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RESEARCH ARTICLE

# The TMAP Framework: Describing the Design Space of Technology-Mediated Audience Participation in Live Music

**OLIVER HÖDL[1,2] AND LUCA TURCHET[3], (Senior Member, IEEE)**

[1]Cooperative Systems Research Group, Faculty of Computer Science, University of Vienna, 1090 Vienna, Austria
[2]Department for Smart and Interconnected Living, University of Applied Sciences Upper Austria, 4232 Hagenberg, Austria
[3]Department of Information Engineering and Computer Science, University of Trento, 38123 Trento, Italy

Corresponding author: Oliver Hödl (oliver.hoedl@univie.ac.at)

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**ABSTRACT** Technology-mediated audience participation (TMAP) offers a wide variety of ways to enhance the involvement of spectators during a music performance. Technological change has created rich new opportunities for such interactive performance experiences. Effective design of TMAP requires balancing knowledge from diverse human and technological perspectives and taking into account very different characteristics and requirements in live music performance. However, research in this distinctive area of interaction design is limited, and the provision of practical guidance for designers has been scarcely addressed thus far. To bridge this gap, we propose the TMAP Framework, which describes the design space of audience participation in a practice-oriented way to support design-related processes. This descriptive framework is grounded on existing literature from the last 25 years, and has been iteratively improved and peer reviewed with different experts. It was validated using actual TMAP performances not included in the framework development. The TMAP Framework contains 180 entities in a tree-like sorted structure on four levels. Alongside the contribution to knowledge of extensively describing the design space of TMAP in live music, with the validation of the framework, we demonstrate its completeness, stability and generalisability. In this regard, the framework may also serve as a common language between different perspectives and practitioners, thus addressing the highly interdisciplinary nature of the TMAP field.

**INDEX TERMS** Technology-mediated audience participation, interaction design, design space, live musical performance.

## I. INTRODUCTION

Technology-mediated audience participation (TMAP) in live music is a highly interdisciplinary field, which concerns with novel artistic and entertainment forms where audience members actively contribute to live performances beyond *only* consuming them (e.g., [6], [14], [18], [27], [43]). Designing, developing and deploying novel TMAP performances concern multiple disciplines such as interaction design, engineering, music and performing arts and requires the involvement of designers, artists and engineers alike (e.g., [12], [16], [21]).

Examples of TMAP in music exist over decades. One of the early examples is *Radio Net* from 1977 that used the analogue telephone network to involve thousands of people in a networked performance [35]. During the last two decades the number of TMAP performances increased drastically. Some of them stand for themselves as artwork or present novel concepts and systems [7], [11], [16], [29], [39], [47]. Other examples are subject to research and reflected on particular issues, such as user experience or interaction design [4], [12], [19], [27], [47], [50].

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Concerning the design of TMAP, different scholars have proposed frameworks in this space from multiple perspectives. Stuart [37] proposes a framework for a rather general design of interfaces in public performance settings, which also applies to music. His framework provides a terminology to describe interaction in a public setting (e.g., centre-stage, behind-the-scenes, front-of-house) and different roles that are involved (e.g., actor, participant, audience, bystander, orchestrator).

Among the most explicit formal descriptions within the field of audience participation in live music there are the six metrics to describe and evaluate concepts for participatory performances proposed by Dario et al. [32]. They directly address aspects of participatory performances at the conceptual and technical levels: active/passive audience affinity, focus, audience interaction distribution, audience interaction transparency, system versatility and control design freedom. When talking about design in relation to participatory performances, Dario et al. [32] point out how choices in terms of paradigms and technology "can deeply influence the whole piece experience" (p. 29). However, in the research context of their work, the authors do not claim to describe the design space of TMAP. They rather use their metrics to evaluate their own and four other systems realising audience participation.

An actual framework for participatory live music performance is presented by Wu et al. [47] as part of their *Open Symphony* system. This classification framework, similarly to the one reported in Dario et al. [32], is intended to classify participatory live music performance systems. New to this framework is that the authors focus on creativity and in particular the level of audience creative participation and other creative aspects. Moreover, this framework by Wu et al. [47] is the most fine-grained and detailed so far. The twelve entities are: two aspects on the creative participation from the audience (level and motivation), three aspects on creative participation in general (modalities, media and affordances), four aspects on agency (distribution, mediation, degree and constraints) and three others on user interfaces, situation and scalability [47] (p. 50).

A recent *Spectrum of Audience Interactivity for Entertainment* was presented by Striner et al. [40], which they propose as a "common vocabulary for the design space across entertainment domains" [40] (p. 214). The focus of this spectrum lies on how audience members are involved in entertainment from least to most active or from observing passively to take over performance [40] (p. 221). While they cover audience interactivity across entertainment domains, they do not consider the perspective of the performer or "describe audience characteristics (e.g., culture, size, and location)" [40] (p. 225).

The works reported above address audience participation, participatory or interactive performances from different viewpoints. They are quite different in their concept and appearance. Dario et al. [32] present six metrics, the classification framework described by Wu et al. [47] has twelve entities considering also creative aspects, while the spectrum proposed by Striner et al. [40] works across entertainment domains, but does not consider audience characteristics. These frameworks show that there is an agreement on their value for various purposes, such as design, description, classification or evaluation. But there is no coherent exploration and overarching analysis of TMAP in live music. Also, existing approaches did not aim to describe the design space of this highly interactive field in a comprehensive way as they are based on a few case studies.

In this article, we explore the design space of technology-mediated audience participation broadly. Our investigation is grounded on existing literature and considers different perspectives of potential participants, various approaches towards design, and existing paradigms in this context. On this basis we propose a framework rich in detail but versatile enough to be applied for design-related processes.

## II. ADVANCEMENT OF TMAP PERFORMANCES

There is still a growing number of diverse examples for TMAP in live music either standing for themselves as artwork, presenting novel concepts and technical systems or target specific questions in research from multiple perspectives. Table 1 gives an overview of the TMAP performances we review in this section to present the advancement of TMAP performances throughout the last decades.

### A. EARLY APPROACHES OF TMAP IN LIVE MUSIC

Among early approaches to audience participation in live music using a "technology" (or rather a tool as an interface) are musical dice games that emerged in the 18th century [24]. Amadeus [34] was one of the famous composers who tried to make his music interactive for the audience using dice, although not in the sense of an interactive performance, but by letting people participate in the composition. In his piece *Das musikalische Würfelspiel* (German for *musical dice game*) spectators roll dice and thereby rearrange parts of the composition [20], [34].

Nearly 50 years ago in 1977, Neuhaus used the analogue telephone network to involve thousands of people in a networked performance [35]. He describes his approach with "two hours over which ten thousand people found their way into the work and made sounds" (p. 13).

### B. FIRST MOBILE DEVICES IN TMAP PERFORMANCES

During the last two decades the number of TMAP performances in live music increased together with the rise of mobile technology. In 2001, Golan [29] used the audience's mobile phones to collaboratively create the concert *Dialtones*. As the title suggests, he combined ringtones of individual spectator's mobile phones for the performance. During the concert the performer on stage called numbers of phones the spectators registered before the performance. At the same time, the spectators they called were highlighted with a white

**TABLE 1.** **Chronological overview of the TMAP performances to present the advancement throughout the last decades. For names marked with a * we could not find unique performance names.**

| Name | Year | Technology | Reference |
| --- | --- | --- | --- |
| RadioNet | 1977 | telephone | Neuhaus [35] |
| Dialtones | 2001 | mobile phones | Levin [29] |
| Hand gesture recognition* | 2004 | PDAs | McAllister et al. [33] |
| Glimmer | 2005 | light sticks | Freeman [6] |
| hpDJ | 2006 | pressure sensors, laser, camera | Cliff [2] |
| Visual station for DJ* | 2007 | touch screen, scanner | Kaiser et al. [22] |
| Detecting participant's motion* | 2007 | wireless motion sensors | Feldmeier, Paradiso [5] |
| BioMuse | 2009 | bio-sensors | Knapp et al. [25] |
| MobileMuse | 2011 | bio-sensors | Knapp, Bortz [26] |
| MoPhO | 2011 | smartphones | Oh, Wang [36] |
| CoSCoS | 2012 | smartphones (motion) | Hödl et al. [18] |
| echobo | 2013 | smartphones (touchscreen) | Lee, Freeman [27] |
| massMobile | 2013 | smartphones | Weitzner et al. [44] |
| Experio | 2014 | laser and light sensors | Hout et al. [14] |
| Sense of Space | 2015 | smartphones (ultrasound) | Hirabayashi, Eshima [12] |
| Open Symphony | 2017 | smartphones (touchscreen) | Wu et al. [47] |
| Embodied iSound | 2018 | smartphones | Gimenes [9] |
| Crowd in C | 2019 | smartphones | Lee, Willette [28] |
| Fruit Genie | 2019 | touch sensors | Lips [30] |
| The Singularity | 2019 | smartphone (touchscreen), Wiimotes | York [49] |
| Poème Numérique | 2020 | smartphones (ultrasound) | Hödl et al. [16] |
| personic | 2022 | smartphones (geolocation and motion) | Xambó, Goudarzi [48] |
| Hack the Show | 2023 | smartphones | Jung, Clester [21] |
| Stringesthesia | 2023 | functional near-infrared spectroscopy (fNIRS) | Hopkins et al. [13] |
| MoNoDeC | 2024 | smartphones | Hwang, Marasco [15] |
| Pharospones | 2024 | mobile phones | Ma et al. [31] |

spotlight from above and could see themselves in a mirror. This work is of particular importance because it illustrates the combination of sound and visuals.

Still before smartphones became popular, in 2004, Graham et al. [33] designed an interactive performance system with wireless hand-held devices (Personal Digital Assistants) to let individual audience members transmit gestures to the performers on stage. In 2005, Freeman wrote a special composition for chamber orchestra and audience [6]. In his piece *Glimmer*, the musicians play music based on the audience using light sticks to collaboratively create instructions.

### C. SENSOR-BASED TMAP PERFORMANCES

In the first decade of the 21st century, the technological advance on sensor-based technologies had implications on TMAP performances. In the area of DJ performances, Gerrit et al. [22] presented a system that allows the audience in a dance club to transmit visual material to a VJ (Visual Jockey), who selects and creates live visuals according to the music. Other researchers in nightclubs used biofeedback of the audience for an automated DJ [2] or carried out studies on DJ-audience interaction [8]. Also using sensor-based technologies for biofeedback, Knapp et al. [25] developed a system called *BioMuse* and used purpose-built chairs to collect physiological data of the audience to control sound generation through emotion and motion. Later, they took advantage of mobile technology and presented *MobileMuse*, a new approach measuring both physiological and kinematic data via a mobile phone for the purpose of mobile music creation by the audience through emotional states [26]. Feldmeier, Paradiso [5] used wireless sensors that were given to the audience to collect information about the audience's rhythm and activity.

A sensor-based design from 2014 is *Experio* by Van et al. [14], an interactive dance concept for audience participation in club settings that uses laser light and sensors to track the movement of the dancing audience. *The Flaming Lips* [30] developed a live show in 2019 where the audience used giant inflatables fruits filled with sensors. When audience members touched these fruits, notes were added to a song. Recently in 2023, Hopkins et al. [13] developed a TMAP performance called *Stringesthesia* based on the artist's trust while performing. The more the artist trusted the audience (measured with a functional near-infrared spectroscopy, fNIRS) the more agency was given to the audience members using microcontrollers.

### D. TMAP USING SMARTPHONES AND TABLETS

Around a decade ago, the number of people with smartphones increased continuously and modern smartphones combine a wide range of sensor and network technologies in one off-the-shelf device. Hence, studies on TMAP in live music using smartphones rapidly increased during the last couple of years. An early work in 2011 presents "techniques for enabling audience participation based primarily on using smartphones" (p. 665) by Jieun and Ge [36]. But also Marcelo [9], Masami and Kazuomi [12], Oliver et al. [18], Won and Jason [27], Weitzner et al. [44], Wu et al. [47] in the following years or most recently Jung and Clester [21] developed TMAP systems using mobile devices such as smartphones or tablet which have been evaluated in live performances. More recent studies using smartphones for TMAP in live music from 2019 and 2020 respectively are presented by Won and Aaron [28] on the effect of social interaction, and by Hödl et al. [16] on the role and use of smartphone technology both in the context of large-scale TMAP performances. *Pharosphones* is another large-scale TMAP performance from 2024 with 200+ participants where the audience uses their phones as visually tracked light points for modulating sampling parameters [31].

More generally, the usage of devices for the audience which are equipped with wireless connectivity, sensors and actuators, along with their interconnection with devices of performers (in co-located or remote settings) falls in the remits of the field of the Internet of Musical Things (IoMusT) [42]. To date the opportunities offered by the Internet of Musical Things paradigm for creating TMAP performances has been scarcely investigated [41], but there is some recent work on TMAP and IoMusT. *The Singularity* by Adrian [49] is a jazz-related TMAP performance from 2019 where so called "audience-performers" can improvise live using an iPhone and four Wiimote controllers. In 2022, Xambó and Goudarzi [48] presented an online TMAP performance that integrates the geolocation and motion sensors of mobile devices from the audience around the globe. Most recently, in 2024, smartphones and IoT-driven speakers were used for an immersive and spatial audio experience in a TMAP performance [15].

### E. NON-TECHNOLOGICAL ARTEFACTS IN TMAP PERFORMANCES

For TMAP performances with any form of mobile device, the audience obviously brings and operates the technology by themselves to participate. However, there are also TMAP performance concepts that use technology in a more unobtrusive way and let the spectators participate with rather non-technological artefacts. For the piece *Experimence* in 2014 the movement of a large balloon within the audience is visually tracked to influence the sound modulation of the piano in real-time Oliver et al. [17]. In 2021, Spronck et al. [39] developed a TMAP performance named *Empty Minds* for symphonic orchestra enabling the audience to participate using coloured hats video cameras and projections. In an early sensor-based TMAP approach from 2008 by Barkhuus [1] the audience does not even use artefacts but their own clapping and cheering, which is measured acoustically.

### F. SUMMARY

In conclusion, we can say that the examples and approaches to TMAP in live music are manifold and heterogeneous. From an historical viewpoint, some dates back to decades using analogue technology [35] or even centuries if we consider dice as a technology in the broad sense Philipp [24]. Notably, a sharp increase happened during the last 20 years with the rise of digital technology and in particular mobile, smart and sensor-based devices.

From a conceptual point of view and considering the motivation behind TMAP performances, some stand as pieces of art for themselves [24], [29], [35] while others explore the technical feasibility of TMAP performances [12], [16], [33], [36]. Finally, for some TMAP performances also studying the experience of either the audience or the artists or both is key [17], [18], [28], [39].

## III. METHODOLOGY

The methodology behind the development of the TMAP Framework is following three strategies. Firstly, the framework should directly build on the manifold studies and use cases of TMAP in live music evidenced in literature by "rendering what would otherwise be a meaningless aspect of the scene into something that is meaningful", as [10] describes the purpose of what he calls a primary framework (p. 21). Secondly, as a descriptive framework it is intended to map out and describe the design space of TMAP in such an extensive way that it serves as a lingua franca within a highly interdisciplinary field [38]. Thirdly, the TMAP Framework should be applicable in practice in relation to the design of new TMAP performances.

Hence, to ground our proposed framework in real use cases of TMAP performances, we started with an extensive data collection from the existing literature. This literature review of TMAP studies was continued with a content analysis and category building to identify and categorise all potentially relevant design aspects. Finally, we reviewed and optimised the framework together with different domain experts (from music, music computing, and interaction design) for the sake of balancing entities and to achieve completeness.

With a validation of the TMAP Framework we tested its completeness and suitability to describe the design space of TMAP in live music. For this validation we used two strategies to test the TMAP Framework against use cases of TMAP performances. First, we applied our framework on TMAP use cases from literature published after the development of the TMAP Framework was finished. Second, we used the TMAP Framework to describe actual TMAP performances that were developed as part of an art-based research project and where the first author was mainly involved in the curating team.

Both the development and validation process of the TMAP Framework were qualitatively driven. The framework itself appears like a mind map or as a tree-like structured collection of categories on four levels. In practice, we used paper-based versions of the framework for the different stages of the development and throughout validation. During the development phase, these printed versions of the framework were used for the reviewing and optimisation processes (e.g., together with domain experts). During the validation phase, these printed frameworks were used to annotate and map design aspects identified in the TMAP use cases. The same printable version of the final TMAP Framework is available as supplementary material in VII and online.[1]

## IV. FRAMEWORK DEVELOPMENT

### A. DATA COLLECTION

The first step in the process of developing the TMAP Framework was to collect as much data as possible on existing work on technology-mediated audience participation to provide a broad basis for our proposal. Thus, we did not limit ourselves to scientific literature, but also searched for artistic pieces or rather generic sources, which we found in online videos or blog articles, for instance. We leveraged search engines such as Google Scholar and Scopus, as well as the common Google search engine or the popular video platform YouTube.

This data collection process resulted in 48 unique examples within the period of the late 1990s until 2019 representing approaches to audience participation. Note, the choice for this time frame was intentional as the empirical work for this study was conducted shortly after COVID-19 and we decided to focus on pre-COVID-19 performances before the increase of online performances. Most of these examples (33) were directly related to technology-mediated audience participation in music. The rest were collaborative music making approaches (7), audience participation without any technology (4) and interactive art installations (4).

In the end, all 48 examples were different and interesting from a conceptual point of view. Concerning the individual quality and body of information, some sources were rich in detail while others were rather concise in terms of content or short in length. For instance, *Dialtones* is a concert where every spectator uses (and needs to bring) a mobile phone for participation [29]. There is only a video and a short description available, which nevertheless is good enough to get an impression of the concert and understand the concept including its key aspects. In *Engaging the Crowd* [1] no one has to bring a device or has any additional knowledge. The performance uses technology for measuring the audience's cheering to identify the winner in live rap competitions, which is all described in detail in a scientific publication, including an observation of the concert experience. Both example were quite different in terms of quality (i.e., source, content, length), but nevertheless represent two different and relevant approaches to technology-mediated audience participation. Moreover, these two examples already demonstrate the wide range of design possibilities involved in TMAP. In both performances, the audience acts as a group and the participation is not focused on individual spectators. However, in *Dialtones* every spectator who wants to participate needs to bring a mobile phone while in *Engaging the Crowd* nothing more than cheering is required to participate.

[1] https://www.drhoedl.com/permalink/tmap-framework (last access 24.01.2025)

### B. CONTENT ANALYSIS AND CATEGORY BUILDING

In the second step, we used all available data (e.g., written content, video material) of the examples for TMAP from the data collection for a qualitative content analysis. The goal was to systematically identify and categorise all design aspects that can be relevant for a TMAP performance.

Soon after starting the content analysis, we faced a challenge which we illustrate with the example of *MassMobile* [45]. The idea behind *MassMobile* is a client-server system with a range of features to adapt for participatory performance using smartphones. In their work, the authors describe scenarios where *MassMobile* was used for voting to change lighting configurations or the collaborative improvisation among spectators using loops. As in *MassMobile*, but also other examples, we identified design aspects explicitly mentioned (e.g., audience participation targets light configuration, spectators use smartphones) although theoretically the systems are capable of much more. In the case of *MassMobile* only loops are mentioned explicitly, but the systems can enable other musical concepts as well can support audience participation.

Another challenge was that some design aspects we identified were rather general while others were specific. If we recall *Dialtones* [29] and *Engaging the Crowd* [1], in those examples we extracted different and rather general interaction settings (i.e., participation concerns individual spectators or the audience as a group) and at the same time specific technologies (i.e., smartphones and video-walls).

Our solution to resolve these challenges during the content analysis and categorising the identified design aspects consisted in using a tree-like hierarchical structure (or mind-map) with different levels of granularity: the closer to the root the more general a design aspect was (e.g., music, visuals, people). On the lowest level, and farthest away from the root, the very specific design aspects were located (e.g., loops are used for participation, spectators participate individually, in groups or all together). For this qualitatively driven process we inductively built general design aspects originating from particulars [3] (p. 4). This process included the supplement of additional design aspects and finding new (sub-)categories. At the same time, we removed redundancies by reorganising the overall tree structure (e.g., if a new design aspect was identified and did not fit in the existing structure).

To illustrate the process of content analysis and category building more concretely, we use the example of *visuals* as a category in the design space of TMAP performances. The following list shows the category *visuals* after the content analysis and the initial clustering. We can see a list of design aspects as extracted from the literature (e.g., light, video-walls, wristbands) thematically clustered (i.e., ambient on/off stage, information on/off stage):

- ambient on stage
  - light (e.g., spotlight, strobe speed)
  - video-walls/projections (e.g., videos, animations)

- ambient off stage
  - light (e.g., darker/brighter)
  - wristbands (e.g., changing colours)
  - smartphones (e.g., display colours, flash)
- information on stage
  - graphical visualisation (e.g., shapes, drawings)
  - data visualisation (e.g., charts, bubbles)
  - light (e.g., pointing laser beams)
- information off stage
  - smartphones (e.g., text, messages, numbers)

As we can see, among the design aspects are either general ones (e.g., light) or rather specific ones (e.g., smartphones). Some design aspects even appear more than once (e.g., light, smartphones) or have different labels for similar purposes (e.g., video-walls/projections compared to graphical visualisation). A reorganisation during the process of category building resulted in the following final category *visuals*:

- location
  - on stage (e.g., spotlights, video projections)
  - off stage (e.g., directly among the audience)
  - off venue (e.g., live stream)
- aesthetics
  - ambient (e.g., light)
  - information (e.g., text, voting charts)

Some design aspects (e.g., wristbands, smartphones) were reorganised and came to a different branch within the category *feedback*:

- distribution
  - individual (e.g., everyone gets feedback on a smartphone/wristband)
  - group (e.g., only people in front of the stage)
  - none (e.g., something is measured/observed)
  - all (e.g., the whole venue is addressed with an influenced sound)

### C. REVIEWING AND OPTIMISATION

Overall, the content analysis of the collected 48 examples for TMAP and categorisation of identified design aspects led to a tree-like structure with four levels from general categories to specific design aspects which was already well balanced. Based on this, the third step to conclude the framework development phase consisted of reviewing and optimising the TMAP Framework.

We did this review together with three experts from related different domains: a music computing expert, a musician with a special interest in interactive music, and finally an HCI researcher and interaction designer. All experts had more than 15 years professional experience in their respective domain, they were hired through direct contacts of involved researchers and were not paid for their reviews. In practice, we looked at all entities step by step together with the experts in individual sessions. We used printed versions of the current


**FIGURE 1. Overview of the final TMAP Framework. The four frames refer to detailed and readable views on separate pages in the following and are not part of the framework visualisation (for details see Appendix).**

TMAP Framework and annotated all entities with suggested revisions according to the expert's input.

Throughout all reviews, the fundamental structure of the tree-like framework with its four levels did not change. Instead, reviewing the framework with domain experts helped to remove still existing redundancies between different tree branches. Next, through the reviews we could resolve ambiguity between categories especially because two experts were English native speakers, which helped to improve on a distinctive wording throughout all entities. Finally, the reviews helped to add potential categories not explicitly identified in the literature but still considered relevant from the different perspectives of the domain experts. For instance, there was no evidence in literature during development that a motivation for TMAP can be a business case to collect data or that a marketing/PR person of the artist's management could be concerned with a TMAP performance. If explicitly mentioned, most TMAP performances had an artistic or technological motivation. However, when reviewing the framework with experts and reviewing the already existing categories *artistic* and *academic* the potential use case of *commercial* was raised and added.

### D. FINAL TMAP FRAMEWORK

The final version of the TMAP Framework contains 180 entities in a tree-like sorted structure organised on four levels. A thumbnail of the final TMAP Framework is shown in Figure 1. A printable version of the TMAP Framework is available in the Appendix and online[2] ideally to be printed out on A3 paper format in landscape. The details and all entities of the framework are presented on four following pages in Figures 3 to 6. For the purpose of this written article and its preservation, we decided to include the TMAP Framework in this way (to print it out, for instance) rather than providing an online interactive version. This is a trade-off we are aware of

[2]https://www.drhoedl.com/permalink/tmap-framework (last access 24.01.2025)

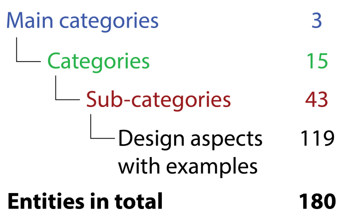



**FIGURE 2.** Overview of the TMAP framework structure.

and a dynamic online implementation of the framework could better serve other purposes for its use, which we will revisit later when reflecting on future work.

Figure 2 gives an overview of the framework structure and how all its entities are subdivided into four levels. The root contains the three main categories *Impact*, *Motivation* and *Interaction*, along with three questions to point out the purpose of each main category:

- Impact: How will the interaction affect performance aspects?
- Motivation: Why are participants motivated to become involved or prevented from being involved?
- Interaction: What are the parameters of the interaction?

All other levels (two, three and four) are shown in Figures 3, 4, 5 and 6. Note, for spatial reasons and better readability of the framework, the visualisation of the root as well as the main categories were left out and the framework was divided into four parts. Also, we will not describe all entities and the TMAP Framework in detail here. Instead, the focus will be placed on different branches during the framework validation, which is described in Section V.

## V. VALIDATION

The goal of the validation was to test the stability and completeness of the TMAP Framework in describing the design space of technology-mediated audience participation. For this validation process, we selected six different performances with technology-mediated audience participation as use cases and described them using the TMAP Framework. Three of the performances were described in recent publications as part of a scholarly study [28], [39], [46] and the other three were actual performances with a sole artistic focus and purpose. We will explain later why these six performances were chosen for the validation. In the same way as occurred during the development phase, we analysed these performances, extracted design aspects and tried to map each identified design aspect to an entity of the TMAP Framework. Notably, these six performances used for the validation process happened after the development of the TMAP Framework, thus they were not used to develop the framework.

### A. VALIDATION USING LITERATURE

We conducted a literature review to find three thoroughly described and well-documented TMAP performance use cases for the framework validation. Thus, this time we focused on scientific literature only. We set the following criteria for the literature review: (1) we focused on well-established publishers and databases for our searches (e.g., IEEE Explore,[3] ACM Digital Library;[4]) (2) we searched for peer-reviewed publications only; (3) we had a pre-defined selection of keywords (e.g., audience participation, participatory performance, interactive performance); (4) the study setting had to be a concert or performance and any form of technology must be involved. A systematic literature review following our criteria resulted in a database of 31 publications. We selected the most recent ones for the validation [28], [39], [46], which were all published after the framework development. The actual second entry in our literature database was Hödl et al. [16] which was not taken as it relates to one performance by the first author, which instead was used for the second part of the validation.

The process of the validation was always the same for each of the three articles. We illustrate with the performance *Empty Minds* reported in Spronck et al. [39] how different entities of the TMAP Framework were used to describe the performance. **The following quote shows an original paragraph that describes *Empty Minds* [39] (p. 221) where we highlighted in yellow all identified characteristics of the performance which we needed to *trace* in the branches of the TMAP Framework:**

> *The two concerts did not take place in a regular concert venue. Instead, the orchestra played in pop music venue Complex in Maastricht, and in the refurbished industrial building of Strijp S, Eindhoven. When we, as researchers and audience members, entered the Klokgebouw of Strijp S, we received a yellow or blue paper hat. On a video screen above the entrance of the venue, a looped instruction video was played. As if we were watching safety instructions on board a plane, the video asked us to put the hats on our heads before we entered the performance space. We followed the instructions and entered the space. Musicians were already there. There were no chairs to sit on: not for us, nor for the orchestra. The musicians stood on low platforms, divided into small instrumental groups over the large refurbished factory hall. As an audience member, one could walk around in between the musicians. The unfamiliarity of the situation triggered reactions: people laughed, made selfies with the coloured hats on, or looked around curiously. The floor of the performance space was covered with an intricate web of blue lines, yellow dots, lists of instruments, and a grid of white tape. This visual pattern, we learned from the programme leaflet, was a visual representation of the score of one of the compositions that would be played: Empty Mind I.* [39] (p. 221)

[3]https://ieeexplore.ieee.org (last access 24.01.2025)
[4]https://dl.acm.org (last access 24.01.2025)


**FIGURE 3.** **The main category Impact: How will the interaction affect performance aspects?.**

The first characteristic we highlighted, for instance, is that every spectator "received a yellow or blue paper hat" [39] (p. 221). We could directly *trace* this aspect in the branch *Interaction* (What are the parameters of the interaction?) which is shown in Figure 6 following the nodes *Awareness*, then *Preparation* and finally *not required*. The aspect of using provided objects is even mentioned in the design examples of this node on level four: "e.g.,

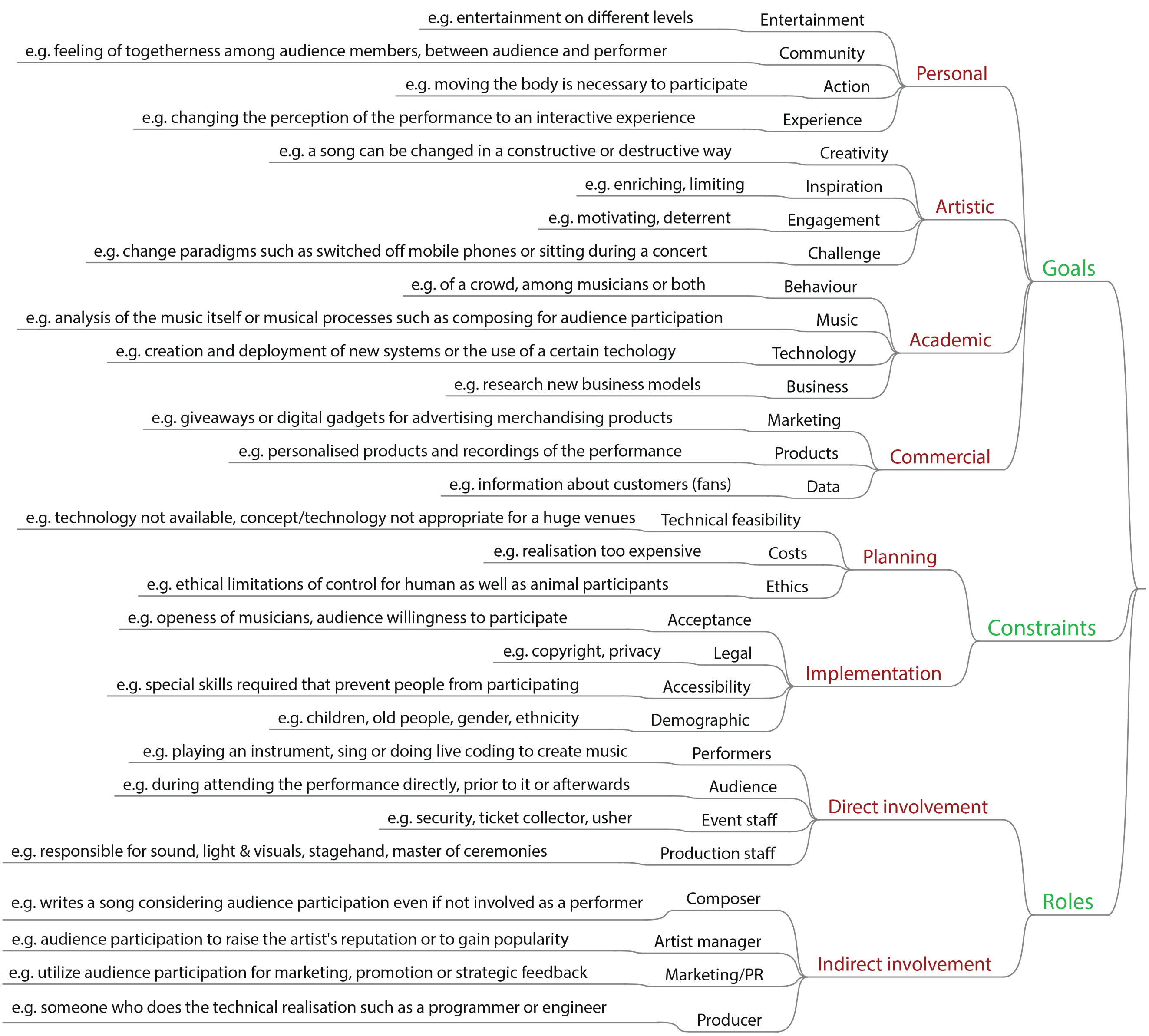



**FIGURE 4.** **The main category Motivation: Why are participants motivated or prevented to be involved?.**

no objects are needed for the participation or they are provided''.

The description continues with ''on a video screen above the entrance of the venue, a looped instruction video was played.'' (p. 221) Again, this aspect can be mapped to the *Interaction* main category, then the category *Knowledge*, the sub-category *Skills* and finally the design aspect *learning approaches*. One of the given examples in the TMAP Framework for this design aspect namely ''e.g., learning something step by step'' relates to the provided instructions on video screens in the *Empty Minds* performance as well. The next four highlighted words are ''no chairs to sit on'', ''low platforms, divided into small instrumental groups'', ''large refurbished factory hall'' and ''one could walk around in between the musicians.'' All of them can be traced in the branch*Interaction* following the nodes *Space* - *Movement* and *Setting* respectively for the first, the third and fourth one, and *People* - *Unit setting* for the second one.

In this manner, we went through the whole article. A few pages further, for instance, it says, ''by wearing hats with two different colours, yellow and blue, audience members would function as moving notes in the musical score'' (p. 225). However, not many more details on the actual impact are given concerning how the music or composition of the piece which is influenced by moving audience members except: ''audience members could see what was going on in real-time


**FIGURE 5. The main category Interaction: What are the parameters of the interaction? (upper half).**

on a large video screen on one side of the space. Via this screen, it would become visible to the conductor what part of the score the audience decided to play next''. To map this aspect of the performance in the TMAP Framework, we started with the main category *Impact* (How will the interaction affect performance aspects?) as shown in Figure 3, then chose *Music* and finally *Composition* on the third level of the framework. Due to the lack of further details in the description, we could not choose a concrete design aspect on level four.

These three examples show how we identified design aspects in the description of the performance and how we were able to map them directly to different entities of the TMAP Framework. In the end, we were able to map all identified design aspects of this performance to the TMAP Framework's entities and most of them were on the fourth level.

In the same way, we used the other two use cases [28], [46] and could describe both systematically with the TMAP Framwork. As with *Empty Minds* the different levels and granularity of the TMAP Framework turned out to be useful when some aspects of a performance were described in less detail than others.

### *B. VALIDATION USING PERFORMANCES*

The other three performances we used for the TMAP Framework validation were all part of the *Breaking the Wall* event which happened during the same named art-based research project.[5] For this event and all three performances,

[5]https://www.piglab.org/breakingthewall (last access 24.01.2025)

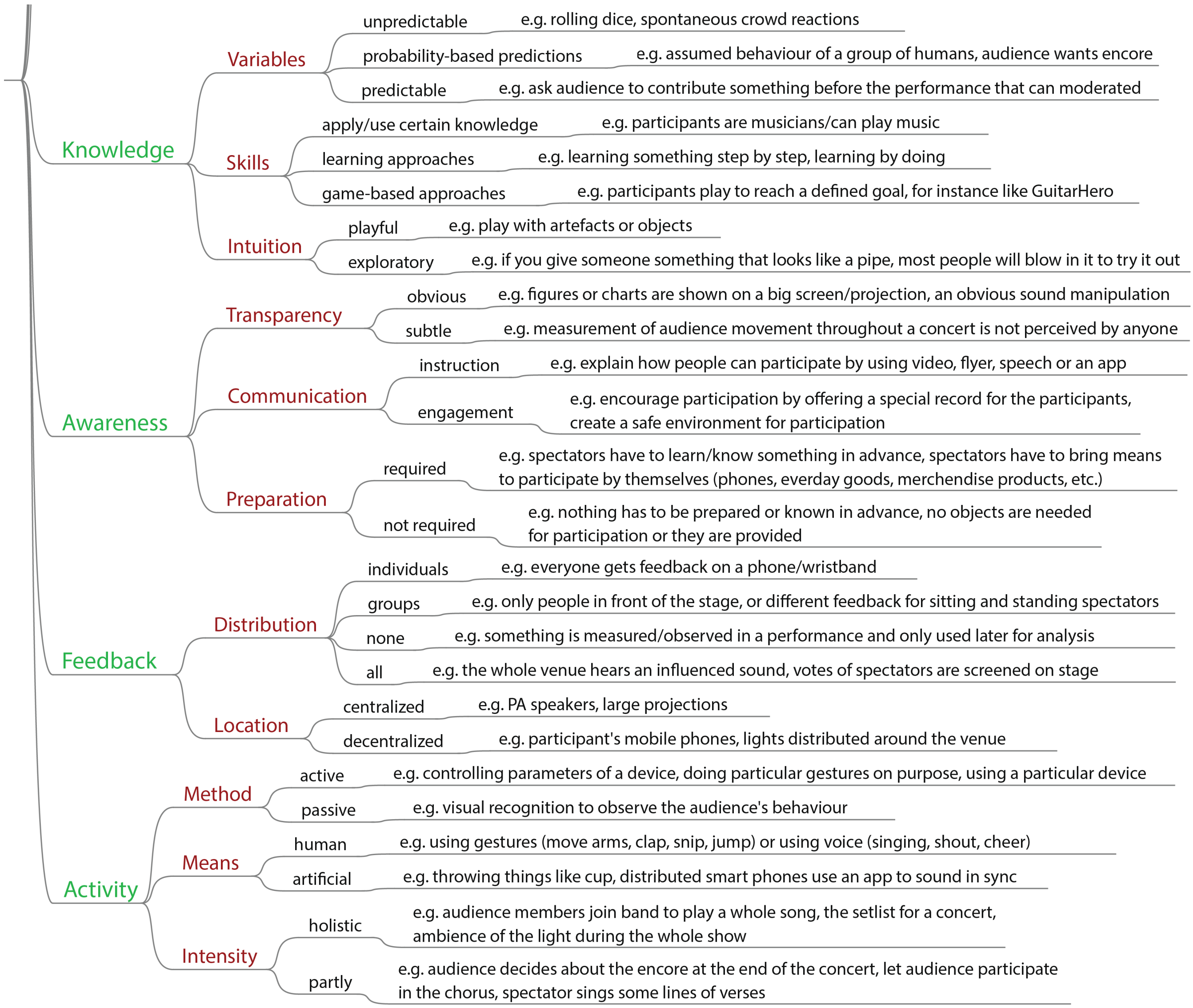



**FIGURE 6.** **The main category Interaction: What are the parameters of the interaction? (lower half).**

the first author of this article was part of the curating team, thus familiar with all aspects of the performances. A summarising description of all three performances is available in Kayali et al. [23]. In Hödl et al. [16] the performance *Poème Numérique* is described in detail and we use this description to demonstrate how we mapped performance characteristics to the entities of the TMAP Framework.

The *Poème Numérique* performance uses a dedicated smart phone app to let the audience act with their devices as a set of distributed, moving loudspeakers. One conclusion was that "using a cross-platform development environment enables to reach as much of the audience as possible" (p. 203). This points to the main category *Motivation* (Why are participants motivated or prevented to be involved?) which is shown in Figure 4. The applicable category within *Motivation* is *Constraints* and the referenced issues around cross-platform development environment points us to the sub-category *Implementation*. The related design aspect on the fourth level is *Accessibility* as not having a smart phone excludes a spectator from participation. For those having a smart phone, the cross-platform development enabled the developers to provide an app for all platforms within reasonable development effort. The cross-platform development, however, requires a trade-off: "At the same time, it has to be considered that cross-platform development imposes restrictions regarding software features. Using a cross-platform app platform voided the use of platform-specific audio processing which would have enabled more flexibility and lower latency". This points to a second entity within the category *Constrains* which is the sub-category *Planning* and the related design aspect *Technical feasibility*.

In the end, we were able to describe all three performances of *Breaking the Wall* using the TMAP Framework. In parallel to the validation using literature, all design aspects of the performances could be mapped to entities of the TMAP Framework (and, again, most throughout to the fourth level).

## VI. DISCUSSION

The main goal of this study was to develop a framework for describing the design space of technology-mediated audience participation in live music, which could be rich in detail and versatile enough for application in design-related processes. Ultimately, such a framework was conceived to be concretely used by artists and researchers for the design and evaluation of TMAP performances. In the following section we provide a comparison of the TMAP framework with respect to other frameworks previously proposed, as well as we offer a critical reflection on its completeness and stability as well as on its usage.

### A. COMPARISON OF FRAMEWORKS FOR AUDIENCE PARTICIPATION

Following our initial strategy to build the framework upon the existing literature, we were able to build the TMAP Framework on an extensive data collection. The content analysis and systematic extraction of design characteristics revealed the need for different degrees of abstraction early during the framework development, which is the main difference between the TMAP Framework and other previously proposed frameworks for audience participation.

Compared to other frameworks such as those reported in [32], [40], and [47], the TMAP Framework offers different granularities, namely from rather general categories to more specific design aspects. Nevertheless, despite this core difference with respect to the previous efforts of scholars in this space, the TMAP framework is still capable of maintaining the core ideas of previously proposed frameworks, while at the same time describing the design space of TMAP in an extensive and detailed manner. For instance, in the *Spectrum of Audience Interactivity for Entertainment* by [40] the core idea is to map different forms of participation from least to most active. Similarly, in [32] one of the six metrics is *Active/Passive Audience Affinity*. This aspect is also part of the TMAP Framework, given the fact that the degree or depth of participation from passive to active is an important characteristic for TMAP performances. However, in the TMAP Framework active and passive are considered interaction methods and are on the same level among 119 design aspects that can play a role for TMAP performances (see in Figure 6 the category *Activity* in *Interaction*). Also, in comparison to other frameworks, the TMAP Framework uses discrete categories and design aspects instead of continuous axes. However, with its 15 categories, 43 sub-categories and 119 design aspects it still offers a high granularity and thus many concrete design ideas than a few continuous axes may provide. Moreover, especially the *ranges* on the fourth level still offer a certain continuity and allow a mixture or in between values (e.g., active/passive, sitting/standing/mobile, large-/medium-/small-scale). With these examples we want to emphasise that the TMAP Framework considers important characteristics according to other frameworks but still leaves enough room for many other characteristics of the TMAP design space.

The need for such a higher granularity in describing the design space becomes more obvious when we compare the TMAP Framework and the *Framework for Participatory Live Music Performance* by [47]. One of their twelve categories is ‘‘Creative participation modalities’’ which they describe as ‘‘examples include audition (audience generates sounds), vision, multimodal audition and vision’’. In a similar way, the TMAP Framework refers to *music* and *visuals* explicitly in the main category *Impact* which describes how the audience participation possibly affect performance aspects (see Figure 3). Then the TMAP Framework goes into further detail on possible creative impact on music when we look at the sub-categories on the third level (e.g., timing, sound, composition) or the concrete design aspects on the fourth level (e.g., pitch, dynamics, harmony).

### B. COMPLETENESS, STABILITY AND GENERALISABILITY OF THE TMAP FRAMEWORK

For the validation of the TMAP Framework, we used all entities to systematically describe six different TMAP performances which occurred after the development of the framework. In the end, we were able to map all characteristics of these performances to entities of the TMAP Framework.

During the validation, the different levels of abstraction offered by the TMAP Framework proved to be particularly useful. In most cases, identified characteristics of the six TMAP performances could be mapped to design aspects with the lowest abstraction, i.e., on level four. This was the case especially for the three performances were the first author was mainly involved in the curating team and was largely familiar with all details. In contrast, with *Empty Minds* [39] not much details were given on how the music or rather the composition was affected by the spectators' movement wearing coloured hats. Nevertheless, we were able to use the more abstract category *music* and sub-category *composition* without going deeper to a concrete design aspect on the fourth level.

There might be different structures possible (e.g., more or less levels of abstraction, different branches), but the current version of the TMAP Framework fulfils the requirements on a complete and stable descriptive framework. Only the examples or suggestions associated with each design aspect on the fourth level could be in principle extended with every new TMAP performance that comes up with a new technology or approach being used for TMAP. Thus, they serve as an additional source of information if the rather concrete design aspects on the fourth level are still too abstract for the user of the framework.

Concerning the universality of the TMAP Framework and following its original intention to describe the whole design space of TMAP performances, the focus of the final

TMAP Framework is shaped by the three main categories Impact, Motivation and Interaction, which puts emphasis on interaction design and conceptual aspects rather than concrete technical considerations. Nevertheless, concrete technical aspects are addressed throughout the framework in different categories and design aspects.

For example, the dimensions relating to networking aspects (e.g., latency within networks, number of supported participants, the kind of technology used) are explicitly considered in the framework, but from the viewpoint of interaction. Therefore, the main category *Interaction* has - in the case of *latency* - the category *time* and sub-category *accuracy* which distinguishes between (a) time critical interaction (e.g., sound synthesis which should have none or very low latency) and (b) latency tolerant interaction (e.g., data collection, audience opinion or behaviour). The number of participants are considered in the category *space* and the sub-category *quantity* which distinguishes between (a) large-scale (e.g., more than thousand up to stadium), (b) medium-scale (e.g., a couple of hundred) and (c) small-scale (e.g., intimate up to a hundred). Concerning the kind of technology used, phones or smartphones, for instance, are explicitly mentioned seven times in different branches of the framework.

### C. USING THE TMAP FRAMEWORK FROM DIFFERENT PERSPECTIVES

We consider the TMAP Framework to be viewed from different perspectives. Let us review the main category *Impact* which asks "How will the interaction affect performance aspects?" (see Figure 3). A designer or spectators with little or no technical knowledge of music who is involved in the design process of TMAP can use the more general entities closer to the root to understand that audience participation might have an influence on the *music* in general or on the *timing*, *sound* or *composition* in particular. Instead, a composer who is involved in designing a TMAP performance and most likely knows about musical details can directly approach particular aspects such as *mode*, *harmony* or *melody*. In this case, the different levels of abstraction and tree-like structure benefit the use of the TMAP Framework from different perspectives (as it was the case for us during the validation with more or less information about the details of a TMAP performance).

Another main category is *Motivation*, which asks: Why are participants motivated to be involved? (see Figure 4). This motivation does not only mean the "direct motivation" of participants (e.g., artists, spectators) but an "indirect, implicit or intrinsic motivation" as well that can be decisive to "motivate" a TMAP performance (e.g., legal issues, costs). Performers are directly involved, for instance, and we can assume that performers usually know their audiences best. And a performer might have a particular interest in possible *constraints* of a technology-mediated participation in a live performance, which are listed as a separate category on the second level. Thus, performers can get detailed information about how different parameters can affect and potentially constrain the participation such as *acceptance*, *accessibility* or *demographic* issues in relation to the audience. An engineer who develops the technology to mediate participation, or a person who organises a concert is indirectly involved in a TMAP performance. They might focus on other parameters that possibly constrain participation such as *technical feasibility*, *costs*, *ethics* or *legal issues*.

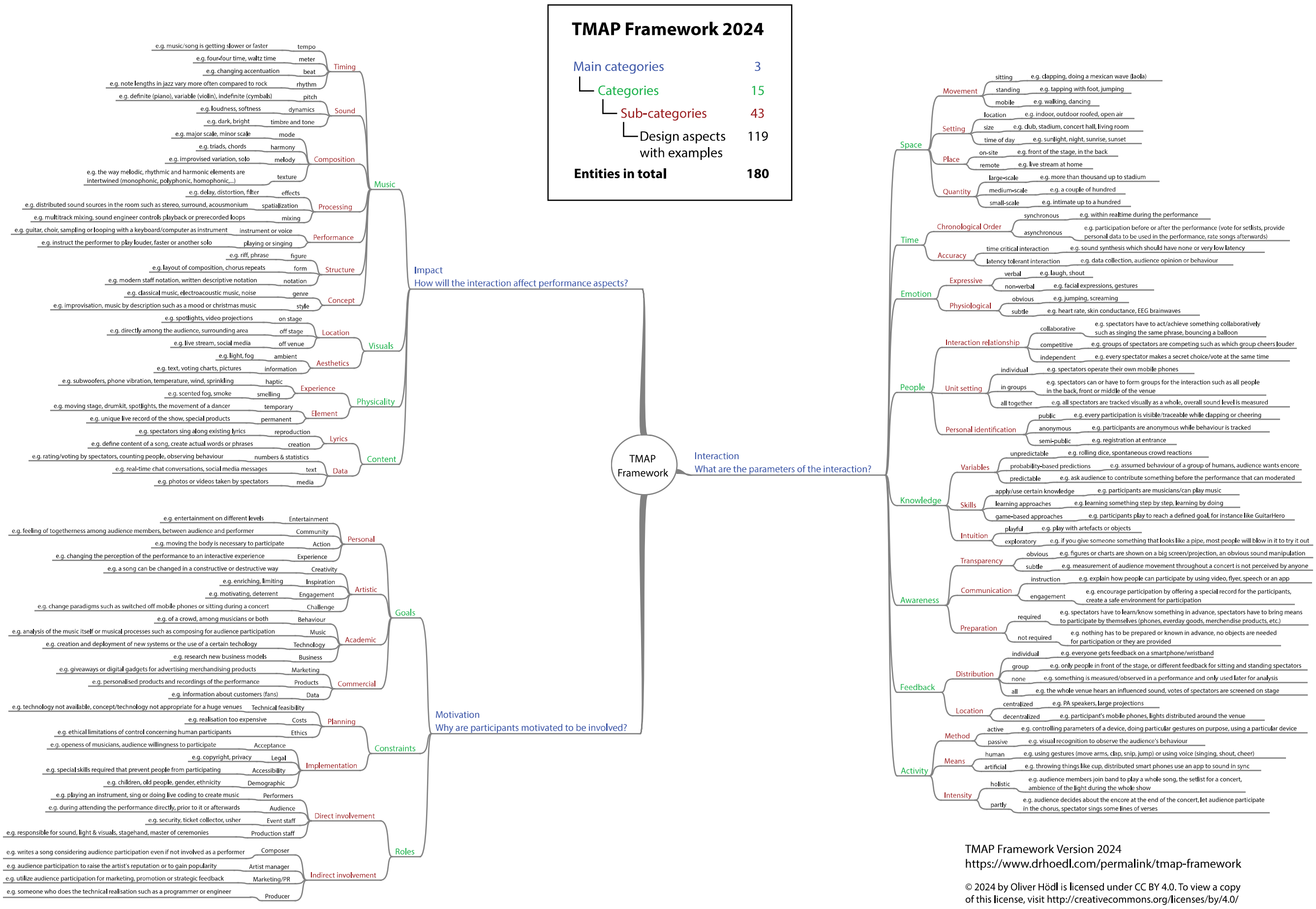
This example of the category *constraints* illustrates both the guiding potential of the TMAP Framework and the raising of challenges that can be an issue in the design of audience participation. In fact, all aspects within the category *constraints* have to be considered to some extent depending on the perspective or particular participants, the setting or other requirements. To follow our example of how the performer and the engineer can share different concerns with constraints, we can see that the TMAP Framework acts as a guiding "checklist" and a way to address challenges by highlighting certain decisions or compromises.

Finally, we look closer at the main category *Interaction* to discuss different perspectives on the TMAP Framework (see Figure 4). An interaction designer knows about different forms and the importance of an effective interaction, thus can directly use the details about possible ways to consider the *unit setting* or *interaction relationship* of the people involved, for instance, think about a *collaborative* or *competitive* interaction relationship. Spectators and performers might be interested in how interaction happens as well, but can start with superior entities to approach interaction issues. They might start with *people* from a more general level and can stop before it goes into details they might not be concerned with.

Furthermore, just like other frameworks, the TMAP Framework can serve as a common language between different perspectives and practitioners. In addition, the different levels of abstraction allow different stakeholders to communicate issues that concern the actual design of a TMAP performance from their respective perspective and level of knowledge. Of course, we do not know at this point to what extent the TMAP Framework supports communication between different practitioners and stakeholders concerned with a TMAP performance. Nonetheless, the validation process has shown how the TMAP Framework is suitable for describing and organising diverse aspects of a TMAP performance and for considering different levels of knowledge.

## VII. CONCLUSION

The field of technology-mediated audience participation in live music is a highly interdisciplinary field and the recent technological advances have created rich opportunities in this area. However, these interactions are challenging to design taking into account different (human) roles. Effective design of TMAP in live music requires a combination of knowledge from a variety of perspectives and insights into the needs




of diverse stakeholders (e.g., artists, spectators, engineers). Systematic research in the area and guidance for designers have both been very limited thus far. To bridge this gap, we have synthesised and validated a descriptive framework for supporting the design and evaluation of TMAP in live music. This TMAP Framework contains 180 entities in a tree-like sorted structure on four levels and the majority of these entities are categorised as design aspects.

In comparison to other frameworks for audience participation, we built the TMAP Framework on an extensive literature-based data collection. The systematic analysis of design characteristics revealed the need for different degrees of abstraction and details, which is the main difference between the TMAP Framework and other frameworks. Moreover, the TMAP Framework offers different granularities, namely from rather general categories to more specific design aspects.

With the validation of the TMAP Framework, we demonstrated its completeness, stability and generalisability. We were able to map all characteristics of six performances to entities of the TMAP Framework. During this evaluation, the different levels of abstraction proved to be particularly useful. In this regard, the TMAP Framework may also serve as a common language between different perspectives and practitioners and addresses the interdisciplinary nature of the field. However, to prove this, we need to do further studies with different TMAP practitioners and might develop a web applications of the TMAP Framework to allow a more interactive use than with the current version. Also, one intention of the TMAP Framework is to use it for the design of new performances. While we assume that the framework can be useful when creating new TMAP performances, further studies are needed were the TMAP Framework is applied in practice. Finally, for this work we considered TMAP examples from literature until 2019 for the framework development and some from right after for the evaluation. Thus, we have not included much artistic work created during the COVID-19 pandemic with potentially new TMAP online formats in live music.

Finally, we offer the TMAP Framework to researchers, designers and artists when creating and assessing their TMAP performances. In addition, the content of this article shall stimulate further discussions within the music technology community and also extend the scope of the framework to other participatory art forms than music, e.g., theater.

## APPENDIX PRINTABLE FINAL TMAP FRAMEWORK

The Appendix contains the Final TMAP Framework in a printable version (See top of page), which is also available online.[6]

[6]https://www.drhoedl.com/permalink/tmap-framework (last access 24.01.2025)

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**OLIVER HÖDL** was born in 1982. He received the M.Sc. degree in computer science and the Ph.D. degree (summa cum laude) in human–computer interaction from Vienna University of Technology, in 2005 and 2016, respectively, and the Habilitation (venia docendi) degree from the University of Vienna, in 2024. During the Ph.D. studies, he was an Invited Researcher with permanent residencies at the University of Nottingham, U.K., and The Open University, Milton Keynes Campus, U.K., from 2011 to 2015. He is a Professor with the Department for Smart and Interconnected Living, University of Applied Sciences Upper Austria. From 2013 to 2018, he was a Lecturer and an Academic Advisor with the SAE Institute and Middlesex University London, U.K. After the master's studies, he was with the software industry and working as a freelance Entrepreneur and a Musician, where he founded the sound and physical computing studio in the mountains of Upper Styria, Austria. He has an extensive track record of internationally peer-reviewed publications and serves as a coordinator and a principal investigator for large-scale international research projects, managing over €24 million in funding.

**LUCA TURCHET** (Senior Member, IEEE) received the master's degree (summa cum laude) in computer science from the University of Verona, in 2006, the master's degree in classical guitar and the master's degree in composition from the Music Conservatory of Verona, in 2007 and 2009, respectively, the Ph.D. degree in media technology from Aalborg University Copenhagen, in 2013, and the master's degree in electronic music from the Royal College of Music of Stockholm, in 2015. He is an Associate Professor with the Department of Information Engineering and Computer Science, University of Trento, Italy. His scientific, artistic, and entrepreneurial research has been supported by several grants from different funding agencies, including the European Commission, the European Institute of Innovation and Technology, the European Space Agency, the Italian Ministry of Foreign Affairs, and the Danish Research Council. He is a Co-Founder of the music-tech company Elk Audio. He is the Chair of the IEEE Emerging Technology Initiative on the Internet of Sounds and the Founding President of the Internet of Sounds Research Network. He serves as an Associate Editor for IEEE TRANSACTIONS ON HUMAN-MACHINE SYSTEMS, IEEE ACCESS, and the *Journal of the Audio Engineering Society*; and a Guest Editor for *IEEE Communications Magazine*, *Personal and Ubiquitous Computing*, *Journal of the Audio Engineering Society*, *Frontiers in Virtual Reality*, and *Digital Creativity*.