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DIGITAL TRANSFORMATION IN MUSICAL ART: NEW OPPORTUNITIES IN VOCAL AND CHORAL ART AND INSTRUMENTAL PERFORMANCE

TRANSFORMAÇÃO DIGITAL NA ARTE MUSICAL: NOVAS OPORTUNIDADES NA ARTE VOCAL E CORAL E NA PERFORMANCE INSTRUMENTAL

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Abstract

The article represents an attempt to comprehend the paradigm shift observed in musical art, musical education, and social applications of music technologies. Based on interpretivist research philosophy and applying the elements of scoping review and case study, a range of trends in digitalization of music creation and teaching music was identified and analyzed, and appropriate emerging phenomena. Digital technologies such as VR, AR, and AI are presented as a facilitator of the development and establishment of significant creative innovations within the whole ecosystem of contemporary musical arts. Due to this field being a relatively unexplored area of research, there was a need to 'map the territory', which allows us, as authors,

Resumo

O artigo representa uma tentativa de compreender a mudança de paradigma observada na arte musical, na educação musical e nas aplicações sociais das tecnologias musicais. Com base na filosofia de pesquisa interpretativista e aplicando os elementos da revisão de escopo e do estudo de caso, foram identificadas e analisadas uma série de tendências na digitalização da criação musical e do ensino da música, bem como fenômenos emergentes apropriados. Tecnologias digitais como RV, RA e IA são apresentadas como facilitadoras do desenvolvimento e estabelecimento de inovações criativas significativas em todo o ecossistema das artes musicais contemporâneas. Devido a este campo to discover new phenomena and identify emerging patterns. In particular, opportunities for collaborative instrumental performance and virtual chores are considered, justified by appropriate studies reporting significant positive results.

Keywords: Digital Transformation in Music. Technology in Vocal and Instrumental Art. Online Music Collaboration. Virtual Choir. Digital Pedagogy in Music.

ser uma área de pesquisa relativamente inexplorada, houve a necessidade de "mapear o território", o que nos permite, como autores, descobrir novos fenômenos e identificar padrões emergentes. Em particular, são consideradas oportunidades para performances instrumentais colaborativas e coros virtuais, justificadas por estudos apropriados que relatam resultados positivos significativos.

Palavras-chave: *Transformação Digital na Música. Tecnologia na Arte Vocal e Instrumental. Colaboração Musical Online. Coro Virtual. Pedagogia Digital na Música.*

1 INTRODUCTION

Music performance is being profoundly impacted by digital revolution, which affects everything from the production and distribution of music to its consumption and experience. It is changing the music industry and the connections between artists and audiences because to innovations like streaming services, artificial intelligence, and digital production tools. Artists can freely create high-quality music thanks to the efficient music composition, mixing, and mastering made possible by Digital Audio Workstations (DAWs) and other applications. A greater variety of sound options are available to performers thanks to the employment of digital technology in performances through microphones, electronic instruments, effects pedals, and PA systems (Salvaggio, 2025). Live music is still a valuable experience for many people, even as online performances have grown in popularity. Digital transformation is looking for ways to improve and supplement live events.

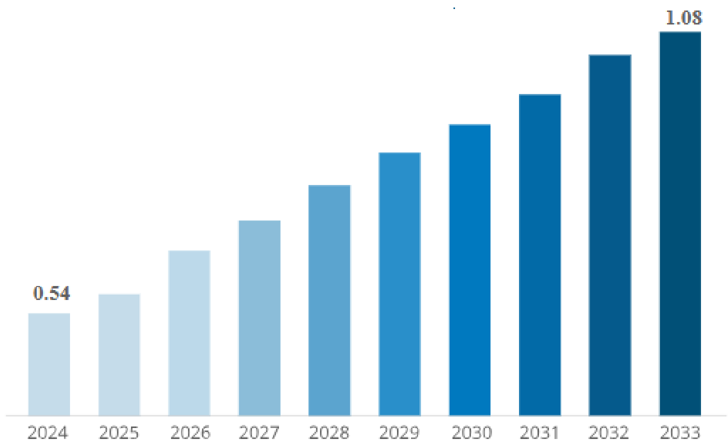
Two significant shifts have resulted from the digitization of the arts: the way that art is created and how artists view their art. Art was created by hand using basic tools prior to the digital age. In the domain of music art, musicians require other organizations that distribute their work in order for it to reach listeners. because the distribution of the artwork is done outside, not inside. In contrast, musicians can interact with listeners directly in the digital age without relying on a third party. To reach listeners, musicians utilize a variety of freely selected digital media (Arifin, et al., 2022).

Technology has completely changed the singing industry by changing the way voice performances are recorded, produced, and enhanced. Modern technology has had a significant impact on the music industry, from digital audio workstations and auto-tune to social media and virtual reality performances. The whole paradigm of music creation is being altered by virtual reality and augmented reality, which have created new opportunities for live performances and enabled vocalists and musicians to provide engaging, interactive concert experiences. With new tools for composition, vocal synthesis, and individualized learning, artificial intelligence and machine learning have the potential to completely transform singing and music creation.

Interestingly, the global market for virtual musical instruments was estimated to be worth USD 0.54 billion in 2024 and is projected to grow at a compound annual growth rate (CAGR) of 8% from 2025 to 2033, reaching USD 1.08 billion by 2033 (see Fig. 1) (Virtual Musical Instrument Market Size, Share, Growth, and Industry Analysis, 2024). The market for virtual musical instruments (VMIs) is centered on software programs that simulate actual acoustic instruments for music production, recording, and performance. These instruments can mimic the sounds of electronic musical instruments as well as those of common instruments like the piano, guitar, or drums. VMIs are widely used in film scoring, game sounds and music, music composition, and teaching. They are closely related to DAWs. Generally speaking, the primary drivers of this sector have been the rise in created content, the acceptance of augmented and virtual reality, and people’s desire to produce music without the need for specialized knowledge. Additionally, they enable musicians to experiment with new compositional ideas without actually owning musical instruments, which increases the need for both professional and amateur musicians at VMI.

Figure 1

Global virtual musical instruments market size 2033 (USD billion)



Source: [26]

The worldwide market for virtual musical instruments can be divided into several categories based on their type, including drums, guitars, and pianos.

- Guitar: Using program interfaces, users can create the ideal blending or bending style of real guitars by simulating the tone and motions of real guitars.
- Piano: Without the need for authentic musical instruments, app-based sound models of pianos can perform complex music using brands of real pianos, such as grand pianos and electronic keyboards.
- Drums: Users can create their own drum set and program electronic beats for a variety of musical styles, from rock to electro house, using virtual drums that simulate percussion instruments.
- Others: This category includes synthesized instruments designed for electronic and creative music, as well as a range of plucked and bowed strings, brass and woodwind, resophonic, and other classical studio samplesolian and experimental instruments.

A paradigm change in music education, performance, and invention was fueled by the digital transformation of musical art. Current advancements in the digital singing and instrumental performance scene highlight the transformative power of technology in modern music, creating opportunities for further interdisciplinary research and algorithmic improvements.

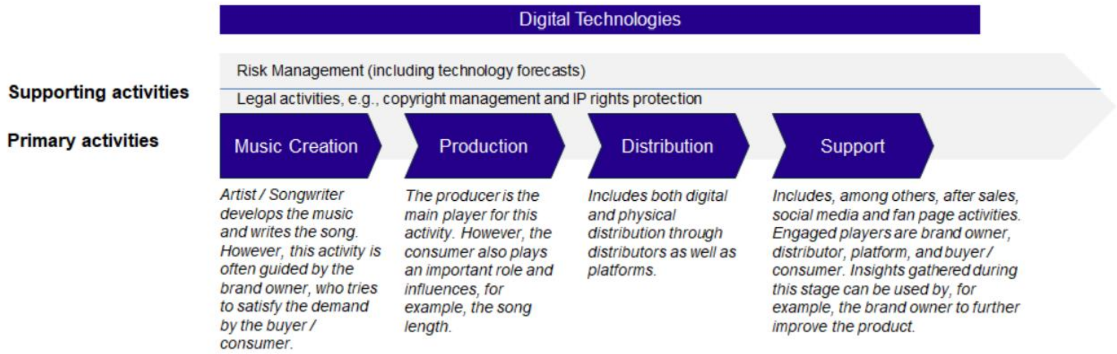
2 LITERATURE REVIEW

We now have a better knowledge of the possible digital disruption in the music industry according to recent study. Numerous studies have examined the possible effects of various digital technologies and have concluded that future changes in digital products would affect established enterprises more than expected (Ross, et al., 2016). For example, by altering how information is created and presented, artificial intelligence and virtual reality applications upend the current power dynamics among major media firms and, by extension, the music industry (Hess, & Constantiou, 2018).

The value chain for the audio industry was expanded upon by Darvish and Bick (2023), who were looking at the function of technology in the music industry. They subsequently modified it for the music industry (see Fig. 2). The four main actions that directly contribute to value creation that is, the creation of a music product make up the audio industry value chain, which is discussed below with an emphasis on music. In the early phases, value creation frequently involves multiple partners engaging in various activities in response to shifts in long-term customer behavior. Two support activities, including technology forecasts, go hand in hand with the four main activities. These activities are crucial to its creation even though they don’t directly add value. For the purposes of this study, technologies are represented as supporting activities that span the entire value creation process in accordance with Porter’s value chain.

Figure 2

Value chain and digital technologies music industry



Source: (Darvish, & Bick, 2023)

As the digital era began in the 1970s, Bell and Carey's (2019) paper aims to argue for a compositional ideal (the mimetic transfer of a recorded or synthesized sound to the instrumental/vocal domain) that has become more realistic thanks to modern technologies for animated/distributed musical notation. This ideal was first introduced as a general aesthetic with composers like Tristan Murail and Gerard Grisey, or in the realm of computer music with Jean-Claude Risset's practice. In the article, the idea of mimesis is explored as a (post-)spectral composing approach as well as a common element of numerous musical score/representation formats. The "In memoriam Jean-Claude Risset" cycle of compositions, which were scored for ensembles of different sizes (small chamber music groups with players wearing head-mounted displays, choir and electronics, large instrumental groups with choir, and for the performance of an opera), are then used as musical examples and software demonstrations to illustrate these theoretical considerations. All of these performances were made possible by the SmartVox Score distribution system (Ueno, & Tachibana, 2005).

The COVID-19 pandemic has had a significant impact on artists' capacity to engage in person. Online instruction, rehearsals, and performances have become necessary due to physical distance and travel limitations. Accepting the limitations of videoconferencing platforms intended for communication has also been necessary when using them in musical contexts. For instance, low-latency audio is typically sent with a distinct video image in networked music performance (NMP). Performers frequently disregard each other's visual images in order to keep a constant pace because videoconference systems typically have a larger degree of built-in latency. Researchers posed the question: Could virtual reality serve as a good substitute for videoconferencing if artists typically avoid eye contact during NMPs? Virtual reality has made a comeback in recent years as an immersive medium that may unite individuals in an online environment. Accordingly, Loveridge (2020) investigates studies in the nexus of virtual reality, virtual worlds, and networked music performance. It concludes that virtual reality, as a visual substitute for videoconferencing in NMP, merits more study and identifies areas of focus for subsequent studies.

Yıldız and Islim (2021) examine the use of virtual reality in vocal training. The purpose of their qualitative study was to investigate how virtual reality affected the vocal training of music students at a Fine Arts Faculty and their experiences with virtual reality.

Eight students participated in semi-structured interviews to provide the study's primary data, while three voice trainers provided the secondary data. The study's findings showed that students could control their breathing more naturally, that resonance gaps were opened, that they could generate a stronger voice, and that they could produce an upper-level vibrato voice in a more comfortable and straightforward manner.

Music production has historically only taken place in physical locations, such as studios, where producers and artists work together using consoles and instruments. However, virtual reality (VR) overcomes these physical limitations and enables artists and producers to work together virtually. Imagine putting on a virtual reality headset and entering a studio where time and location are irrelevant. In a shared virtual environment, artists from around the globe can produce and alter sounds, experimenting with acoustics that mimic actual studios or even fantasy settings that defy physics. For musicians and performers, rehearsal spaces and performance spaces set the tone. Musicians' acoustic and visual experiences in the venues where they play are intricate and natural, involving constant engagement with the surroundings. Schärer and Weinzierl (2015) explain how musicians use their surroundings as an instrument in and of themselves. According to Ueno et al. (2010), objective variations in the pace and degree of vibrato used reveal that artists subconsciously modify their playing style in response to the physical features of concert halls. According to a cognitive model of musicians' actions, Ueno and Tachibana (2010) demonstrated how musicians extend their physical senses into the concert hall's sound field to perceive all of its features in order to create the intended musical image during a performance.

A basic summary of distance concert performance and the challenges involved is given in the work by Mroz et al. (Mróz, Odya, & Kostek, 2022). Additionally, it alludes to the theoretical underpinnings of ambisonics, a sound reproduction format that emphasizes the listener's involvement in the soundscape. The entire recording process of the Academic Choir concert at Gdansk University of Technology is demonstrated, from the planning phase to the musician recordings to postproduction. It talks about issues with sound synchronization and gives a description of the sound and video engineer's workshop. Lastly, in a network-like setting, the eye-tracker is used to analyze how musicians divide their attention between the conductor and the music notation. The quality of experience (QoE), which is crucial in the performance sector, is connected to this feature.

Yu et al. (2023) contributed to instructional design in the creation of a virtual reality musical instrument by focusing their research on promoting musical instrument learning in virtual reality environments. Feng (2023) created a virtual reality-based music education system. According to Zhang (2025), AI shows notable benefits in the field of education. Based on an empirical evaluation of how incorporating AI into the conventional academic curriculum affected students' growth in choral arrangement musical skills and creative abilities, he discovered that AI integration significantly improved students' creative and specific musical skills.

The scope of studies and developments in the field of digital technologies application in singing and performance evidently speaks about paradigm shift in music making, caused by digital transformation, and shows huge potential of emerging digital technologies for musicians, composers, and music disciplines students.

3 MATERIALS AND METHODS

This study used a qualitative exploratory design. To create evidence synthesis, which attempts to methodically identify and map the range of evidence available on a given issue, we used qualitative methodology based on the components of a scoping review. Data gathering, data reduction, data presentation, and conclusion drawing were all phases of the study process that were carried out in a sequential fashion. This method made it possible to map the literature and elucidate ideas in wide-ranging, recently developed research fields pertaining to the digital transformation of the music arts.

We used interpretivism as a philosophy for conducting our research. According to interpretivism, reality is shaped by society. To put it another way, that reality is not independent of the observer but rather subjective, created by the observer by their perception of it. This approach seemed appropriate for our field of study because these kinds of studies frequently examine intricate social phenomena and individual viewpoints, which are inherently more subjective and complicated.

Case-study method was also applied, making it possible to enable a kind of triangulation of the results obtained by summarizing theoretical provisions contained in the literature. Moreover, case study method allowed covering diverse areas of VR technology application in music making domains – in professional music making, musical education, and even elderly social and medical care.

4 RESULTS AND DISCUSSION

Researchers at Stanford University's Center for Computer Research in Music and Acoustics (CCRMA) experimented with recording, streaming, and two-way musical exchanges over networks around the start of the twenty-first century. Due to the considerable video delay at the time, maintaining visual synchronization was one of the biggest issues. As a result of these CCRMA tests, JackTrip.8, an open-source program, was created. Over the internet, the program could transmit uncompressed digital audio across several locations while providing redundancy in case of data loss. Additionally, it might be operated on a small computer with little hardware, just needing a microphone, an audio interface, and an internet connection with a minimum upload speed of 1 Mbps per connection (Loveridge, 2020). Simultaneously, recognizing and accepting network latency in performances became a topic for further online musical research. The average musician can now participate in home-based collaborative experiences thanks to improvements in consumer internet speed. This has created opportunities to improve instruction and training in a variety of subjects, including music. Course delivery, instrumental instruction, remote recording, rehearsals, improvisation, community development, and music therapy interventions are among the real-world applications of NMP. These exercises demonstrate how NMP might reduce isolation among geographically scattered musicians while also promoting beneficial social bonds.

An efficient real-time musical collaboration should be delayed by no more than 20 to 30 milliseconds, according to early research on the impact of delays on group performance. Musicians using acoustic instruments conducted these experiments. Since it assisted in defining the upper bounds for performances of steady-beat rhythmic music, this research result was crucial. Experts further classified different types of musical interplay in an NMP, with the Realistic Interaction Approach (RIA) being defined as the approach that most nearly resembles a realistic interaction between two musicians in the same room. An example of two rhythm-based instruments performed online with a consistent one-way latency of less than 25 ms serves as the foundation for the RIA style.

Due to soundcard and network delays, the maximum feasible distance between two locations employing RIA is thought to be around 1,000 kilometers. Research on the relationship between tempo and latency in RIA-style performances has shown that performance tempo falls in proportion to network delay. Video is typically viewed as irrelevant in the process, even if audio delays might result in different and frequently fascinating kinds of interactions. However, it has also been demonstrated that visual cues play a significant role in how musical expression is perceived during performances. Furthermore, even with limited information, it is possible to discern expressive nuances from a musician's body language (Paitan, et al., 2024). All of this points to the fundamental significance of including visual communication into a musical performance. This begs the question: What impact do technological constraints have on the use of images in an NMP?

Stanford University in Palo Alto, California, and Peking University in Beijing collaborated on a multi-ensemble performance called "Pacific Rim of Fire" in 2008. Terry Riley's "In C" was selected as a suitable work because of the known limits that would enforce the transmission delay due to the 6,000-mile distance between stations. Using JackTrip, high-quality uncompressed audio was transmitted over the network and measured with a 110 ms one-way delay. Based on a feedback-locking mechanism, the two sites were able to play in a tight rhythmic alignment, although not being within the parameters of an RIA-style performance. The crowd and the musicians were able to communicate visually because to the video delay, which was measured at about one second each way. Higher frame-rate cameras and more bandwidth would have been needed to evaluate the event and achieve synchronized audio and video, which would have further delayed the audio stream. This trade-off was thought to be unnecessary because musicians would not be looking at one another all the time during the performance. With differing degrees of success, researchers have attempted to address the problem of latency over video. In order to address the challenges of linking distant artists, LoLa (LOw LAtency audio visual streaming system) was developed in 2005 and first shown in public in 2010. In order to manage the video connection, LoLa requires a significant audio-visual setup that includes a powerful computer and a sizable network bandwidth of up to 1 Gbps. It also permits audio and video exchanges. Although technological problems like latency and availability to high-speed networks are mentioned as significant obstacles, LoLa has been shown to be a useful instrument for networked music activities. Virtual reality technology aid in removing these restrictions. "Presence", or the sensation of being in the same place as someone else despite being physically separated, is one of the main affordances that virtual reality (VR) can offer. In contrast to traditional media, like radio and television, which can only offer cerebral immersion, virtual reality (VR) can offer a sensation of presence or physical immersion (Redhead, 2024).

The creation of virtual instruments in virtual environments has been the subject of more and more research in recent years. Anıl Çamcı and Rob Hamilton's work creates new kinds of instruments and interactions by combining game engines with VR headsets. Coretet enables musicians to play sounds from a virtual stringed instrument while in virtual reality. It was created for a co-located live performance setting. Players network together in the same physical performance area, sharing a virtual environment while viewing each other's instruments and avatars. EXA: The Infinite Instrument is a virtual reality program that allows remote performers to share virtual instruments. Player involvement is enabled through a variety of methods, including live sound triggers, looped recordings, and verbal communication via an in-built headset microphone. Latency issues persist when the distance between performers exceeds the permissible level for live performance (Hamilton, 2019, January 31).

Pre-recorded 360-degree footage was used to investigate virtual choir performance. Helena Daffern et al. discovered that users felt limited since they couldn't walk around the space or had a rendered body. A longer-term goal of the project was stated as the ability to explore interactive VR with avatars while investigating latency issues. An initial investigation into how latency affects presence in a networked setting was carried out in connection with learning and performing music. This was accomplished by having musical duos read from a score while facing one another on a video screen. According to the results, future research should look into more immersive audio-visual feedback options like full-body projections and binaural rendering. Additionally, well-designed spatial elements in remote interactive environments may help compensate for time-dependent misalignments in communication and performance (Delle Monache, et al., 2018).

Tamplin et al. (2020) published a case study on the application of virtual reality in a networked music therapy session (see Fig. 3). This study demonstrated how VR could offer individuals with spinal cord injuries a life-changing experience by allowing them to participate in group singing as a therapeutic activity. Their approach, which merged virtual reality and RIA, revealed that people who sang in the VR situation felt less self-conscious. It was liberating, according to participants, to not be able to see the actual world around them or how other people were responding. The possibility of integrating virtual reality and NMP into a single system was one of the recommendations arising from this effort.

Figure 3

Music therapist Dr. Jeanette Tamplin performs during a trial of the "Music Therapy in Virtual Environments" study at the Royal Talbot Rehabilitation Centre, Melbourne, Australia

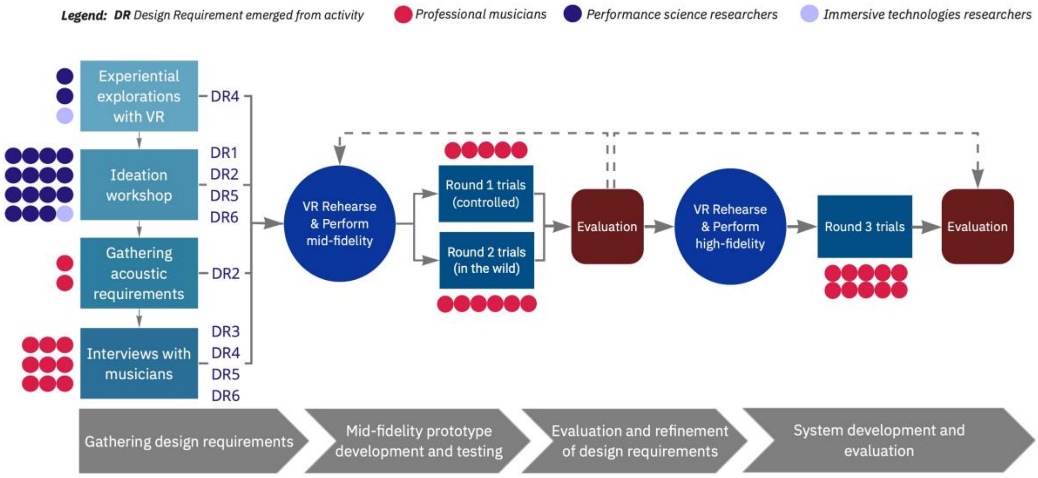
Source: Tamplin et al. (2020)

The optimal VR musical performance or interaction experience has been the subject of additional recent research. In order to achieve larger human goods, successful VR design makes use of the fundamental characteristics of the medium, such as isolation, interaction (agency), immersion, presence, embodiment, and viewpoint (Atherton and Wang, 2020). One step toward accomplishing the goals Lanier put forward some thirty years ago is their work in enabling the user to create audio experiences within the VR setting.

Musicians' acoustic and visual experiences in the venues where they play are intricate and natural, involving constant engagement with the surroundings. According to Ppali et al. (2022), the initiative used virtual reality (VR) to help musicians with their creative process by immersing them in new visual and aural environments. Based on design specifications acquired from musicians and performance specialists, the authors created VR Rehearse & Perform, a musician-centered VR system that includes a variety of acoustic and visual virtual environments. The authors conducted semi-structured interviews after conducting iterative testing with 19 musicians to examine how VR might be developed to assist artists in their creative musical practice. According to the results, virtual reality (VR) may help with a variety of creative musical activities, including practicing, performing, and improvising. Insights and ideas for creating musician-centered virtual reality experiences for a range of musical activities can be found in the research of Ppali et al. (2022). Through an ideation workshop, the authors aimed to generate ideas for a VR tool prototype that could enhance performance preparation. They also collected acoustic requirements by exposing musicians to audio spatialization solutions, such as the 3DTi Toolkit, an open-source system for creating and rendering realistic audio spatialization and reverberation models. Finally, they discussed how immersive technologies might help musicians by understanding the range of techniques they employ in their music practice. Eleven musicians, fifteen performance researchers, and two researchers with expertise in creating immersive technology experiences participated in the numerous activities conducted within (see Fig. 4). The authors used video cues to guide conversations on immersive technologies that were influenced by the invisible design concept. They also conducted design exercises in which participants were invited to sketch and play out their ideas. Six fundamental design specifications for immersive musical practice were developed in light of this (Fig. 4).

Figure 4

Developing VR Rehearse & Perform – a user-centered iterative process

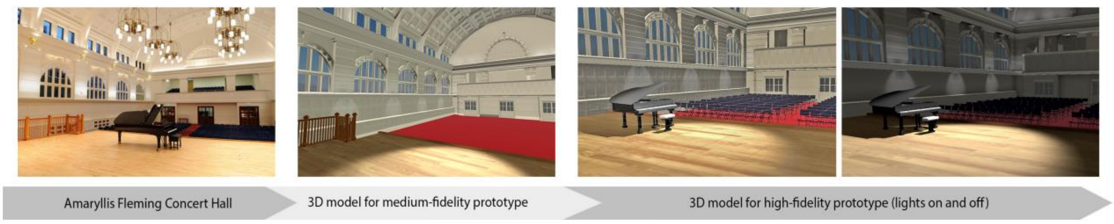


Source: Ppali et al. (2022)

A 3D model of the Amaryllis Fleming Concert Hall at the Royal College of Music was selected as the virtual environment for this prototype version (Fig. 5, first image). Using Maya 2020, a low-polygon 3D model was created from a high-quality point cloud of the location that contained texture data (Fig. 5, second image).

Figure 5

The Amaryllis Fleming Concert Hall - from a physical space for musical practice to its 3D representation in VR Rehearse & Perform



Source: Ppali et al. (2022)

The project’s collaborating musicians thought the acoustic experience was realistic. Some participants used a variety of coping strategies to cope with the latency, which had varying effects on musicians’ experiences. Some musicians valued the distinctive soundscape produced by Oculus Quest’s built-in audio system, while others favored the more focused sound the headphones offered. They explained how VR

Rehearse & Perform supported and encouraged new kinds of music-making while allowing them to focus their creative energies on musical expression itself. The majority of artists saw the possibility of training more successfully at home or in locations that don't suit their acoustic requirements. Two participants have now purchased a VR headset and incorporated it into their musical practice after being inspired by their VR Rehearse & Perform experience (Ppali, et al., 2022).

The emergence of virtual choirs, a ground-breaking trend that has completely changed how artists compete and interact, is among the most notable recent advancements. Through the creation of platforms where voices harmonize across continents and boundaries dissolve in the common pursuit of musical greatness, these competitions serve as prime examples of the union of artistry and technology. Despite being greatly accelerated by the worldwide epidemic, this new paradigm has developed into a lively and enduring feature of the contemporary music industry. It signifies a cultural change in how we view and engage with music-making in addition to a technological advancement. As a result, in an increasingly digital world, virtual choir competitions are continuing to influence the future of musical collaboration by providing fresh chances for innovation and connection.

In the paper by Feng (2023), a VR-based music teaching system is suggested as a way to improve the use of computer-aided instruction technology in music education. Initially, a virtual piano was created utilizing Unity3D, associated SteamVR plug-ins, and Leap Motion plug-ins as software platforms, and the HTC Vive kit and the helmet-mounted Leap Motion sensor as hardware platforms. After that, an algorithm for gesture recognition was developed and put into practice. To gather the user's gesture command input, the Dual Channel Convolutional Neural Network (DCCNN) is specifically used. The gesture command in the video and the feature information in the image were extracted using a dual-size convolution kernel, which the DCCNN then identifies. The DCCNN receives Red-Green-Blue (RGB) color pattern images and optical flow images after the spatial and temporal information has been extracted. The final recognition result is obtained by combining the prediction results. According to the experimental results, DCCNN can recognize the Curwen gesture with an accuracy of up to 96%, and the accuracy varies depending on the convolution kernel used. In contrast, it is discovered that the size of the convolution kernel influences the recognition impact of DCCNN. The recognition accuracy can be increased to 98% by combining convolution kernels of sizes 5×5 and 7×7. The study's findings have broad applicability and popularity and can be utilized for music instruction on the piano and other VR goods.

An intriguing study outlining the potential for creating virtual choirs in assisted living facilities is presented by Daffern et al. (2019; 2025). The VR intervention was technically sound, easy to use, and enabled group singing by several people. Although some residents found the headsets uncomfortable, participants and staff demonstrated a great deal of excitement for the intervention, with residents enthusiastically participating in singing and activity. This implies that virtual reality choirs might be a useful and expandable activity in assisted living facilities, particularly in situations when face-to-face facilitators are not accessible.

AR follows a somewhat different path. By superimposing digital data on top of the physical world, it improves it. In the context of music production, this could entail viewing a digital interface superimposed over actual equipment, manipulating effects and mixes using hand gestures, or visualizing sound waves in the air. In addition to streamlining the production process, this fusion of digital and physical components also makes it more engaging and intuitive. By giving the music performance a new dimension, AR can provide a more captivating and immersive visual experience. With AR, artists may produce breathtaking visual effects that go well with their music, adding to the audience's enjoyment of the performance as a whole.

Education and accessibility are two areas where VR and AR in music production have the most effects. Unlike traditional techniques, beginners can learn about sound engineering and mixing in a more interesting way by immersing themselves in interactive tutorials within a virtual reality environment. Additionally, AR can offer visual signals and direction during studio sessions or live performances, reducing the learning curve for beginners.

Additionally, augmented reality can be used as a medium for creative expression and innovation. Musicians can experiment with new sounds, visuals, and stories by using augmented reality technology. It gives musicians a platform to push the limits of convention, allowing them to freely express themselves and offer a more in-depth analysis of their music. In the end, augmented reality (AR) can help music evolve by giving musicians the opportunity to explore new areas.

AR is causing a stir in the realm of digital music production in addition to improving conventional musical genres. It gives users a completely new canvas on which to compose and work with sounds in a 3D, immersive environment. AR platforms, for instance, enable users to interact with virtual instruments in their surroundings to create music. This engagement might be as basic as using hand motions to control sound waves or as complex as striking a virtual drum. This new method of creating digital music using augmented reality (AR) not only gives experienced musicians additional options, but it also makes the process easier for inexperienced music lovers. It offers a creative outlet and broadens the range of musical exploration.

Additionally, VR and AR create new opportunities for artistic expression. Artists are able to create multi-dimensional soundscapes that allow listeners to experience music. This may be listening to a virtual orchestra play all around you or strolling in a forest while birds chirp in time with the music. Holograms and interactive light displays that go well with the music are two examples of how augmented reality (AR) can improve the live performance experience for the audience.

Auto-Tune is one of the noteworthy options. The pitch of voice and instrumental recordings can be automatically corrected and adjusted with this software tool used in music creation. It improves the precision and regularity of performances by analyzing audio signals and adjusting pitches to fit a selected scale. In addition to pitch correction, Auto-Tune can be imaginatively applied to produce distinctive vocal sounds. Dr. Andy Hildebrand initially created Auto-Tune in the late 1990s as a tool for non-musical uses including seismic investigation. But the music industry soon saw its potential, and it went on to transform the recording and production of music. The program analyzes the pitch of an incoming audio input and instantly adjusts it to the closest desired pitch using a technique known as pitch correction. Sophisticated algorithms are used to determine the vocal signal's fundamental frequency and adjust it to match the intended pitch. The user can change the level of correction, from minor adjustments to a whole overhaul of the vocal performance.

To fix pitch issues and alter voice performances, Auto-Tune employs a technique known as "formant shifting". The program detects the incoming audio signal's pitch in real time and corrects it to match the target pitch when a performer sings off key. Because it entails rounding the pitch to the closest desirable value, this procedure is frequently referred to as "pitch correction" or “itch quantization”. As a result, there are no unwelcome pitch variations in the voice delivery, which sounds polished and professional. Auto-Tune can be used to produce more dramatic effects like "pitch-bending" or “glide’ effects in addition to pitch correction. These effects entail progressively altering the pitch over time, frequently in a subtle and fluid way. Musicians can produce intricate and captivating soundscapes that take their songs to new levels by fusing these effects with other audio processing methods. Auto-Tune’s sophisticated formant shifting algorithm offers countless creative expression options, making it a useful tool for both producers and musicians (Duinker, 2025).

Additionally, Auto-Tune offers a number of settings that users can modify:

- Retune Speed: As stated earlier, this controls the rate at which the pitch is adjusted.
- Humanize: When employing fast retune speeds, this option enables users to give sustained notes more reality.
- Input Type: By anticipating the type of sound it will receive, Auto-Tune is able to detect pitches more precisely.
- Custom Scales: Users can create their own scales for music that does not fit into conventional Western-style scales, making sure that the corrections match the song’s distinct tone.

Actually, Auto-Tune is a tool that many professional singers utilize to help them perform at their highest level. Singers can concentrate on their tone, dynamics, and phrasing instead of worrying about hitting the precise notes by utilizing Auto-Tune to fix small pitch mistakes. This enables them to communicate the desired message to their audience while also appealing to their emotions. Additionally, singers can push the limits of what is possible with their voices by experimenting with various sounds and genres thanks to Auto-Tune’s sophisticated formant shifting technology. Furthermore, more nuanced and sophisticated vocal harmonies can be produced with Auto-Tune, giving a song additional depth and texture. In the end, technology such as Auto-Tune is a supplement that can improve singing technique and provide musicians additional creative options rather than a substitute for conventional vocal abilities. The final step in the vocal-instrument ecosystem, which starts with air leaving the lungs and finishes with the voice as heard through loudspeakers or headphones, is thus represented by Auto-Tune’s molding of the voice as heard. Auto-Tune plays a digital part in this process, and because it is inextricably linked to the voice, it helps turn the voice into a digital musical instrument, or DMI.

Additionally, because AI is used in music creation tools, it is one of the newest trends in the Virtual Musical Instrument (VMI) market. By listening to a user, artificial intelligence-related virtual instruments can produce music, accompaniment, harmony, or even a whole song, boosting efficiency and creativity. With the help of these improvements, musicians can discover new ways to play an instrument or create new musical styles. Machine learning is used to replicate different instruments and, in the end, provide suggestions for the user's favorite songs or bands. As more producers, composers, and amateur musicians look for the finest ways to make their jobs easier, this trend only looks to becoming more trustworthy. Since real-time sound creation and adaptive music generation might lead to new creative possibilities, this AI integration is unique in live performances and will likely inspire future VMIS.

The two primary subfields of AI music generation are audio music generation and symbolic music generation. Different levels and types of music making are represented by these two approaches. AI technologies are used in symbolic music production to produce musical symbols like piano rolls, sheet music, and MIDI files. The foundation of this method is understanding chord progressions, melodies, rhythmic patterns, and musical structures in order to create works with coherent and well-structured music. Discrete note data is usually handled by these models, and the output can either be played immediately or subsequently processed into audio. LSTM models have demonstrated great capability in the creation of symbolic music. For example, DeepBach creates Bach-style harmonies using LSTMs, generating melodic chord progressions from provided musical pieces. Long-term connections and complicated structures are difficult for symbolic music creation to capture, though, especially when creating music on the scale of whole movements or songs, where it might be challenging to sustain long-range musical dependencies (Chen, Huang, & Gou, 2024) More effective methods for capturing long-term interdependence have recently been shown using Transformer-based symbolic music generation models. For instance, the Pop Music Transformer (Huang, et al., 2023) significantly improves pop music generation by combining Transformer design with self-attention processes. MuseGAN, a GAN-based multi-track symbolic music generation system, can also produce multi-part music that is appropriate for composing intricate harmonies and rich layers. The MuseCoco model (Liu, & Guo, 2025) is perfect for developing intricate symbolic music compositions because it blends natural language processing and music creation. It creates symbolic music from text descriptions and gives fine control over musical parts. However, the limitations of symbolic music creation are highlighted by the fact that it primarily concentrates on notes and structure, with little control over timbre and expressiveness.

Using continuous audio signals that may be played back directly or utilized for audio processing, audio music production directly creates the audio signal of music, including waveforms and spectrograms. This method can create realistic and intricate musical content because it is more akin to the recording and mixing phases of music creation.

Widely used in voice synthesis and music production, WaveNet is a deep learning-based generative model that produces expressive music by capturing minute changes in audio signals (Atherton, & Wang, 2020). With the help of OpenAI's Jukebox, which blends autoregressive and VQ-VAE models, it can produce full songs with intricate structures and lyrics that sound as emotive and high-quality as actual recordings. However, creating audio music usually calls for a significant amount of processing power, particularly when working with big audio data sets. Controlling the logic and structure of music over long periods of time is another difficulty for audio creation models.

Diffusion models, which were first applied to image production but are now also being used to audio, have advanced significantly in recent years. Two exemplary methods for audio creation are DiffWave and WaveGrad. The former uses a progressive denoising technique to produce high-fidelity audio, while the latter uses a similar diffusion process to produce detailed audio. By combining language models (LMs) with diffusion probability models (DPMs), the MeLoDy model solves computational efficiency challenges by minimizing the number of forward passes while preserving good audio quality. Based on diffusion theories, Noise2Music (Huang, et al., 2023) examines the relationship between generated music and text prompts, showing that it can produce music that is closely related to input text descriptions.

In general, the two main approaches to AI music generation are audio and symbolic music generation. While audio music creation concentrates more on the expressiveness and nuances of audio signals, symbolic music generation is more suited for handling and producing structured, interpretable music. These two approaches could be combined in future studies to improve AI music generation's expressiveness and usefulness, facilitating smooth transitions from symbolic to auditory and offering more thorough technical assistance for music production.

Tools like the Vocal AI Analyzer and Smart Vocal Coach use artificial intelligence to improve vocal abilities. Pitch, dynamics, timing, and timbre are among the technical elements of voice performance that the voice AI Analyzer focuses on analyzing. 158 students from a prestigious music school participated in the study by Liu and Guo (2025), who split them into control and experimental groups. Surveys and testing were among the techniques used, in addition to AI-based programs like Smart Vocal Coach and Vocal AI Analyzer. Comparing the experimental group to the control group, the results showed a significant improvement in both voice abilities (from 3.5 to 4.5) and inventiveness (from 2.9 to 4.1). With instant feedback and individualized education, the AI-based tools proved to be quite effective. The potential use of these technologies in music education institutions to improve instruction and foster students' creative potential is where the research's practical value resides.

A systematic review of AI in music generation is presented by Paitan et al. (2024). By highlighting advancements in electronic music, automatic music generation, music evolution, contributions to music-related fields, particular studies, the revitalization of western music, hardware development, and educational applications, the analysis examines the advantages of artificial intelligence (AI) in music generation. Neural networks, automation and simulation, neuroscience approaches, optimization algorithms, data analysis, Bayesian models, computational algorithms, music processing, and audio analysis are all included in the methodologies that have been found. These methods demonstrate the intricacy and adaptability of AI in music production. There is a clear interdisciplinary influence that extends into cognitive neuroscience, music therapy, and sound engineering.

5 CONCLUSION

The use of VR, AR, and AI in music production is not without its difficulties, despite the fascinating potential. Obstacles that must be addressed include the high expense of technology, the requirement for specialized knowledge, and possible health issues including motion sickness. These difficulties should, however, lessen as technology advances and becomes more widely available.

Looking ahead, the creative process is about to be redefined by the combination of VR and AR with music production. Creating a realm of sound that transcends the speakers and envelops the performer and the audience in a fully immersive auditory experience is more important than simply producing music. The act of producing music will become as boundless as the human imagination as these technologies advance and open up new creative possibilities.

In summary, the combination of VR and AR with music production is a paradigm change rather than a passing fad. These technologies are changing the music industry by removing physical obstacles, improving creative visualization, and facilitating more accessible and interactive creation. The future of music production is about immersive experiences that inspire and engage in ways that were previously unthinkable, not just about sounds. Furthermore, more research may be done on how technology and digital platforms affect musical authenticity. This includes how social media, streaming services, and artificial intelligence affect musicians' authenticity.

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All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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