Journal of Metaverse
Research Article
Received: 2024-12-30 | **Reviewing:** 2025-01-05 & 2025-04-30 | **Accepted:** 2025-04-30 | **Online:** 2025-06-02 | **Issue Date:** 2025-12-31
Year:2025, **Volume:**5, **Issue:**2, **Pages:**104-111, **Doi:** 10.57019/jmv.1609739

Exploring Musical Affordance of a Virtual Reality Malay Gamelan Through Qualitative Study

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***Abstract*— Many virtual gamelans are designed to give users alternative access to learn about the gamelan instruments. As the gamelan instruments are physically big and heavy, there is typically limited access to ordinary people who want to learn about the instruments. In recent years, there have been many efforts to virtualize gamelan instruments using various advanced technologies to attract the younger generations and make them accessible. New musical technologies often afford novel interactions that are unattainable with their physical counterparts. This paper investigates the affordance of a virtual reality (VR) gamelan instrument called Air Bonang. Using the qualitative methods under the User-Centered Design (UCD) approach, the affordance of Air Bonang is explored through a 'breaching experiment' with the Malay gamelan community. Findings showed that the affordance of the VR gamelan instrument is contextual to three aspects: traditional, exploratory, and collective. The traditional context was based on how Air Bonang was played like the actual bonang, while the exploratory context presents a novel virtual interaction with the instrument. The collective context was afforded through ensemble playing of the instrument. This encompasses how the VR instrument is used in different musical settings regarding its purpose, practicality, relevancy, and reliability.**

Keywords*— *Musical affordance, Virtual gamelan, Malay gamelan, Virtual musical instrument

I. INTRODUCTION

The rapid advancement of computer technology has given rise to many new musical interfaces, introducing novel ways to interact with them. Exploring and utilizing these new interfaces often influences how they are afforded. Coined by a psychologist, James Gibson, affordance refers to all possible actions with an object depending on the user's physical capabilities [1]. Over the years, the term has been widely used and adopted across various disciplines, and nowadays, readers understand it as a property an object possesses that communicates possible actions to a user [2]. The term was later adopted in the design community [3], where it was redefined as with perceivable action possibilities, meaning actions which users consider possible [4].

In music interaction, which brings together the ethos of HCI into music, affordance can be conceptualized as a set of propositions that a system may present to users as meaningful, i.e., how the system is intended to suggest to users what they may gain or experience [5]. Studies have shown that different interactional patterns emerge when users interact with virtual musical interfaces rather than physical or actual musical instruments [6, 7, 8]. This paper investigates how users interact with a VR musical instrument, Air Bonang, based on the bonang instrument of the Malay gamelan. Despite its Indonesian roots, the Malay gamelan differs slightly in its instrumentation, techniques, tuning, repertoire, and purpose [9,10]. Virtualizing the Malay bonang impacts how it is afforded individually and collectively, as the instrument is typically played in an ensemble setting. The study investigates the affordance of Air Bonang in these two different settings to gain a deeper understanding of how it impacts various musical contexts. The study is conducted in two phases involving the Malay gamelan community, gamelan experts, and non-gamelan players. The first phase focused on the individual use of Air Bonang within a controlled setting, followed by the collective use of the instrument in the second phase. The study hopes to shed light on how a novel musical interface is contextualized within existing Malay gamelan musical practices.

II. MUSICAL AFFORDANCE

Previous works on the affordance of musical interfaces encompass many different aspects and are often explorative. It can be conceptualized as a set of propositions that a system may present to users as meaningful, i.e., how the system is intended to suggest to users what they may gain or experience [5]. Many researchers relate this to gestural interaction with interactive music systems [11]. Based on the idea that music can evoke certain gestures [12] is reflected in many affordance studies of music interaction, including gestural interaction with diverse musical systems. In a Collective Sound Checks workshop, participants were given access to different mobile applications, which represent different scenarios, where they could explore and make music collectively. The scenarios were presented in different ways, where users could afford various gestural movements of the mobile devices, such as touch, shake, jiggle, and tilt, to produce collective musical performances [13]. For tangible musical systems, the Electronic Khipu integrates the gesture of khipu, an ancient Andean knot-weaving technique, to generate electronic sound used to compose music. Here, the affordance is preconceived from the art of weaving and simulated into a musical performance [14].

Affordance explored in virtual reality (VR) musical systems is more contextual to the design of the interfaces. VR offers more flexibility in its interaction as it is integrated with sound, visual, and gestural input in one system. Çamcı et al [6] explored different affordances with four Virtual Interfaces for Music Expression (VIMEs), focusing on the interaction design of these interfaces. Their findings addressed four aspects of

Cite (APA): Saffian, K.A., Norowi, N.M. (2025). Exploring Musical Affordance of a Virtual Reality Malay Gamelan Through Qualitative Study. *Journal of Metaverse*. *5*(2), 104-111. **Doi:** 10.57019/jmv.1609739

interaction: performance behaviors, mental association, presence, and control. Ham et al. [15] on the other hand, explored the affordance of VR drumming to understand the complexities of polyrhythmic drumming in relation to spatial identity in immersive environment. In addressing the issue of physical and system constraints with modular synthesis, Wakefield et al. [7] introduce Mischmasch. This virtual modular synthesis can provide flexibility in instantiating and deleting modules on the fly, quickly storing and recalling patches and parameter settings, and potentially finer synthesis algorithm adjustments within modules.

III. The Current Study

The current study explores how a virtual reality gamelan is used within different musical contexts. It aims to understand better how people would use it in music-making activities. The Malay bonang is constrained by its physicality in size, weight, gong layout, sitting position, mallet, and playing techniques [16]. Hence, it limits the mobility and flexibility of the instrument so that it can be further manipulated exploratively. Although recent contemporary compositions of the Malay gamelan have attempted to challenge this by incorporating borrowed musical techniques from other musical instruments [17], this is still subjected to and limited by the physicality of the bonang itself. Virtualizing the bonang can further explore its affordance to enhance musical creation and interaction.

A. Method

This study uses the 'breaching experiment', which involves introducing new technology into users' 'familiar settings' to assess its impact [18]. This explorative study also adapts the Media and Arts Technology (MAT) proof-of-concept method, which examines how people respond to a single MAT and their experience with it [19]. In this study, the prototype is treated as a 'musical instrument' in a real-world music setting and played alongside the gamelan ensembles. This study employed the convergent mixed method [20] based on the multiphase iterative design [21]. However, this paper only discusses the qualitative aspect of the study.

B. Participants

Three gamelan groups were recruited for this study. They were categorized into expert, amateur, and novice groups. The groups recruited represent the different levels of skills, expertise, and experience within the Malay gamelan community (Table 1). Summary Of Demographic Information Of The Gamelan Groups.

Group	Expert	Amateur	Novice
Number of Participant	9 (6 male, 3 female)	11 (3 male, 8 female)	16 (8 male,8 female)
Participants' Profiles	Musician Gamelan student Composer Arranger Music Director	Undergraduate and postgraduate students of various academic programs	Undergraduate music student who plays various musical instruments

In total, 36 participants were recruited, comprising 44.1% male (n = 15) and 55.9% female (n = 19). The participants' ages ranged from 18 to 29. 38.2% (n = 13) have had experience with VR, while 61.8% (n = 21) have not.

C. Hardware and VR equipment

This study was conducted in a workshop setting at three different venues, where the performing groups conducted their usual gamelan rehearsals. Each group used its own set of gamelan instruments. However, other tools for the experiment were provided. One Meta Quest 2 VR set was used for the expert and novice groups, while an additional unit was provided for the novice group. Like the previous study in Phase 1, the VR device was videocast to a laptop using the OBS Studio streaming software to capture the internal VR interaction. As the study involved collective musical creation, a speaker unit was used for sound reinforcement and placed in front of the gamelan ensemble for everyone to hear, connected to the headset using a 2mm stereo cable. The gamelan instruments are typically loud; thus, no sound reinforcement was needed. Two external video cameras were placed in front and on the side of the participants to capture their body movements externally (Figure I).

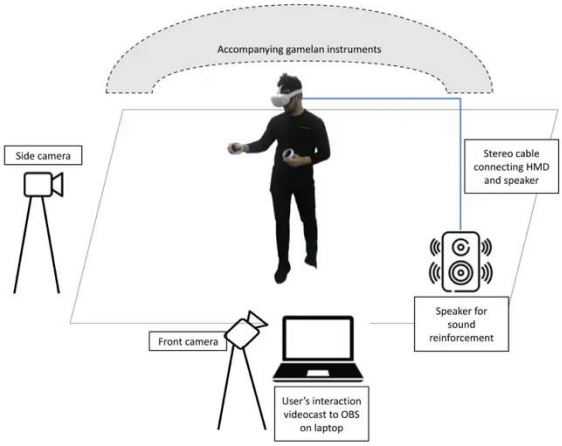

Fig. I. Experiment Setup For The Study

Fig. II. Placement Of Gamelan Instruments

The experiment setup was kept similar for all venues with minimal necessary adjustments to suit their physical limitations. Generally, the gamelan instruments used were arranged in a semicircle behind the VR user. Some of the bigger and heavier gamelan instruments, such as the gong,

kempul, and kenong, were left fixed in their original positions as they were difficult to move around (Figure II).

D. VR Gamelan: Air Bonang

The Meta Quest 2 headset was installed with a VR gamelan application named Air Bonang. Air Bonang is designed to provide users with two gameplay modes: Traditional and Exploratory. The Traditional mode simulates the natural playing of the bonang instrument, while the Exploratory mode presents a 3D environment where the virtual bonang can be moved around the virtual space. Some customization features include a sensitivity control switch, display of bonang pitch number, and bonang size. Air Bonang VR application also includes a video tutorial, selected numbered notation of gamelan songs, and general instructions. Figure 3 shows the Exploratory mode of Air Bonang, which is the focus of the study.

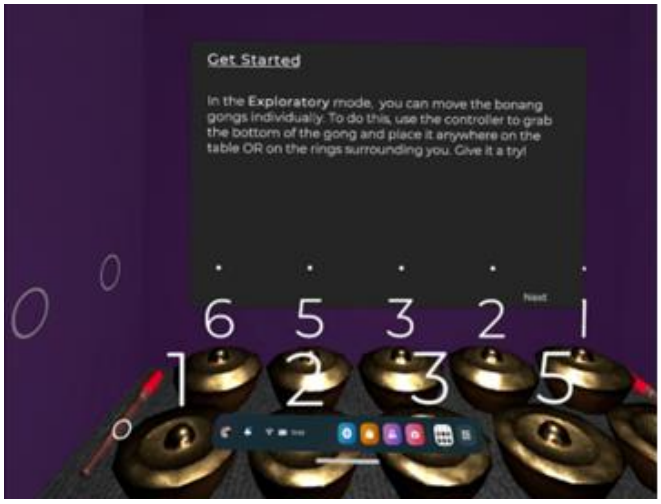

Fig. III. EXPLORATORY MODE OF AIR BONANG

E. Procedures

The study aims to explore the users' affordance of the VR gamelan in real-world musical settings. It is narrowed down to three aspects: the prototype's practicality, relevancy, and reliability. Using the breaching experiment method, the study looks at how novel technologies are deployed "in the wild" to elicit practices from potential users and the socially organized contingencies they encounter in an attempt to make the technology work [22]. Thus, designing it as a workshop allows the gamelan groups to explore, collaborate, and determine how best to use Air Bonang in their musical practices. The researcher set no performance goals [23]; instead, the musicians determined them.

The participants were instructed to explore Air Bonang freely. Since the participants were more familiar with their skills and the dynamics of their musical practice, they were free to decide which pieces to play, which instruments to play the accompaniment, which sections of the pieces to play, and which gameplay modes (Figure IV). After executing the required task, all participants were given an online questionnaire to fill out. Additionally, a focus group discussion was conducted with the expert group to gain in-depth insights into their experience due to their expertise in gamelan.

Fig. IV. PARTICIPANTS PLAYING AIR BONANG IN THEIR GAMELAN ENSEMBLES

IV. DATA COLLECTION AND ANALYSIS

The qualitative data collected includes observation, interaction videos, and focus group discussions. The observations were conducted directly or in situ, as the conditions and environments of the groups and workshops vary. Using the inductive approach, the analysis moves from the specific to the general, where the general represents a concrete and objective conclusion supported by logic and evidence [24]. A comparative analysis was conducted to find the similarities and differences in how they create music using Air Bonang. Meanwhile, the videos and focus group discussions were analyzed thematically in Atlas.Ti 23 software. As the interactions were not structured, the video analysis was conducted in an exploratory manner to find common themes and patterns, particularly on musical and non-musical affordance.

V. FINDINGS

The study reveals the participants' affordance collectively as performing groups, which include musical practices, practicality, relevancy, and reliability.

A. Musical Practices

Overall, the three gamelan groups observed had different musical practices, influencing how they interacted with Air Bonang. The expert group was more flexible and explorative using the prototype in their ensemble. There was clear communication within the ensemble on different aspects of musical creation, such as determining the song selections, exploring various musical ideas (i.e., how to play), and executing musical directions (i.e., what and where to play). The members were skilled and knowledgeable on various gamelan repertoires; thus, various gamelan pieces were played. They were also seen at ease playing music impromptu with Air Bonang and other gamelan instruments.

The amateur group had been actively rehearsing for an upcoming event prior to the study. Two gamelan instructors were present to lead the ensemble. The members, mainly university students, relied heavily on gamelan notations as guidance, as only three traditional gamelan pieces were played, and the music scores were displayed in Air Bonang. Only the instructors played several contemporary pieces in the Exploratory mode of the VR gamelan. The group's instructors actively led the ensemble musically and dynamically throughout the session. As the group members were mostly students, they were not as independent in determining their musical direction but relied heavily on instructions given by the instructors.

Meanwhile, the novice group, which consisted of gamelan beginners, was hesitant to use Air Bonang due to their limited knowledge and skills. The participants took much longer to practice the piece before being ready to play with the accompaniment. All participants only played one gamelan piece in the Traditional mode despite being encouraged to try the Exploratory mode. As there was no instructor present, it affected the group's collaborative dynamic and communication.

B. Practicality

The practicality aspect refers to the ability to play various gamelan music of different styles, genres, and techniques, which is deemed useful in a musical context. In all of the workshops, the experts played the most significant number of gamelan pieces (n = 13), followed by the amateurs (n = 6) and the novices (n = 1). The experts also played a more diverse type of music, consisting of traditional and contemporary gamelan music and improvisation. Throughout the workshops, ten (n = 10) traditional pieces were played across all groups, and the experts and amateurs played five (n = 5) contemporary pieces. The experts also created music impromptu, identified as improvisation (n = 3). Table II displays the breakdown of the repertoire list played by the ensembles.

The gamelan pieces played during the experiment had diverse musical styles, techniques, and tempos. According to the expert participants, Air Bonang worked well with traditional gamelan pieces as they are mostly in slow tempo and steady melodic and rhythmic passages. In contrast, it was more challenging to play contemporary pieces due to varying tempos, dynamics or loudness changes, and technical demands. There was also a lack of control over the dynamics, where they were unable to hear the changes in loudness despite striking with various levels of force. The sound samples used for Air Bonang are the recordings of the actual instrument. Being a knobbed-gong percussion instrument, the sound is produced once it is struck and will last depending on the resonance of its metal body. The sound can be shortened by dampening it with a wooden mallet; however, this technique was not simulated with Air Bonang. Meanwhile, the loudness of the mid-air strikes depends on the speed values of the hand controllers. Additionally, the lack of physical feedback with mid-air striking took away the sensation of physically striking the instrument.

TABLE I. LIST OF GAMELAN MUSIC PLAYED BY THE PARTICIPANTS IN THE STUDY.

Group	Expert	Amateur	Novice
Total no. of pieces	13	6	1
Style	Traditional (n=7) Contemporary (n=3) Improvisation (n=3)	Traditional (n=4) Contemporary (n=2)	Traditional (n=1)
Repertoire	Timang Burung, Ayak-Ayak, Ganda Melati, Lambang Sari, Lenggang Kangkung, Topeng, Perang Manggong, Selerak, Lebah Lincah, Dia, 3D Improvisation, Caklempong Rhythms, and Kotekan.	Timang Burung, Togok, Perang Besar, Canggung, Kamrai, and Ria.	Timang Burung

Fig. V. ***P8*** (WEARING HMD) PLAYING A *KOTEKAN* PATTERN WITH ANOTHER MEMBER (***P6***) ON THE BONANG SEATED IN FRONT

Playing Air Bonang differs significantly from the instrument in terms of executing musical techniques. The participants could effectively execute the fundamental bonang techniques when playing traditional pieces. However, playing the contemporary repertoire posed some challenges. For example, two experts also attempted to play the *kotekan*, a gamelan technique where the gong is immediately muted to produce a short and detached sound. Typically, they would

play *kotekan* on the same instrument, striking it interlocking while facing each other. For this experiment, however, the technique was attempted with one person playing his part on Air Bonang while the other played his part separately on the real bonang (Figure V).

Another challenging attempt was playing the *glissando.* The lack of physical feedback posed a gestural challenge to execute this technique, especially with mid-air striking. This study reveals that simulating certain musical techniques might call for different gestural interactions in the virtual world compared to the physical instrument.

The practicality of the VR gamelan might be limited to specific contexts. Air Bonang is deemed more suitable for playing traditional gamelan repertoire or music at a slow tempo and does not require drastic tempo and technicality. Air Bonang was designed to simulate the fundamental *bonang* techniques to preserve and provide access to the instrument [16]. Therefore, other advanced or borrowed musical techniques were not simulated at the point of the study. However, the study's findings reveal a demand for the prototype to do more than that. Table III shows the list of Air Bonang control features, based on the findings of the study.

TABLE II. AIR BONANG CONTROL FEATURES

Feature	Yes/No	Notes
Fundamental b*onang* techniques	Yes	Traditional gamelan repertoire
Contemporary *bonang* techniques	Yes	Limited to repertoire with slow tempos
Dynamic/Loudness control	Yes	Minimal dynamic changes with mid-air striking
Timbral control	Yes	Change in setting
Latency	Yes	Minimal

C. Relevancy

The relevancy of Air Bonang looks at whether it is relevant to be used in real-world musical contexts, such as playing gamelan pieces in ensemble settings. During the workshop, the participants used the prototype to play the bonang's musical parts; thus, its role within the gamelan ensemble was not altered. The accompaniments played by other gamelan instruments were able to support the Air Bonang musically in the usual way.

In terms of the collective affordance of Air Bonang, it can be categorized into different contexts: traditional, exploratory, and error. In the Traditional mode, the participants mostly played the traditional gamelan repertoire. Here, the instrumental bonang techniques are afforded, similar to how they would play on the instrument, which influenced their behaviors of abiding by the etiquette of playing the gamelan. As the Malay culture is typically associated with mystical and spiritual ownership [25], none of the participants were seen attempting behaviors that would disrespect the virtual bonang even though it was artificially designed.

The exploratory context, however, saw the participants 'breaking' this traditional rule. The participants were afforded the flexibility of the Exploratory mode to try out interesting movements, such as hitting two gongs together in mid-air or placing the gongs on different walls (Figure VI). Affordance within the reality-virtuality continuum, specifically on Musical XR, often advocates for experiences surpassing reality's boundaries, coined as 'magical interaction' [26, 27]. In contrast to reality, the etiquettes and taboos of the Malay gamelan, as well as the physicality of the bonang, restrict the gamelan player from affording the instrument in the way they did with Air Bonang.

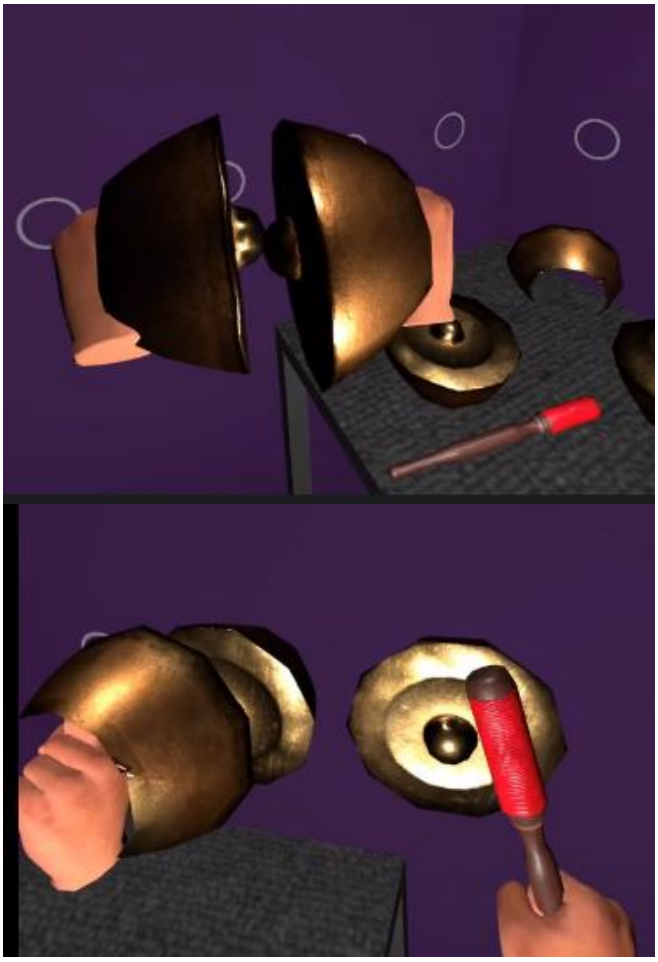

Fig. VI. NEW GESTURAL INTERACTIONS IN THE EXPLORATORY MODE: ***P9*** HITTING TWO GONGS TOGETHER (TOP) AND STRIKING WITH A MALLET AND A GONG (BOTTOM).

When interacting with a new system, errors or mistakes are bound to be made. In this study, some participants encountered errors, such as accidentally dropping or flipping the individual gong and the virtual mallets. As the gestural interaction in the Exploratory mode can be deemed novel, it takes some familiarity for the participants to grab the virtual gongs steadily off the table and stick them on the walls. The gesture was something that the participants needed to experience by themselves to get a good grasp of the movement. The participants also attempted to fix the errors made by picking up the dropped gongs and virtual mallets, which they could do easily.

The relevancy of Air Bonang in this study relies on how the participants collaborate to make music in an ensemble setting. The study combined two different environments, the real and the virtual worlds, and it impacted how they collaborate as musical ensembles. In terms of presence, the Air Bonang users

admitted to feeling isolated, as they were the only ones wearing the VR headset, compared to the rest of the group. It was one of the challenges that affected the group's dynamic in their musical collaboration. The participants also found it challenging to communicate with their fellow musicians, especially in non-verbal communication, due to their limited views from wearing the headset. In their typical practice, the expert would communicate non-verbally, relying on their eyes and body language to engage with the ensemble. However, the disconnection between the two parties compromised the playing quality and musical output.

Combining the real and virtual worlds in one collaborative setting requires optimizing the performance setup. Due to the issues discussed previously, the study's equipment setup could have done more justice to the gamelan ensembles. Optimizing the performance setup ensures that the ensemble can see, hear, and communicate with one another to create music instantly and cohesively without a barrier. Despite some challenges in implementing Air Bonang in current musical settings, the participants saw the potential for the VR instrument with future improvements, such as minimal latency, dynamic controls, striking accuracy, and multiplayer, to provide a more reliable and cohesive virtual interaction.

D. Reliability

The reliability aspect of Air Bonang looks at the consistency of its performance in a musical setting. Despite playing various music of different tempos and dynamics, as discussed previously, the performance of Air Bonang did not meet the users' expectations, thus hindering it from being used reliably in ensemble settings as synchronicity in producing melodic, rhythmic, and harmonic components is crucial. They found that it was not responsive enough for them to play fast passages or specific techniques as it did not detect the striking immediately. This issue might need to be addressed for its implementation in an ensemble performance setting; however, it is seen as fit and reliable for individual use for learning and practice. On a more positive note, the vibration of the hand controllers through haptic feedback was well-simulated to compromise the lack of physical striking. The participants also commended Air Bonang as a sustainable alternative to the bonang instrument in a musical way. The participants thought that it was more accessible and portable than the actual instrument, making it attractive and appealing in its own way.

VI. DISCUSSION AND CONCLUSION

Both studies revealed insight into how a VR gamelan instrument is implemented in various musical settings. Generally, the participants used Air Bonang as a musical instrument to mainly perform and improvise music individually and collectively. The implementation can be narrowed into three contexts: *traditional, exploratory,* and *collective*.

Firstly, the *traditional* context was based on how the VR instrument was afforded, like the actual bonang. During the studies, it was primarily used to play various gamelan music, including traditional and contemporary repertoire, by incorporating fundamental instrumental techniques into the musical pieces. Implementing Air Bonang in this way did not alter the instrument's traditional role. As affordance is also influenced by constraint [7], some borrowed musical techniques were attempted with Air Bonang but could not be executed. For example, the *glissando* and *tekap* techniques could not be played smoothly due to the lack of physical feedback, which is one of the constraints of Air Bonang. Executing these different techniques might require a novel gestural interaction suitable to the mid-air interaction of the VR instrument.

The second context of musical affordance is inclined towards the *exploratory* interaction of Air Bonang, which presents a new virtual environment and interaction different from the usual way of playing the actual bonang. Thus, it afforded more flexibility and versatility in producing musical outputs. The three-dimensional environment was exploited in terms of its virtual space, sound, and gesture. It was afforded through the placement or arrangement of the bonang gongs on the virtual walls, where the 360-degree perspective is utilized for musical output. Melodies, rhythms, and harmonies played in this surround perspective influenced both sound output and gestural interaction, unconstraint by the horizontal playing position of the actual instrument. It was also complemented by playing in a standing position, where the user's movement is more flexible than the usual sitting position. Aside from the three-dimensional aspect of the musical affordance, new playing or striking gestures were also explored. The flexibility of moving the bonang gongs around afforded new playing techniques, such as striking the gong using another gong and not with the mallet on the wall or handheld. The actual bonang gong is relatively heavy to lift in such a way and is fragile; hence, hitting two gongs together would be challenging due to their weight and would damage the instrument. The exploratory affordance of Air Bonang integrates the concept of 'magical interaction,' one of the design principles of virtual reality musical instruments [26], describing interaction that is not limited by real-world constraints.

Thirdly, Air Bonang's affordance was also discovered through the *collective* use of the VR instrument. Unlike some existing VR applications, Air Bonang was not designed to have a multiplayer function; however, it was used in a collective setting where it was played alongside other musical instruments. The collective affordance of Air Bonang was particularly explored in terms of its synchronicity within the gamelan ensemble. Playing musical instruments in any ensemble requires synchrony between the members and is linked to the temporal relationship in musical creation (i.e., producing musical tones) [28]. Air Bonang afforded this by playing existing gamelan music and improvising. In the second user study, the participants attempted to match each other's tempo to maintain a consistent beat. They independently determined this aspect based on the music they were playing, rather than having the researcher dictate it. During some instances, they had to slow down the tempo to accommodate the Air Bonang user, so that everyone would be in sync. Synchronicity was also explored through the pairwise collaboration of two participants attempting to recreate the *kotekan* technique. Originating from the *gong kebyar* orchestra of the Balinese gamelan. This technique was adapted to the Malay bonang, where two musicians played rapid interlocking

melodic and rhythmic patterns. The participants afforded this technique where one player played his part with Air Bonang while another on the bonang instrument aimed to synchronize with one another.

Despite some limitations, Air Bonang meets eight out of nine design principles for Virtual Reality Musical Instrument (VRMI) [26, 29] as described in Table IV.

TABLE III. AIR BONANG DESIGN FEATURE AGAINST NINE VRMI DESIGN PRINCIPLES

Design Principle	Details of Design Principles	Air Bonang
1: Design for feedback and mapping	Design should focus on sound, visual, touch and proprioception in tandem, as well as consider the mappings between these sensory modalities	Yes
2: Reduce latency	Limit any delay between the player's gestures and the generated multisensory feedback	Yes
3: Prevent cybersickness	Avoid 'wrong' mappings, for example, between vision and proprioception, that can cause the user to experience motion sickness	Yes
4: Make use of existing skills	Do not copy but rather leverage expert playing techniques derived from interactions existing in the real world	Yes
5: Consider both natural and magical interaction	Reflect on the use of interactions that conform to real-world constraints as well as interactions not limited by them	Yes
6: Consider display ergonomics	Reflect on the potential strain and discomfort introduced by wearing VR devices	Yes
7: Create a sense of presence	Devise methods that allow the player to experience the sensation of 'being there' in a computer-generated environment	Yes
8: Represent the player's body	Consider the representation of a player's body in the virtual world by tracking and mapping the real body to a virtual representation	Yes
9: Make the experience social	Create social shared experiences while the instrument is being played	No

Air Bonang was designed with the intention of providing a natural and expressive yet explorative VR musical instrument that is targeted at novice and expert users. Hence, it was carefully designed based on experts' feedback [16] as well as VR design guidelines [26, 27, 29]. As a musical instrument, Air Bonang did not incorporate gamification features as other VR gamelan [30, 31] did, as the intention is to play it like an actual musical instrument. While there are some helpful features like demonstration videos showing basic bonang techniques and numbered music notations for certain songs, these are just meant to help users play the VR instrument, not to teach them about gamelan like in earlier works [32, 33].

VII. LIMITATIONS AND FUTURE DIRECTIONS

Both studies only engaged the participants in one-off sessions, despite incorporating iterative processes in designing and evaluating the Air Bonang. Multiple sessions of the prototype evaluation might yield more meaningful results. The limitation faced on time and financial constraints had put a setback to the practicality of more iterations of the prototype development.

Leveraging VR technology can significantly reshape the Malay gamelan for virtual performance. Future research should consider exploring more interactive musical aspects that can be embedded into the VR gamelan, such as establishing a complete set of gamelan instruments that can be played by multiple users (multiplayer) within the same virtual environment, among others. As the Malay gamelan performance has evolved over the decade, VR gamelan could offer gamelan performances that challenge the limitations of the physical world and elevate its culture as a whole.

ACKNOWLEDGEMENT

We thank the Supervisory Committee, Mr. Mohamad Faris Hakimin Yusoff, Gangsapura, Gamelan Anjung Seni, and Fakulti Muzik Universiti Teknologi MARA for their guidance and expertise in this research.

FUNDING

This research did not receive any outside funding or support. The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

AUTHORS` CONTRIBUTIONS

Conceptualization, methodology, investigation, original draft preparation, editing, K.A.S., conceptualization, methodology, review, N.M.N. All authors read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

ETHICAL STATEMENT

This article followed the principles of scientific research and publication ethics. This study has obtained ethical clearance from Universiti Putra Malaysia Ref. No: UPM/TNCPI/RMC/JKEUPM/1.4.18.2 (JKEUPM).

DECLARATION OF AI USAGE

No generative AI tools were used for content creation in this manuscript (e.g., drafting, rewriting, or generating ideas).

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