Better Together: Responding to Crisis through Transdisciplinary Approaches and New Tools

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Abstract *Challenges posed by the climate crisis are highly complex and are overwhelming for people to face and to tackle. To address these challenges, it is necessary to consider and integrate together different perspectives and expertise from various stakeholder groups, including those of scientists and civil society. However, including citizens in city planning for climate resilience is demanding, especially in times of scientific scepticism and disbelief towards climate change, and therefore their inclusion requires new approaches. Transdisciplinary research can address these challenges by including scientists and citizens from an early research stage leading to a high interest in, and a need for a co-design approach as well as co-creative and transdisciplinary ways of working and researching. For transdisciplinary research to unfold its full potential in addressing complex, real world problems holistically, it has been effective in the recent past to implement co-designers in new approaches such as living labs or real-world labs (German: Reallabor) in order to meaningfully include all these different perspectives as well as providing a purposeful approach for transdisciplinary work across different disciplines.*

Cologne University of Applied Sciences aims to enable co-creative research in real-world labs and is therefore piloting the project Co-Site which focuses on the topic of green, blue and critical infrastructures in the region with the aim of strengthening climate resilience and management in crisis situations. Within the Co-Site project, three laboratories or tools for the co-design work are planned to be set up: (1) an Extended Reality (XR) laboratory; (2) a mobile laboratory; and (3) a co-creative workspace as a laboratory for collaborative work with citizens and other stakeholders, which are thus the focus of the here presented study. In order to follow a participatory approach and to co-creatively set up these three laboratories, the authors conducted an online study within the project focusing on the research question "how do experts from different disciplines envision their transdisciplinary work with stakeholders in the laboratories as part of a real-world lab focusing on climate change adaption strategies and climate crisis, and which methods and tools could enable their co-creative work within?

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In the study, 11 members of the newly started real-world lab project answered various questions regarding their idea of working transdisciplinary with stakeholders and citizens in the three laboratories in the coming years. Results showed that participants plan to use the co-creative space more as a collaborative space and use the mobile laboratory more to interact with communities and stakeholders. In contrast, the focus of the XR-laboratory is on the visualisation of climate change and urban planning.

Author keywords *co-design; climate change; real-world labs; transdisciplinary methods*

1. Introduction

In the current state of climate change and climate crisis, new tools and approaches are needed to find solutions to complex problems, one of them being behaviour change of individuals within the wider society (Owen, 2020). Behaviour change is often associated with effort, such as economical effort (Fankhauser, 2017). Therefore, constructive solutions with a visible benefit for affected stakeholders and communities, and consequently a higher chance of successful execution are needed (Williams, 2020). This poses the question of how such solutions can come into existence and can be implemented.

The real-world lab is one approach addressing such complex societal challenges by allowing various stakeholders from science, the public sector and civil society as well as citizens to be part of the process and solutions that are generated in a co-creative way, thus allowing for wider acceptance of the solutions created (De Flander, Hahne, Kegler, D. J. Lang et al., 2014; Parodi et al., 2016; Bergmann et al., 2021). Co-designers and co-design methods are often used in these settings to work with those varying stakeholders in order to integrate them into the project (Defila & DiGiulio, 2018). Thereby, co-design can be understood as an umbrella term for different collaborative design methodologies, e.g., social design, participatory design, and community design (Murdock, Osgood & McCarvill, 2023).

The transdisciplinary *Co-Site* project that started in January 2023 and is led by the University of Applied Sciences Cologne follows a real-world lab approach, while exploring different tools—namely three participatory laboratories—which are supposed to support the co-design and the co-creative aspect of the project. The aim of the project is to apply co-creation in sites near the city of Cologne, in order to address climate risks such as flooding and heat and to develop climate adaption strategies while developing systemic and innovative transfer. The regional partners and their respective regions were amongst others heavily impacted by flooding in July 2021 (Federal Ministry of the Interior and Community of Germany and Federal Ministry of Finance of Germany, 2021). Therefore, the focus of the project is not only the scientific expertise, but more so the transdisciplinary cooperation between science, the public sector and local practitioners, such as the communities, and the integration of different forms of knowledge through participatory work and new ways of learning together (De Flander, Hahne, Kegler, D. Lang et al., 2014).

In this paper, the authors explore through a study with members of the research project how new tools in the form of three laboratories could be useful in order to work collaboratively and transdisciplinary with stakeholders and communities on the topic of crises and climate adaption strategies. This question arose as part of a co-creative process, led by the co-design team, to design and set up these laboratories as an infrastructure for the project: (1) a co-creative space for collaborative work located in Cologne, especially to integrate the transdisciplinary project into student programs, such as game-based learning (Varney, Mai & Varney, 2023); (2) a mobile laboratory in the form of a van in order to reach citizens, communities and stakeholders in the cities and regions that are project partners; and (3) an Extended Reality (XR) laboratory with Virtual Reality (VR) and Augmented Reality (AR) equipment, which will be integrated into the co-creative space as well as into the mobile laboratory.

The aim of the study is to integrate the needs of the project-internal researchers from different disciplines; for instance green- and blue infrastructures (GBI) such as urban parks or urban waterways (Venkataramanan et al., 2019); critical infrastructure (CRITIS), meaning organisations and facilities which would result in lasting supply bottlenecks in case of a failure (Federal Ministry of the Interior of Germany, 2006); VR/AR programming; co-design; and science communication. The co-design team conducted the here presented study to better understand the researchers' needs and various ways of envisioning working in the aforementioned laboratories, to come up with a concept for the shared project infrastructure for the co-design work within them. It lays open the differences between disciplines and different ontologies and the challenges they pose to transdisciplinary ways of working in collaboration and setting up the "right" spaces for these ways of working. In this paper, the conducted study is presented. The theoretical context of real-world labs, participation and co-design are particularly illustrated, since participants (project members) plan to use the laboratories as tools for such research. The procedure and analysis of the study is depicted in detail due to the qualitative character of the conducted study. Within the discussion, the results are contextualised and analysed in relation to everyday co-design practices.

2. Real-world Labs, Participation and Co-Design

The idea of a real-world lab (German: *Reallabor*; Parodi, Steglich & Bylund, 2023) is to develop and create sustainable transformation for, with and in society which requires transdisciplinary research and participation, meaning research with different disciplines and practice partners, such as communities and other stakeholders (Bergold & Thomas, 2010; Defila & DiGiulio, 2018). According to De Flander et al. (2014), the value of the real-world lab work is in the generation of context-specific, socially robust knowledge, which promotes social innovation locally (De Flander, Hahne, Kegler, D. Lang et al., 2014). Furthermore, real-world labs include the users and their needs in the process, allow their participation, and create with it opportunities for solutions that are alternatives to the common problem-view within the context of technical and organisational feasibility, a view which is prevalent in Living Labs (Parodi, Steglich & Bylund, 2023). Living Labs focus on user-centric innovation and co-creation of products, services and technologies in real-life temporary test settings in an open and distributed innovation process (Bergvall-Kåreborn et al., 2009; Liedtke et al., 2015; Hossain, Leminen & Westerlund, 2019). In contrast, real-world labs are designed to conduct transdisciplinary research with a long-term orientation and experiments in real-world settings to address societal challenges and contribute to transformations (Bergold & Thomas, 2010; Schäpke et al., 2018; Bergmann et al., 2021). Their wider scope includes societal, economic and environmental dimensions and is often focused on specific geographical areas to address systemic challenges within those areas.

Participation in the context of real-world labs involves practice partners and stakeholders who are affected by the results of the work in real-world labs (Defila & DiGiulio, 2018). Stakeholders are hereby understood as people "who choose to involve themselves in a particular issue" (Creighton, 2005, p. 23) similar to practice partners (Defila & DiGiulio, 2018) or community engagement (Natarajarathinam, Qiu, & Lu, 2021). In this context, the focus is on participatory transdisciplinarity, such as the full inclusion of the practice partners into the knowledge production process and therefore the equal validation and acceptance of the knowledge of everyone involved (Mobjörk, 2010). Such involvement of a variety of stakeholders requires different disciplines, including domain expertise (in GBI and CRITIS) and facilitation skills (e.g., social sciences or design; Sanders & Stappers, 2008; Evans & Terrey, 2016) because researching in real-world labs involves the deliberate use of participation to achieve a tangible impact (Seebacher, Alcántara & Quint, 2018).

Co-design plays a central role within participation and research in real-world labs (Defila & DiGiulio, 2018), because it is a practice where people come together to connect their skills, knowledge and expertise to create solutions for complex problems with designers having the facilitator role in this process (Lotz-Sisitka et al., 2016; Tromp & Hekkert, 2019; Chapa, Perez Rubi & Hack, 2023). co-design can create a shared understanding and common ground within a project and therefore enables and enhances the transdisciplinary collaboration (Bergmann et al., 2021). Dependent on the origin and scientific area, co-design entails different design and working strategies, such as collaboration, co-operation or connection of practices and resources (Zamenopoulos & Alexiou, 2012), one approach being social design

(Murdock, Osgood & McCarvill, 2023). co-design in real-world labs and social design share commonalities; both are inter- and transdisciplinary, user-centric approaches, using interventions and experimentation, and they both heavily rely on involving communities in order to address complex societal challenges (Defila & DiGiulio, 2018; Tromp & Hekkert, 2019). The idea behind co-design is the deliberate utilization and integration of a variety of stakeholders from different perspectives to bring about positive change (Vargas et al., 2022) and therefore it is essential for participatory transdiciplinarity in real-world labs (Seebacher, Alcántara & Quint, 2018). Within these approaches, participatory processes are used to empower people to redesign better alternatives for their communities (Zamenopoulos & Alexiou, 2012; Tromp & Hekkert, 2019).

Empirical research shows that co-design methods are useful in promoting interactions between relevant stakeholders (White & van Koten, 2016) and significantly increasing idea generation in innovation processes (Mitchell et al., 2016). Hence, co-design can increase the quality of knowledge generation in real-world labs by, for instance, figuring out relevant research topics (Rhodius et al., 2016). However, a central part of co-design is the deliberate choice of the tools and methods depending on the context, stakeholders and the planned outcome (Zamenopoulos & Alexiou, 2012). Hence, co-design approaches vary strongly dependending on the context and stakeholder integration, and range from individual interviews, focus groups, design thinking or prototyping, even to the integration of new methods such as VR or makeathons (Evans & Terrey, 2016; Dübner, Fanderl & Heydkamp, 2018; Reed et al., 2019). Therefore, the question arises as to how different experts in transdisciplinary research can work and research with different stakeholders, practice partners and communities and which methods can enhance participatory transdisciplinarity and co-design research in the context of a real-world lab project regarding climate change and climate crisis.

3. Methods

Online Study

To co-develop the three different laboratories (XR-laboratory, mobile laboratory and co-creative space) used as infrastructure and tools for co-design and participation within the transdisciplinary *Co-Site* project, the authors conducted an online study via SoSci Survey (Leiner, 2019) with qualitative and quantitative questions regarding these laboratories. An online study was chosen because it allowed a time-efficient and individual schedule for participation due to a tight timeline for planning and realising the laboratories. A method that limits the external influence on the participants coming from other participants (e.g., focus groups) or the authors (e.g., via interviews) was chosen since all participants and authors work together on a daily basis, and possible group dynamics could have influenced the answers (Mayerhofer, 2007). By conducting an anonymous online study, the plan was to decrease the chance of influence on data. To deal with the challenge of the participants' not being able to ask questions in online studies, participants were encouraged to reach out to the authors for any questions.

To deliberately include the researchers' needs and co-design the laboratories, the study was conducted in an early stage of the project. Hence, not all participants might have already worked in a participatory manner. The research question addressed with this study is the following: how do experts from different disciplines envision their transdisciplinary work with stakeholders in the laboratories as part of a real-world lab focusing on climate change adaption strategies and climate crisis, and which methods and tools could enable their co-creative work within? The evaluation of the laboratories will be continued throughout the project.

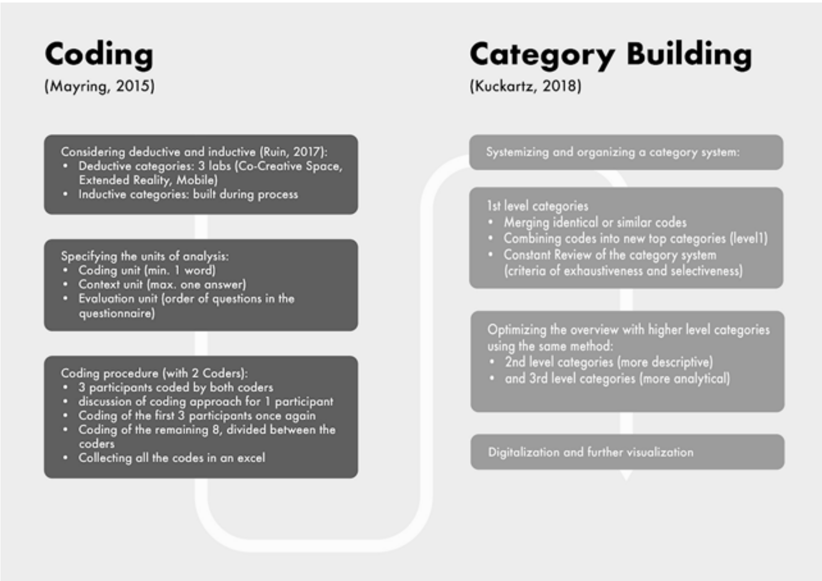
Eleven Experts from different fields (two co-designers, one science communicator, three GBI engineers, one CRITIS engineer, two AR/VR programmers, and one project manager) participating in the transdisciplinary research project *Co-Site* answered questions to explicate their needs in the period between March 30 and May 10, 2023. For each laboratory, eleven participants of the study (six women, four men, one person did not specify their gender; age: $M = 36.4$ years, $SD = 10.06$) were introduced to the general concept of the laboratory via a small explanatory text. Afterwards, participants could submit their planned way of working participatorily in one of the laboratories and answered questions regarding the working situation, such as "what does the work situation look like?" or "what methodological approaches could you implement in the creative and experimental spaces?" Furthermore, a question was posed regarding how the laboratory should be designed and whether specific tools are needed for the experts to work in a participatory manner sufficiently. Finally, participants were asked to name further relevant people needed to be involved in the design process, and how often they plan to use the different laboratories (Scale from 0 = very rarely – 100 = as often as possible). Access to the questions is possible through the Open Science Framework storage (Bickert-Appleby et al., 2023).

Analysis of Qualitative Data

For the qualitative data analysis, the approaches of the qualitative content analysis by Mayring (2015) and Kuckartz (2018) were combined. For the analysis of the three laboratories, the first step consisted of coding the qualitative data. Coding describes the scientific method of systematically handling the material based on a category system by summarising qualitative answers into a few terms (Kuckartz, 2018). Further steps were to bind the codes into broader categories. With respect to Mayring (2015) and Ruin (2017), the three laboratories formed pre-determined deductive categories. The inductive categories were built during the process of coding and categorising. The coding procedure was carried out by two coders and is presented in detail in Figure 1. They coded three participants individually and discussed their approaches regarding one participant to understand each other's way of thinking. Based on their discussion, the answers from the first three participants were coded again and the remaining eight participants were divided between the two coders for final coding (cf. blue boxes in Figure 1).

Afterwards, the coders categorised the codes as a team to include as many perspectives and possibilities of interpretation as possible (Kuckartz, 2018). To form the first category level (L1-category), identical or similar codes were merged and combined into categories for each laboratory and each question. During this procedure the category system was constantly reviewed considering that the categories needed to make sense and to be exhaustive and selective. Following Kuckartz (2018) similar L1-categories were bound into second level categories (L2-categories, more descriptive) and third level categories (L3-categories, more analytical) for optimising the overview (c.f. orange boxes in Figure 1). This process resulted in four L3-categories for the co-creative space, five for the XR-laboratory and three for the mobile laboratory.

Figure 1: Diagram of coding process.



4. Results

For each laboratory, L3-categories of the laboratories are the final results of this qualitative analysis. Due to exploratory qualitative research being characterised by its process-oriented manner, for each laboratory one example intends to make the process of the qualitative analysis clearer to the reader.

Regarding the co-creative space, L3-categories are *Transdisciplinary Working, Knowledge Management, Creative Equipment* and *Space*, as can be seen in Figure 2. The grey boxes show the L3-categories, each consisting of two to three L2-categories (orange boxes in Figure 2). As an example, the coding strategy for L3-category *Transdisciplinary Working* was the following: The coders decided for this L3-category because the L2-categories (*Collaboration, Methods* and *Stakeholders*) indicate a general coming to terms with the main idea of the project, which is to find out ways to transmit knowledge in a transdisciplinary network including many stakeholders. L1-categories for *Collaboration* bundled up from *Collaboration, Participation* and *Joint Activities*. The main aspect under which these three terms were grouped together by the coders was the idea of sharing either ideas, workload, or information in some sort of synergetic way.

Figure 2: Level two (orange) and level three (grey) categories of Co-creative Space.

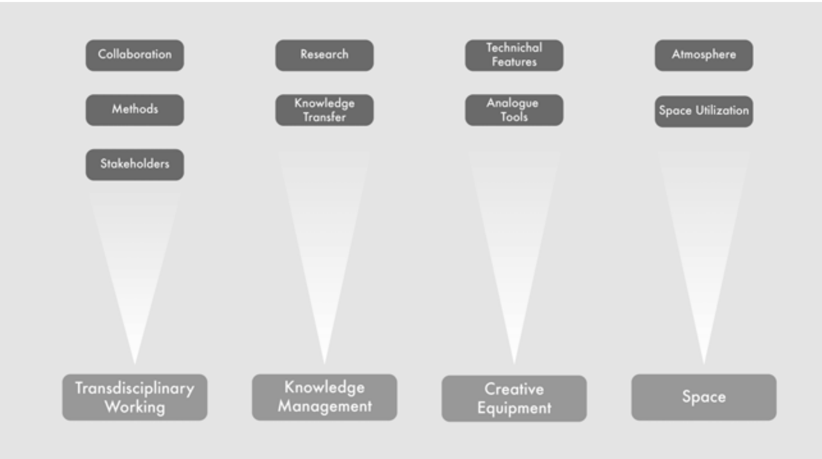


Figure 3: Level two (orange) and level three (grey) categories of XR-laboratory.

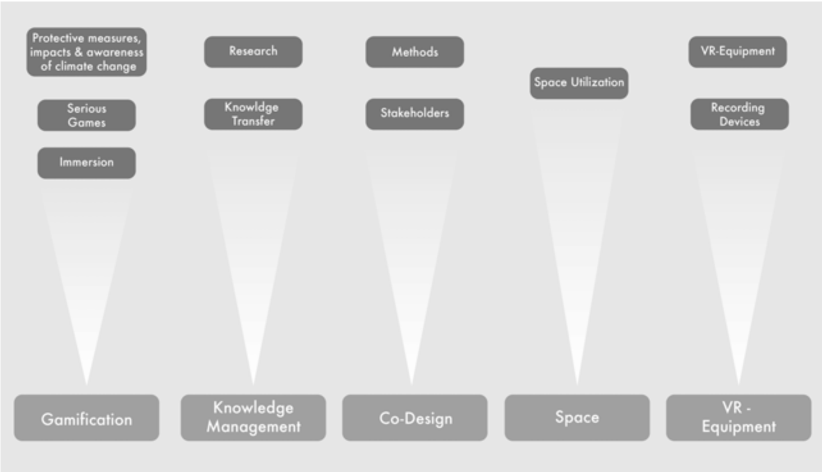
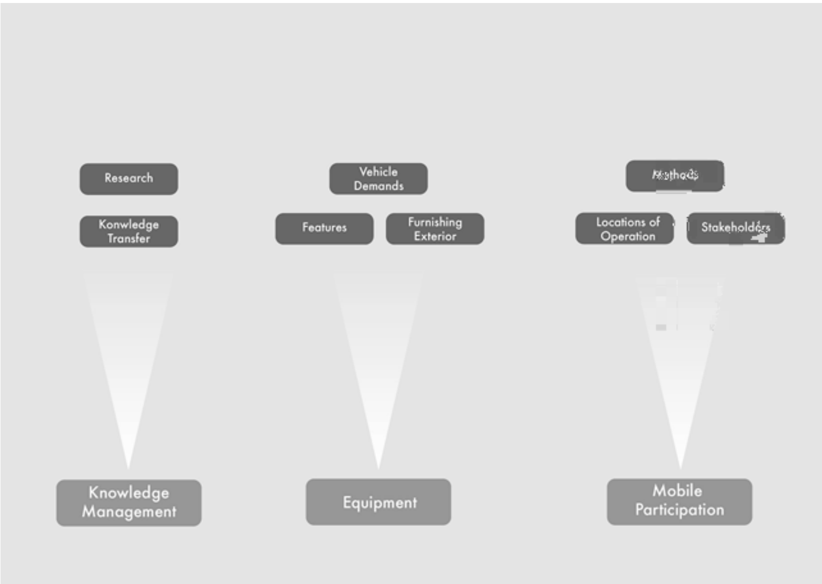


Figure 4: Level two (orange) and level three (grey) categories of Mobile Laboratory.



Considering the XR-laboratory, the L3-categories are *Gamification, Knowledge Management, Co-Design, Space* and *VR-Equipment* (cf. grey boxes in Figure 3) consisting of one to three L2-categories (cf. orange boxes in Figure 3). As an example, L3-category *Gamification* consists of the L2-categories *Protective measures, impacts & awareness of climate change*, *Immersion* and *Serious Games*. The coders recognised as the main idea of the L2-categories the aspect of immersing oneself into climate scenarios, whether they are related to sensitization or knowledge transfer. Gamification refers to the feature of enhancing motivation of learning and engagement through game-like elements mostly used in XR environments (Strahringer & Leyh, 2017). The L2-category *Protective Measures, Impacts & Awareness of Climate Change* is made up of the L1-categories *Impact of Climate Change, Protective Measures, Climate Change Awareness, Identification Conflict Areas* and *Depicting Climate Change in VR*. Main pillar of this category is the idea to educate, build resilience and take action to stop climate change.

Concerning the mobile laboratory, the L3-categories are *Knowledge Management, Equipment* and *Mobile Participation* (cf. grey boxes in Figure 4). Each L3-category has two or three L2-categories (cf. orange boxes in Figure 4). To pick an example, L3-category *Mobile Participation* was chosen as a category by the coders due to all L2-categories (*Methods, Locations of Operation* and *Stakeholders*) being centred around the process of creating a knowledge transfer that is not bound in time and space and can thus reach more people regarding diversity and quantity. L2-category *Methods* in turn is made up of many L1-categories including *Interviews* and *Participative Methods*. Here, a commonality can be seen in the fact that their overarching goal is eliciting discussions and reflections in people while collaborating on these methods. Access to all categories, their deriving and their frequencies is possible through the Open Science Framework storage (Bickert-Appleby et al., 2023).

5. Discussion

The aim of this study was to investigate how experts from different disciplines envision their transdisciplinary work with stakeholders in the laboratories as part of a real-world lab focusing on climate change adaption strategies and climate crisis, and which methods and tools could enable and enhance their co-creative work within. Therefore, an online study was conducted in which members of the transdisciplinary project *Co-Site* answered questions regarding their planned participatory work with stakeholders, practice partners and communities in the three planned laboratories (co-creative space, XR-laboratory, mobile laboratory), which led to three to five main categories for the laboratories in the analysis. In what follows, the results will be discussed and analysed regarding their relevance for the three laboratories as tools and infrastructure for everyday practice in co-design.

Co-creative Space

Within the co-creative space category, the highest frequency was the L3-category *Transdisciplinary Working* (n = 72). This indicates that the focus of the co-creative space is neither the space itself nor the needed equipment, but the work done together in transdisciplinary teams in this space, especially since all L2-categories from *Transdisciplinary Working* (*Collaboration* (n = 31), *Methods* (n = 20), *Stakeholder* (n = 21)) are part of the 5 most mentioned L2-categories. Participants plan to utilise already known methods (n = 7) as a starting point for their research, but also creativity (n = 4) and new methods (n = 4) to enhance their expertise and knowledge and to increase the quality of research in real-world labs. Especially, interviews (n = 5) were mentioned as a research method example presenting one reason why we need not only domain experts but also co-design experts in the real-world lab, (n = 2) who know how to conduct interviews and facilitate other interactive research methods engaging people, such as stakeholders and communities (Sanders & Stappers, 2008; Evans & Terrey, 2016).

Regarding the construction and conceptualization of the co-creative space, one can see the perceived importance of working in collaborative transdisciplinary teams in the context of real-world labs, confirming De Flander et al. (2014): the heart of the real-world lab work is transdisciplinary collaboration, meaning working for, with and in society (Bergold & Thomas, 2010), such as in communities. This also highlights the fact that there is a need to learn more about other co-creative, co-design and participatory methods from other disciplines, a central aspect for transdisciplinary work, to unleash its full power (Nicolescu, 2010). Consequently, transformation benefiting stakeholders, practice partners and communities can occur, since not the space itself makes the co-creative space but the transdisciplinary work and the opportunity for interaction within (Goermar et al., 2021).

Beside the importance of collaborative research and work, participants frequently mentioned aspects regarding *Space Utilization* (n = 32) and *Technical Features* (n = 21), which include aspects of the room design and the relevant equipment. Further scrutiny reveals a focus on the needed modularity (n = 14) of the equipment and the room design especially regarding the need for collaborative (n = 3) and individual work (n = 4). This indicates the needed flexibility within the co-creative space and the collaborative work within. Similar to many already existing co-working spaces used for co-creation (Goermar et al., 2021) the co-creative space as a tool and part of the infrastructure for successful everyday co-design and co-creation needs to reflect the variety and modularity of co-creative, co-design and participatory methods as everyday practices. Especially, the variable group size needs to be accounted for, since, depending on the context, stakeholders and the outcome, the number of participants in co-design methods can vary immensely from one-on-one interviews to groups around 5 to 8 people in focus groups (Bohnsack & Przyborski,

2007) and up to 20 people or more in lectures or presentations (Bergmann et al., 2021).

Extended Reality Laboratory

Regarding the XR-laboratory, participants mentioned the L3-category *Gamification* (n = 72) including the L2-categories *Protective Measures, Impacts &Awareness of Climate Change* (n = 45), *Serious Games* (n = 9) and *Immersion* (n = 18) most often. Hereby, participants focused on the aspect of experiencing climate change (n = 45), including presenting climate change impact (n = 20), awareness of climate change (n = 13), and protective measures in disaster scenarios such as flooding (n = 12). Participants planned to use the XR-laboratory mainly as an information and communication platform which is an advantage of XR, since people can experience possible future scenarios of GBI (Helbig et al., 2023) or first-hand disaster scenarios without being in danger (Mol, Botzen, & Blasch, 2022).

Due to climate change, extreme weather situations happen more frequently and will continue to happen even more often (Intergovernmental Panel on Climate Change, 2023). Thus, experiencing the impacts of climate change without being in danger promotes awareness and willingness to prepare (Mol, Botzen, & Blasch, 2022), increasing the chance for communities to be prepared for the next extreme weather situation, like the flood in Germany in 2021 (Federal Ministry of the Interior and Community of Germany and Federal Ministry of Finance of Germany, 2021). Additionally, XR cannot only visualise scenarios but, especially with co-design practices, new scenarios can be created (Postert, Wolf & Schiewe, 2022). XR might stimulate some people to present and co-create new solutions regarding climate change adaptation (Bailenson, 2018).

This aspect goes hand in hand with the second frequently mentioned L3-category: *co-design* (n = 39) with the L2-categories *Methods* (n = 14) and *Stakeholders* (n = 25). Especially, aspects like participation (n = 4) and interaction in VR (n = 3) were mentioned as possible methods in the XR-laboratory. This indicates that participants see the potential of XR as one tool for participatory work and are here in line with co-design and participatory research (van Leeuwen et al., 2018; Reed et al., 2019; Postert, Wolf & Schiewe, 2022). However, since participants focused mainly on information and communication, education regarding the possible versatile usability of the XR-laboratory might enhance the quality of successful usage of XR in co-design. Hence, a wider understanding and knowledge of possible co-design methods opens a more specific selection and combination of such methods in the individual context (Beecroft et al., 2018; Bergmann et al., 2021) increasing the chance of successful co-design practices leading to a higher chance of results benefitting to communities.

Mobile Laboratory

In terms of the mobile laboratory, participants mentioned most often the L3-category *Equipment* (n = 89) including *Vehicle Demands* (n = 38), *Features* (n = 37) and *Furnishing Exterior* (n = 14) which are essential aspects for the construction of the mobile laboratory and therefore central to the researchers who plan to work in a participatory way with the stakeholders. However, the second frequently mentioned L3-category was *Mobile Participation* (n = 69) involving *Methods* (n = 47), *Locations of Operation* (n = 11) and *Stakeholders* (n = 11). Here, various methods regarding stakeholder involvement (n = 5) are planned, such as qualitative (n = 3) and quantitative methods (n = 5), participative (n = 8) and human-centred methods (n = 4). What all these methods have in common is the need for facilitation skills and expertise (Sanders & Stappers, 2008).

Here, participants plan to use different co-design methods in comparison to the focus of collaboration in the co-creative space. Even though the kind of methods are not specifically mentioned as this strongly depends on the context of the individual situation, one can still conclude that the planned utilization of the two laboratories has a different focus compared to everyday co-design practices. The direct participatory stakeholder, community and citizen involvement is mainly planned in the mobile laboratory and the collaborative work in the transdisciplinary team is more focused on the co-creative space. This is understandable since the co-creative space will be located in Cologne and the main research locations and areas are located around the city. However, this suggests that the participants in the study were able to envision participatory work with communities better outside "in the field" than in the co-creative space, in line with social design focussing on fieldwork and interventions in, with and for communities (Bergold & Thomas, 2010; Chen et al., 2016).

Despite the difference in their intentions concerning the use of the laboratories, participants see a similar importance for all the three laboratories for everyday co-design practices. When asked about their planned frequency of using the laboratories, participants plan to use them equally often (co-creative space: M = 67, SD = 29.63; XR-laboratory: M = 63, SD = 31.22; mobile laboratory: M = 68, SD = 31.76). This might be an indication that all three laboratories together may provide a multi-method approach for participative ways of working with different people, ontologies, and disciplines; and thus together they might enhance the quality of transdisciplinary, transformative and participatory work on climate change adaption in the region. Future research will focus on the implementation of the laboratories and the first experiences with the co-creative work and everyday co-design practices within.

Lessons learned and future research

Thanks to the possibilities it provides concerning individual and time-efficient participation, an online study was conducted. Furthermore, participants were able to answer with their individual opinion without being affected by any external influences, such as comments from other participants in focus groups (Mayerhofer, 2007). As mentioned earlier, to encounter the missing possibility to ask questions within an online study, the participants were encouraged to reach out to the authors for any questions regarding the online study. However, through the course of the study, it became apparent that certain technical terms like "co-creative space", "serious games" and "co-design" were understood differently by different people. The opportunity to ask questions and a broad explanation of the terms within the online study were not sufficient to meet this challenge. The answers partly showed that the variation in understanding might have frustrated participants of the study. The authors learned that the format of an online study at this early stage also needed a more practical approach, e.g. an interactive workshop format as part of a longer design process (Meinel, Leifer & Plattner, 2011).

As a result, the authors conducted a co-creative prototyping workshop with the same participants three months later, focusing on the same topic. Here, participants were able to practically experience the idea and concept of the co-creative space by, for example, prototyping a possible working day in the space and the individually appropriate design of the co-creative space. This change of format provided the authors with more in-depth insights and a higher level of respondence of the participants. The results from this workshop form the basis for further research processes and everyday co-design practices.

Team communication and shared understanding of technical terms are equally important for cognitive synchronisation between team members as is the shared knowledge of the design situation and a shared awareness of contextual design procedures, which are all key in co-design processes (Gero & Milovanovic, 2019). The study showcased challenges in working with different ontologies from different disciplines, and to create a common understanding of different technical terms as a prerequisite for co-creative work, which poses a challenge to a complex, multi-stakeholder multi-expert-domain project. However, not creating a common understanding of these terms creates ground for frustration and misunderstanding. It hinders people from fully engaging in the co-creation and co-design process and creates barriers. Hence, extra effort must therefore be contributed to defining the technical terms in order to achieve a common and practical understanding to be able to conduct everyday co-design practices, since co-design and action research are central aspects of research in real-world labs (Alexandrakis et al., 2021). Additionally, the authors have experienced that the challenges mentioned in this work call for an active design and management of co-creation and co-design processes, especially in transdisciplinary projects and therefore require training and further research into co-design practices and competences.

Conclusion

In conclusion, the study has revealed that the three laboratories (co-creative space, XR-laboratory and mobile laboratory) can be seen as powerful tools for transdisciplinary co-creative and co-design work as everyday practice within real-world lab projects to work with stakeholders and communities in crisis situations. Specifically, it became clear that there is a common understanding of the mobile laboratory being an important tool for participatory work that all disciplines seemed to engage with and envisioned for their work, whereas the co-creative space and the concept of workshops for engagement and co-creation were less direct associations for all disciplines. Further, the study has revealed the XR-laboratory as a new tool across the disciplines for engaging with stakeholders, communities and citizens, while the aspect of co-creation scenarios and solutions using XR has not been recognized yet by the participants, but will be explored in further research.

However, the tools and spaces are not as relevant if the various stakeholders, such as researchers, practice partners, and communities, cannot find common ground and common language concerning main technical terms and approaches. Therefore, the authors see common understanding and action as a priority before tools, methods or spaces for collaborative work. Common ground can also be found in a shared goal such as delivering value for people, even if co-design brings a variety of people together that speak different languages, have different lenses and are employing different modes of thinking and doing (Tromp & Hekkert, 2019). Hence, the authors conclude that after having created a shared understanding of technical terms, successful transdisciplinary work needs not "the right" but a variety of spaces for collaboration as it offers multiple ways for different disciplines to engage in this practice.

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Statement of compliance with ethical standards

The study was conducted guaranteeing respect for the participating volunteers and human dignity. Specifically, participants gave informed consent prior to the study and were properly debriefed after completion of the study.

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