e.g. by being part of urban decision processes [8] or independently creating flower beds and beehives for a more sustainable city [20]. Empowerment is, on the one hand, the process through which individuals, communities, and organizations gain control over their own matters, and, on the other hand, the result of that process [21–23]. On an individual level, also called psychological empowerment (PE), empowerment consists of different motivational, cognitive and behavioral aspects, such as self-efficacy and motivation to control (intrapersonal component, here called perceived empowerment), knowledge regarding the socio-political environment (intrapersonal component) and empowering behaviors (behavioral component) [24]. These different components can be a basis for an analysis of participatory methods and processes regarding individual empowerment in transdisciplinary research processes.

In transdisciplinary research, AR and VR have been utilized as tools in different participatory methods, such as immersive visualization in participatory decision processes [8] or augmented co-creation [9]. However, an overview of the current research regarding the possibilities and issues of AR and VR concerning perceived empowerment and empowering behaviors is still missing. Therefore, the following theoretical overview investigates potential and challenges of Virtual (VR) and Augmented Reality (AR), regarding perceived empowerment (intrapersonal component of PE) and empowering behaviors (behavioral component of PE) in context of transdisciplinary research. In doing so, this work will start with an introduction to transdisciplinary research and participatory methods including the influence on psychological empowerment (Chapter 2). Next, Chapter 3 will investigate challenges and potential of AR and VR applications by focusing on perceived empowerment and empowering behaviors. Finally, identified challenges and opportunities will be summarized, and directions for future research will be discussed including an example of a transdisciplinary research process supported by AR and VR in participatory methods (Chapter 4).

2 Participatory Methods in Transdisciplinary Research: A Possibility to Empower Stakeholders

Transdisciplinary research is a scientific approach in which researchers and practitioners from various relevant disciplines and expertise work together to solve societal-relevant problems [1, 3, 11]. Hence, in transdisciplinary research, practitioners are more than a target group or object of investigation, but members who participate in the research process [3, 12]. This means relevant stakeholders are part of framing the societal-relevant research problem, developing solution-oriented knowledge as well as finding and implementing suitable solutions [1]. Therefore, stakeholder involvement includes not only information, but also co-creation and other forms of participation [11, 25, 26], similar to participatory research [27] or action research [28].

An important aspect of participation as part of transdisciplinary research [11] is to choose participatory methods fitting to the aim, context and dialogue group that is supposed to be involved [29]. Similar to co-design methods [14] or co-creation tools [15], participatory methods are here understood as any kind of technique or practice that facilitate relevant stakeholders to participate in the transdisciplinary research process. Participatory methods are spatially, temporally and contextually closed, similar to real experiments in real-world laboratories [10]. This can range from one-day workshops [30] to month-long participation processes as in the application of Delphi methods [16]. Dependent on the level and method, participation enables the possibility of empowering involved stakeholders [6, 19, 25], such as co-deciding a future park design [8] or co-creating nature-based solutions for a more climate resilient city [31].

Empowerment is both the process through which individuals, communities, and organizations gain control over their own concerns, and the outcome of that process [21–23]. Individual empowerment, also called psychological empowerment (PE), encompasses peoples' beliefs and behavior regarding their possibilities to exert control about relevant aspects in their life or environment. Zimmerman [24] distinguishes between three components: First, the intrapersonal component (here called perceived empowerment) represents the individuals' beliefs and perception of empowerment. It is based on perceived control, which consists of first a personality domain (locus of control) that stands for a general disposition to expect a connection between one's activities and their consequences. The second domain is a cognitive domain (self-efficacy) focusing on one's assessment individuals make about their ability to execute behaviors required to reach their desired aims. Lastly, the third domain is a motivational domain (motivation to control [24]), which relates to the concept that gaining mastery over the environment fulfills a natural wish to affect it [21].

The second component of PE involves an understanding of the socio-political environment (interactional component) containing knowledge of relevant causal actors. Finally, the third component is the behavioral component (here called empowering behaviors) which includes any kind of participatory activity that empowers

individuals [24]. Research has shown that individuals who feel empowered (higher level of intrapersonal component) show more empowering behaviors (higher level of behavioral component) [32, 33].

With respect to participatory methods with AR and VR, research has already shown that immersive technologies have a positive influence on participatory processes [8, 9, 34]. VR has been used for visualization in co-decision processes on e.g. urban park designs [8], and AR has been developed for independently creating future scenarios [9]. Furthermore, there are approaches of connecting VR with AI for high quality results from laypeople [35] or utilizing AR as part of urban planning games [36, 37]. Current research regarding AR and VR in participatory methods focuses mainly on information and consultation (see Simonofski and colleagues [38] for a systematic review). However, research focusing on the role of AR and VR in feeling empowered and empowering behaviors is still scarce. Hence, this theoretical overview examines research involving participatory methods applied with AR and VR technologies in the context of transdisciplinary research. It evaluates the potential and challenges of these methods, with a focus on perceived empowerment (intrapersonal component of PE) and empowering behaviors (behavioral component of PE).

3 Augmented and Virtual Reality in Transdisciplinary Research

3.1 Potential of Augmented and Virtual Reality

Participatory Decisions with AR and VR. Augmented (AR) and Virtual Reality (VR) both fall under the umbrella term "Extended Reality (XR)" together with other immersive technologies, such as Mixed Reality (MR) or Augmented Virtuality (AV) [39–41]. VR generates a fully immersive virtual environment, making users feel as if they are present within the simulated setting [42]. On the other hand, AR superimposes digital objects into the real world, allowing for interaction with them in the real world [43]. Currently, AR and VR are mainly found in two areas of participatory research: participatory decision with VR [8, 44] and AR [45], and participatory creation with AR [9, 34], opening up potential for both perceived empowerment and empowering behaviors.

With VR, people are not bound to their imagination [46]. Instead, by seeing scenarios in VR they can experience possible and impossible future settings [8, 47]. It allows users to immerge into these settings by letting them experience the scenarios as if being present and interacting with them [8, 44, 48]. In participatory decision processes, this increases the chance for laypeople to be able to make a decision based on experiences, rather than solely on physical models [49] or simulations shown on a computer [50]. Weber and colleagues [44] investigated whether VR as a visualization technique has an influence on voting behavior in a fictitious participatory method. They found that more participants decided to change their voting behavior based on VR scenarios than only by text. Interviews after the experience revealed multiple affecting factors, such as liveliness of immersive pictures or the VR design itself. In connection to perceived empowerment, VR might have a chance to increase self-efficacy and following perceived control, because people might increase their comprehension of the options they can vote. Concerning empowering behaviors, Weber and colleagues showed that VR actually changed the participants' voting behavior in a fictitious scenario. In actual participatory decision methods, VR might show similar effects increasing empowering behavior.

For participatory urban planning, stakeholders can get a holistic perception of their environment with VR. Ma and colleagues [51] created a VR design in which participants were able to see infrastructure from above and belowground of a neighborhood to design a more coordinated infrastructure management plan for urban ecology. In a stakeholder workshop, they found that workshop attendees had a "further understand[ing]" of the structure and system above and belowground including its connections [51]. In addition, approaches to include AR in participatory methods within transdisciplinary research exist. Allen and colleagues [45] designed an AR app to present future architecture designs of already existing buildings. In a related user study, especially young participants stated that they would be more willing to participate in urban development projects with the AR app than without. Participants mentioned that this approach could support stakeholders to understand the design's purpose more effectively in comparison to only drawn plans. In participatory decision methods, this might increase the chance of making decisions based on holistic experience. Regarding perceived empowerment, this might create a possibility for stakeholders to get a deeper understanding of each option. This may increase laypeople's self-efficacy, since understanding the possible options to choose from is one important aspect of participation and empowerment [52]. Focusing on empowering behaviors, AR and VR might enable more people to be part of participatory decision methods with this higher level of self-efficacy.

Furthermore, research has shown that it is important for citizen to talk with facilitators in participatory decision methods with VR. In one participatory decision method with VR, citizens from the neighborhood were invited to choose between different urban park designs [8]. Independently of the visualization device – VR or paper map –

citizens felt surer about their decision if they were able to ask facilitators questions regarding the options, potentially leading to a higher level of self-efficacy. Hence, VR can be a door opener especially since utilizing VR in participatory decision methods is still rather new [44] increasing the chance of being interesting. Even individuals who might not be that interested in participating still might be interested to experience possibilities via VR. In relation to perceived empowerment, the combination of experience in VR and discussions with facilitators might increase motivation to control since stakeholders would have multiple communication styles to understand their available options thoroughly. Additionally, the still new idea of utilizing VR in participatory decision methods might increase empowering behaviors because people might first be interested in testing VR and then utilizing it in participatory methods.

Summarizing, participatory methods with AR and VR as part of participatory decision might have the potential to increase self-efficacy and motivation to control – both aspects of perceived empowerment. With AR and VR, stakeholders have the chance to experience the different options in decision-making in a more holistic way than only by computer visualization or without any technology. However, research has shown that citizens prefer the possibility to ask questions to ensure an informed decision, independent of the visualization device [8]. Here, VR might be a door opener for discussion to not only include stakeholders who are interested in participating but also those who might first be interested in the technology, increasing potentially empowering behaviors. In fictitious participatory decision methods, research has already shown that VR changed participants' voting behavior [44]. This shows potential to transfer such approaches into actual participatory decision methods, which might lead to more empowering behavior.

Virtually Creating Something New. With participation, empowerment is already part of the process and not only the result since stakeholders have the chance of self-determining and co-determining their affairs in the ongoing process [19]. One possible way to use VR and AR in participatory methods is to let stakeholders create their own future, by adding or moving new objects [53, 54]. Saßmannshausen and colleagues [9] designed an AR app for citizens to create their own environment by visually placing new objects into the existing environment. With this app, citizens were able to create their own future park and could share their creations with others on social media. Results have shown that participants would be interested in using the app for participation at launch. This shows potential for empowering behaviors especially since stakeholders might start creating their own future independently of a facilitator moderating the participatory process. Concerning perceived empowerment, this indicates an increased motivation to control since participants felt motivated to participate.

Also, Hunter and colleagues [34] created AR apps to increase citizen participation. They found that apps in which citizens could interact and create something new on their own were preferred than only communicative visualization apps because they felt a higher sense of agency. Focusing on the potential of perceived empowerment, AR apps in which stakeholders can create their own future have a higher chance of letting them feel empowered, because especially motivation to control might rise. In connection with a close link to actors in power, such as local government, empowering behaviors might increase, especially if there is a credible assurance that the outcomes of participatory creation methods with AR are taken into account in further creation processes.

Since Artificial Intelligence (AI) is rising, in connection with VR it offers potential for new creative design changes. In their research, Bussell and colleagues [35] combined VR and a text-to-image AI-framework. Their idea was to integrate this AI-framework into VR-mediated co-design workshops and hence support urban design participation. By utilizing this AI-framework, workshop participants could create their ideas of alternative scenarios by only using words, which Bussell and colleagues could transfer into VR scenarios in the next step. Focusing on perceived empowerment, such connection might have a potential of increasing self-efficacy since involved stakeholders would not need good skills in drawing or be otherwise creative. Instead, dependent on the quality of AI stakeholders would have the chance to create their own vision by expressing their ideas presented in VR. Similar to perceived empowerment, the connection of VR and AI have potential for empowering behaviors, especially due to the possible reduction of quality differences between experts and laypeople in designs.

In transdisciplinary research, often research is focused on future urban planning [1–3]. Hence, participatory processes might be location-based. In connecting AR and VR with GPS and other location data [54, 55] participatory methods with AR and VR might open up the chance for location specific creation by stakeholders. On the one hand, this might create a possibility to new future designs created by stakeholders and easily located. On the other hand, it might decrease understanding barriers about relevant locations for future participatory creation. Regarding perceived empowerment, in the first case, self-efficacy might increase because stakeholders might have a clear location to participatory re-create in combination with the creative vastness of AR and VR. The second case might have the potential for increased motivation to control because long and frustrating discussions about relevant locations might decrease. Both these cases might increase empowering behaviors, since

the first case creates a clear located topic to participatory work on. In the second case, by possibly decreasing long discussions, more time might be available for action.

In summary, participatory methods with AR and VR as participatory creation tool have potential to increase perceived empowerment and empowering behaviors. Research has already shown that creating something with AR creates a higher sense of agency than only visualizing [34]. Hence, especially in combination with AI and location-data participation with a high quality creation of location-specific designs might be possible, which might increase perceived self-efficacy and motivation to control, both relevant aspects of perceived empowerment. If also believable assurance of further processing participatory created results in the final design exists, perceived control might increase as well, and empowering behaviors enabled through AR and VR might succeed.

3.2 Challenges of Augmented and Virtual Reality

Real participation requires at least some sort of participatory decision or creation – in transdisciplinary research [6, 25, 56] or other contexts [5, 19, 57]. Otherwise, one is only at a preliminary stage of participation, meaning no actual participation exists and the impact of stakeholders in the final result is limited [52, 57]. This might lead to only an "illusion of power" without real possibility for the stakeholders to influence the outcome [58]. Following, to actually increase perceived empowerment and empowering behaviors, participatory methods with AR and VR need to ensure stakeholders that their input is taken into account, which is not automatically the case [45]. After developing their AR application for visualizing planned reconstructions at a building, Allen and colleagues [45] asked citizens about their willingness to participate. They found that participants of a user study were not sure how their opinion mattered to the constructions and whether their voting would be taken seriously. Especially, they mentioned that facilitators would be more interested in the opinion of businesses than the public. This shows that even though voting systems with visualization via AR shows potential for perceived empowerment, especially motivation to control and self-efficacy might be reduced in such a case, leading to reduced empowering behaviors.

Additionally, Fegert and colleagues [59] found that stakeholders were only willing to participate up to a certain participatory level: mainly information. In their development process of AR and VR applications for participation, stakeholders from different transdisciplinary contexts – citizens as well as project initiators – raised concern about citizens' competence to participate. Regarding perceived empowerment, this indicates a general low level of self-efficacy: Citizens and other stakeholders did not perceive the public's expertise to be high enough to be able to participate reliably in a participatory budgeting process. This shows that core challenges in participation in transdisciplinary research as well as other participatory projects, such as addressing practitioners' needs [2] or understanding non-academics as "extra-academic experts" [60], do not stop with AR and VR as part of participatory methods. Instead, the question raises whether AR and VR may be able to meet these challenges and how that might be possible.

With participatory creation methods, perceived empowerment has a chance to be higher than only visualizing future settings. Citizens perceived a higher level of agency in case of interacting with and creating new environments than only experiencing visualizations in AR [34]. However, similar to visualization apps this feeling may fade soon if stakeholders think that their input is not valued, since self-efficacy might decrease and following motivation to control. Due to the connection between perceived empowerment and empowering behaviors [32, 33], empowering behaviors might be decreasing as well. Hence, to increase perceived empowerment and empowering behaviors, it may be crucial to assure participating stakeholders that their contributions are considered in the final design. Otherwise, if stakeholders feel undervalued, their motivation to control and self-efficacy and following perceived control might ultimately decrease. In practice, this brings challenges for participatory methods in general, but also for participatory methods with AR and VR: How can be ensured that results are taken into account into the further creation, design and development process? How can participating stakeholders be sure that their work is not only appreciated, but also reflected in the final designs?

Within transdisciplinary research, practical challenges of AR and VR application may arise in the utilization in participatory methods, like in other contexts. Even though quality of VR increased immensely since first development [46, 61], motion sickness still becomes an issue from time to time (see Saredakis and colleagues for a systematic literature review [62]). Especially, younger people (<35 years) are more vulnerable to motion sickness, a dialogue group that preferred participating with AR technology rather than without [45]. Focusing on perceived empowerment and empowering behaviors, this example shows that there is not a one-fits-all solution for participatory methods. Even, AR and VR are not able to empower every stakeholder. Instead, researchers need to be aware of their dialogue group and stakeholders with their needs and wishes to conduct according participatory methods with or without AR and VR.

Even though potential for participatory methods with AR and VR exist for perceived empowerment and empowering behaviors, examples of participatory methods with AR or VR as enabler of empowering behaviors are still scarce. In their systematic literature review, Simonofski and colleagues [38] found no independent citizen

activities enabled or supported by AR or VR. AR and VR were mostly utilized for information and consultation [38], both preliminary levels of participation [57]. Therefore, the question arises why examples for AR and VR utilized on higher levels of participation, such as participatory decision [45, 50] or participatory creation [9, 34] are still scarce. What hindering reasons exist? What challenges reduce the potential for empowering behaviors in practice?

Summarizing, challenges emerge on the one hand in the further utilization of results from participatory methods with AR and VR. If stakeholders do not see reason to believe, that their input will be reflected in the final design, or if they do not feel competent enough to enter valuable feedback, self-efficacy and motivation to control may diminish. On the other hand, empowering behaviors enabled or supported by VR or AR are not often found in research. Therefore, the question arises: what reasons hinder AR and VR to show their potential in participatory methods? Additionally, participatory methods with AR and VR are not a one-fits-all solution. Hence, for successful participation with AR and VR in transdisciplinary research scientists need to be aware of their dialogue group and choose their participatory method accordingly – with or without AR and VR.

4 Conclusion and Future Directions

4.1 Possibilities to Increase Perceived Empowerment and Empowering Behaviors

In this article, a theoretical overview was presented focusing on possibilities and challenges regarding perceived empowerment and empowering behaviors utilizing Augmented (AR) and Virtual Reality (VR) in participatory methods in context of transdisciplinary research. Results have shown that AR and VR have potential to increase perceived empowerment and empowering behaviors due to the possibility of perceiving holistic [44] and future scenarios [8] with immersive images [44], creating independently one's own future [9] in high quality in connection with AI [35] and easily spreading ideas via social media [9]. However, especially empowering behaviors enabled and supported by AR and VR are still scarce [38], questioning what hindering factors may exist.

In relation to potential and possibilities of participatory methods with AR and VR in transdisciplinary research, results have shown that current research presents chances for AR and VR to increase perceived empowerment (intrapersonal component of PE [24]) and enable empowering behaviors (behavioral component of PE [24]) of stakeholders. Current research shows two directions of participatory methods: participatory decisions with AR and VR [8, 45] and participatory creation with AR [9, 34]. Both directions have potential for perceived empowerment since they might increase self-efficacy and motivation to control (see Chapter 3), with an even stronger chance for participatory creation with AR [34]. Regarding empowering behaviors, simulations of participatory decision making already showed a change of voting behavior based on VR [44], indicating possibilities for real participatory decision making with VR.

Additionally, AR and VR have the advantage of a possible connection to AI [35] and location data [54, 55] which might have the chance of increasing self-efficacy leading to a higher level of perceived control. Since perceived empowerment and empowering behaviors are connected to each other [32, 33] these potentials should stand as well for empowering behaviors. In addition, with the connection of AR and social media [9] stakeholders may be able to spread their ideas amongst communities, hence, possibly extending reach and influence. With regular evaluations of conducted participatory methods with AR and VR in transdisciplinary research, future research may get a deeper understanding of their influence on perceived empowerment and empowering behaviors. Empirical evidence can reveal which aspects of perceived empowerment – such as the motivation to control and self-efficacy – are particularly enhanced by using participatory methods with AR and VR. Additionally, empirical evaluations may show which of these aspects may increase empowering behaviors enabled by AR and VR.

4.2 Future Research – Meeting Challenges and Further Empirical Testing

Encouraging Empowering Behaviors with AR and VR. Since examples for actual empowering behaviors are still little [38], challenges in practical implementation of AR and VR in participatory methods might exist hindering the actual realization of transdisciplinary research. One challenge of AR and VR as supporters for empowering behaviors might be the lack of time. Participatory processes in transdisciplinary research take time [2]. Relevant stakeholders need to be identified, and fitting participatory methods need to prepared, conducted and analyzed. In context of AR and VR as part of participatory methods, this preparation time can take even more time since relevant technology needs to be designed [9]. Due to the frequently short-term nature of research projects [63], this timeline may result in incomplete participatory processes and the lack of actual use of AR and VR in participatory methods within transdisciplinary research. Consequently, it may fail to enable empowering

behaviors of relevant stakeholders via AR and VR. Whether time is a limiting factor for empowering behaviors may be seen in future long-term research projects focusing on AR or VR as part of participatory methods. Additionally, if stakeholders are already part of the development process of AR and VR technology, similar to the AR application developed by Saßmannshausen and colleagues [9], interest in being part of participatory methods can already be reached while development. This could be another way to alleviate the practical issue of time, as the technology may already be familiar and tested by the relevant stakeholders, potentially enhancing their ability to use it effectively.

Another challenge for empowering behaviors via participatory methods with AR and VR might be the multifaceted expertise for a long-term utilization of AR and VR as part of participatory methods. To be able to utilize AR and VR as part of participatory methods, on the one hand moderating and facilitation skills are needed, skills which are often associated with social sciences and design [4, 14, 64]. On the other hand, skills regarding utilization and (further) development of AR and VR are needed to ensure an ongoing quality and usability guarantee – skills that are often affiliated with computer science and engineering [61, 65]. Hence, a connection of these two skill sets might be necessary, which especially long-term members from various stakeholders might need to enable empowering behaviors through participatory methods with AR and VR in transdisciplinary research. Whether learning these skill sets, such as teaching co-creation, as part of study programs [65] or via mutual learning through transdisciplinary research [1, 2] might be a requirement for a long-term utilization, may be investigated in future transdisciplinary research projects focusing on participatory methods with AR and VR.

In addition, one challenge of AR and VR in relation to perceived empowerment and empowering behaviors may be to ensure the further utilization of participatory created results believably. This is not guaranteed automatically [45]. So, how is it possible to assure credibly that input conducted by participatory methods with AR and VR matter? In PE, the third component – interactional component – focuses on the knowledge of actors in power [24]. Participatory methods with AR and VR showed two general directions of participatory methods: participatory methods with a person as facilitator [34] or without [9]. In the first case, if the facilitator is an actor of power or has direct connection to them, the trust may be created via the facilitator. In the second case, other ways to ensure further utilization of the created input must be found. Here, social media [9] or other communication connections may be successful. Future research on these two cases is needed to investigate ways to believably ensure stakeholders that their participatory created results are reflected in the final design.

Summarizing, multiple challenges conducting participatory methods with AR and VR might come up, like needed multifaceted expertise, time-consuming technology designs or the long-term utilization of participatory results. Challenges that empirical research in conducted participatory methods within transdisciplinary research will show. However, focusing on these challenges and meeting them accordingly might allow AR and VR to show its advantages in comparison to other techniques of participatory methods within transdisciplinary research, like a holistic understanding of future designs in participatory decision or a participatory creation of one's own future individually.

A Transdisciplinary Research Process with Empowering Participatory Methods with AR and VR. In this theoretical overview, multiple advantages and challenges for AR and VR are presented concerning perceived empowerment and empowering behaviors. This leads to the question how AR and VR can support participatory methods to increase perceived empowerment and empowering behaviors, and how to meet the mentioned challenges in transdisciplinary research. Currently, AR and VR are integrated into two primary areas of participatory methods: participatory decision making and participatory creation (see Chapter 3). Additionally, participatory methods with VR and AR are either with a person present as a facilitator [8, 34] or without [9]. As mentioned above, with participatory creation people feel more empowered than with participatory decision-making. However, the right form of participatory method is not only dependent on the maximum level of empowerment but also on the context, stakeholder and outcome [29]. Hence, an exemplary transdisciplinary research process with possible participatory methods with AR and VR will be presented here:

According to Lang and colleagues [1], a transdisciplinary research process starts with framing collaboratively the research problem. Dependent on the broadness of the research problem, VR in connection with AI could support here the transdisciplinary research framing by giving stakeholders the opportunity to not only describe current existing problems but also design them in VR, similar to Bussel and colleagues [35]. Hence, transdisciplinary researchers and other stakeholders could get a deeper understanding of the problem, as Ma and colleagues [51] mentioned in their research. This might especially increase self-efficacy and following empowering behaviors.

In case of location-based problems, such as urban planning [2, 3, 31], a connection of GPS and other location data systems [54, 55] with AR might bring the problem designed with AI and visualized by the stakeholders together with its direct location. Stakeholders could conduct this location-based problem search with AR

independently of a facilitator as a person, similar to Saßmannshausen and colleagues [9]. This possibility for asynchronous and convenient problem finding might increase motivation to control and empowering behaviors. Such independent participation requires an easy understanding of the AR application. It needs to be able to lead participating stakeholders through the participatory task individually. Important is here to accommodate citizens' wish for a contact person to talk to as van Leeuwen and colleagues [8] found. Hence, the technology needs to take upon the role of the facilitator. In addition, if the AR app also shows a direct contact to actors in power, and how the results of the asynchronous participatory method contribute to the general transdisciplinary research, it might increase especially motivation to control and self-efficacy without losing the influence of the facilitator role in transdisciplinary research. Summarizing, in the collaborative framing phase relevant societal problems might be found sufficiently via VR and AR. Hence, stakeholders might perceive empowerment as well as show empowering behaviors through participatory methods with AR and VR in this early transdisciplinary research stage.

After collaborative framing the research problem, the transdisciplinary research team generates co-creatively knowledge to find solutions for their research problem [1]. Here, AR and VR can support participatory creation. In case of urban future planning, a drag-and-drop system of prepared virtual objects connected with location-data could allow the design of new futures without quality reduction similar to Saßmannshausen and colleagues [9]. In connection with AI, stakeholders could even create these virtual objects on their own analogous to Bussel and colleagues [35], allowing a higher level of motivation to control. To accommodate the concern of laypeople's lack of expertise [59], transdisciplinary researchers could start such asynchronous participatory solution creation by in-situ workshops. In such a workshop, stakeholders could experience solutions in other contexts in VR, such as nature-based solutions of other cities, as well as get a further holistic understanding by presenting the current situation including its constraints in VR, as Ma and colleagues [51] did. In connection to PE, such forms of utilization of AR and VR as part of participatory methods might increase perceived empowerment and empowering behaviors.

In the last phase of a transdisciplinary research process, the co-created solutions need implementation into the scientific and real-world [1]. Here, AR and VR may specifically support with participatory decision-making. Similar to van Leeuwen and colleagues [8] decisions between multiple design options may be holistically made if experienced in VR. As mentioned above, VR already had an influence on simulated voting behavior because of the immersive experience amongst others [44]. Hence, perceived empowerment and empowering behaviors might increase, as long as above mentioned aspects like the concern of citizens' lack of expertise [59] are sufficiently accommodated.

Future research should investigate in all phases of transdisciplinary research how AR and VR can support participatory methods accordingly. Especially, empirical studies should bring systematic insights on the different aspects of perceived empowerment (intrapersonal component of PE [24]) and empowering behaviors (behavioral component of PE [24]). Empirical studies with qualitative, such as semi-structured interviews of participating citizens, and quantitative data collection, including validated questionnaires (see Cyril and colleagues [66] and Nordink and colleagues [67] for systematic literature reviews on empowerment measures) could answer questions regarding perceived empowerment. For empowering behaviors, additionally quantitative data of participating stakeholders like the amount of people or number of different results could increase the current research knowledge. With qualitative research, the quality of outcomes of participatory methods in transdisciplinary research could enlighten the effect of AR and VR in transdisciplinary research.

In conclusion, this theoretical overview searched for potential and challenges of AR and VR as part of participatory methods regarding perceived empowerment and empowering behaviors in transdisciplinary research. Potential for perceived empowerment might be the holistic and immersive experience as well as virtual creation of future designs. In combination with AI and social media, AR and VR might bring a level of quality and importance into stakeholders' designs, which might enable empowering behaviors – especially for laypeople. One challenge of AR and VR as part of participatory methods for perceived empowerment is the further utilization of created results. In addition, citizens' potential lack of expertise need appropriate consideration. For empowering behaviors, practical challenges might exist, such as lack of time in transdisciplinary research and a possible requirement of a multifaceted skill set to conduct successful participatory methods with AR and VR. With focusing on how to meet these challenges, future research might overcome them and reveal the fully potential of AR and VR in participatory methods in transdisciplinary research.

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