Toward a Secure Educational Metaverse: A Tale of Blockchain Design for Educational Environments

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***Abstract*—In the era of social distancing, distance learning represents a crucial educational challenge. Several 2D information technologies have been provided, yet these share multiple limitations and have negative social, educational, and psychological implications for learners. Metaverse promises to revolutionize education as we know it: this is a persistent, virtual, three-dimensional environment that is supposed to address most of the limitations of 2D information technologies. Nonetheless, there are still software engineering challenges to face to enable such a metaverse, especially when turning to software security and privacy. In this paper, we aim at performing the first steps toward an improved understanding of the security perspective of educational metaverse, by analyzing how blockchain can be employed within educational environments and how applications may be designed. Our ultimate goal is to provide insights into how blockchain can be further tailored in the context of educational metaverse. We conduct a systematic literature review, which targets 20 primary studies. The key findings of the study showcase the use of blockchain in 3 educational tasks, other than describing the blockchain design approaches, which protocol they commonly use and the associated limitations. We conclude by developing a conceptualization of a blockchain-based educational metaverse.**

***Index Terms*—Metaverse; Blockchain; Systematic Literature Review; Educational Metaverse; Education.**

I. INTRODUCTION

Over the last decades, and even more in the current pandemic times, there has been a growing interest in the provisioning of technological and pedagogical architectures to support the so-called *distance learning*, that is, an educational method through which learners attend lectures without the need of physically attend a school or a college [1]. Most of the recent advances have been made in terms of 2D information technologies [2], [3], [4], with notable examples such as GOOGLE MEET[1] and ZOOM,[2] just to name a few.

Those platforms have been crucial in pandemic times to guarantee continuity of training, research, and educational activities, other than allowing companies to stay on the market, and are still widely used worldwide [5], [6]. At the same time, their widespread adoption has sharpened and globalized new types of problems and challenges, especially in the educational domain [7], [8], [9]. Examples include disparities in technology upgrades, inadequate learning aids, insufficient knowledge of educational technologies, loss of social iterations and the psychological effects that follow [10].

[1]The GOOGLE MEET platform: https://meet.google.com.
[2]The ZOOM platform: https://zoom.us/.

The *metaverse* represents one of the most popular emerging technologies nowadays: this is based on the concept of having a persistent, virtual, three-dimensional environment where individuals may communicate, engage, and collaborate [11]. Researchers, practitioners, and companies are seeing in this new technology the potential to address most of the negative implications that social distancing may pose and, more importantly, a brand new communication revolution that may limit the short- and long-term social, interaction, psychological issues of 2D solutions [12], [13]. Education is a special use case: the metaverse would not limit itself to the presentation of an exact digital replication of the surrounding educational world, but can also empower it from various angles by offering new teaching tools, creating scenarios and realistic online learning experiences, and lowering physical, geographic, and financial barriers for students with disabilities and those from low socioeconomic status or from rural areas [14].

However, all that glitters is not gold. The potential of the educational metaverse strictly lies in the technologies that enable it. While at this early stage researchers contributed already to the conceptualization of the tools and technologies that would be required to make this metaverse real, there is still a lack of software engineering instruments and investigations that may inform how to actually design a metaverse that makes an effective use of the available tools and technologies [11].

In this paper, we aim at performing the first step toward understanding how to tailor existing technologies to address two key non-functional requirements, namely software security and privacy, in the metaverse. We take the case of *blockchain* [15], i.e., a popular technology that enables secure computing by storing data in a distributed and decentralized manner, by investigating how it may be used to support education environments. To this end, we conduct a systematic literature review (SLR) to elicit the *goals* for which blockchains can be used within educational environments and how applications have been *designed* to include them. Our ultimate goal is to collect the current knowledge of blockchain within educational environments to provide insights into how blockchain may be further tailored in the context of an educational metaverse—this was required because of the lack of studies that explicitly focused on the relation between blockchain and metaverse.

From an initial candidate set of 413 articles, the systematic process leads to 20 primary studies that are further analyzed to address our research objectives. The results of our study show that blockchain has been employed to support 3 main educational tasks. More importantly, we identified how application designs change with respect to these educational tasks. Finally, those findings let us develop a conceptualization of a blockchain-based educational metaverse which we hope may serve as a basis for further research on the matter.

Structure of the paper. Section II overviews the related literature, while Section III presents the design of our study. The results are discussed in Section IV. Our conceptualization of a blockchain-based educational metaverse is proposed in Section V, with the limitations of our study discussed in Section VI. Finally, Section VII concludes the paper and outlines our future research agenda.

II. Related Work

Lee et al. [16] and Wang et al. [17] formulated the problem of metaverse security as the problem of ensuring data reliability, traceability, and privacy. Blockchain represents the most promising technology: if properly engineered, its characteristics would indeed allow metaverse designers to accomplish the expected security requirements [17].

A blockchain can be defined as a type of data structure that enables the creation of a digital record of data and sharing that data among a network of unrelated parties. It is designed based on the following properties: (1) Each node has an immutable copy of the transactions that have occurred; (2) Once information is loaded into a block, it cannot be deleted or modified without the permission of the majority of the nodes constituting the structure; (3) The transactions take place only after the application of a consensus strategy verified by all nodes; (4) The information contained in the blocks is individually encrypted through hash functions, with the processes of encryption and decryption requiring a large amount of computational power. The choice of one type of blockchain over another may be functional in solving different problems. In fact, the issues related to the process of computerization of education result from various phenomenologies involving all actors in the educational system, from students to teachers, from schools to companies. In addition to the continuous uploading of personal data, various educational institutions are dispensing an increasing amount of online multimedia educational resources. Currently, many digital diplomas issued by one institution may not be recognized by another [18]. The resolution of these problems has resulted in establishing a research strand of the blockchain-education pair, as observed from the various publications in the literature.

More particularly, while the theoretical foundations of blockchain were given in 2008 [19], the first applications of this technology to the educational context date back to 2016. Thus, the first literature reviews on the matter were able to synthesize only a relatively low number of papers. Alammary et al. [20] followed the guidelines by Okoli and Schabram [21] to investigate (1) the types of blockchain-based applications for educational purposes and (2) the positive effects and challenges of their use. The results mainly highlighted the growing scientific interest in using blockchain for educational purposes. Similar results were found by Hameed et al. [22].

As an additional perspective, they surveyed the main blockchain protocols employed. However, their work was able to identify a very limited amount of primary studies (i.e., 11) and, as a consequence, the resulting discussion is limited to listing and describing which protocols were chosen for each individual study analyzed and does not suggest any guidelines to facilitate the choice of one protocol over another. Additional literature reviews were more recently proposed [23], [24], [25], [26], [27]: while they surveyed a larger amount of resources, they had similar goals and conclusions as those discussed above.

Our work can be seen as complementary to those mentioned above for two reasons. Most related work focused on the *goals* for which the blockchain has been employed within educational environments: on the contrary, we also assess how applications were *designed* to include blockchains—the focus on the design represents a premiere of this paper. Secondly, none of the existing literature reviews applied the guidelines by Kitchenham et al. [28]: as such, the completeness of those studies might be threatened—the higher amount of papers identified in our work, as reported in the next section, seems to confirm the limitations of previous studies. Finally, the ultimate goal of our work is represented by the conceptualization of a blockchain-based educational metaverse. As such, our work advances the state of the art by providing (1) a complementary view on how educational applications have been designed to include blockchains; and (2) insights into how to tailor current knowledge to educational metaverse.

III. Research Method

The *goal* of our study was to understand how the current blockchain-based applications can support educational environments, with the *purpose* of providing insights into how they may be tailored in the context of an educational metaverse. The *perspective* was of both researchers and practitioners: the former are interested in understanding how blockchains can support educational environments; the latter are interested in overviewing the currently available solutions to possibly deploy them in practice. We conducted a SLR, i.e., a systematic approach aiming at collecting and synthesizing the body of knowledge on a specific matter [29]. We adopted the guidelines by Kitchenham et al. [28] and formulated two research questions (RQs) that drive the entire process.

> **RQ_1:** What are the **goals** for which blockchains have been used within educational environments?

With $\mathbf{RQ}_1$ we were interested in analyzing the literature studies to understand the reasons the use of this technology in educational environments and, more importantly, the goals that blockchain aims to address.

> **RQ_2:** How are applications **designed** in order to include blockchain for educational environments?

$\mathbf{RQ}_2$ aimed to highlight the choices about the design made when using blockchains within applications for educational environments and provide insights into the factors influencing their successful implementation.

Figure 1 overviews the main steps conducted to address our RQs, highlighting the SLR phases —reported in grey round squares and further elaborated in the next sections—along with the authors involved in each phase—a green circle indicates that the i-th author has been conducting the step, while a green rhombus indicates that the i-th author has been reviewing the activities conducted. In terms of reporting, we followed the *ACM/SIGSOFT Empirical Standards*[3] and, in particular, the *"General Standard"* and *"Systematic Reviews"* guidelines.

A. Search Strategy

Our search strategy focused on search parameters to find the most pertinent terms to produce valuable results. First, we selected the research domain, analyzing primary or secondary studies terms, such as *Educational Environment* and *Blockchain technology*. Once the initial terms were obtained, we then derived a set of alternative words to get articles dealing with the same topic but using different spellings:

Educational Environment ("*educational environment*" OR "*remote learning*" OR "*distance learning*" OR "*online learning*" OR "*remote education*" OR "*distance education*").

Blockchain technology ("*blockchain technology*" OR "*blockchain*" OR "*block structure*" OR "*decentralized structure*").

Finally, we combined the above terms with the AND operator to aggregate the domain outcome, while synonyms were grouped using the OR operator, thus obtaining a ready-to-use query to increase the reliability of the obtained items:

Query: (("*blockchain technology*" OR "*blockchain*" OR "*block structure*" OR "*decentralized structure*") AND ("*educational environment*" OR "*remote learning*" OR "*distance learning*" OR "*online learning*" OR "*remote education*" OR "*distance education*"))

The obtained search query was run against four search engines, i.e., *IEEExplore*,[4] *ACM Digital Library*,[5] *Scopus*,[6] and *Web of Science*.[7] on December 14, 2022, obtaining 413 hits. As shown in Figure 1 41 of them came from *IEEEXplore*, 184 from *ACM Digital Library*, 124 from *Scopus*, and 64 from *Web of Science*. Afterwards, we removed duplicates, reducing the total number of papers to 336 ($\simeq$ 81% of the starting set).

B. Article Selection Process

Using exclusion and inclusion criteria, quality assessment, and data extraction are essential components of a systematic literature review [28] to answer the proposed RQs. Both exclusion and inclusion criteria have the same purpose i.e., to help ensure that only relevant studies are included by assessing each one. As for the exclusion criteria, a paper was discarded if at least one of the criteria was met:

- *it is not peer reviewed*;
- *it is not written in English*;
- *it is a poster o similar*;
- *it is not entirely available for free*.

A total of 76 papers matched one of the criteria and were discarded. The remaining 260 papers ($\simeq$ 63% of the starting set) were eligible for the next stage. An article was included if at least one of the following inclusion criteria were matched:

- *it includes the main **goal** of the blockchain in educational environments*;
- *it includes the educational blockchain application **design***.

At the end of this phase, 200 papers were discarded, and the remaining 60 papers ($\simeq$ 15% of the starting set) were included for the next step, i.e., the quality assessment, which is done to ensure that the primary studies actually contained reliable information to address the research questions of the study. In particular, we defined the following checklist:

- *Does the article clarify the goals that blockchain wants to address in educational environments?*
- *Does the article clearly and in detail describe educational blockchain application design?*

As one can expect, it was necessary to label the answers with "Yes" or "No". In addition, the paper's first author also found it necessary to consider an average case labeled "Partially". For measurement purpose, it was necessary to assign numbers. The following values were scored: "Yes" = 1; "Partially" = 0.5; "No" = 0. The final score of each primary study was obtained by summing the score defined for each quality assessment question. We classified the quality level into *'High'* ($score = 2$), *'Medium'* ($1.5 \leq score < 2$), and *'Low'* ($score < 1.5$). As a result, 20 papers received a score between *'High'* and *'Medium'* and were included in the final our SLR paper list, while the remaining 40 were discarded.

Next, the first two authors of the paper defined a data extraction form and jointly proceeded with the reading of the primary studies to elicit all relevant information required to address our RQs. The data extraction process was constantly monitored by two senior researchers, who double-checked the activities performed to reduce inconsistencies. Then, the first two authors of the paper proceeded with synthesis of the extracted data, employing *thematic analysis* [30] to systematically analyze and identify common themes arising from the data. The research method was applied in an iterative manner and each step refined the themes emerged from the previous one. Also in this case, the process was double-checked by the other authors of the paper to avoid inconsistencies.

IV. Analysis of the Results

Most of primary studies subject to our systematic synthesis were published between 2018 and 2022, with 80% of them being published between 2020 and 2022—hence confirming the acceleration brought by the COVID-19 pandemic.

[3]The *ACM/SIGSOFT Empirical Standards*: https://github.com/acmsigsoft/EmpiricalStandards.

[4]*IEEExplore*: https://ieeexplore.ieee.org.

[5]*ACM Digital Library*: https://dl.acm.org.

[6]*Scopus*: https://www.scopus.com.

[7]*Web of Science*: https://www.webofscience.com

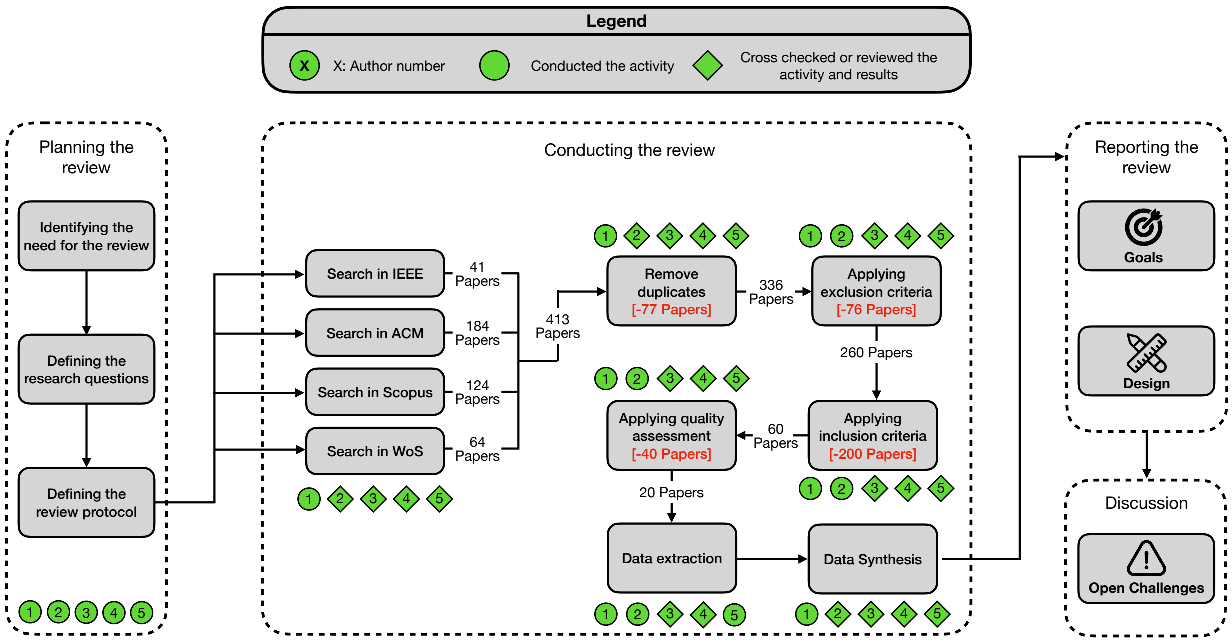

Fig. 1. Overview of our research process.

A. *RQ_1: What are the goals for which blockchains have been used within educational environments?*

As for the goals for which blockchain has been employed within educational contexts, we were able to classify them under three main categories, which we discuss in the following.

Application. Blockchain has been proposed as a means to improve information sharing and distribution in platforms without the need for central control or ownership. Several studies [SLR1], [SLR2], [SLR3], [SLR4], [SLR5] investigated the integration of blockchain in Massive Open Online Course (MOOC) platforms to enable stakeholders, such as students, faculty, and administrative staff, to upload lecture videos, engage in discussions, take notes, evaluate students, and evaluate courses. Additionally, Navya et al. [SLR6] proposed using virtual coins to stimulate student participation in online classes, allowing them to use earned virtual currencies to pay fees or purchase other university resources.

Data Management. The studies in [SLR7], [SLR8], [SLR9] highlighted challenges that could negatively affect the quality of online courses due to the lack of security. The challenges stem from the uncontrolled data proliferation, inconsistent standards for student recognition, and difficulty in sharing resources. Blockchain technology can securely manage student data by decentralizing it over a peer-to-peer network instead of storing it on a centralized server, overcoming the mentioned challenges. Additionally, Zhuoya et al. [SLR10] highlighted the security benefits of using blockchain, as it would enable the recognition of students through smart contracts, managing data such as courses passed, grades, and obtained certifications, facilitating the processes of verification and migration of students to other universities [SLR11] and ensuring compliance with sensitive issues, such as fairness. Blockchain can also enable students to perform transactions such as payment for reserved courses and sharing additional resources with other students.

Security Aspects. Last but not least are security objectives such as (1) transparency, (2) efficiency, (3) privacy, (4) authenticity, and (5) accessibility [SLR12], [SLR13]. Transparency enables all stakeholders to access the data and verify learners' activities, [SLR14]. Blockchain's smart contracts automate administrative processes and tasks without an intermediary like an academic office, thus ensuring efficiency [SLR11]. Students can benefit from this technology in managing grades, exams, and notes and monitoring progress in sports disciplines [SLR15]. Privacy, authenticity, and accessibility are essential to safeguard academic careers, and the data stored on the blockchain are immutable to prevent tampering by students or third parties [SLR16], [SLR17]. These security objectives must be ensured to maintain the integrity and reliability of student data.

RQ_1 – Summary of the results.

☞ The main goals of blockchain are to create ad-hoc applications for educational environments, ensuring proper data management and student privacy.

B. *RQ_2: How were applications designed to include blockchain for educational environments?*

As a foreword, Zheng et al. [31] define the blockchain in three types of systems: public, private, and consortium. Public blockchains are open to everyone, while private blockchains are available to restricted people. Consortium blockchains are a hybrid of the two. A key outcome of our study showed that although all blockchain types are widely spread and used, replicating an entire blockchain's development for general software systems is highly complex. In our research domain, each application that includes the use of blockchain is associated with a *blockchain protocol* that adapts the basic principles depending on the application's domain of use. On the one hand, our results show that the most used protocols in general educational systems are those referred to as public blockchains (i.e., 6 articles report the use of the Ethereum protocol). On the other hand, specific educational systems are developed using private protocol blockchains (i.e., 4 articles use one among Hyperledge Fabric, MultiChain, and Ethereum Private Blockchain protocol). Lastly, multi-purpose educational applications use the consortium blockchain type with the same protocol as the private one (i.e., 2 articles use the Hyperledge Fabric protocol).

Public Blockchain. In comparison to current educational platforms, those utilizing an Ethereum-based public blockchain are limited in functionality to managing student progress, saving grades, and academic multimedia data. These platforms employ smart contracts that can initiate a series of actions on the occurrence of predefined conditions. Different studies [SLR16], [SLR18], [SLR6], [SLR8], [SLR11] have shown a similar architecture comprising three main layers: (1) Application Layer, (2) Communication Layer, and (3) Data Storage. The topmost layer contains the procedures for developing the graphical user interface. Therefore, the most used technologies refer to lightweight Spring Boot frameworks or React.js library for cross-platform development. The data storage layer allows smart contracts to be executed and saves data permanently in blocks. The middle layer acts as a communicator between the application layer and the storage layer. It contains all the procedures for developing smart contracts using the Go programming language, consensus algorithms to validate the inserted blocks, and Peer-to-Peer network protocols. As a matter of fact, the Ethereum protocol and architecture focus on smart contracts, which are to verbalize academic grades [SLR11] and reward students who participate in classes [SLR8] using cryptocurrencies [SLR6]. As a final note, Kerr et al. [SLR3] uses the same architecture but aims to replace current MOOC platforms and divides the storage layer into Infuria IPFS, Blockchain Ethereum, and MongoDB. Because of the large amount of memory requested for multimedia, files will be saved on IPFS, which returns a hash code on the Ethereum blockchain and acts as an index for future accesses. MongoDB, on the other hand, will collect student analytics because of the high frequency of use of the platform and the large amount of data to be collected.

Private Blockchain. Research studies employing private blockchain technologies utilize protocols like Hyperledger Fabric, Ethereum Private Blockchain, or MultiChain more frequently to perform extensive tasks than public blockchains. These private blockchain-based platforms usually follow a similar architecture to public blockchains, with a 3-layer architecture consisting of the Teaching Domain, Interaction Middleware, and Blockchain Infrastructure Domain, as observed in [SLR19], [SLR1], [SLR15]. One of the primary motivations for employing private blockchains is to restrict access to resources only to recognized actors, such as students, faculty, institutions, and administrators, by establishing permissions for each of them [SLR1], [SLR15], [SLR20]. However, Access and permissions management in private blockchains can be achieved by incorporating certain procedures in the platform architecture. For instance, with the Hyperledge Fabric protocol and a "*Certificate Authority*", valid credentials can be obtained to manage read and write permissions on the blockchain [SLR1], [SLR15]. Only users with permission recognized by the CA can access the resources. On the other hand, the Ethereum Private Blockchain protocol can use a relational database (MySQL) to manage user access and permissions [SLR20]. In the former case, the change involves adding a CA procedure, which affects the data storage layer. In contrast, differences in the application and storage layers are required in the latter.

Consortium Blockchain. As mentioned before, the consortium blockchain combines the features of public and private types while maintaining security and privacy requirements. It aims to provide a complete platform rather than one designed for specific purposes. As a result, the architecture of a consortium blockchain increase in complexity, as it needs to accommodate a wide range of functionalities and heterogeneous users. In a recent study [SLR9], an 8-tier architecture using the Hyperledger Fabric protocol was proposed. The layers include (1) application tier, (2) learning systems and business abstraction tier, (3) cross-chain tier, (4) adaption tier, (5) contract tier, (6) security tier, (7) storage tier, and (8) network tier. However, to simplify the design, the authors merged some layers into three main layers: (1) Trusted Open Learning Application, (2) Cross-Chain Layer, and (3) Blockchain Consortium. The Trusted Open Learning Application provides multi-purpose open learning applications such as credential sharing, student progress sharing, academic management, and intellectual property application management. The Cross-Chain Layer manages interactions between heterogeneous blockchains, including governance, task and permission management (via Certificate Authorities), and data adaptation through APIs. The Blockchain Consortium layer consists of the components that form a blockchain consortium network, including the structure of the blockchain, features for managing consensus in the network, and customization of smart contracts. While permission management is incorporated into the cross-chain layer in the architecture proposed in [SLR9], another study [SLR7] proposes a design that does not require permission management through Certificate Authorities and relational databases. The platform allows multiple universities on the network to share resources while guaranteeing intellectual property to all students.

In general, the design complexity and choice of blockchain type depend on the level of maturity of the applications to be developed for the educational domain. The lower level is suited for a public blockchain platform with limited functionalities that can address only a subset of educational objectives. In contrast, the middle level is better suited for private blockchains that require permission management since their access is restricted to authorized users. Consequently, private blockchains can support more diverse tasks than public blockchains. Finally, the highest level of application maturity is achieved through consortium blockchains, which encompass a complete set of software solutions for managing the entire university ecosystem, focusing on access management.

RQ$_2$ – Summary of the results.

☞ The type and complexity of a blockchain depend on the application's maturity. Public blockchains are limited to educational goals, while private blockchains have permission management and support more tasks. Consortium blockchains are designed for high-level applications like university management with access management features.

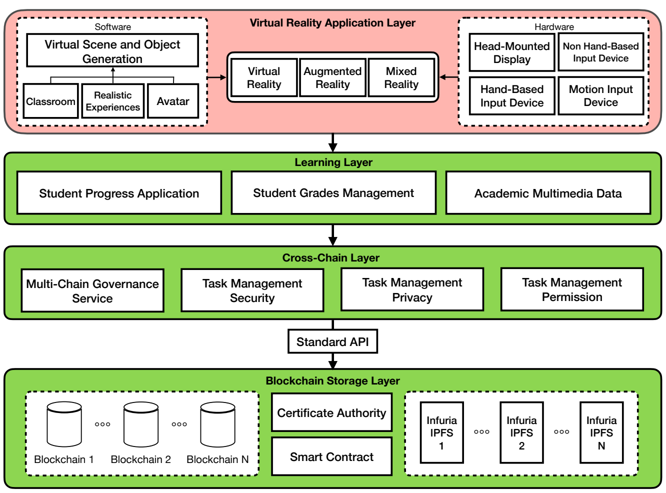

Fig. 2. Proposed Application Design for Secure Educational Metaverse

V. Toward a Secure Educational Metaverse

The ultimate goal of our research was to understand how the blockchain technology can be exploited within the context of an educational metaverse. As such, we elaborate on our findings in an effort of providing insights into how the knowledge acquired through the systematic literature review can be tailored to account for the key aspects characterizing the metaverse. Figure 2—also available in the online-appendix [32]—outlines a possible layout of a blockchain-based educational metaverse, which we designed based on the results of the study and use for the discussion.

In the first place, our findings demonstrate the rapid evolution of blockchain and its ability to facilitate various tasks and objectives. However, while blockchain seems promising, further investigation is required to determine how it can be adapted to the metaverse. In particular, the metaverse aims to create an immersive experience that bridges the physical and virtual worlds and encourages participation from both teachers and students. Integrating the blockchain technology into the metaverse is not a distant prospect, as it can be seamlessly incorporated into existing applications. The real advantage of the metaverse lies in its immersive potential, which requires further development of the application layer. The upper layer shown in Figure 2 represents the transformation from the application layer described in Section IV to the virtual reality layer. In more detail, virtual reality can be enabled using software and hardware components to create virtual scenes, e.g., classrooms, realistic experiences and avatars. The latter empowers the immersive between the physical user and the avatar. Educational activities can be conducted using the *'Learning Layer'*, which contains multi-purpose open learning applications, including credential and student progress applications, academic management for student grades, and academic multimedia data, i.e., the tasks identified in the context of **RQ**$_1$. Furthermore, the *'Cross-Chain Layer'* would represent a crucial software layer that enables interoperability between blockchain networks and the metaverse. Its modules provide the necessary governance, security, privacy, and permission features that ensure the smooth execution of cross-chain transactions [SLR9]. Last but not least, it is worth noting that the blockchain layer focuses on several aspects. First, reference is made to the blockchain, in which different blockchains can be included to ensure access by multiple institutions or departments. Because of this heterogeneity of access, it is necessary to establish read and write permissions on the blockchains using a Certificate Authority [SLR9]. In addition, to ensure the management and use of multimedia data, an Infura IPFS must be associated with each blockchain. The use of such a resource is motivated by the fact that the blockchain cannot hold extensive data. Therefore, multimedia data will be saved on IPFS, generating a hash code to be kept on the blockchain. This hash code will be used as an index to retrieve the file [SLR3]. It is essential to emphasize that each layer of the proposed design has been specifically tailored based on the outcomes acquired from **RQ**$_2$. As a concluding remark, moving from the application layer to the virtual reality layer would address the limitations of existing applications, such as the lack of control over students' attention during classes and the prevention of unethical behavior during knowledge verification. However, creating realistic virtual experiences remains challenging due to the development complexity and the number of experiences required for each subject of study.

› **Take Away Message.** While the current blockchain technology is sufficiently advanced to be integrated within an educational metaverse, it should be adapted to take the immersive nature of metaverse into account—this requires further development of applications and interaction between virtual reality and blockchains. The proposed layout of a blockchain-based educational metaverse may serve as a conceptual basis to enable additional research on the matter.

VI. Threats to Validity

Some aspects might have biased the conclusions drawn in our systematic literature review. In the following, we discuss the major threats to validity and how we mitigated them.

Literature selection. A critical challenge of any systematic work is the identification of a complete set of primary studies. We approached the search process by adhering to the guidelines by Kitchenham et al. [28], who defined a set of standard steps to ensure the completeness of the information retrieved. It is worth remarking that the search has been applied to multiple search engines, in an effort of collecting the largest possible amount of resources to further elaborate. Of course, we are aware that the reliance on the guidelines does not necessarily maximize the recall of the search process, yet it makes us confident of the procedures applied. Our future research agenda includes additional investigations into the matter that may corroborate the findings of our study. In addition, we released all the data employed in the study [32] to allow further researchers to replicate our work and possibly extend it with additional insights.

Literature analysis and synthesis. Upon completion of the search process, we proceeded with the systematic investigation of the resources identified. We applied a number of exclusion and inclusion criteria to make sure to identify the most appropriate set of primary studies that could address our research questions. Perhaps more importantly, we also applied a quality assessment of the resources retrieved in an effort of ensuring the soundness of the primary studies with respect to the quality of information required to address our objectives. These steps have been manually conducted: we acknowledge risks connected to subjectiveness and/or human error. To mitigate those potential issues, we defined a formal collaboration structure. On the one hand, the two first authors of the paper constantly collaborated during the steps of the systematic process, opening discussions and solving disagreements whenever needed. On the other hand, the other authors of the paper were involved in one-hour meetings every week: these meetings had the goal to double-check the entire process conducted by the first authors and provide further advice on the next steps to conduct. Such a formal structure made us confident of the conclusions drawn in our work.

VII. Conclusion

We conducted a systematic literature review of 20 primary studies to analyze the current status of blockchain in educational environments, letting emerge the tasks supported and how applications were designed to include blockchains. We then use the findings coming from our investigation to propose a layout of a blockchain-based educational metaverse, which might be serve as a basis for the next research and technological steps to be performed.

To sum up, our work provided the following contributions:

1) A systematic synthesis of the educational tasks supported through blockchain and how educational applications were designed to include blockchains;
2) The conceptualization of a blockchain-based educational metaverse, which we derived from the current knowledge and that may serve as a basis for tailoring blockchain within the scope of an educational metaverse.
3) An online appendix [32] which provides full access to the data used in our work and that can be employed by researchers to replicate or build on top of our findings to further investigate whether the role of blockchain in educational environments.

The implications of the analysis represent the main input for our future research agenda, which will be focused on the design and evaluation of software engineering instruments to enable the use of blockchain within the educational metaverse.

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