underlying approaches which may be able to provide a solution that can subsist the test of time by being integrated around a more centralized conceptualization. The sustainability of such a system demands ways of managing the addition of new data while adapting to new demands using the latest technology. Rather than highlighting the techniques implemented, we detail in the following sections key concepts to manage the integration of technological evolutions into a modular system. Our proposition to move away from the current trend of separating achievements (preservation vs. visit for non-specialists) and the most sustainable approach is to set up a flexible evolving system. It comes at a cost: we are moving away from the "one-shot" logic and site managers must, therefore, acquire new skills to be able to support the development and maintenance of the system while using and enriching it optimally.

**4. Methodology**

In this project, we were inspired by the design methods used in geographic information science which are themselves derived from the methods developed in information science. The approach followed was a user-centered prototyping. This choice was primarily dictated by the tight deadlines and agile/iterative deployment constraints which such a design alleviates through a fast production of a working solution as illustrated in [83] or [84]. Users were put at the center of the process and we assumed that an information system must meet the needs of an organization or a set of users. It is quite common that these needs are not clearly identified, or in any case, not sufficiently formalized. The prototyping approach implies that new stages start with feedback on the previous stages. This section covers only the first pass as presented in Figure 4, which is then iteratively reproduced to obtain various outputs detailed in Section 5 and Section 6. We started with a needs analysis phase (Sub-Section 4.1.) with an iterative co-construction between the development team and the users. This phase relates to the definition of the specifications, the development of the conceptual model and the development of interfaces. Then, a double cascade development phase was initiated, which concerns data curation through multi-resolution 3D mapping (Sub-Section 4.2), followed by the optimization for the various usages of the data and knowledge integration (Sub-Section 4.3), which were usable through various outputs export of which several VR prototypes (Sub-Section 4.4). The operational systems included database management systems populated with 3D data and were searchable through VR interfaces.

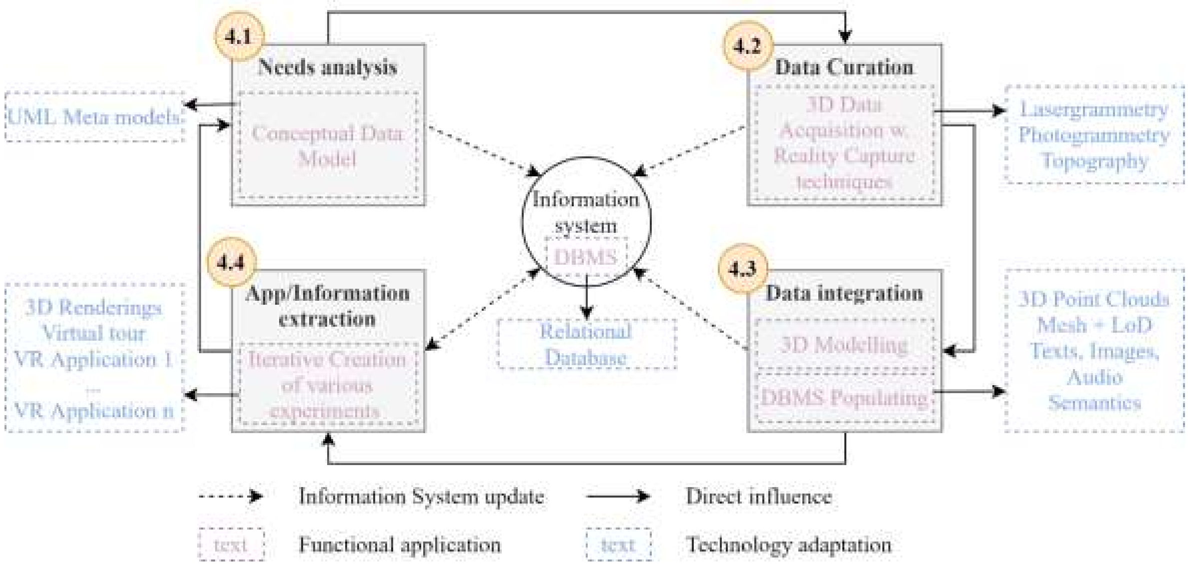


**Figure 4.** Global workflow for the realization of a comprehensive virtual reality experience for heritage tourism. It comprises the three layers from the conceptual methodology to the technology adaptation through the functional layer.

Figure 4 shows the proposed framework and its functional application to our use case detailed in Section 5, as well as its technology adaptation for VR heritage tourism. In the next sub-sections, we will describe each main block and provide a meta-model that participates in a sustainable reflection to set up a sustainable system.

*4.1. Needs Analysis*

The needs analysis aimed to identify the requirements of the project and to take note of the expected elements. It is about contextualizing the project and analyzing the expectations to give a framework to the project. A needs analysis usually gathers insights from several meetings at different points in time. This allows the different decision-makers involved in the process to describe enough parameters for constructive conceptual modeling. The contributions of a needs analysis permit the project to be based on real needs, oriented the project toward satisfying these needs, and better construct the project.

After the framing phase, the process was usually oriented toward the user need requirements and collecting the technical requirements, to finally list the functional operations and prioritize them to answer to the best of the constraints (Figure 5).

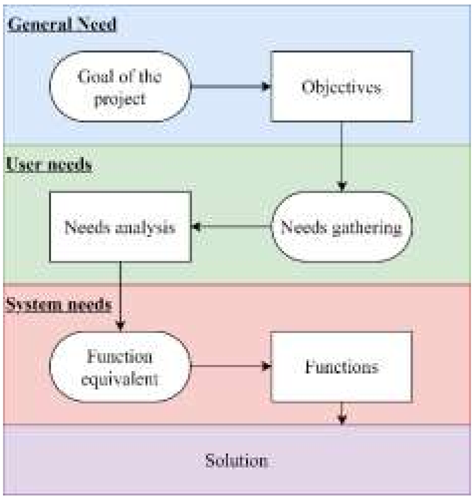


**Figure 5.** Needs analysis diagram. The solution is obtained by following a narrowing gathering process from the general need to user needs and system needs.

It is the sensitivity of the project teams and the involved persons that determine the attributes of the requirements gathering process, and whether it is focused on the technical or user dimension. In absolute terms, a comprehensive need gathering phase considers all dimensions and determines the project requirements from a holistic perspective (overall vision, cross-functional, and multi-disciplinary approach). The collection of needs was formalized in a framework note and is a powerful tool for building a coherent project, meeting user expectations in each context. Our approach then based its decision on a Bayesian bandits decision-making algorithm. Our choice was motivated by the fact that a user-centric design has many iterations, and we wanted to use the one that maximizes positive outcomes. To gather the needs one seeks, among other things, to:

- Contextualize the project: main facts, target, positioning.
- Characterize the objectives of the project.
- Carry out the work of expressing the needs.
- Conducting the work of collecting user requirements.
- Establish the list of content needs.
- Draw up the list of functional requirements.
- Define, clarify and explain the functionalities that meet each need.
- Order and prioritize functionalities in order of importance.

- Create a synoptic table of content functions and their impact on the product.
- Identify the resources to be activated for production.

In all cases, the purpose of collecting the requirements was to facilitate exchanges between all the profiles throughout the project. The results of this approach are listed in Section 5.1. The high-level conceptual models of the different aspects of a heritage tourist VR application were initially built from Figure 6 expressed from the initial need's analysis design.

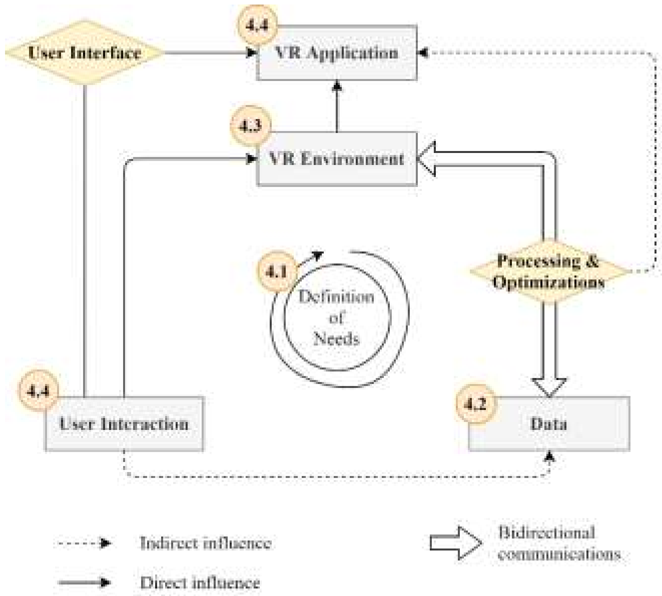


**Figure 6.** Definition of the different categories influenced by the needs analysis. First, the data part is treated in Sub-Section 4.2, followed by the virtual reality (VR) environment creation in Sub-Section 4.3, and the optimizations needed for specific interactions are in Sub-Section 4.4.

This graph was cross-validated following a Bayesian bandits strategy with the needs analysis and was constrained to obtain several conceptual models of the functionalities to develop, and the entry points to keep for further processes if the need arises. Additionally, we highlighted the specificities of the VR such as:

- **VR needs to have a use**: the value that AR and VR are promising in terms of providing needs to be clearly understood and relevant in the tourist context [24].
- **Quality environment**: by offering a high-quality of resolution or sound, more authentic VR and AR environments in which tourists can be fully immersed should be provided [85].
- **No distraction:** avoid distractions for the users, bugs, irrelevant information [31].
- **Consumer-centric:** one should carefully consider how this object creates meaning for the visitor, how it connects to his/her values, and enables the visitor to create his/her version of the experience [24].

*4.2. Reality Capture Methodology for 3D Data Acquisition*

The mission first initiated the use of a terrestrial laser scanner (Leica P30—resolution set to 1.6 mm @ 10 m) for the full survey of the site. It was initially mounted with an external camera to obtain a colorization of the point cloud. Later, several photogrammetric campaigns took place indoors and outdoors. All this data was redundant from a full topographic survey of the site via the total station (Leica TCRP 1200à), including the precise control point distributed along strategic points (we used a GNSS receiver Trimble R10 in RTK mode on 15 established points measured for 5 min each; each point was also stationed with the total station to establish the main polygonal; the mean error was 1 mm in XY, and 2 mm in Z overall points after a Helmert transform). Thus, the three methods were