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CONCEPTUAL PROCESS MODEL FOR METAVERSE ARCHITECTURE - SSADT'S DESIGN PROCESS

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Abstract

At the articulation of the two themes: "Virtual Environments and Emerging Realities" and "Parametric Design and Digital Fabrication," our proposal subscribes at the intersection of innovative technologies in architectural practice, such as blockchain, collaborative platforms and digital twins. Our purpose is to propose a conceptual design process model for architectural digital twin as a compound of metaverse architecture. The challenge is to achieve a Shared and Secure Architectural Digital Twin (SSADT). To model our SSADT's design process model we are based on blockchain approach. To do this, we will firstly start by defining the principal compounds of an architectural digital twin. Secondly, we will explain the different steps for modelling a blockchain application. Then we will prototype our process for a SSADT. Finally, we will discuss our results and we will explore future perspectives.

Keywords

Digital twins, Blockchain, collaborative platforms, process, Architecture.

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ABSTRACT

At the articulation of the two themes: "Virtual Environments and Emerging Realities" and "Parametric Design and Digital Fabrication," our proposal subscribes at the intersection of innovative technologies in architectural practice, such as blockchain, collaborative platforms and digital twins. Our purpose is to propose a conceptual design process model for architectural digital twin as a compound of metaverse architecture. The challenge is to achieve a Shared and Secure Architectural Digital Twin (SSADT). To model our SSADT's design process model we are based on blockchain approach. To do this, we will firstly start by defining the principal compounds of an architectural digital twin. Secondly, we will explain the different steps for modelling a blockchain application. Then we will prototype our process for a SSADT. Finally, we will discuss our results and we will explore future perspectives.

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ملخص

في تمحور مفصلي بين الموضوعين: "البيئات الافتراضية والحقائق الناشئة " و"التصميم البارمتري والتصنيع الرقمي" يتمركز مقترحنا في تقاطع التقنيات المبتكرة في الممارسة المعمارية مثل تقنية البلوك تشين، والمنصات التعاونية والتوائم الرقمية. هدفنا هو اقتراح نموذج فكرى لعملية التصميم للتوأم الرقمي المعماري باعتباره عنصرًا من عناصر البيئة الافتراضية الموازية. ويكمن التحدي فى تحقيق توأم معماري مشترك وآمن. ولتحقيق هذا التحدي نعتمد على منهج البلوك تشين حيث نبدأ أولًا بتحديد المكونات الرئيسية للتوأم الرقمي المعماري، ثم نشرح الخطوات المتبعة لتصميم وتطبيق البلوك تشين ثم نقوم بتقديم نموذج ونختم بمناقشة النتائج وكشف وجهات النظر المختلفة.

الكلمات المفتاحية: التوأم الرقمي، البلوك تشين، المنصات التعاونية، عملية تصميمية، هندسة معمارية.

1. INTRODUCTION

Digital twin is a concept that refers to the digital model of a physical object, system or process that exists or may exist in the physical world. It lives and evolves in a computer, like a virtual avatar (Geneux, 2021). The concept of a digital twin, relatively new to architecture, is becoming a desirable prospect. It is a favourable innovation to build a fine insight into the static and dynamic state of infrastructure or building at each phase of its life cycle. It is a catalyst for increased collective intelligence by combining different information from each trade and citizens. It offers them the same global and systemic vision of a project to build or operate. However, the concept of “digital twins” is not just a “buzzword”, but it is the cornerstone of an engaged, responsible and sustainable digital transformation.

To ensure all interactions and exchanges of data, the digital twin must be coupled with a “collaborative platform.” Blockchain technology is considered as a key to the development of such platforms (Girault, 2020). It's laying the foundations for a new decentralized internet. It has already transformed the business world. From finance to construction, the possibilities for leveraging blockchain are limitless (Massimo, 2017).

Girault (2020) defined the key components for modelling a digital twin of the project and the locks for its implementation. The Gemini Principles set out values to guide the national digital twin and the information management framework that will enable it (Bolton and al., 2018). We will base on research to model our SSADT’s design process. To unlock the locks, we propose to take advantage of the benefits of blockchain technology defined by Teisserenc & Sepasgozar, (2021).

What process model could we propose for the design of a shared and secure digital twin? At what level could we integrate the application of blockchain in the design process? And ultimately, what could be the impact of such a digital twin on design processes?

2. TOWARDS A SHARED AND SECURE ARCHITECTURAL DIGITAL TWINS: SSADT

For the implementation of an architectural digital twin, two key components were defined by Girault (2020):

- **A collaborative platform** to collect and host all the data produced by each actor, consolidate them, ensure their consistency, and ensure that the digital twin offers the "point of truth" of the project. Other technologies have to be coupled with this platform to offer better relevance and efficiency to the digital twin such as the structuring of digital twin data, the conversion of data between different formats, the management of data access modes and the protection of Intellectual Property. This will also guarantee the traceability of actions, requests, and data exchanges, between actors, provides access to knowledge bases and business services and ensures the long-term archiving of data.
- **The process of co-evolution: the “*backbone of the digital twin”***

  Co-evolution allows the monitoring and the piloting of the entire project during its life cycle. *“The coevolution is similar to a chain of formulations of design problems (Pi) and prototype solutions (Si) – sequential and/or parallel sequences that begin with the initial formulation of the project problem and end with solutions that point to nil (marking the end of a sequence).”* (Girault, 2020). To visualize the traces of the co-evolution process Girault defined a representation in the form of a map that he called the “PST-map”. It provides access to all data through problem formulation and requirements. Therefore, it will be possible to manage the co-evolution to be able to restore the genesis of the project. The different actors will be able to understand the evolution of the problem formulation during the project, the choices that have been made and their justifications and to propose alternatives.

Visualizing the co-evolution process in the form of a PST-map can be very cumbersome, even too tedious for designers. User interfaces could therefore be envisaged to facilitate and lighten the designers work and to automate certain time-consuming operations.

The relevance of an architectural digital twin is its ability to host all project data and ensure digital continuity. According to the Gemini Principles, digital twin ecosystems for the public good should be secure, reliable, trusted, open, transparent, and collaborative, with data interoperability and access control rules guaranteeing privacy. Blockchain technology could guarantee the trust, security, and transparency required for integrated shared DT platforms (Sallaba & al., n.d.). We are pointing to a shared and secure architectural twin (SSADT). Interoperability, security, and transparency are therefore the key concepts and the major challenges for modelling our model. Blockchain technology can enhance proof of provenance, data trustworthiness, data security, and data traceability for digital twin of manufacturing supply chains (Mandolla et al., 2019).

Therefore, to meet these challenges we have thought of relying on blockchain technology to design our process model. *"BCT* (block chain technology) *could guarantee the trust, security, and transparency required for integrated shared DT(Digital Twins) platforms"*(Teisserenc & Sepasgozar, 2021). The architectural design process is characterized by ever-increasing flows of information between the various stakeholders: Exchange of data and paperwork such as tenders, contracts, authorizations, claims but also many other administrative details. We propose to integrate blockchain technology into the architectural design process to enhance trust, collaboration, transparency, efficiency, data sharing, and information security. A complete platform could be provided to ensure design, administration, and project management transactions in a simultaneous manner.

2.1. A Blockchain Application for a SSADT's Design Process

The blockchain technology allows everyone involved in the process to standardize and manage all data in a single, reliable, and incorruptible platform. It can ensure trust, by facilitating the information exchange through the long-term chronological keeping of an archive. According to Scott Nelson, CEO of Sweetbridge, in Harvard Business Review: "*Traditional project management techniques still work, but projects can benefit from a more decentralized and agile approach, where transparency is high, and where parties can be remunerated for the results as well as the work done."* .

The Blockchain technology could be a key pillar for an engaged and responsible digital transformation (Beddiar & Imbault, 2018). With information about each building material, designers will be able to make better decisions about efficiency, economy, and sustainability. This will allow access to the history of each material, know these origins, and predict the cycle life of a building and its impact on the environment.

2.2. The Modelling Steps for a Blockchain Application

Before the modelling of our process, we start by clarifying our idea. Firstly, we have to identify the main reasons for which we think to integrate blockchain technology in our SSADT's design process model. "*Blockchain is an emerging technology that is being used in many industries and businesses to achieve authenticity, transparency and to overcome some difficulties in their operation processes"*(Muthu, 2022). The principal challenges of using the Blockchain technology, in our case, are:

- **Security:** We aim for a decentralized process. Blockchain technology is more secure than centralized database systems. This means that a Blockchain is much less likely to be a hack attempt target, as there is no single point of failure. The project data will be more secure because it will not only provide stakeholders with insight into data, but also it will allow them to control access to it.
- **Interoperability :** Blockchain improves interoperability in each phase of the process between the different actors, the public institutions and the other construction service providers (Muthu, 2022). All these stakeholders will be able to collaborate and to benefit from an equitable and synchronous perception on the progress of different phases of the design and to control the evolution of the project to be designed.

- **Transparency:** Blockchain systems can also give to different stakeholders enhanced levels of transparency on data related to the execution of the different design tasks for each phase. They also provide an additional level of security against inconsistencies and possible errors. Thanks to smart contracts, blockchain technology helps to avoid intentional falsifications.

Secondly, we identify the importance of blockchain in the process (Is it really necessary to integrate this approach into the architectural design process?): The architectural design process is characterized by a high number of data flows: regulatory and technical data, (structural, environmental, economic, etc.), quantitative and qualitative data relating to construction materials and organisational data relating to the planning and execution times of the various design tasks and of the project execution ... Blockchain technology makes sense to manage the transaction and guarantee the security of this data, and to ensure mutual trust between the various stakeholders. To increase the level of security and respect the intellectual property, we plan to manage the mode of access to the data either in reading or in modification. This means that, each actor can access only the data to which he has the rights in reading and/or modification. This will allow us to ensure all exchange traceability and its origins. Each stakeholder works in his own environment, and he can receive the data transmitted by the other actors. "*In processes of digital exchanges between heterogeneous actors, by introducing this system of proof, an exchange inscribed in a blockchain becomes a signed contract, which protects the one that emits as well that he who receives"*(Beddiar & Imbault, 2018). We need a centralized security system for each module (in the inter-modular environment) and decentralized in the intramedullary workspace (in our case the collaborative platform). We are advancing a hybrid Blockchain (Consortium).

Then we must define the problem to solve by combining blockchain technology with digital twins' design process. On the one hand, the higher the data flow and the greater the numbers of speakers, the more difficult will be to manage, to transmit and to capture information in a fast and efficient manner. Nowadays, we need to build faster, and we are searching for more efficient communication interfaces such as 5G. In addition, the implementations of digital twin are limited due to a lack of standards and recognized interoperability, especially in the manufacturing domain (Muthu, 2022). On the other hand, it is still difficult to ensure a digital continuity for an architectural project and to visualize all the data relating to its history. In the case of a project restoration, for example, designers do not always have access to its history: the data relating to the supporting structure, the materials used, the proposed solutions to problems encountered during the execution...

Our model aims to facilitate data sharing among stakeholders by focusing on relations (how information is received—understood and heard) and to ensure digital continuity throughout the project life cycle.

Fourthly, we define our system actors (in our case the SSADT design process): Our process model focuses on those involved in architectural design, namely designers (architects, interior architects, engineers, etc.) to facilitate communication and information sharing. It also takes into consideration:

- The client: to promote a participatory approach;
- The public institutions: to monitor the proper application of regulatory standards;
- The services companies: to manage tenders documents for the execution of the project;
- The administrator: The IT specialist (a computer scientist) to architecture the platform, and the blockchain system.

Referring to Muthu (2022), actors can be divided into many categories, under to the role they play in the system: Developers are charged with writing and reviewing the code that builds the Distributed Ledger Technology (DLT) and its interconnecting systems. Administrators control access to the system's central code. Gateways are fundamentally the entities that help the system fulfil its tasks in developing the processes transacted by their components. Gatekeepers ensure participant access to the network. Oracles are in charge of communicating the external data to the network. Issuers are in charge of issuing or exchanging tokens that represent the assets registered in the system. Participants who represent the interconnected design teams (often referred to nodes) that criss-cross information and messages in order to create the digital twin.

Finally, we have to identify the most appropriate consent mechanism. This is a job of the system administrator who selects the most appropriate consent mechanism for each project.

3. GLOBAL ARCHITECTURE OF THE SSADT DESIGN PROCESS

We start by defining the different design phases of our SSADT system. Each phase corresponds to a private workspace for a team of predefined designers. In each phase, we have to define a problem (P^x) to arrive at a solution (S^x). To achieve an optimal solution in each phase, it is necessary to use a prototyping of possible solutions. This is the process of co-evolution that we defined earlier. As a result, each workspace has a *"PST-map^x"* delivered at the end of each phase for other stakeholders to develop the other phases. The proposed solutions correspond to the different models of prototyping and representations of solutions developed and transformed throughout the design process, such as sketches, plans, drawings, perspective drawings, 3 D computer models...

The data in each phase should be stored, shared, processed, and accessed securely. As a result, each workspace in each phase corresponds to a blockchain network. The Blockchain offers more transparency to each workspace, as it maintains a distributed directory within the team of designers involved in the network. At the beginning of each new project, the architect is in charge of creating a new project file which is in our case the SSADT. He then defines the teams of dedicated speakers for each phase. Therefore, each involved in the design process is registered in advance in the system in the workspace to which he has the right of access. Each actor will therefore have its own account and access keys to the workspaces to which it is entitled. Once the project file has been created, we will be able to make copies distributed and shared to all teams of the different phases. This is the network of nodes of the blockchain. "*Unlike a «classic» database, a blockchain only allows additions. Different copies of a register exist simultaneously on different computers (which are both clients and servers: we speak of node of the blockchain network). When a block is added, it is added on all nodes*" (Beddiar & Imbault, 2018). Actors will be able to view all the data related to the project design and add more (Figure 1).

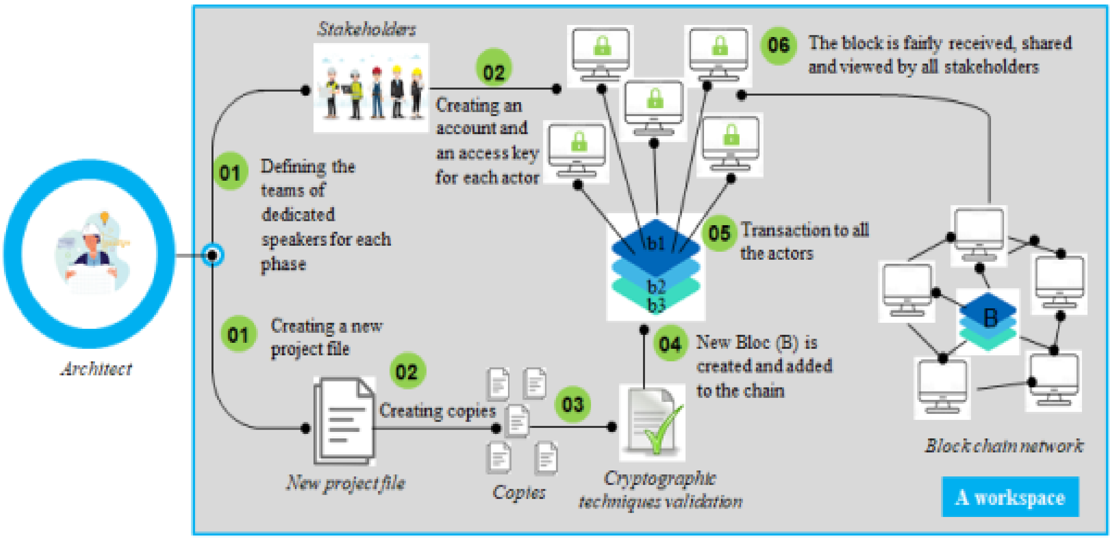

Fig.1: Global operation of our blockchain

When inserting a new data, the system must first check the Blockchain validity. At this time, the system will detect any kind of violation that might happen to the project file. And since there are several copies of this folder in the Blockchain network, the data can be recovered simply, so we are able to recover the folder validity. After the validation task, each data added will be injected to the project folder by creating a new block. This new block will only be added after approval of all stakeholders. In the extra-modular space that is the collaborative platform, the client can only consult the evolution of his project, view it or leave comments in a discussion space.

We define four phases of our design process model.

3.1. A First Phase B1: Problem Formulation

This phase is defined by referring to Girault (2020*) "the resolution of design problems results from the co-evolution of problem formulation and solution development."*

In this phase, the problem formulation is defined at the time the architect begins the project design. It is based on the various data available or transmitted by information, guidelines and directives contained in the programme. That defines the expectations and constraints to be considered in developing the solution. This first block is divided into four levels (sub-blocks):

- Level 1 (b_1^1): Contains project context data. These data allow the definition of the nature of the project, its environment, its level of complexity, the human, financial and material resources to be mobilized, the constraints identified throughout the design process, use cases, etc. and the specific needs of the system as well as possible assessment tools for decision-making and validation of solutions.
- Level 2 (b_1^2): It stocks data related to the constraints and technical requirements set by the specifications, as well as environmental, geographical, social, cultural, and economic data. It holds also, the human, financial and material income to mobilize. The time allowed for the design process, the specific needs for each given SSADT and the tools and means available for the evaluation, decision-making and validation of the solutions.
- Level 3 (b_1^3): The objectives and requirements set, generally, by the owners (owner, user) that correspond to the definition of the program and its expectations (description of functions, zones, materials, etc.).

3.2. A Second Phase B2: Development of Possible Solutions

- Level 1 (b_2^1): It concerns all research related to the morphology of the physical twin.

  During the design phase, architects are required to produce images to give shape to his project and communicate it. To do this, they are basing on a chosen architectural concept, style, or references. The projet must show originality. At this level, architects are working on a real process of creativity.
- Level 2 (b_2^2): At this level, architects search for solutions related to the functionality. "Form follows function" (Sullivan, 1896). By functionality, we mean all the functions of the physical twin, its role, its usefulness, the action they exert on us and on its environment.
- Level 3 (b_2^3): This level is for communication and configuration.

  The professional responsibility of the designers is to bring all the parameters back into the field of the project which is in our case the SSADT. They deal with these different parameters according to their knowledges and techniques to meet the challenges. It is through the communication established between the different actors that the SSADT is created in continuous iterative returns until a consensual solution.

3.3. A Third Phase B3: System Behavior Simulation

To simulate the behaviour of our twins, we propose an MEI flow modelling classified according to three levels of blocks: It is by reconciling these three levels that the research space as well as the SSADT evolve during the process by enriching its selves with new knowledges related to the sciences or trades.

- **Level 1 (b_3^1):** material flows (M);
- **Level 2 (b_3^2):** Energy flows (E);
- **Level 3 (b_3^3):** information flows (I).

The consensual solutions in B2 are considered like reservoirs, since it corresponds to stocks of materials, energy, and information. To visualize this, we are referring to the analogies of D'Arcy W. Thompson (1917) for whom *"the form is a diagram of forces"*. The developers will simulate the SSADT's behaviour, by using operating rules valid for all systems. Our system is then endowed with behavioural laws, which make it possible to inject values into the different flows that animate the interactions between the two twins. The integration of the time variable favours simulation, since it becomes possible to play with the values associated with the initial conditions, to create prospective alternative scenarios. Then the designer will be able to study and predict the behaviour of our SSADT.

3.4. A Fourth Phase B4: Formulation of the Optimal Solution

It involves using the model to target our SSADT, learn from it and design again in the B1 (Reformulation of the problem), or make decisions that allow action in the actual design (Physical Twin). Designers can follow several studies:

- **Qualitative study:** it corresponds to a descriptive pathway. It is a question about detailing the SSADT qualitatively so that it can be considered as an optimal solution validated by all designers and stakeholders. It's not just the technical details of execution, but also information about data, context, constraints, purpose, elements and relationships, operating rules, etc. This information allows the designer to develop his self-referential, by a reference space dedicated to the practice of architecture in a general way.
- **A quantitative study:** it corresponds to a prescriptive pathway. Quantitative research of the SSADT system with precision and real measurement to improve it by working on its formalisation or by quantifying some of its interactions.
- **A heuristic study:** this study is for the construction of possible scenarios based on our theoretically developed SSADT to look for all reasonably conceivable solutions to a given problem.

The three studies may be continued simultaneously or consecutively or in parallel.

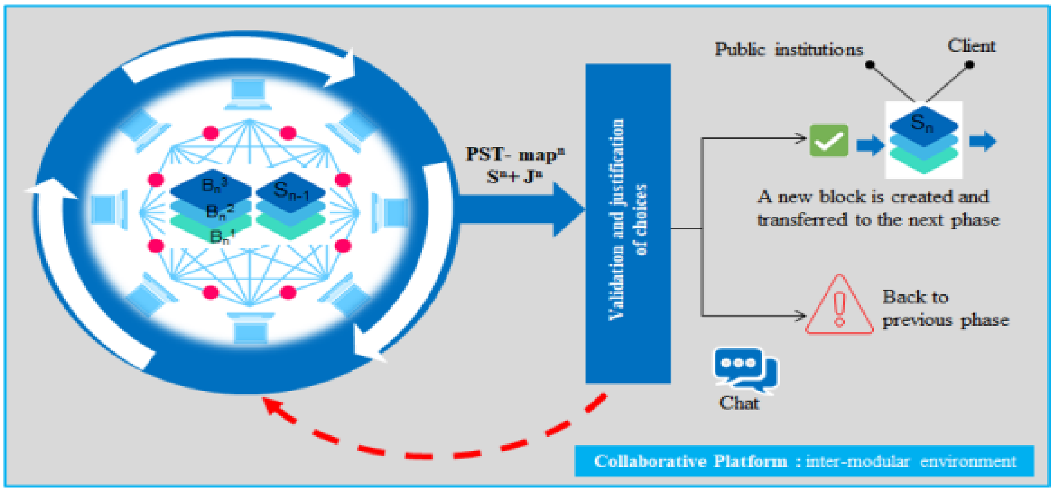

Fig.2: Phase operation

As we said earlier our proposed model focuses on relations. We have not indicated the direction of the relations in the model because we think that it must be characterized by the designers (it can be one-way or two-way, have a positive or negative effect on the system, be inhibitory or arousing, regulate and feedback, etc.). This will give our model flexibility to adapt to the nature of the project. There may be different hierarchical or nested relational networks in subsystems (phases). In all cases, we try to offer a subjective freedom to designers, to ensure a continuous balance between the logic imposed by the rules prescribed by the specifications, and the creative logic of the invention.

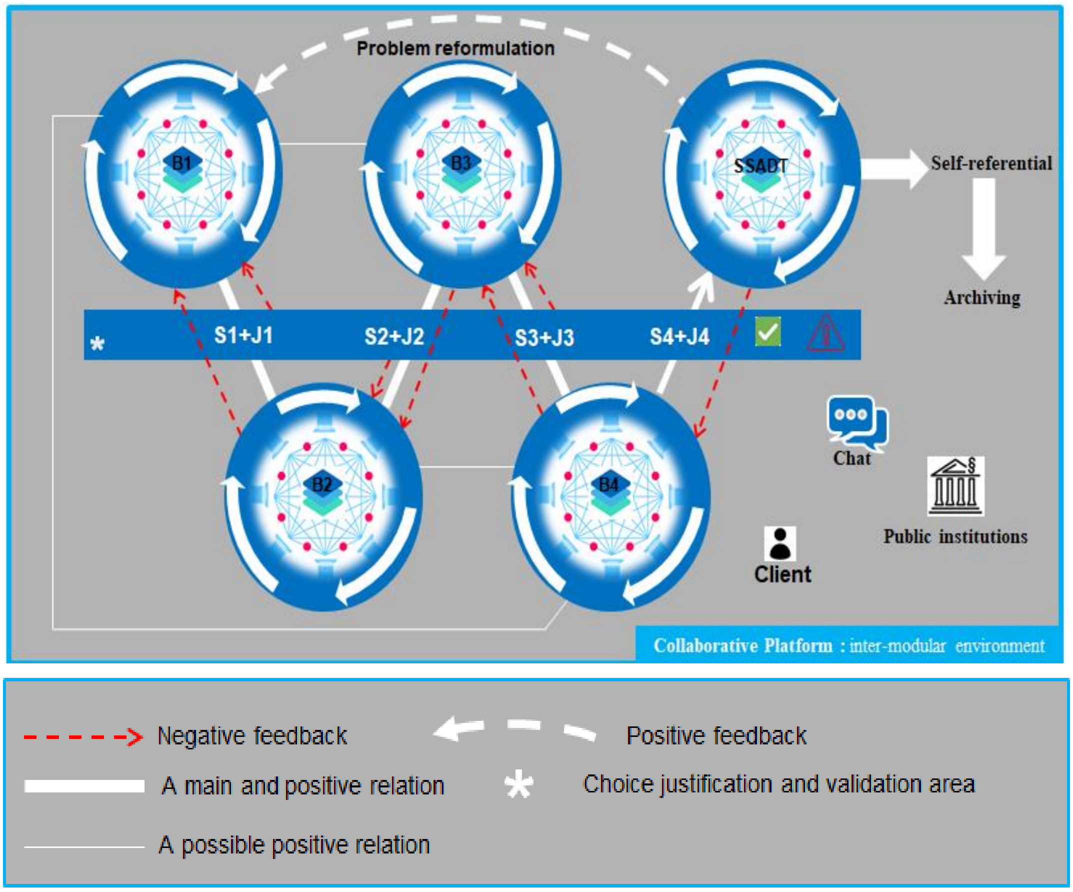

Fig.3: Conceptual design process for an SSADT

4. CONCLUSION

We consider the blockchain technology to be promising. It paves the way for a committed and responsible digital transformation in the field of architecture. Through this reflection, we were able to shed light on the issues that we can meet if we integrate blockchain technology into the design process because we have noticed that it is little explored in the field of architectural design.

The major contribution of this reflection is that through the proposed model it is possible to adopt a participatory approach in the design process while ensuring on the one hand a fair foresight to all stakeholders on the state of the project in real time and on the other hand data security and respect for intellectual property. However, an empirical study remains essential to validate this process model in real-life cases of metaverse architecture.

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