Note Block Studio: A Music Creation Application for Minecraft Note Block Songs

Bernardo Costa[1]*, **Flávio Luiz Schiavoni**[1]

[1]ALICE - Department of Computing (DCOMP) - Federal University of São João del-Rei (UFSJ)
Av. Visconde de Rio Preto, S/N - Colônia do Bengo - São João del-Rei - MG

bernardo.costa@aluno.ufsj.edu.br, fls@ufsj.edu.br

Abstract. *Note Block Studio (NBS) is an open-source music creation application for desktop computers. It aims to help anyone easily create music for the critically acclaimed video game Minecraft, using blocks that emit musical notes. NBS features an intuitive grid workspace, where a user can arrange musical notes to create songs. These songs can then be exported to a musical circuit, allowing them to be played in-game. Since its first release in 2011, NBS has gathered a vibrant community with tens of thousands of players and musicians. Many software tools and plugins have been developed to enhance the app's native capabilities, deeply enriching the project's ecosystem. Moreover, advanced compositional techniques have been created to overcome the limitations of note blocks. These advancements have paved the way for hundreds of musical works, visualizations, and even collaborative pieces to emerge around the app, which have reached millions of players through online social platforms and multiplayer virtual worlds. In this paper, we provide an in-depth analysis of NBS and its features, showcase its community, and present some of the modern initiatives powered by the app. We also explore how its appeal has helped it secure a solid position within Minecraft's musical community. Ultimately, our goal is to introduce NBS to the academic community, building a strong contextual foundation to support future research and development of its ecosystem.*

1. Introduction

Minecraft is a sandbox, open-world video game developed by Swedish company Mojang Studios. In the game, players explore a virtually infinite, three-dimensional world with procedurally generated terrain that's entirely made up of voxels (called *blocks* in-game). Every block in the world's 3D grid can be collected and placed, offering players unlimited creative freedom. Released in 2011 and purchased by Microsoft in 2014, the game has become the best-selling video game of all time, surpassing 350 million copies sold [1]. With nearly 200 million monthly active players, it has become a massive cultural phenomenon and is considered one of the most influential video games of its decade [2, 3]. More about Minecraft will be presented in Section 2.1.

Among the vast array of game mechanics offered by the game, the **Note Block** stands out as one of the game's music-oriented features. When placed in the world, this block emits a musical note when hit by a player or powered with an electric signal. Interacting with it changes the key of the note it produces, and the block immediately under it determines which sound it makes. It empowered players to create musical circuits that play tunes, such as doorbell jingles, alarms, and even entire musical pieces. Over the years, a wide community gathered around note block music creation, with videos and tutorials showcasing these musical circuits quickly spreading online [4]. Some Minecraft concepts relevant to note blocks are elaborated in Section 2.2.

In this context, a tool was developed to facilitate the planning and construction of such circuits. **Note Block Studio**(NBS) is a music editor aimed at helping Minecraft players plan and arrange note block circuits. The app features an intuitive, grid-like workspace made of rows and columns. Each row in this grid represents a layer (or track) in which multiple notes can be stacked to form chords. Each column represents a tick — the time interval at which Minecraft's game logic is recalculated. By arranging notes in this grid, users can create complex songs consisting of multiple melodic lines, chords, drums, and sound effects. NBS can then automatically generate a circuit to play the song in-game, bypassing the need to build the circuit manually. Created by Swedish developer David Andrei in 2011, NBS was initially released as a closed-source app. However, its development ceased around 2017, which led to its release as open-source software in 2019 [5]. An in-depth description of the features and workflow of NBS is presented in Section 3.

Since its debut as an open-source project, a vibrant community of players and musicians has gathered around NBS and its ecosystem. Thousands of songs created with the app have been shared and viewed on online platforms such as YouTube. Large multiplayer server networks have incorporated full note block soundtracks backed by NBS. Community members have developed a variety of tools, plug-ins, and even musical techniques to overcome the limitations of note block circuits. They also regularly engage in competitions, challenges, and collaborations. These initiatives have yielded notable musical works, including a 20-minute collaborative medley arranged collectively by 23 musicians, and a full-length musical album created by 14 artists [5]. Beyond its use in entertainment, music education literature cites NBS as a suitable educational tool for teaching music to K-12 students, which can provide meaningful experiences in a classroom setting [6]. These initiatives are further explored in Section 4.

The prevalence of NBS among the Minecraft music-making community reveals its potential as a powerful creative medium, whether in recreational, professional, or

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educational settings. We discuss the reasons behind its popularity in Section 5. In light of the rich ecosystem of tools surrounding NBS, its thriving community, and its potential impact in various musical environments, we advocate for its legacy to be preserved and enriched. There's great potential for further development and research initiatives, which are explored in Section 6. This paper aims to introduce NBS to the academic community, establishing a robust contextual foundation to support future research and development of its ecosystem.

2. Theoretical Framework

As this paper's contributions cannot exist outside the creative framework provided by Minecraft, this section offers a brief introduction to some of its fundamental concepts. We see this overview as essential for understanding the role of NBS in the game's community, as well as its relationship to the broader gaming and music creation ecosystems.

2.1. Minecraft

Minecraft is a sandbox, open-world video game created by Swedish developer Markus Persson, beginning in late 2009. Developed in the Java programming language, it was made available in an early-access model, followed by its official release in 2011. In 2014, Minecraft was acquired by Microsoft. Following the acquisition, development of a new, cross-platform version began alongside the original version's development. The game is now present on a wide array of platforms, including video game consoles, computers, mobile phones, and even Virtual Reality (VR) devices.

In the game, players explore a virtually infinite, three-dimensional world with procedurally generated terrain that's entirely made up of voxels (*blocks*). Every block in the world's 3D grid can be collected and placed, offering players unlimited creative freedom. The default and most popular game mode is *Survival mode*, where players must collect resources and fight creatures to survive. However, the game's ecosystem goes far beyond its out-of-the-box experience. Downloadable worlds created by players, self-imposed challenges, and even modifications to the source code can be easily incorporated, which enabled a vast and diverse ecosystem of tools and projects to flourish around the game [2]. Prominent projects include entire art galleries, interactive recreations of fantasy worlds such as Hogwarts and the USS Enterprise, and fully functional recreations of popular video games , pushing its potential as a powerful creative platform [2]. The game's experience is shaped by its community, and its success has strongly shaped and inspired many games that followed it [3].

Besides merely creative applications, Minecraft has been extensively employed in social transformation initiatives. In the *Block by Block* project, it empowered young people living in neglected urban spaces to participate in designing the changes they would like to see in their environments, transforming them into vibrant places and vastly improving quality of life in these spaces [7]. In *The Uncensored Library*, it hosts an interactive, online repository

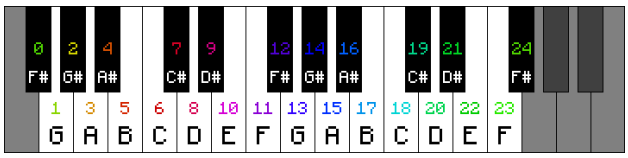

Figure 1: Pitch range available to note blocks.

with thousands of journalistic reports and books censored in certain countries, leveraging its accessibility to circumvent censorship in countries without freedom of the press [8]. In the educational space, a version called *Minecraft: Education Edition* is used in hundreds of schools to teach topics like chemistry, physics, computer science, and geology [2]. Lastly, it has been used to culturally preserve the Elfdalian language, an endangered, ancient Scandinavian language spoken by about 3 000 people in a small town in Sweden [9]. As of publishing, Minecraft is, by a large margin, the world's best-selling video game, with over 350 million copies sold and 200 million monthly players [2]. It has become a massive cultural phenomenon, and is largely considered one of the most influential video games of its decade [2, 3].

2.2. Note Block Music

Among the vast resources and materials available to Minecraft players, **Redstone** can be used to create electrical circuits. When placed in the world, it acts like an electrical wire. It can also be used to craft redstone components. Buttons and levers act as power sources. Torches invert an incoming signal, acting like a NOT gate. Repeaters repeat a weakening signal, introducing a configurable delay. One of these components is the **Note Block**, a wooden block with a textured pattern resembling a jukebox. Placed in the world, it emits a musical note when triggered, either manually by a player or with a redstone signal. By default, it's tuned to F♯ — interacting with it transposes it one semitone higher. Once it reaches two octaves above the default note, interacting with it again 'resets' the pitch to the lowest available. This gives note blocks a chromatic range of two octaves. In simpler terms, the number of interactions performed with a note block after it's placed determines which note it produces, spanning the range 0–24. Figure 1 shows the pitch range available to note blocks, and the number of interactions required to set one to a given note. Each number has the color of the note particle emitted when a note block is set to that key. Gray keys are not reachable with regular note blocks.

The sound produced by a note block is determined by the block placed immediately under it. Each sound represents a different real-world instrument, and some are tuned to different octaves, resulting in a six-octave pitch range if all instruments are considered. The relation of blocks to instruments can be seen in Table 1. The double bass and didgeridoo are bass instruments. The bell, xylophone, vibraphone, and cowbell are hammered, tonal percussion instruments. Hi-hat, snare, and bass drum are non-melodic percussion instruments — despite this, they can still be tuned regularly. The chimes and flute are airy and soft.

Block	Instrument	Range
Wood blocks	Double Bass	$F\sharp_1$–$F\sharp_3$
Sand blocks	Snare Drum	–
Glass blocks	Click (Hi-hat)	–
Stone blocks	Bass Drum (Kick)	–
Block of Gold	Bells (Glockenspiel)	$F\sharp_5$–$F\sharp_7$
Clay	Flute	$F\sharp_4$–$F\sharp_6$
Packed Ice	Chimes	$F\sharp_5$–$F\sharp_7$
Wool	Guitar	$F\sharp_2$–$F\sharp_4$
Bone Block	Xylophone	$F\sharp_5$–$F\sharp_7$
Block of Iron	Iron Xylophone (Vibraphone)	$F\sharp_3$–$F\sharp_5$
Soul Sand	Cowbell	$F\sharp_4$–$F\sharp_6$
Pumpkin	Didgeridoo	$F\sharp_1$–$F\sharp_3$
Block of Emerald	Bit (Synthesizer)	$F\sharp_5$–$F\sharp_7$
Hay Bale	Banjo	$F\sharp_3$–$F\sharp_5$
Glowstone	Pling (Electric Piano)	$F\sharp_3$–$F\sharp_5$
Any other block	Harp	$F\sharp_3$–$F\sharp_5$

Table 1: Instruments produced by Minecraft note blocks and their pitch ranges.

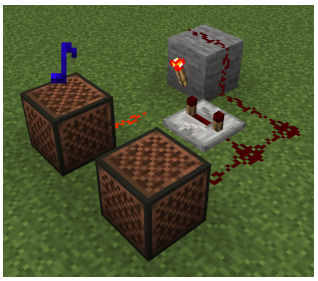

Figure 2: A looping note block circuit.

Harp, guitar, and banjo have a plucked sound. The harp is gentle and quiet, the guitar is deep and intense, and the banjo has a distinct metallic sound. Pling and bit are typical synthesized sounds, one resembling an electric piano and the other evoking chiptune, 8-bit sounds characteristic of retro arcade video games.

Due to their property of being redstone components, note blocks can be arranged into a redstone circuit to create music. By using redstone repeaters, it's possible to introduce delays between activations of different groups of note blocks. Note blocks that are triggered in the same game tick form a chord. Note blocks that are triggered a few ticks apart can form a melody. By joining chains of note blocks in a circuit, it's possible to create motifs, phrases, and even entire musical pieces. Repeating, cyclical structures can be made by connecting a circuit back to itself, forming musical loops. Such a structure is shown in Figure 2, which plays alternating notes with a delay.

The limited musical framework accessible to players, coupled with Minecraft's broad appeal to audiences of various ages, makes note blocks a powerful medium for exploratory music creation. However, creating these musical circuits manually can be difficult and time-consuming, requiring careful planning around layout, wiring, and block placement. To facilitate arranging note block songs before they're built in-game, a software tool was developed to aid in planning such circuits. This tool is the primary subject of this paper and will be elaborated on in the following section.

3. Note Block Studio

Note Block Studio (NBS) is an open-source music editor for Windows computers, created to facilitate arranging music using note block sounds. Originally called *Minecraft Song Planner* (MCSP), it was released by Swedish developer David Andrei in early 2011, only a week after note blocks were introduced to Minecraft [5]. The app's goal is to enable users to arrange and plan a song before incorporating it into the game. It provides an intuitive, grid-like workspace that allows users to freely add, remove, change, and rearrange note blocks, as well as easily listen to their arrangement. Each row in the grid represents a *layer* in which multiple notes can be stacked together to form chords. Each column represents a *tick* — the time interval at which game logic is recalculated in Minecraft. By arranging musical notes in this grid, a user can create complex arrangements. This provides an abstraction to the game's 3D block grid, making it easier to plan and build complex musical circuits. Besides its arrangement features, the app can detect input from MIDI devices and record live performances. It can also import MIDI files and convert them into note block arrangements. Finally, it can automatically generate a redstone circuit's structure from a created song, which can then be imported directly into Minecraft — eliminating the need to build the circuit manually. In this section, we provide a comprehensive overview of the app's workflow and the primary features it offers to musicians.

3.1. Workflow Overview

Launching the app immediately reveals its main view, shown in Figure 3. It features a central area with the workspace used for arranging notes, a layer control panel to its left, and a piano at the bottom. Surrounding these elements are a toolbar with options for editing the song, a menu bar at the top, and a status bar at the far bottom, which displays useful information about the song and the workspace.

Notes. Writing notes in the workspace is very simple. Clicking a key on the piano sets it as the current active key. Clicking one of the sixteen instrument icons in the toolbar selects it as the current active instrument. Left-clicking the working area places a note block with the currently selected key and instrument at the position of the click. Each note block in the grid shows its key and octave at the top, and the number of clicks to reach that note at the bottom. Each note's color represents a different instrument. Notes that cannot be played by note blocks, either because they use a custom sound or lie outside the two-octave range supported by Minecraft, are highlighted in red — the same applies to out-of-range keys on the piano. Multiple notes can be selected by clicking and dragging the mouse cursor

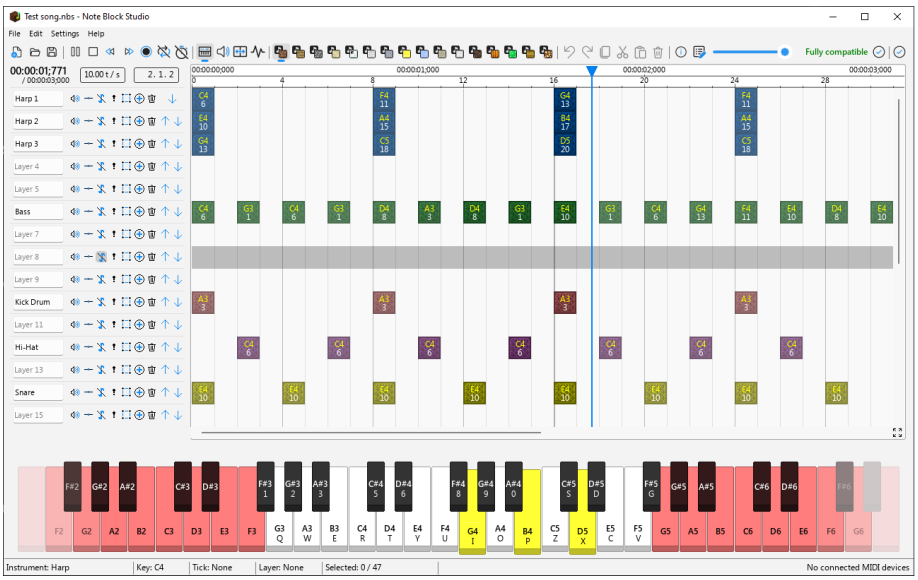

Figure 3: The main view of NBS.

in the workspace. Selected notes can be moved, deleted, or modified all at once. Right-clicking the workspace displays a context menu with further options to manipulate notes, such as assigning a different instrument, transposing the key, selecting notes of a particular instrument, or expanding and compressing the selection, which folds and unfolds its notes horizontally, making them play faster or slower. Furthermore, the top toolbar features four selectable edit modes, each letting the user change different parameters of notes: key, velocity, panning, and fine-pitch tuning.

Layers. With the layer control panel located at the left of the workspace, it's possible to insert, delete, or reorder layers (rows) of the song. Each layer can be assigned a unique name to aid in organization, and its volume and stereo panning can be adjusted. To preview or isolate certain parts of the song, it's possible to lock or solo each layer. Locking mutes all of its notes and prevents them from being modified. Soloing a layer does the opposite, isolating its notes as if all other layers were locked. It's also possible to select all notes in a layer to easily manipulate them.

Instruments. NBS supports the addition of custom instruments, enabling users to select arbitrary sound files to be used alongside the default instruments provided by Minecraft. This allows users to enrich the soundscape of their creations while maintaining the general feel of note block music. Although regular note block circuits cannot play these custom sounds, they can still be imported into Minecraft with 'cheats' (modifications) to the game. It's possible to add, remove, reorder, and rename custom instruments from the Settings menu, besides assigning a sound file to each instrument.

Playback and Tempo. The top toolbar features playback controls, such as play/pause, fast-forward, rewind, and options to enable looping and toggle a metronome. As mentioned in Section 2, Minecraft updates the world and computes its game logic in ticks. Since the song's compatibility is closely tied to the capabilities of redstone circuits, NBS primarily measures musical tempo in ticks per second. By default, the tempo is set to 10 ticks per second, matching the speed of redstone circuits, which translates to 150 beats per minute (BPM). The song's tempo can be modified in increments of 0.25 ticks per second. The tempo bar, located above the layer area, displays the current position of the marker and the song lengthIt's possible to drag the playback marker horizontally or click the time ruler to jump to a different point in the song.

Saving and Loading Songs. The File menu allows loading a song or saving the current song to a file. Songs are saved in the **Note Block Song** (`.nbs`) file format, a lightweight, binary file format designed to store songs created with the app[1]. A song can also be imported from a MIDI file, which automatically converts its arrangement into note blocks. Due to its convenience, this option is highly popular among NBS users, as it overcomes the need for time-consuming manual transcription. Finally, songs can be saved directly to an audio file for external use.

Song Properties and Stats. In the *Song Properties* window, it's possible to change the song's metadata attributes, such as the title, description, author, and original author — if the song is a cover, this field holds the artist who created the original song. If provided by the song's creator, this information is shown when the song is opened in the app. The *Song Stats* window collects statistics about the song, such as the number of note blocks per instrument and their percentage relative to the total number of notes. It also tracks actions taken during the song's creation, such as the

[1] https://noteblock.studio/nbs

time spent editing the song and the number of notes placed or removed.

MIDI Devices. NBS recognizes MIDI devices connected to the computer, enabling the user to input notes and hear them played back in the app, as well as record the device's input. When recording is enabled, NBS waits for a note to be pressed, then starts playing the song and recording pressed keys as notes on the workspace. Since notes in NBS have no duration, only the initial pressing of each key is captured — long-pressing a key has the same effect as releasing it immediately.

Exporting songs to Minecraft. The app's strongest capability lies in its native game export option. In the top-right corner, the app displays a compatibility indicator that shows whether the current song is compatible with note blocks. Clicking it reveals a comprehensive checklist of the incompatible features used by the song, allowing the user to take corrective actions to 'fix' the song so it becomes compatible again. If the song features notes outside the two-octave supported range, they can be automatically transposed to fit in that range. If it features custom sounds, an asset pack is supplied that allows these sounds to be loaded in-game. If the tempo doesn't match the tick rate of redstone circuits, it can be set to the nearest compatible tempo. The export process saves a `.nbt` structure file, a format that Minecraft can read to import a structure into the world, or a data pack — a set of instructions that perform various actions within the game's world, including playing sounds.

3.2. Release and Impact

Over the years following its release, NBS would grow to become a huge success, consolidating itself as a standard tool for building complex songs in Minecraft. Many YouTube channels began appearing around that time, publishing videos of original and cover songs featuring note block circuits generated with NBS, which started a feedback loop that significantly boosted the app's popularity. As of 2015, the original version of Note Block Studio had been downloaded 400 000 times.

In 2017, as the development of the original version slowed to a halt, the app began to fall out of date. This prompted its release as open-source software in 2019, which led to multiple contributors participating in its development. An open-source organization, *OpenNBS*, was established to centralize efforts and guide further development of the app. A discussion hub for the project was founded in the instant messaging app Discord. The app's community, previously scattered, now had a central place to discuss the project, share their music creations, and meet other fellow note block musicians. This marked a new era for the project, with the gap between developers and users bridged, and a cohesive ecosystem emerging around the app [5].

4. Community

Just as Minecraft owes its success to its vibrant community, the same can be said about NBS. As of publishing, the app has been downloaded over a million times. Its public Discord community holds over 3 800 members, who share dozens of songs every week. Over time, developers within the community have created a variety of libraries, tools, and plugins to expand the capabilities of NBS, significantly expanding its ecosystem. Moreover, members share dozens of music tracks and previews every week, discuss the app's development, and engage in collaborative music creation activities, such as competitions and jams. In this section, adapted from [5], we highlight prominent initiatives done by the community.

4.1. Musical Works and Techniques

The app's versatility warrants its utility on multiple levels, from players who enjoy the challenge of building circuits themselves to those who prefer to minimize manual work. Players who want to build their circuits manually can use it to plan the song before building it in-game. Players who wish to avoid building entirely can use the native structure export capabilities. A third group of creators, however, is not at all concerned with importing music into the game and completely ignores the limitations of vanilla note block circuits, instead pushing NBS itself to its limits.

In this regard, a variety of musical techniques have emerged to circumvent these limitations, including the lack of note durations and the narrow instrument selection. For instance, sustained notes are simulated by repeating the same note consecutively, and applying volume and panning modulations to subsequent notes, making the repetition more subtle and less perceptible. As a result, many modern songs easily reach hundreds of thousands of notes, challenging the limits of NBS. In one ambitious initiative, various orchestral instruments — such as organ, strings and choir — were sampled, and the frequencies of their harmonic components were mapped to pitch values of corresponding notes within NBS. This resulted in an accurate recreation of the 12-minute orchestral piece *Stained, Brutal Calamity* comprising 4.6 million note block sounds, which had to be combined externally as NBS could not handle the complete file. Furthermore, sounds from other game elements are often 'borrowed' and used in conjunction with the default sounds to simulate different instruments, while still maintaining the distinctive feel of note blocks. These range from explosions and fire sizzles used as crash cymbals to creature growls used as vocals, which creatively enrich the soundscape of creations made with the app. When surfaced, knowledge of these tricks is widely shared among community members, leading to the cross-pollination of ideas and constant refinement of existing techniques.

More than just sharing experiences, the community regularly engages in competitions, challenges, events, and collaborations centered around note blocks, which resulted in remarkable collective musical works. Among these is the *Note Block Megacollab*, a 20-minute collaborative medley comprising 50 parts of existing songs, each covered by a different artist. The piece compiles works with varied levels of experience, ranging from simple arrangements to complex sections that showcase multiple of these advanced techniques. Music jams have also been organized

within the community, resulting in a collaborative album with 29 original and cover tracks created by 14 note block musicians, spanning 73 minutes. Both works have been published online on the video-sharing platform YouTube, which also hosts a growing number of channels entirely focused on note block music.

Beyond powering individual music creations, NBS is behind soundtracks of complete games and experiences created within the game's universe. Many game servers, as well as downloadable worlds, have utilized the app's lightweight song authoring format to power in-game music playback systems. Dozens of composers are involved in bringing these soundtracks to life. One such soundtrack was released as a physical, limited-time CD in 2021 by Australian musician *ShinkoNet*, marking the first physical album to be entirely composed with note block music.

4.2. Plugins, Libraries and Tools

The community's contributions are not only artistic but also technical in nature. Various developers involved with the community have released open-source parsing libraries for manipulating `.nbs` files in a variety of programming languages, including Python, JavaScript, and Java. These libraries enabled the development of a vast collection of tools and plugins to expand the app's native capabilities, unlocking forms of creative expression beyond traditional music creation. In line with the official project's mission and spirit, many of these tools have been released as free, open-source software [5].

Within the game, advanced circuit layouts are made possible by these tools. Some utilize the game's free 3D space to position note blocks at precise distances from a listening point, enabling volume and stereo panning modulations despite the lack of native support for these parameters in note blocks. Another tool seamlessly modifies a small set of note blocks that lie in front of the player in real-time, simulating a small, elegant jukebox. A giant mechanical machine has been created to play any song encoded in a specific sequence of blocks, resembling a punch-card music box. An accompanying Python script converts any song to a format compatible with that structure, enabling it to play any music track created with the app.

Visualizers, an entire category of software tools, focus on turning music into novel and engaging visual experiences. These showcase not only note blocks but light particle shows, firework sequences synced to the music, and mosaic arrangements of each instrument in the song. One such initiative shoots flying blocks in sync with the music, resulting in a profuse, energetic stream of colors propelled in rhythm with the music in a kaleidoscopic display of movement. These are just a few of the possibilities opened up by the community's parsing libraries. New, engaging visualizations and tools are continually developed, unlocking ever more creative opportunities beyond the native capabilities of NBS.

4.3. Music Education

Beyond its use in entertainment, music education literature cites NBS as a viable educational tool for teaching music to K-12 students [6]. Possible lesson dynamics include both individual and collaborative activities. In individual device environments, students may work independently or with guidance from a teacher to practice creating and editing music, either through free composition or completing proposed tasks. In shared device environments, students can rotate in groups using the same computer, finishing their work before the next group begins. Students may also work together on a collaborative project and submit it as a group. In single-device environments, the teacher can invite students to the board one at a time to contribute to a larger class composition, as well as have the class create their own compositions as a group or multiple rotating groups on the board. Finally, in remote environments, students can download and run NBS on their Windows-based computers, and work independently after receiving instructions on how to use the program.

Once completed, songs may be played in a gallery walkthrough by rotating around the room and listening to each other's compositions, or by having each student post their completed files in an online classroom forum. They can also send completed works directly to the teacher, either as a `.nbs` song or an audio file. The teacher can then play them using NBS or a regular media player for the entire class. Students can then use an evaluation rubric to assess their own work or critique their classmates' submissions. As an additional step, creations can be imported into Minecraft if the game is available, allowing students to see their compositions presented within the game [6]. This can provide an appealing reward as the outcome of completing the lesson, making the composition process more engaging.

Limitations of this approach include the app's complexity, which may require several lessons for students to fully explore; its limited sound quality; and its current availability, which is limited to Windows computers [6]. Despite these limitations, the potential uses of NBS in educational contexts highlight its beginner-friendly approach to musical concepts. In line with this demonstration, multiple users in the NBS community report having pursued professional careers in the musical field, following their initial contact with music through Minecraft and NBS.

5. Discussion

The community initiatives presented raise interesting questions about the popularity of note blocks. Is there something special behind its appeal, beyond the worldwide acclaim of the game that hosts them? This section attempts to answer this question.

Physical music circuits, such as those created with note blocks, evoke the feeling of self-playing, mechanical music instruments popularized in the late nineteenth and early twentieth centuries with the advancement of mass-production technology [10]. *Museum Speelklok*, in Utrecht, the Netherlands, houses a vast collection of such instruments — music boxes, musical clocks, pianolas, street

organs, orchestrions, and a carillon. Featuring intricate clockwork inventions, massive mechanical boxes, moving figures in time with the music, and forests of blowing pipes [11], it's arguable whether these instruments are more entertaining to hear or watch. The mechanical music aesthetic was revived contemporaneously with the *Marble Machine* — a two-meter-high, crank-powered mechanical music instrument powered by 2 000 falling steel marbles [12]. Handcrafted out of plywood by Martin Molin — composer, engineer, multi-instrumentalist, and leader of Swedish folktronica band *Wintergatan* —, the machine has become a worldwide phenomenon, grossing over 260 million views on YouTube [13]. Its universal acclaim speaks to the success of another digital music visualization project, cited by Molin as a large inspiration: *Animusic*, a 3D computer animation project which depicts futuristic, otherworldly mechanical contraptions driven by music. Powered by MIDI and specially crafted 3D animation software [14], the project's animations have been released on DVDs and seen online by a massive audience. There seems to be more to this kind of mechanically generated music than just the sound — it's mesmerizing to watch music emerge from these strange, exquisite creations. They provoke the listener to marvel at the intricate engineering behind their operation, akin to a Rube Goldberg machine or a one-man band. This suffices to explain the strong popularity of note block creations among Minecraft's community, beyond simply a natural consequence of its wide player base. The general sentiment, as denoted by thousands of comments left across online videos, is that it makes the creators of such circuits look like musical wizards — after all, "any sufficiently advanced technology is indistinguishable from magic" [15].

Note block circuits are a concrete, tangible representation of the abstract concept of music, where each note in a song is represented visually and located at a specific physical position. Essentially, they have introduced an entirely new paradigm to music-making. In contrast to sequenced music, where a piece lives in a sheet of paper or a MIDI file, or streamed music, where it's stored as a digital audio signal, a music track in Minecraft is represented by a physical — albeit entirely virtual — electrical circuit. This gives rise to a powerful framework, with a set of implicit rules and limitations that can only be navigated through skill and creativity. The resulting circuits, carefully developed and engineered to play a specific piece of music, can be viewed as works of art in their own right. This expressive interface is further infused with the game's mechanics, the player's technique, background, and experiences, alongside their own world's surroundings. A physical piece of music shares space with the player's buildings and creations, adding a layer of emotional and affective meaning. Circuits can be decorated in the theme of their songs, or even embody entire buildings, just as real-life carillons and pipe organs surround and envelop entire cathedrals around the world. Their applications can often be fun, engaging, or even surprising: a mysterious melody may play when someone crosses a secret passage; a catchy doorbell may ring when someone knocks on the door of a house; or a loud, prominent alarm may buzz to alert to something undesired happening in the world. Cannons can be hooked up to launch fireworks in sync with the music, or a minecart track may travel along a song's physical structure as it plays, letting a player watch its complex, intricate circuitry pass by as the melody comes to life. Players can even collaborate in a musical circuit by virtue of the game's multiplayer capabilities. All of these properties make note blocks a highly appealing, easy-to-use, and powerful medium for musical and artistic expression. The endless possibilities it offers can yield impressive and unique results when employed creatively. Many (brave!) players spend countless hours creating such systems by hand. For a player just concerned with music, however, this process can be daunting.

In this sense, NBS is a step up in note block creation, making it more accessible by abstracting the physical mechanics of a song and allowing the player to focus on its musical aspects. It sits between the complexity of note block circuits and a player's musical ideas, serving as a simple yet powerful abstraction over note block mechanics. While very rudimentary in its musical expression, advanced techniques have been developed to overcome its limitations, which serve as a prime example of how constraints can spark creativity. The result is an easy-to-grasp framework that's still complex enough to support advanced creations. NBS, then, strikes a balance between simplicity and complexity, making musical concepts more approachable while gently introducing more intricate ways they can be applied to arrangements. Through that balance, NBS unlocks a one-of-a-kind arranging experience that's closer to that offered by professional music creation tools. Often, these tools can serve as a barrier to entry in the field of musical composition and production. Digital audio workstations (DAWs) may be too advanced, expensive, complex, or inaccessible, making them difficult for beginner musicians to access and develop their musical skills. In contrast to the profusion of features and paths offered by these tools, the simplicity of NBS stands out. Its workflow requires little explanation, allowing anyone with no prior music experience to learn how to use it easily. This can significantly soften the learning curve associated with musical concepts, serving as a stepping stone for more advanced music creation apps, and highlighting its potential as an educational tool.

6. Conclusion

Note Block Studio is an open-source music creation application designed for creating note block music for Minecraft. As outlined in Section 1, we explored its features, highlighted major community-developed initiatives, and examined the reasons that made it a noteworthy creative tool among Minecraft's musical community. We also showcased the app's flexibility, which enabled it to occupy a relevant space in recreational, professional, and even educational contexts. To conclude this work, we will outline limitations with its current implementation and suggest development paths for future research.

6.1. Limitations and Future Work

With the app released almost fifteen years ago and implemented in the GameMaker game engine, it has accumulated

years of technical debt. This made it increasingly challenging to make the necessary modifications and quality-of-life changes required for its continued maintenance. For this same reason, NBS has, as of the time of publication, only been made available on Windows platforms. We acknowledge this as a major limiting factor on the app's accessibility. Work is underway to bring the app to additional platforms, including Linux and Mac.

From a software engineering standpoint, NBS would greatly benefit from an extensive refactoring or reengineering effort. We are currently assessing the feasibility of rewriting the codebase using a cross-platform UI framework, such as Qt, to support further development. A literature review on music software applications may be conducted to aid in this process. This could ensure the long-term sustainability of the app and even unlock paths towards further improvements, such as a plugin system to enable modular extensibility.

As shown in Section 4.1, many users of NBS have collaborated on songs. As of today, this process involves manually sending `.nbs` files back and forth between participants of a project. Real-time collaborative editing would enable multiple users to simultaneously and synchronously work together on the same song, which could be effective in fostering collaboration among community members. This could prove an interesting research path in the field of distributed systems. Still in the context of collaborative music, NBS can be explored as a tool for live music performance over a network.

Furthermore, the community's creations have become increasingly complex over time. It's not uncommon for modern songs to reach thousands of concurrently playing notes per second. While the use of a game engine allows for fast, accelerated rendering, the app currently struggles to keep up with these complex songs, even on powerful computers. Research in the fields of Digital Signal Processing (DSP) and Computer Graphics could explore the application of efficient audio and graphics rendering engines to support the high-performance real-time playback required by these songs.

Section 4.2 has shown multiple tools and applications developed for handling NBS songs. A future version of the app could provide opportunities for tighter integration between these plugins and the app's workflow, enabling features such as real-time preview of visualizations, a programmable MIDI effect pipeline to generate note sequences, and advanced DAW-like workflows to support more advanced use cases.

Applying NBS in the education space is certainly another promising research path to explore. Section 4.3 has shown potential ways that it could be applied in a classroom setting. Further research in this area could involve conducting arrangement workshops using NBS to assess potential difficulty points among beginners, and surveying ways to make it suitable as an educational tool, building upon Minecraft's vast accessibility and appeal.

6.2. Final Remarks

The strong appeal of Minecraft to audiences of all ages, its vast worldwide reach, and its substantial presence in popular culture, coupled with the note block's accessibility and ease of use, have enabled NBS to establish a strong position within Minecraft's musical community, with tens of millions of players impacted by its music. The prominent initiatives developed around the app demonstrate its outstanding potential to become an even more advanced music creation tool. We hope our work can serve as a foundation for future researchers who wish to explore the possibilities offered by NBS, allowing it to remain a powerful tool for creative musical expression, and enabling it to have a long-lasting impact on the global music community.

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This paper displays some assets from Minecraft, which are the property of Mojang Studios. Though copyrighted, these assets are freely usable in this paper [16]. The authors are not affiliated with or endorsed by Mojang or Microsoft.

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