An Intelligent Data Repository Consolidating Artifacts of Music Learning

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ABSTRACT

This paper presents current and ongoing developments towards the implementation of a web-based data repository that is tailored to the needs of networked mediated music education. The repository consolidates digital artifacts that are generated, shared, and negotiated during music learning sessions, which include asynchronous student or teacher interactions, as well as synchronous collaborative online music lessons. These artifacts are represented either as sound files or as symbolic music notation files in various ascii-based formats. The repository provides basic functionalities, such as sharing artifacts through e-learning platforms, as well as rendering and processing them during learning sessions. A distinct focus of this research concerns the integration of intelligent functionalities for sound analysis, description, and processing with the aim of providing efficient mechanisms for search, retrieval, and data exploration.

1. INTRODUCTION

Music education is a creative process which is highly complex in terms of cognitive and sensory-motor interactions. A music lesson is conventionally held in a classroom and concentrates on both the structural (tone, rhythm, tempo, harmony), as well as the expressive elements of music interpretation via repeated teacher-student collaboration. The artifacts that typically mediate the practices of a music lesson vary; they involve structural music elements (i.e., notes, rhythm), music interpretation discrepancies (i.e., the musical instrument) as well as communication and coordination activities (i.e., commands, messages, gestures, etc.).

Technological advancements have allowed the adoption of several innovative ideas in music learning and the way courses are delivered (i.e., online, or blended learning scenarios). For example, Yan [31] outlines how MIDI, music sequencing, and digital mixing have transformed piano performance education. On the other hand, the Internet, as a limitless supply of information, supports instructors and students in finding music resources of different musical genres, works, or styles of interpretation. Besides recordings of music performances which can be found in abundance on online platforms such as YouTube, Spotify etc., specialised repositories for digital music content provide learners with the ability to perform a musical work at the same time as listening a recorded accompaniment (play along). Also, the Internet as a medium, allows dissemination and sharing musical performances, events and collective experience that would otherwise be either impossible or very difficult to become available.

Finally, the widespread usage of video conferencing software has enabled music teachers to organize classes via personal websites or social media and deliver them remotely using teleconferencing or VoIP applications and file sharing platforms. For several years, various initiatives have emerged from the private sector (yousician.com, melodics.com), as well as academia (such as Berklee online courses [29]) to provide musicians with a variety of learning opportunities, including social networking, books and videotaped lectures, daily curricula, and even software applications that capture student performance and provide automatic feedback by analyzing the captured performance.

Therefore, it is becoming evident that modern technology can enhance conventional music education, while also revealing new perspectives in the direction of distance learning. Learners are offered the opportunity to contact well-known instructors, who can conduct classes from their own studios, record, and share learning material, even if they are occupied with concerts, tours, etc. Furthermore, over the last few years, extensive research in the field of artificial intelligence has enabled the integration of creative tools that may be used to assist student improvement and to efficiently create new educational content, such as student assignments.

This paper presents current and ongoing progress on the development of a music resource repository focusing on music

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education. The MusiCoLab repository[1] is part of the homonymous project (please refer to the acknowledgements), which aims at delivering a Web-based environment that will be tailored to the needs of network mediated music education. Compared to popular and well-known music repositories, the MusiCoLab repository focuses on providing intelligent mechanisms for efficient retrieval, sharing and usage of digital artifacts constructed and processed during synchronous and asynchronous learning sessions. Besides hosting metadata for artifact description and supporting permissions determined by user roles that are relevant to the learning process (i.e., course manager, teacher, student), the 'intelligent' functionalities of the repository account to providing automatic descriptions of artifacts, hence saving time to course creators in organizing their course material, as well as querying the repository by example, i.e., searching for a piece of music by providing a musical excerpt. As the accuracy of automatically provided descriptions cannot be guaranteed, they are provided as suggestions that can be reviewed, modified, and confirmed, thus at the same time increasing the reliability of artifact description residing in the repository. Digital artifact descriptions concern descriptive metadata (e.g., composer, instrumentation, genre, tonality, tempo), as well as structural annotations that are temporally aligned with music resources (i.e., beats and chords). The long-term objective of this repository is to acquire descriptions of increasing reliability through continuous usage of resources in music lessons and use this increasingly reliable information to refine the machine learning models that provide automatic suggestions.

The rest of this paper is structured as follows. The next section discusses recent endeavors and cutting-edge initiatives in storing and managing musical artifacts. Section 3 reports on the overall architecture of the MusiCoLab repository and the implementation of fundamental functionality, i.e. creation and preservation of digital music artifacts and interoperability with a Moodle-based Learning Management System (LMS), which is used by the MusiCoLab environment. Section 4 presents the integration of tools and algorithms for automatic artifact description and retrieval. Finally, section 5 summarises current and ongoing development efforts and outlines imminent and long-term objectives for improving the accuracy of music descriptions as well as the usability of the repository to address the needs of music learning and teaching.

2. RELATED WORK

For some years now, research initiatives on distant education have been experimenting with the integration of online digital artifact repositories into the learning process [9]. Using online repositories in education can radically alter basic components of the classroom [10], potentially having a huge influence on teaching and learning. Online repositories provide an information space, in which students may navigate to develop cognitive skills, discover new knowledge, and collaborate with the teacher and the other students.

In the case of music education, the interested reader will discover several publications describing how network technologies, machine learning methodologies, and visualization tools have been used to render musical material in online repositories. Although the repository presented in this paper is not a digital library, it nevertheless shares many structural and functional features of digital libraries. Some examples are the PROBADO project [3], the Levy Collection [30], the OMRAS project [11], the digital version of the Liber Usualis [5] within the SIMSSA project [18], and more recently PatternFinder [14]. These ongoing efforts reflect the increasing trend of facilitating intelligent tools for efficient indexing, search, and retrieval in large music collections.

Following a different approach to digital libraries, Kelkar et al. in [22] present a virtual laboratory for music education. They categorize educational resources for music in experiments and drills, repositories and resources hosting community knowledge. Their work also includes references to sheet music repositories and open source educational platforms, as well as specialized tools. The system primarily focuses on musical skills such as ear training, rhythm, notation and musical theory. Knees et al. [23] explore how virtualization can provide new views for music collections and new metaphors for interactions. Their system uses the similarity among pieces of music to construct a space of relations and represent it as a 3-dimensional landscape. They follow the work of Pampalk et. al. [26] which focuses on the quantification of music similarity perception using feature extraction methods [2].

Some of these initiatives employ machine learning models to enhance user experience and to manage digital content more effectively. For example, the work presented in [27] applied visual pattern recognition techniques for music score recognition using the OpenCV library. Semantic technologies for the World Wide Web were used in [26] and [4] to adapt recommendations according to meta-descriptions of music content. Cherubin et. al. [6] addressed the possibility of providing novel recommendations for large music libraries using methods that extract features from the content rather than meta-descriptions. The authors used a game engine to construct an alternative interface and used 3 dimensional plots to illustrate the space of features. They also conducted a small survey (33 participants) to evaluate their approach.

The application of digital technologies for music is wide, yet there are rather few articles about how technological advances are combined to enrich and improve music education. Digital technologies and the Internet brought dramatic changes to music education as mentioned by Kelkar et al. in [22].The COVID-19 epidemic intensified the use of LMSs. Zharova et. al. [32] explored the effectiveness of the Moodle platform during the pandemic based on an opinion study among students and professors at the Herzen State Pedagogical University, 1335 people in total. Another study, by Ghapanchi et. al. [17] investigated the factors impacting positive learning outcomes in higher education from the use of an LMS. They claim that using such platforms may increase motivation, self-regulated learning, and the overall effectiveness of the learning procedure. The authors use the well-known Technology Acceptance Model (TAM) [8] to assess the validity of their assumptions. The conceptual model of the study included three parameters that predict satisfaction, engagement, and the learning outcome namely, attitude towards e-learning, perceived administrator presence and actual use of the system. The results indicate that the last two factors contribute to the overall quality of the education. Liang et. al [24] present the functionality of the Moodle LMS and how they developed ear training and solfeggio modules. They also discuss its acceptance. Finally, Jiemsak [21] presents how digital technologies may increase the efficiency of

[1] https://musicolab.hmu.gr/apprepository/

learning when used in parallel with more traditional techniques, a common practice in music education.

Considering these inspiring works, the MusiCoLab project attempts to tackle the challenges of music education when exclusively carried out online and investigate how state of the art achievements in Music Information Retrieval (MIR) research may contribute to enhance teacher/student interaction and collaboration in such setup.

3. OVERALL ARCHITECTURE

The data repository presented in this paper has been designed to supplement the LMS of the MusiCoLab environment. MusiCoLab uses Moodle[2] for delivering LMS functionalities. The data repository is implemented as a separate web application, which is however interoperable with Moodle, in terms of user authentication and sharing file resources. Its development was considered necessary in order to allow offering file management processes that are more flexible than those provided by Moodle and more suitable to music resources, in terms of inscribing metadata to a dedicated database and providing tools for content generation, analysis and processing. Moreover, the MusiColab repository allows teachers and students to maintain a private as well as a public collection of digital music artifacts, which is not supported by Moodle. The public collection serves the purpose of sharing useful learning material to the entire MusiCoLab community.

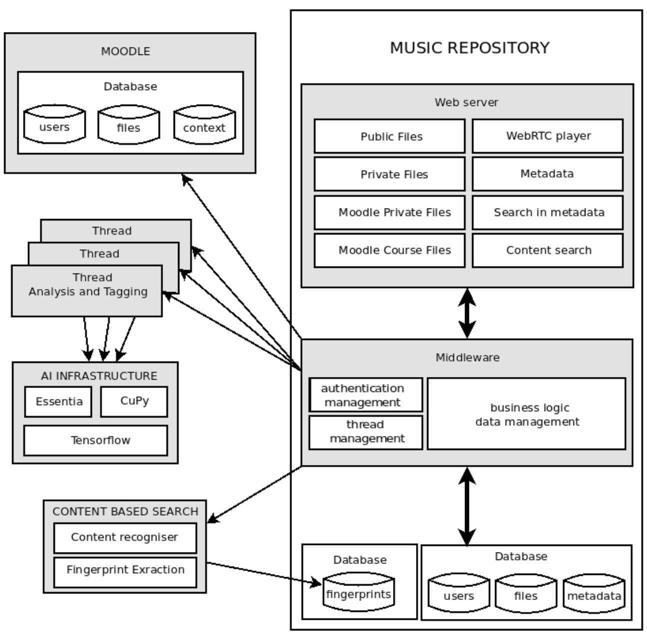

Figure 1: The architecture of the MusiCoLab repository.

The repository allows hosting the digital music artifacts that are used or generated during music learning sessions, transferring them to/from the LMS, providing efficient navigation, exploration, annotation, and search/retrieval mechanisms and, finally, offering a developer workbench for the deployment of cutting-edge tools for intelligent music content description and manipulation. The primary digital artifacts of interest are audio files and symbolic music files. With respect to file formats, it currently supports Flac, Wav and Mp3 for audio and MIDI, MEI, MusicXML, Kern as notation formats.

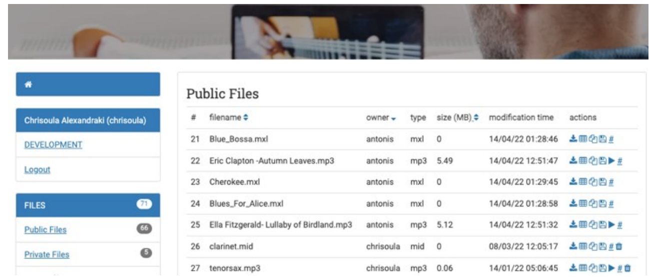

Figure 2: A listing of the public files collection

As depicted on Figure 1, the data repository is designed as a three-tier application. The main components are the web-based frontend, the database, and the intermediate logic (middleware). The user interface of the repository is built using web technologies and it makes use of responsive well-known HTML/CSS frameworks (e.g. the Bootstrap framework) to automatically adjust to any display dimension. The database is autonomous, and the middleware implements the integration with the LMS, the rules and logic of the repository as well as thread management for computationally intensive tasks (e.g. those requiring audio analysis, automatic inference of music content, etc.). This type of design allows the repository to be autonomous and independent of any LMS and use any facility offered by web programming technologies to meet the desired specifications.

Figure 2 provides a screenshot of the repository that displays the list of the public files. The rightmost column entitled 'actions' present users with the possibility to download a file, edit its descriptive metadata, copy it to their private collection, export it to Moodle, render it using dedicated applications of the MusiCoLab environment, provide user tags (i.e. hashtags) and finally remove it. File removal is only permitted by file owners.

3.1 Creation and Preservation of digital artifacts

File resources may be uploaded or captured online. Files may be annotated to provide general descriptions in the form of descriptive metadata, structural annotations of music content, or even inscriptions of interactive activities taking place during collaborative music lessons (e.g. user comments concerning the interpretation of musical passages).

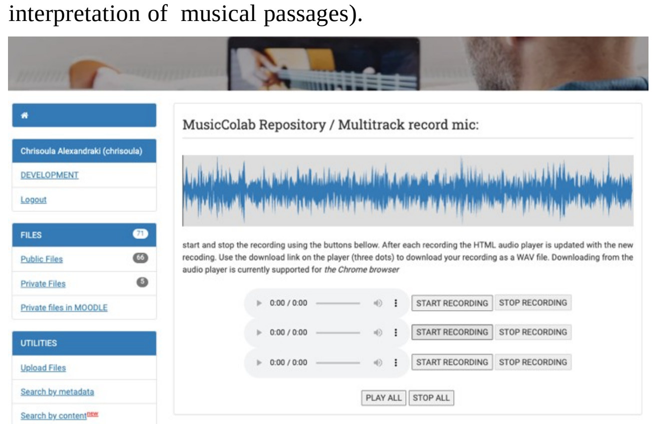

Figure 3: The functionality of recording and preserving a performed musical excerpt.

[2] https://moodle.org/

Figure 3 presents a graphical tool used to record a music track and make it available through the repository. This tool is based on wavesurfer-js[3] waveform visualisation widget. Subsequently to submitting an audio recording users may provide descriptive metadata or retrieve them as automatic suggestions (section 4.1) or they may annotate the recorded audio segment, to provide learning instructions, e.g. 'this is an interesting harmonic passage, remember to practice'. Audio signal annotations facilitates the wavesurfer-js annotation widget[4].

Implementing a similar functionality for symbolic music (e.g. integrating a MIDI sequencer to capture the performance of Digital Music Instruments) is a possible future extension. Rendering a symbolic file residing in the repository uses a custom implementation of the Verovio Humdrum Viewer (VHV)[5] as depicted on Figure 4.

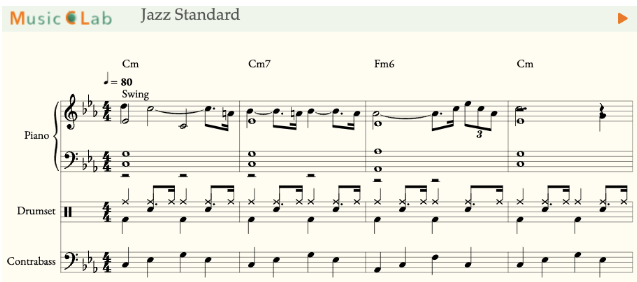

Figure 4: Symbolic music files are rendered using a custom version of VHV.

3.2 Integration with the LMS

Users are authenticated against the MusiCoLab LMS using the encryption mechanisms provided by Moodle. The repository supports roles for administrators, teachers, and students, which are assigned when registering a new user in the LMS. Moodle has formalised the capabilities supported by the system, by assigning contexts. Any capability can thus be assigned to any role and custom, tailor-made roles can be created. Roles may be granted access to specific contexts that is, the whole site, another user, a course category, a course, an activity module, a block, listed from the most general to most specific. The role of each user can be retrieved using structured queries from the role assignment table in the database of the LMS, provided that the identification id of the user is known.

The MusiCoLab repository is capable of listing private files of each user in Moodle, the files associated with the courses he or she participates, and it may also transfer files from the repository to Moodle. To conserve space and file system access, Moodle uses the following custom scheme to manage files: it uses the first two tuples of the SHA1 hash of the file to construct two directories where the file is stored and the whole hash for its name. The structure of the file system is thus bounded in width and depth and arbitrary expansion that would lead to poor performance is avoided. Moreover, the name of the file carries the information about its location. The relevant database table holds the associations of the file with the LMS that is, the relevant context and the user id besides the rest of the required information.

3 https://wavesurfer-js.org/

4 https://wavesurfer-js.org/example/annotation/index.html

5 https://verovio.humdrum.org/

4. INTELLIGENT AFFORDANCES

The integration of intelligent tools in the MusiCoLab repository is under ongoing development. Currently, development efforts focus on supporting two functionalities: auto-tagging and content-based search. Auto-tagging refers to the possibility of offering automatic suggestions of metadata, while content-based search refers to offering users the capability pf searching the repository for music resources by providing a musical excerpt, either in the form of a music file or in the form of a recorded performance generated by users' own musical instrument.

4.1 Suggestions of metadata

In music collections that are either large in volume or implemented for intense user interaction, automatic description of resources is important for data preservation (i.e., easier storage, administration, and querying) and user experience. More importantly, automatic tagging ensures that new resources are always processed so that metadata are populated. At present, research on the automatic retrieval of musical metadata from audio resources appears to be particularly active, as several audio datasets, pre-trained neural networks, and programming libraries are increasingly offered for research and experimentation. [1][25].

In the current preliminary stage of repository development, auto-tagging uses third-party solutions. Specifically, it uses the Essentia library and the YAMNet model. YAMNet [19] is a pretrained deep neural network that predicts 521 audio event classes based on the AudioSet-YouTube corpus [16], and employing the Mobilenet_v1 [20] architecture. The Essentia API [1] provides access to YAMNet as well as an extensive set of capabilities for audio analysis and audio-based MIR tasks.

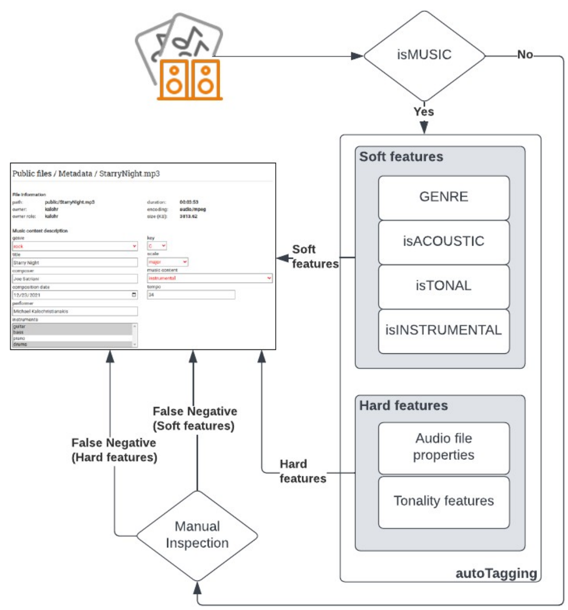

Figure 5: The process of metadata retrieval and inspection.

Figure 5 depicts the algorithm used for metadata retrieval for an audio file residing in the repository. The first step concerns the identification of the content of that file as music or non-music, shown on the figure as the 'isMusic' control structure. If the content of the audio file is identified as music, then the algorithm proceeds to retrieve metadata, otherwise the file is left for manual inspection and description.

The descriptive metadata retrieved through this process are identified as hard and soft features according to the terminology reported in [26]. Hard features are properties that may be either directly read from the file resource or computed via signal processing techniques. Soft features refer to properties that may be statistically inferred using machine learning techniques.

At this stage, the MusiCoLab repository uses as hard features the audio file properties of (sampling rate, bitrate) and the tonality of the music piece, as a key/scale pair. Soft features concern the properties GENRE (referring to music genre), isACOUSTIC (referring to whether the sound is acoustic or electronic), isTONAL (music is identified as tonal or atonal), isINSTRUMENTAL (referring to whether the piece is instrumental or contains vocals).

Hard features are directly inserted in the database of resource descriptions, while soft features are provided to the user as suggestions which the user may edit before submitting to the database. Figure 6 shows the user interface provided for inspection of automatically retrieved metadata.

As the auto-tagging process of Figure 5 is computationally intensive, analyses are executed on separate threads on the server hosting the repository, as shown on Figure 1. Users may request the automatic retrieval of metadata for a specific sound file residing either in private or in the public repository (according to file permission rules), continue working on the repository and later, when inspecting the metadata of that file asked to review the fields provided in red on Figure 6.

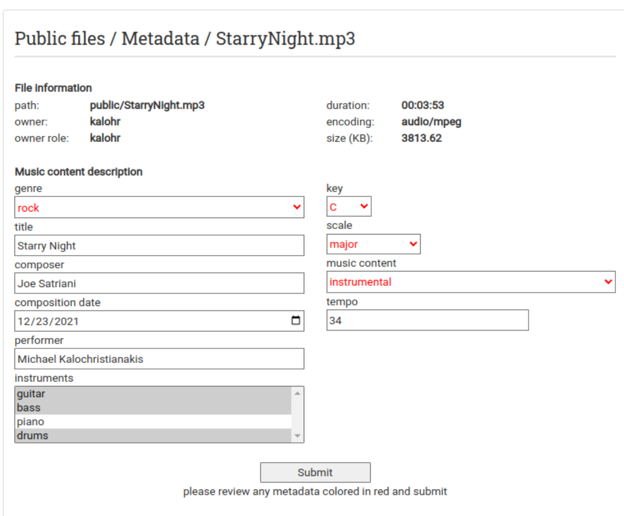

Figure 6: The user interface provided for reviewing automatically provided metadata.

4.2 Content-based search

The MusiCoLab repository allows searching audio files by example. Content-based search is currently under investigation and development. Figure 7 shows the user interface provided for searching a file by example. The example may be provided either as an audio file uploaded to the repository server, or by a user performance recorded online.

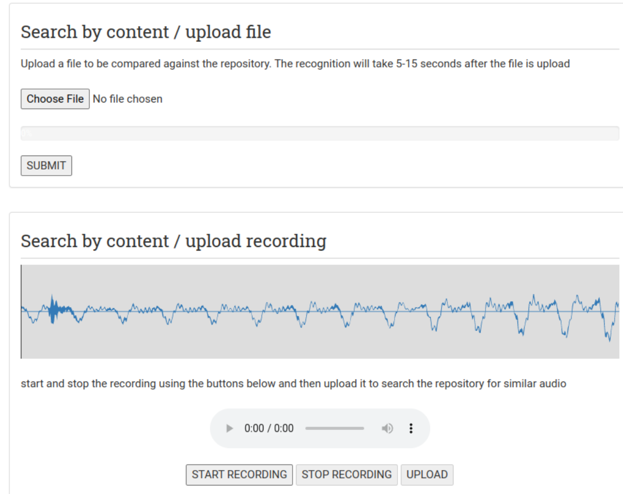

Figure 7: Content-based search in the MusiCoLab repository.

Considering the requirements of the foreseen music education setups, a user may wish to either search for file information by providing an identical, possibly noisy audio signal, or may wish to search for similar music tracks to the one provided. Both possibilities are currently investigated. The former is addressed using the Dejavu implementation of audio fingerprinting and recognition algorithm, while the later uses Bliss music analyzer to provide a playlist of similar tracks. Dejavu constructs song fingerprints by hashing spectrogram peaks and identifies a new song by performing fingerprint alignment [12]. Bliss on the other hand computes a vector of perceptual audio features relating to tempo, chroma, timbre, loudness and uses the Euclidean or the Cosine distance to create playlists based on similarity [7].

The preliminary evaluation for the usability of these algorithms in the MusiCoLab target scenarios focused on the jazz music genre using hand-picked recordings as well as sound files retrieved from the Freesound audio database [14]. Systematic evaluation of the use of these algorithms in educational context will be conducted when a sufficient amount of audio files will be gathered through the forthcoming MusiCoLab pilot experiments.

5. CONCLUSIONS AND FUTURE WORK

This article presents research and development efforts on the implementation of a data repository that consolidates digital artifacts used in music education. The repository forms part of the MusiCoLab project, which aspires to deliver a comprehensive web environment for music education. The MusiCoLab project is on its first implementation year. Hence the developments presented in this paper are yet to be realized through ongoing development as well as several evaluation experiments that have been scheduled to take place in the forthcoming year. These experiments include asynchronous student self-practice and synchronous collaborative music lessons.

Using fundamental web programming APIs, the repository is developed as a web application, which authenticates users against a Moodle LMS. Authenticated users are offered a private as well as a public collection for the preservation of digital artifacts, which may be generated and collaboratively manipulated using dedicated applications of the MusiCoLab environment. Uploading these artifacts either on a private or on the public collection of the repository allows defining metadata that pertain to music descriptions, hence permitting repository exploration as well as artifact retrieval and sharing among different learning contexts, which include the courses that are created and managed by the LMS.

The work presented in this paper is work in progress. A fundamental research challenge relates to the implementation of the repository as a workbench for experimenting with state-of-the-art achievements in the domain of MIR and for inspecting how they can become useful in educational context. In this direction, our present efforts focus on delivering automatic suggestions of artifact metadata and on allowing users to query the repository by-example (content-based search). Future development plans include the automatic analysis of audio and symbolic files with the aim of automatically providing structural music content descriptions (e.g., chords, beats, phrases) that may be curated by repository users to make them more useful in educational context.

These efforts are in experimental stage as the repository is currently poor in file resources, i.e., the cold start problem. It is expected that the evaluation experiments, which are scheduled for the near future will allow assembling a corpus of music learning artifacts that will permit better understanding not only of the needs of students and teachers, but also of how intelligent repository affordances may be fine-tuned to better serve their intended purpose.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Alonso-Jimenez, P., & Bogdanov, D., Pons, J., & Serra, X. 2020. Tensorflow Audio Models in Essentia. 266-270. 10.1109/ICASSP40776.2020.9054688.

[2] Aucouturier, J-J., and Pachet, F. 2002. Music similarity measures: What's the use?. Proc Intl Conf on Music Information Retrieval (ISMIR).

[3] Berndt, R. et al. 2010. The PROBADO Project - Approach and Lessons Learned in Building a Digital Library System for Heterogeneous Non-textual Documents. In: Lalmas, M., Jose, J., Rauber, A., Sebastiani, F., Frommholz, I. 2010. (eds) Research and Advanced Technology for Digital Libraries. ECDL. Lecture Notes in Computer Science, vol 6273. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-15464-5_37

[4] Buccoli, M., Gallo, A., Zanoni, M., Sarti A., and Tubaro, S. 2015. A Dimensional Contextual Semantic Model for music description and retrieval. IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). 673-677. DOI=10.1109/ICASSP.2015.7178054.

[5] Catholic Church. 1961. The Liber Usualis: with Introduction and Rubrics in English. Tournai New York. Desclee Company

[6] Cherubin, S., Borrelli, C., Zanoni, M., Buccoli, M., Sarti, A. and Tubaro, S. 2019. Three-Dimensional Mapping of High-Level Music Features for Music Browsing. International Workshop on Multilayer Music Representation and Processing (MMRP). 19-26. DOI=10.1109/MMRP.2019.00013.

[7] Claude X. 2016. Bliss 1.0 Music Analysis Library. Online: https://linuxfr.org/news/sortie-de-la-bibliotheque-d-analyse-musicale-bliss-1-0

[8] Davis, F. 1989. Perceived usefulness perceived ease of use and user acceptance of information technology. MIS quarterly. 319-340.

[9] Digital Libraries for Distance Education (Editorial). 2022. D-Lib Magazine. Vol 6.

[10] Digital libraries in education. Moscow: UNESCO Institute for Information Technologies in Education, 2003

[11] Dovey, M. 2004. Overview of the OMRAS project: online music retrieval and searching. J. Am. Soc. Inf. Sci. Technol. 55, 12 (October 2004), 1100–1107. DOI=https://doi.org/10.1002/asi.20063

[12] Drevo W. 2013, Audio Fingerprinting with Python and Numpy, Online: https://willdrevo.com/fingerprinting-and-audio-recognition-with-python/

[13] Foote, J. T. 1997. Content-based retrieval of music and audio, in Proc SPIE Multimedia Storage and Archiving Systems II. 3229. 138–147.

[14] Frederic, F., Roma, G., and Serra X. 2013. Freesound technical demo. MM2013. Proceedings of the 2013 ACM Multimedia Conference. 411-412.

[15] Garfinkle, D., Arthur, C., Schubert, P., Cumming, J., and Fujinaga, I. 2017. PatternFinder: Content-Based Music Retrieval with mu,sic21. Proceedings of the 4th International Workshop on Digital Libraries for Musicology (DLfM '17). Association for Computing Machinery, New York, NY, USA, 5–8. DOI=https://doi.org/10.1145/3144749.3144751

[16] Gemmeke, F., Ellis, D., Freedman, D., Jansen, A., Lawrence, W., Moore, R. C., Ritter, M. 2017. Audio Set: An ontology and human-labeled dataset for audio events. Proc. IEEE ICASSP

[17] Ghapanchi, A., Purarjomandlangrudi, A., and Miao, Y., 2020. Uncovering the Impact of University Students' Adoption of Learning Management Systems on Positive Learning Outcomes. 24th International Conference Information Visualisation (IV). 684-688, DOI=10.1109/IV51561.2020.00118.

[18] Hankinson, A., Laurent, P., and Fujinaga, I. 2009. Interfaces for Document Representation in Digital Music Libraries. Proceedings of the 10th International Society for Music Information Retrieval Conference (ISMIR).

[19] Hershey, S., Chaudhuri, S., Ellis D., Gemmeke, J., Jansen, A., Moore, R., Plakal, M., et al. 2017. CNN Architectures for Large-Scale Audio Classification. IEEE International Conference on Acoustics, Speech and Signal Processing

(ICASSP). IEEE. 131–35. DOI=10.1109/ICASSP.2017.7952132.

[20] Howard, A., Zhu, M., Chen, B., Kalenichenko, D., Wang, W., Weyand, T., Andreetto, M., Adam, H. 2017. MobileNets: Efficient Convolutional Neural Networks for Mobile Vision Applications

[21] Jiemsak R., 2021. The Efficiency of Music Learning in a Blended Learning Environment of Undergraduate Students In Phranakhon Si Ayutthaya Rajabhat University. 6th International STEM Education Conference (iSTEM-Ed). 1-4. DOI=10.1109/iSTEM-Ed52129.2021.9625071.

[22] Kelkar, T., Ray, A., and Choppella, V., 2015. SangeetKosh: An Open Web Platform for Music Education, IEEE 15th International Conference on Advanced Learning Technologies, 5-9, DOI=10.1109/ICALT.2015.102.

[23] Knees, P., Schedl, M., Pohle, T., and Widmer G., 2007. Exploring Music Collections in Virtual Landscapes. EEE MultiMedia. 14. 3. 46-54. DOI=10.1109/MMUL.2007.48.

[24] Liang, W., Yuan F., and Ke L., 2021. Design of Music Teaching System Based on Virtual Reality Environment. IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA), 829-833, DOI=10.1109/AEECA52519.2021.9574363.

[25] McFee, B., Colin R., Dawen L., Ellis, D., McVicar, M., Battenberg, E., and Nieto, O. 2015. Librosa: Audio and music signal analysis in python." In Proceedings of the 14th python in science conference. 18-25.

[26] Pampalk, E., Rauber, A., and Merkl, D., 2002. Content-based organization and visualization of music archives. Proc. ACM Multimedia, Juan les Pins, France, 2002.

[27] Săman, O., Muscaliuc, R., and Stanciu, L., 2020, Music panel: An application for creating and editing music using OpenCV and Jfugue. 24th International Conference on System Theory, Control and Computing (ICSTCC), 379-383, DOI=10.1109/ICSTCC50638.2020.9259705.

[28] Schwarz, D., Peeters, G., Cohen-Hadria, A., Fourer, D., Marchand, U., Mignot, R., Spadaveccia, R. 2018. Final Research Report on Auto-Tagging of Music. DOI=10.14279/depositonce-8168

[29] Berklee Online. 2022. Study music online, Online: https://online.berklee.edu/

[30] The Lester S. Levy Sheet Music Collection. 2022. https://levysheetmusic.mse.jhu.edu/

[31] Yan, B., and Ren, F. 2021. The Application and Practice of Computer Technology in Piano Teaching. 2nd International Conference on Information Science and Education (ICISE-IE). 1269-1272. DOI=10.1109/ICISE-IE53922.2021.00284.

[32] Zharova, M., Trapitsin, S., Timchenko, V., and Skurihina, A., 2020. Problems and Opportunities of Using LMS Moodle before and during COVID-19 Quarantine: Opinion of Teachers and Students. International Conference Quality Management, Transport and Information Security, Information Technologies (IT&QM&IS). 554-557. DOI=10.1109/ITQMIS51053.2020.9322906.