ARK-BIM: Open-Source Cloud-Based HBIM Platform for Archaeology

applied sciences

MDPI

Article

ARK-BIM: Open-Source Cloud-Based HBIM Platform for Archaeology

Filippo Diara * and **Fulvio Rinaudo**

DAD Department, Politecnico di Torino, Viale P.A. Mattioli 39, 10125 Torino, Italy; fulvio.rinaudo@polito.it
* Correspondence: filippo.diara@polito.it

Abstract: In recent years, Historic Building Information Modelling (HBIM) methodology has strengthened the documentation and interpretation of archaeological contexts and is regarded as a breakthrough in relation to established methodologies and analyses. Change is also taking place regarding web and cloud-based solutions, and this work acknowledges the importance of cloud-based and web HBIM solutions applied to Cultural Heritage assets and archaeology. More than ever, online platforms are becoming useful services to ease data exchange and validation between collaborators and stakeholders, establishing multidisciplinary approaches. Despite the presence of different cloud-based platforms, Heritage asset documentation can hardly be managed by environments or software developed for architecture and construction design. For this reason, this project is strongly founded on four pillars: online documentation, collaboration, communication and accessibility. Cognisant of these needs, the paper is aimed at the development of a custom HBIM cloud platform for archaeology, on the basis of the BIMData open-source online environment. This platform, called ARK-BIM, can be considered a modular solution leaning on HTML, JavaScript, VueJS, XEOKIT and open-source languages.

Keywords: HBIM; cloud-based BIM; archaeology; accessibility; data exchange; web-development

check for updates

Citation: Diara, F.; Rinaudo, F. ARK-BIM: Open-Source Cloud-Based HBIM Platform for Archaeology. *Appl. Sci.* **2021**, *11*, 8770. https://doi.org/10.3390/app11188770

Academic Editors: Valentina Alena Girelli and Mauro Lo Brutto

Received: 23 August 2021
Accepted: 19 September 2021
Published: 21 September 2021

1. Introduction

This work was the result of several reflections on Building Information Modelling (BIM) documentation, accessibility and data-exchange referring to archaeological contexts. How can online documentation and data exchange of archaeological projects—carried out by BIM methodology [1,2]—be implemented? Do collaborators and project members may have a web HBIM environment designed for archaeology in common? Finally, how can Free and Open-Source Software (FOSS) solutions contribute to this development?

This project began by following the experience of a three-year PhD-research programme on custom HBIM for archaeology via open-source tools [3], following the actual needs of accessibility and data-exchange related to the Historic Building Information Modelling (HBIM) projects of Heritage assets. Moreover, this design can be considered the natural continuation of a previous work in progress related to the initial proposal of a custom BIM platform web development [4].

In recent years, informative solutions based on BIM proved to be essential for historical sites and architectures, changing the methodological approach of documentation and analyses steps. Consequently, cloud-BIM platforms have had a great influence on data transparency and accessibility, not only for Industry Foundation Class (IFC) files, and related BuildingSMART standards [5–8], but also for external semantic data linked to the objects. Being widely adopted for architecture and constructions inside BIM applications, the IFC format has become a standard open format regularized by the International Organization for Standardization (ISO); through these standards [5–8], the IFC schema and dictionary have been set, including the types, entities and functions of BIM objects. This semantic information is therefore fundamental for data exchange and interoperability, both for BIM software and cloud-based services. Exactly as happens with client proprietary BIM software, online dedicated solutions are not suitable for the archaeological domain. For example, Autodesk BIM 360 is probably the most popular online platform designed for the Architecture, Engineering and Construction (AEC) industries and is perfectly integrated with Autodesk Revit. This cloud-based solution is a complete, stable and secure suite for data sharing and exchange, especially regarding BIM projects carried out via Autodesk Revit. Its features rely on a safety management of IFC data in a collaborative cloud environment. Nevertheless, its peculiarities have been designed for new constructions and technical installations [9]. Archaeological BIM projects can be managed within already cited commercial solutions; thanks to the IFC format, information can be dynamically linked to parametric objects referred to archaeological peculiarities. However, this data requires complex, stable and tailor-made databases and management instruments, which is difficult to find inside software designed for the needs of modern buildings.

There are other solutions and unconventional ways to adapt BIM methodologies and instruments to archaeological studies [3,10,11]; in this regard, the utilization and adaptation of FOSS solutions to HBIM and building archaeology research has been demonstrated through the utilization of FreeCAD software [12] in order to obtain an operative, informative system based on BIM methodology [11,13]. For this reason, FOSS tools (in particular, web programming languages) can be utilized and dynamically adapted for generating something new and useful for archaeological purposes [14]. Thus, archaeological and Heritage asset documentation requires specific solutions to ensure data protection and exchange, especially because remote collaborations have become a daily occurrence. Dedicated web and cloud-based platforms should therefore ensure the access and management of information related to excavations or surveys. As has been recently proven by a cooperative project, archaeological collaborations have become difficult due to the distance involved; this project, carried out by Polytechnic of Turin and Sapienza University of Rome, focused on an HBIM design for the integration of archaeological data of the *Domus Regia*, an important religious building of the Roman Forum (Rome, Italy) [15]. Working remotely, both academic teams have used two cloud-based BIM solutions (BIMData and the platform here presented) as common environments for mutual revisions and data integration. In this regard, dedicated online platforms and services become essential for the purpose of shortening distances and time.

For this reason, the main goal of this work was the creation of an ad-hoc cloud-based solution for HBIM projects related to archaeology, designing a platform able to collect different types of semantic data, including instruments for their investigation. Hence, this manuscript shows the design and development of a custom cloud-based HBIM platform suitable for archaeological documentation, in order to ease remote data accessibility and collaborations among project members. This project shows novelties concerning archaeological documentation and collaborations, as well as HBIM data exchange via cloud environments. This proposal, carried out through an ad-hoc web development, attempts to solve remote accessibility and revisions regarding HBIM archaeological projects, creating an online smart environment open to collaborations.

1.1. Cloud-BIM Solutions and BIM Data

BIM projects require multidisciplinary approaches and steady updates through professional collaborations. Cloud environments can ensure the real-time access and control of IFC files; project members and stakeholders can work together on a digital platform which allows the management, inspection and review of the 3D space and semantic data [9]. In fact, web and cloud BIM platforms leaning on a 3D viewer for the IFC model visualization and a database system are mostly composed of IFC information and visualized as a tree of objects depending on architecture classification [4,13]. These platforms are free (or limited) web applications or Software-as-a-Service (SaaS) solutions, especially designed for multiple device access to a common cloud system.

Although the actual panorama of cloud-BIM is strongly affected by the presence of fee-based solutions (e.g., Autodesk Bim 360 and Graphisoft BIMx), the number of free and open-source web applications are growing, also thanks to the increase of WebGL apps and web development [14]. Reliable solutions include BIMServer.center [16] and BIMServer [17]. The first is a free cross-platform for data exchange of IFC models, which is accessible from every device. In addition to the 3D model investigation, it includes a marketplace with stand-alone apps and plugins, allowing several analyses. Lately, the platform allows one to access the BIM project in Virtual Reality (VR) and Augmented Reality (AR) environments, unlocking a new level of accessibility and immersion. The second, BIMServer, is an open-source web platform (via browsers) reachable through a JavaScript server app that allows the management and sharing of BIM projects. It relies on an investigation and revision environment, as well as on a database and query system.

Alongside the presence of these cloud-BIM solutions, another platform represents the perfect match between features, design stability, a user-friendly interface and source code accessibility: BIMData [18].

The BIMData web platform (SaaS licence) is probably the most interesting and flexible cloud solution for managing BIM projects in a smart environment (Figure 1). It includes three suites (free, professional, enterprise) where the differences principally concern cloud storage, the IFC editor, email support and Application Programming Interface (API) access.

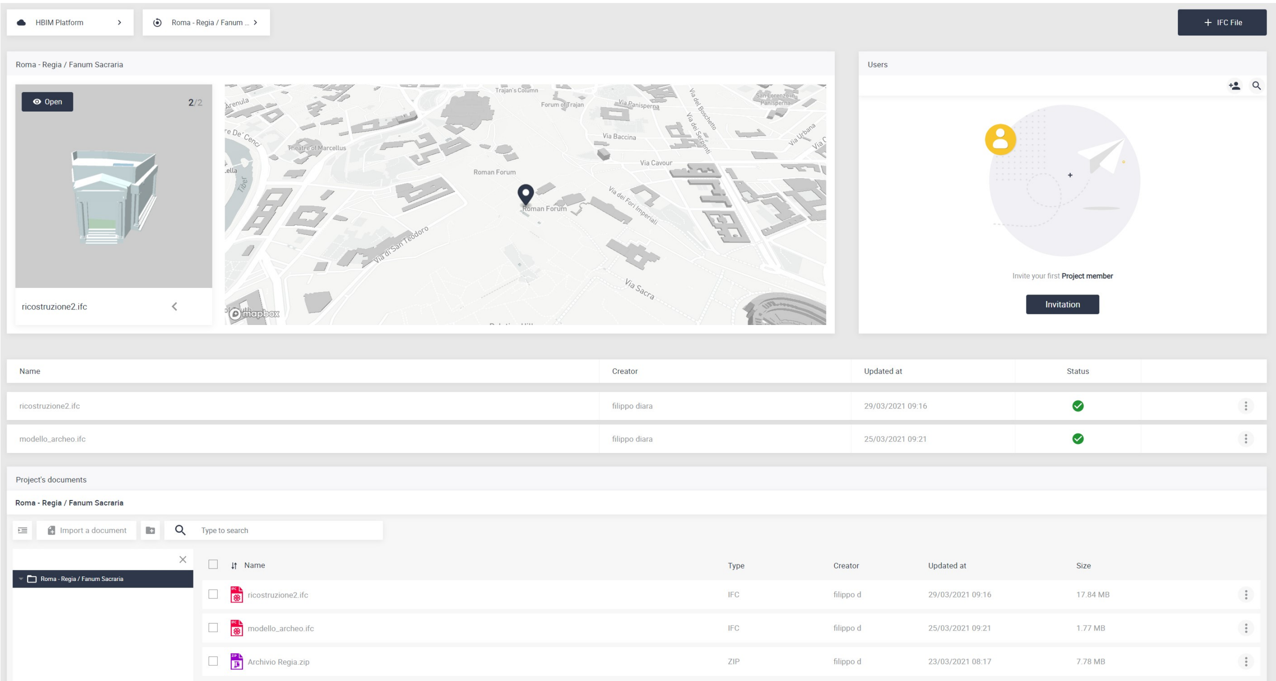


Figure 1. BIMData page account. Sections: IFC model; localization; invitation for users and sources archive.

Inside the platform, IFC files reach complete accessibility, including the related semantic data. The 3D viewer allows investigation of the IFC objects' structures and properties and their edition (Figure 2). This feature is up to stable version 0.8.26; recent versions of free plan no longer have this function.

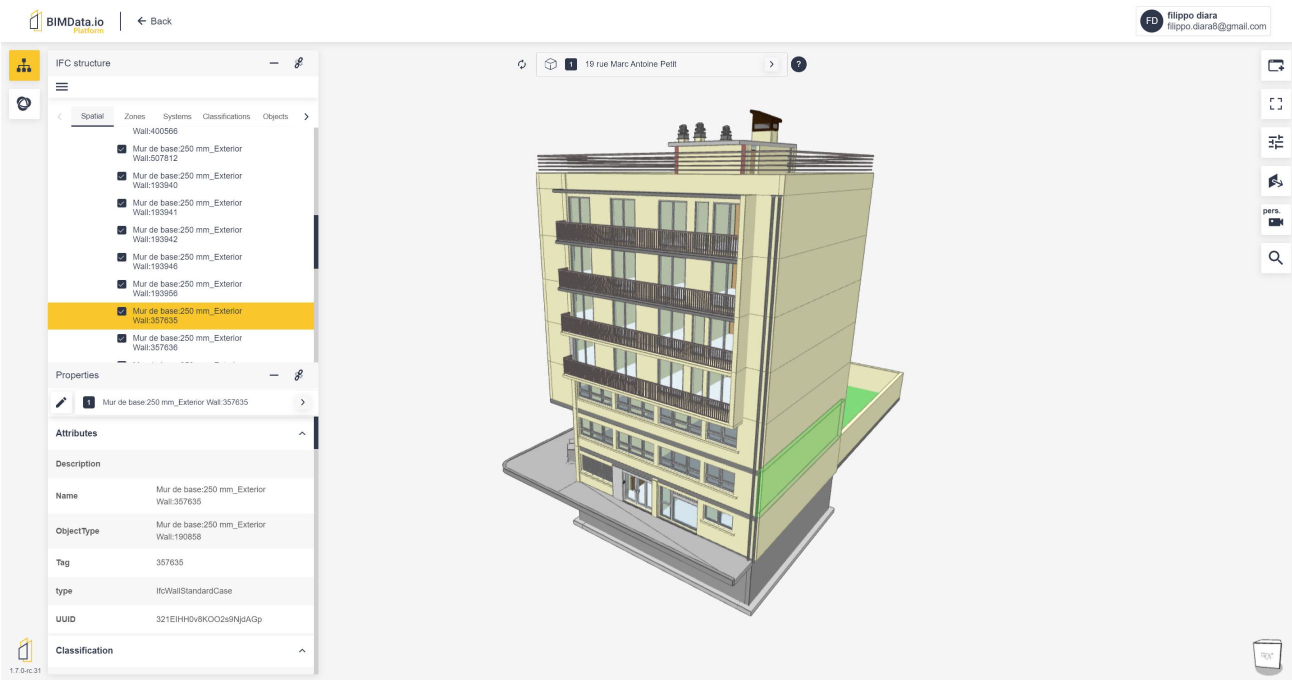


Figure 2. BIMData default platform and viewer. Detail of the sample model with object tree and related properties. Default plugins and functionalities are on either side.

One of the most important features of BIMData is the BIM Collaboration Format (BCF) option, which allows for the reporting of issues and the reviewing of data and file conformities. The access system was conceived to guarantee multiple invitations and permissions (guest, user, admin). The upload and cloud system of BIMData can host any file type associated with IFC digital models: e.g., images, PDFs and datasheets can be managed, consulted and updated inside the web environment.

Behind the attention to detail and the clear and user-friendly interface, there is a precise developing work carried out via open-source programming languages; in fact, BIMData is principally based on VueJS (design system), JavaScript and XEOKIT, which is an open-source programming 3D toolkit (WebGL SDK) developed by XEOLABS [19,20] and designed for BIM and AEC. The BIMData team of developers are committed to sharing source codes, giving users complete access to the main viewer, the interface and the plugins design. In fact, the official website (bimdata.io, accessed on 23 August 2021) includes an important section referring to source code documentation and tutorials; through this section, all developers can access and modify/adapt BIMData codes and structure depending on specific needs.

1.2. The ARK-BIM Idea

BIMData and actual WebGL possibilities have unlocked custom web development scenarios. The documentation and tutorial sections of BIMData provide developers with a comprehensive overview of the platform framework: main viewer, the viewer interface and plugin examples, which are free and open to be utilised.

Cognisant of these opportunities, this project focuses on developing a dynamic cloud-HBIM platform for archaeology based on the BIMData viewer and plugin system (Figure 3). This idea started because of the request for the online BIM documentation and data-exchange of archaeological data.

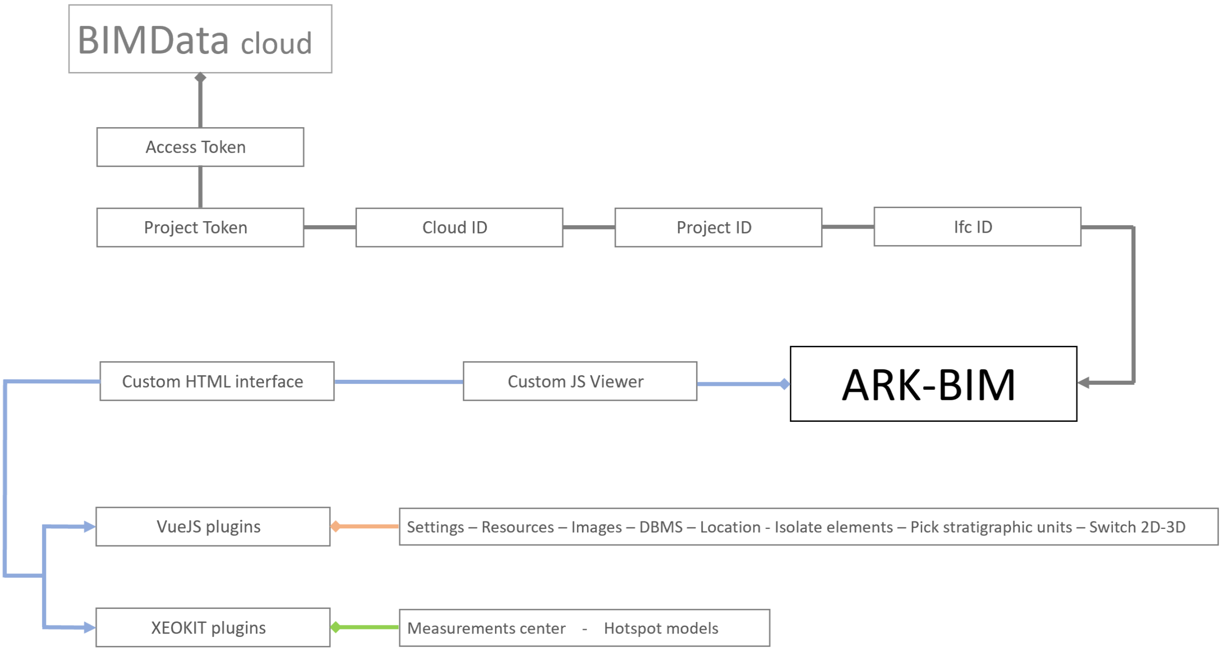


Figure 3. ARK-BIM main framework idea: from the BIMData cloud to the custom platform through security tokens, including ad-hoc plugin developments in a custom viewer.

In fact, as mentioned before, current cloud-BIM solutions have been designed for the AEC industry, and their use for Heritage assets would imply a strong methodological adaptation. Documenting archaeological data involves collecting alphanumerical and graphical data of stratigraphic layers and evidence. This data is mostly related to photographic, graphical (drawings) and textual (paper-based datasheets) descriptions of stratigraphic units. This data is often extrapolated from 3D models or 2D CAD documentation. Smart and cloud platforms for data exchange are therefore important for archaeology.

For this reason, an ideal cloud-BIM solution for archaeology should be able to collect and manage archaeological stratigraphy, stratigraphic analysis, chronological interpretation, 2D graphic drawings, photographic details and iconographic and bibliographic references. The analysis of this data is fundamental for archaeologists, and HBIM projects cannot be separated from this information [4]. The here-presented platform has been designed for the purpose of including this data. It is based on the BIMData main cloud, modified viewer (engine and interface) and ad-hoc plugins for archaeology and Heritage asset documentation and analysis. The name of this custom platform is ARK-BIM [21]: this ad-hoc solution has been designed as a dynamic and modular platform, on which custom-tailored plugins are the main characters.

2. Materials and Methods

The creation process began with the documentation and tutorial pages of the BIMData website, as well as via discussion and contact with the developers. This information and support were both fundamental for the purpose of making precise choices on what it was possible to achieve.

ARK-BIM is reliant on the BIMData cloud storage; for this reason, having a BIMData account is a mandatory requirement, because this is the basis for the next access token processes for accessing IFC files. Hence, the development process required programming languages such as JavaScript, VueJS, HTML and XEOKIT (Figure 4).

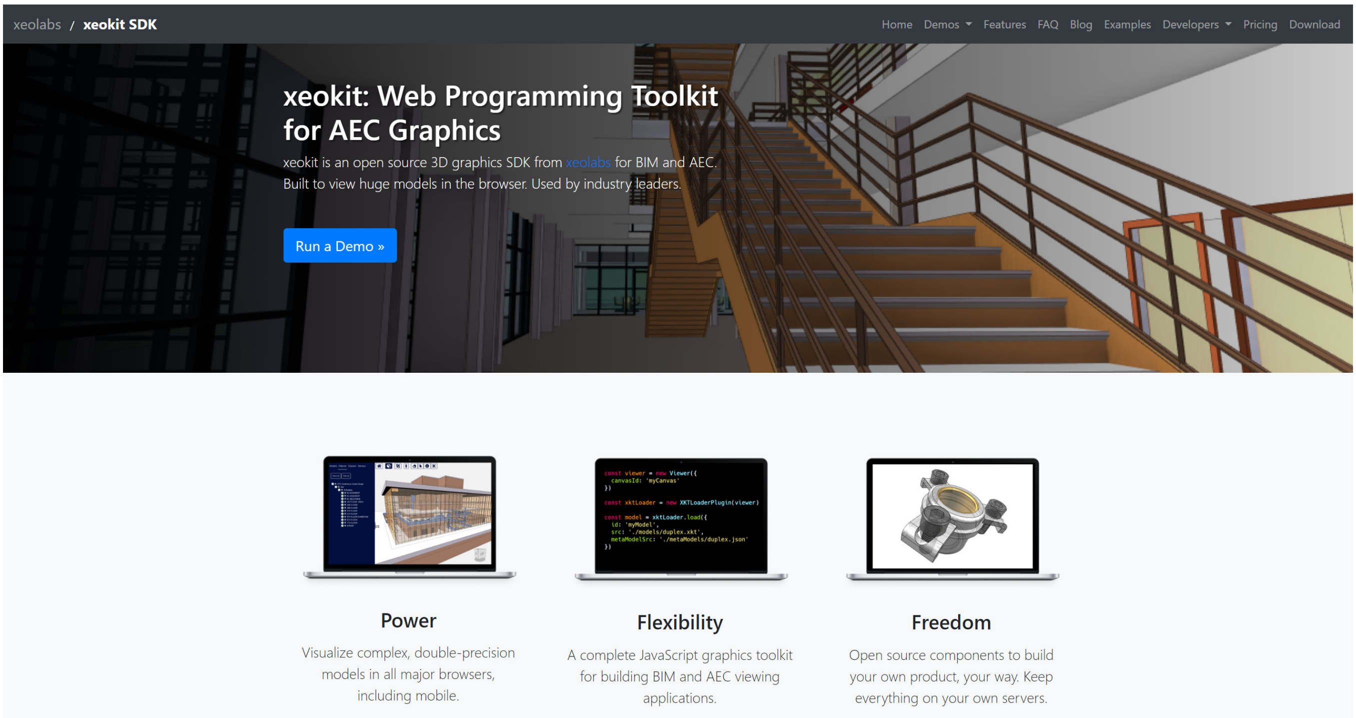


Figure 4. XEOKIT website: homepage with descriptions of functionalities.

The development of ARK-BIM consisted of three main phases: a first phase for the default 3D viewer modification; a second phase for the development of plugins (VueJS) and their inclusion inside the HTML web page; a third phase regarding the external plugins developed by directly using XEOKIT programming tools.

2.1. Early Steps: BIMData Account and Tokens

Before starting the pure development phase, modifying the main viewer and creating ad-hoc plugins, the first step was having an account on the BIMData platform. The account allows one to manage IFC projects in digital-virtual rooms, where models have to be uploaded.

The client ID and the client secret ID of a personal BIMData account are required elements, essential for acquiring the Access and Project Tokens, which allow direct access to IFC models from a project cloud to an external viewers or web-apps.

These processes for obtaining tokens (alphanumerical values) can be performed by command line interface (CLI) or by using Postman [22], which is a collaborative environment for API development. Figure 5 shows an example of an Access Token Call via Postman.

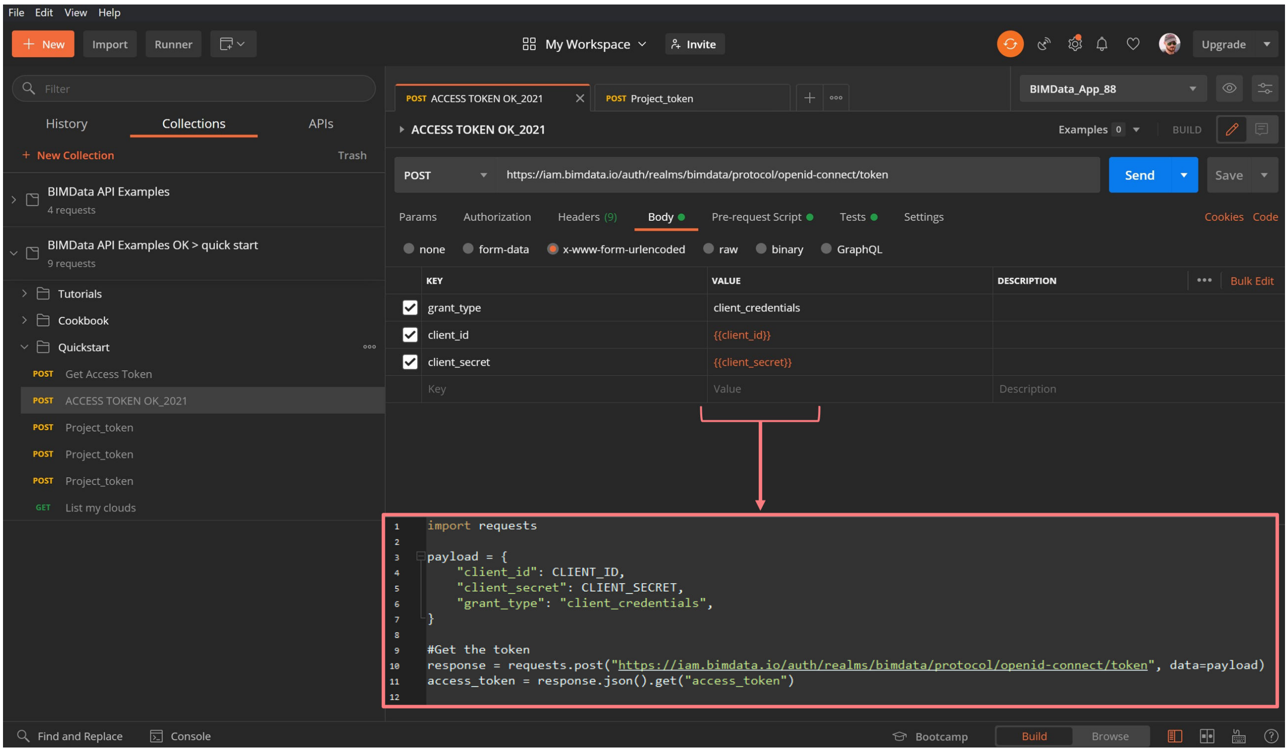


Figure 5. Access Token evocation via Postman (by form encoded and raw Python coding).

2.2. 3D Viewer Modification

The viewer modification regarded both the main viewer engine and the viewer HTML interface. The main viewer of BIMData (*viewer.js*) is located on Unpkg [23], which is a global content delivery network; it is stored depending on the developed versions via JavaScript and XEOKIT. As regards the main viewer, the stable version 0.8.26 was taken as the basis of ARK-BIM creation; although it is not the most up-to-date release, it allows—in addition to the ability to split/merge/export IFCs—the editing of IFC properties in real-time (feature removed after redesigning plans and viewers).

The main viewer, which can be downloaded and saved locally or in a web server, has been subjected to modifications, adjustments and implementations. These are the main changes:

- Unlocked 2D-3D switch view (hidden feature in the code);
- Fixed the possibility of deleting annotations (did not work on default viewer);
- Fixed sporadic error messages;
- Fixed the overlapping of colours in the menu for selected elements;
- Fixed general languages errors;
- Graphical adjustments, fixes and changes.

The default viewer of BIMData (0.8.26 version) includes these features and plugins: tree and properties of IFC files; BCF collaborative environment; fullscreen mode; planar sections option (this allows one to make planar sections on the X-Y-Z planes of the model); selection by objects or types; projection view (orthographic and perspective). These important features have been preserved inside the ARK-BIM viewer, as well as the real-time properties editing. In addition, the default viewer includes important features for model splitting (by objects) and exporting, peculiarities maintained in the custom viewer. In particular, by utilizing the same cloud system, ARK-BIM is linked to BIMData by the IFC model and the BCF option, which guarantees a complementary interoperability. This last feature is a key point for data exchange among cloud BIM solutions [3,24]. Furthermore, revision occurred inside ARK-BIM via BCF option communicate in real time with the

BIMData main account, with which the manager receives and makes changes to the model and automatically gives a revised feedback on ARK-BIM (Figure 6).

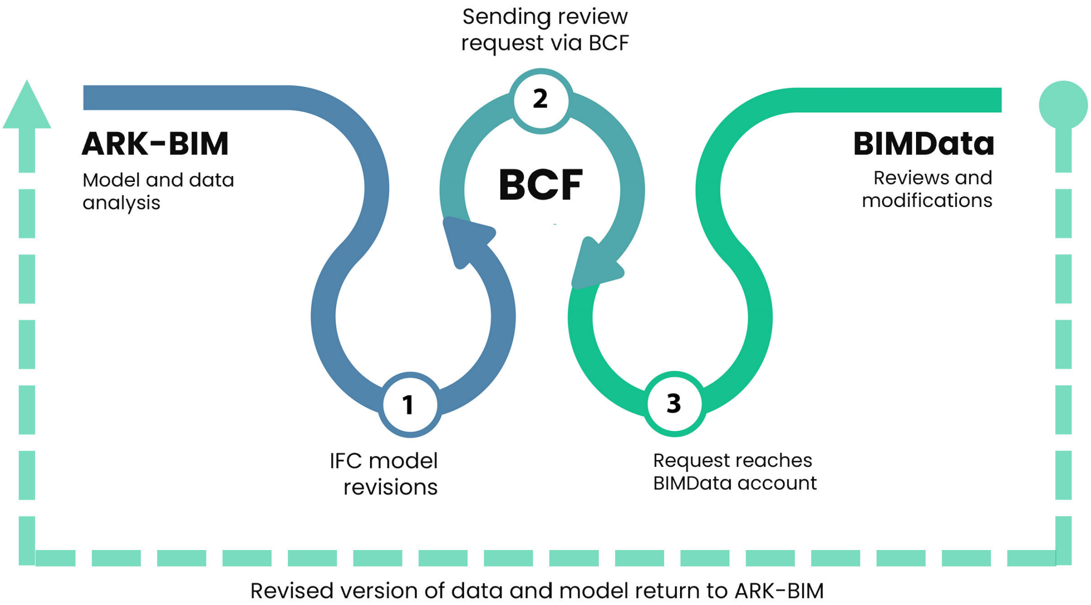


Figure 6. BIM Collaboration Format option behaviour with ARK-BIM and BIMData.

The viewer interface environment is a simple HTML file (web-app). The interface code can be easily accessed and modified via a source code editor (e.g., Notepad++). Graphical adjustment and minor changes also occurred for the interface. For the correct usage, the code includes three important pieces of information: the main viewer link (local or web-server); the Project Token; IDs referring to the cloud-project–IFC in order to extract the IFC model (Figure 7).

```
1  <!DOCTYPE html>
2  <html lang="en" dir="ltr">
3  <head>
4  <meta charset="utf-8">
5  <title>ARK-BIM</title>
6  <script src="C:\Users\Filippo\Desktop\MOD viewer\8X.js" charset="utf-8"></script>
7  </head>
8  <body>
9  <div style="height: 100vh; width:70wh">
10 <div id="app"></div>
11 </div>
12 <script>
13             const cfg = {
14               cloudId: 5333,
15               projectId: 241791,
16               ifcIds: [17886],
17               backgroundColor: 'rgb(220,220,220)',
18               bimdataPlugins: {
19                bcf: true,
20                merge: true,
21                allowExport: true,
22               }
23             };
24             const accessToken = "lxINkEFTNta1FGU1Wnr6hv5w7w2EBa7cPClx9S";
25             const { viewer, store, eventHub, setAccessToken } = initBIMDataViewer(
26                 "app",
27                 accessToken,
28                 cfg
29             );
30 </script>
31 </body>
32 </html>
```

Figure 7. HTML viewer code (interface without plugins): main viewer link on line 6; IFC model coordinates on lines 14–16; identification token on line 2.

2.3. Custom-Tailored Plugins Development

The viewer is customizable through ad-hoc plugins developed via VueJS and Javascript. After the initial modifications and adjustments, the next phase concerns the creation of custom-tailored plugins for the purpose of enriching the viewer through additional features designed for archaeological and Heritage assets data. The default functionalities of BIMData are valuable and essential, but historical context also requires other types of tools in order to offer a holistic approach to Heritage assets information. For this reason, specific plugins have been developed especially related to historical architectural elements and stratigraphic analysis and photographic and archive resources. Plugins were tested on a sample case study; a classical ruined temple, on the basis of another HBIM project related to the *Domus Regia*, was parametrically modelled as an example of an archaeological context.

Briefly, these are the unlocked and created VueJS and Javascript plugins (Figure 8):

- *2D-3D switch* view (Unlocked; hidden feature in the original code);
- *Settings* plugin, with submenu (Info, help, download, fix resolution, no edge mode, dark mode);
- *Resources* plugin, with textual description and bibliographic references;
- *Images* plugin, in order to store context images;
- *Database* plugin, for collecting investigating datasheets;
- *Geographic position* plugin, in order to have a geographic reference;
- *Isolate Elements* plugin, for isolating elements depending on IFC classification;
- *Pick Stratigraphic Units* plugin, in order to pick US typology and numeration on the 3D model as annotations;
- *Legend*, for *picked* stratigraphic units, referring to previous plugins in order to have reference feedback for screenshots.

The *Settings* plugin was built to include different useful options: information concerning ARK-BIM; help option for helping users to navigate the model; fix resolution for optimizing screen DPI and zoom; download option for downloading the model; no edges options for disabling edge emphasis; dark mode option for resting eyesight.

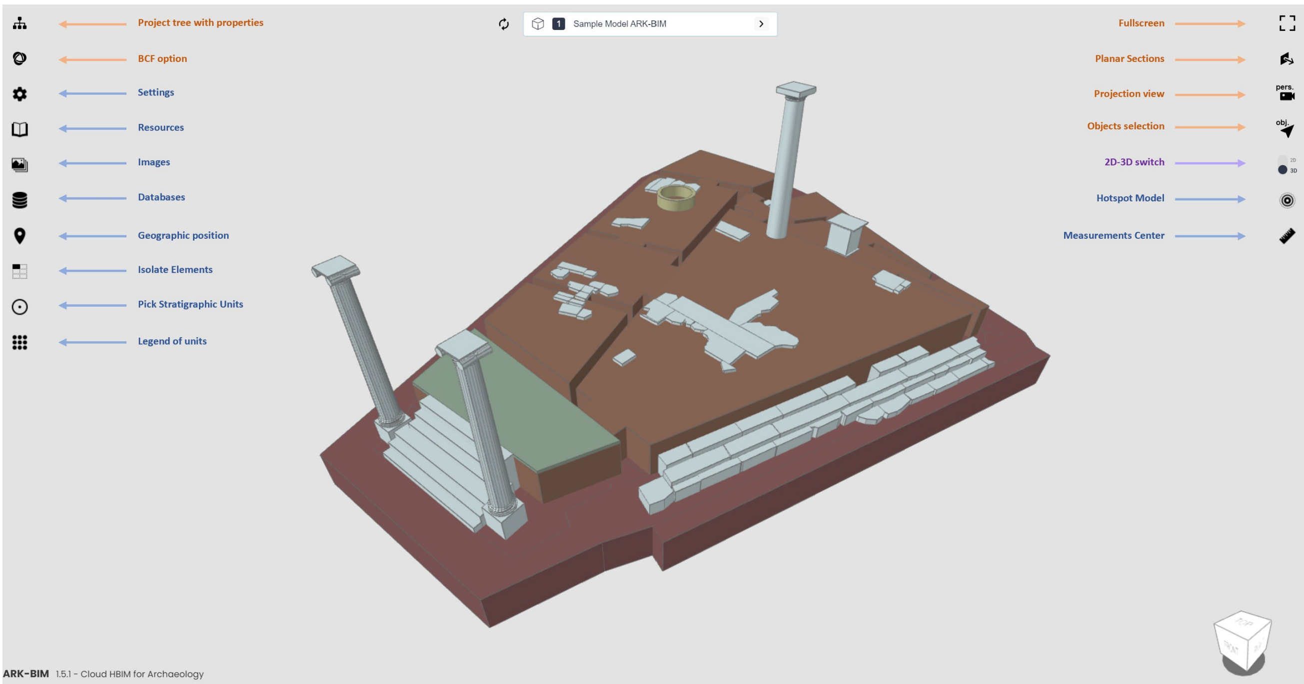


Figure 8. ARK-BIM (version 1.5.1) interface: BIMData default plugins (in orange); unlocked plugins (in purple); new plugins (in blue).

The *Resources* plugin was designed for collecting and investigating textual information concerning the context; in fact, the actual version of ARK-BIM (1.5.1) already contains resources such as description and bibliographic references. This data is displayed through modals, which are dialog box or popup windows. Project collaborators can make analyses and revisions of the content. Thanks to the possibility of managing user privileges, textual resource can also be filtered for different audiences.

The *Images* plugin was designed for implementing the BIM model with deep photographic references, because IFC files do not yet support textures. This possibility is crucial for archaeological contexts, especially for including iconographic pictures as well as photos concerning excavation data (stratigraphic layers, remains, small finds). Images can then be dynamically associated to parametric objects.

The *Database* plugin was built to have deeper information from the BIM model. In fact, IFC properties and additional databases exported from software can be included inside the ARK-BIM database plugin for consulting, filtering and querying information. This is fundamental for the purpose of including the entire stratigraphic database of an archaeological site for comparing 2D data with 3D parametric objects.

The *Geographic position* plugin was included in order to have a quick overview of the context localization. For this reason, a geographic reference from Google Maps was inserted in a box window. Future developments of this plugins, and also ARK-BIM, could concern integration with advanced geographic systems such as web-GIS.

Apart from plugins displaying settings, resources and data, plugins such as 2D-3D switch, *Isolate Elements* and *Pick Stratigraphic Units* are those (built with VueJS and JavaScript) with which more graphic interaction occurs. The first one, built by BIMData and unlocked inside the 0.8.26 viewer code, is fundamental for archaeological purposes, because it allows the model to be shown in a 2D environment (ground plan) coupled with the project tree with objects (Figure 9). Archaeological and reconstructive plans can then be compared with the help of the project tree.

Figure 9. ARK-BIM (version 1.5.1): unlocked *2D-3D switch* plugin for visualizing ground plans of IFC models and related elements.

Furthermore, the *Isolate Elements* plugin is a mandatory plugin for BIM and HBIM projects. It allows the isolation of 3D objects depending on IFC classification; for example, by selecting "wall" entities, the plugin will maintain visually active walls and will hide other elements (wired view). Hence, the 3D scene can be reset to start another graphical query (Figures 10 and 11). This plugin, included as shown by BIMData developers, is the starting point for future development. The actual version of ARK-BIM includes the possibility of isolating elements by IFC classifications. Based on this, the updated version is currently under development tests for the purpose of isolating parametric objects depending on material, descriptions, tags and specific archaeological properties.

```
<!-- ISOLATE ELEMENTS-->

        viewer.registerPlugins([{
          name: "Isolate Elements",
          component: {
            template: `
              <div style="width:250px" class="btn-group">
                <h4 style="text-align: left; font-family: poppins; margin-top: 1px">Isolate Elements</h4>
                <button @click="onIsolateWallsClick">Walls</button>
                <button @click="onIsolateColumnsClick">Columns</button>
                <button @click="onIsolateFootingsClick">Footings</button>
                <button @click="onIsolateWindowsClick">Windows</button>
                <button @click="onIsolateBeamsClick">Beams</button>
                <button @click="onIsolateSlabClick">Slabs</button>
                <button @click="onIsolateStairsClick">Stairs</button>
                <button @click="onIsolateDoorsClick">Doors</button>
                <button @click="onIsolateFurnituresClick">Furnitures</button>
                <button @click="onIsolateElementClick">Building Element</button>
                <button @click="onIsolateRoofClick">Roof</button>
                <button @click="onUnisolateClick" style="background-color: #c7c7c7">Reset scene</button>
              </div>`,
            methods: {
              onIsolateWallsClick() {
                this.$hub.emit("isolate-objects", {
                  ids: this.$utils.getAllObjectsOfType("wall")
                  .map(object => object.uuid)
                });
              },
              onIsolateColumnsClick() {
                this.$hub.emit("isolate-objects", {
                  ids: this.$utils.getAllObjectsOfType("column")
                  .map(object => object.uuid)
                });
              },
                onIsolateFootingsClick() {
                this.$hub.emit("isolate-objects", {
                  ids: this.$utils.getAllObjectsOfType("footing")
                  .map(object => object.uuid)
                });
              },
                onIsolateBeamsClick() {
                this.$hub.emit("isolate-objects", {
                  ids: this.$utils.getAllObjectsOfType("beam")
                  .map(object => object.uuid)
```

Figure 10. Part of source code related to the *Isolate Elements* plugin (the complete code is on the ARK-BIM website).

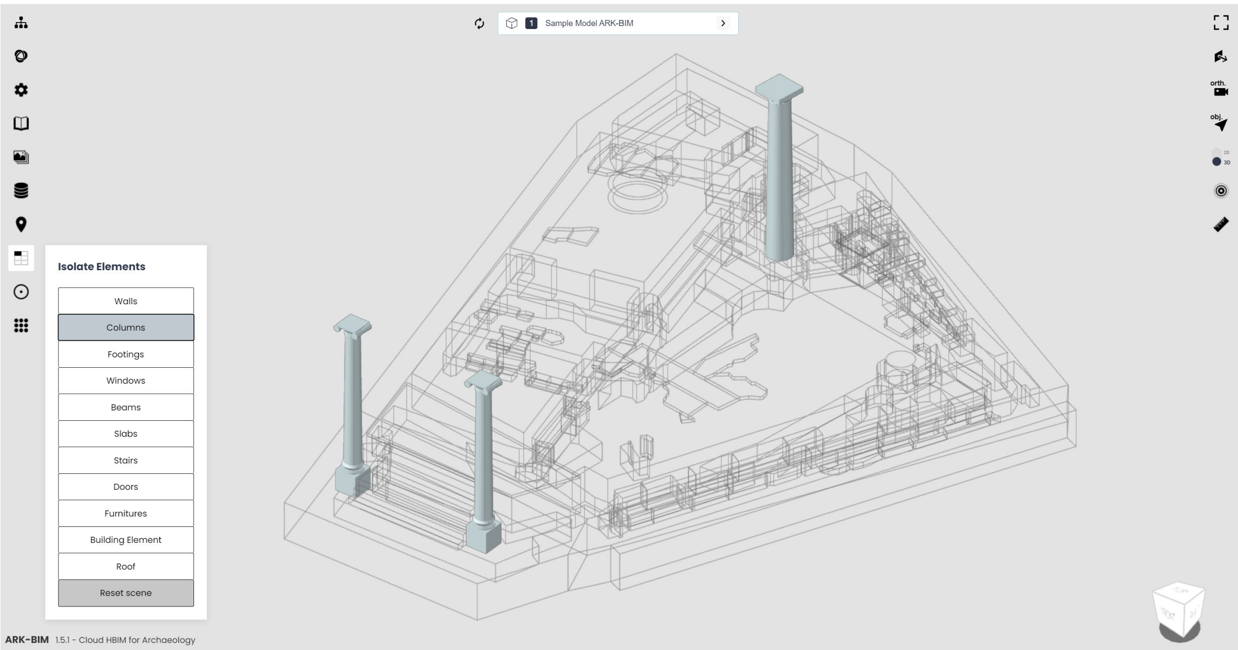
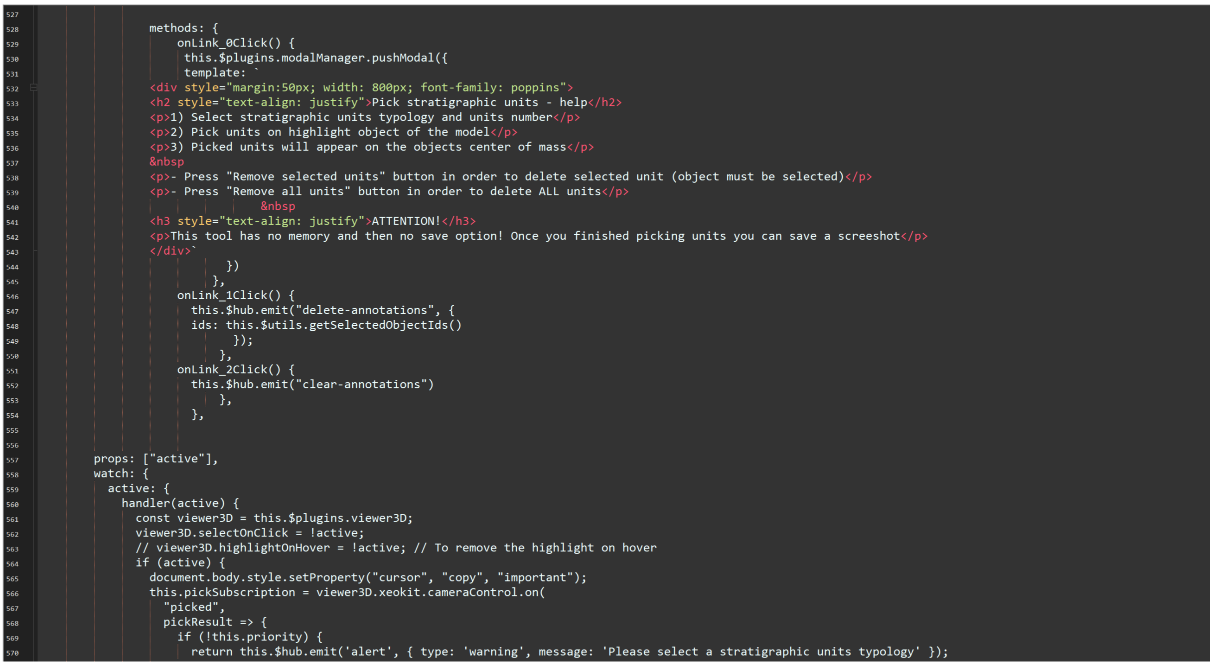


Figure 11. ARK-BIM (version 1.5.1): *Isolate Elements* plugin. Sample archaeological model with isolated columns and other elements in X-ray mode.

The *Pick Stratigraphic Units* plugin (Figures 12 and 13) has been designed for annotating stratigraphic units directly on the 3D model. This functionality plays a key role in archaeological stratigraphy documentation and analysis. Briefly, stratigraphy is the method for understanding archaeological stratification, though it could also be utilized regarding other situations, such as historical architecture. In fact, this court of analyses generated a particular discipline called Building Archaeology [25–27] because this methodology can be applied to historical architecture where the stratification is evident (mostly medieval architecture).



```
        methods: {
          onLink_0Click() {
            this.$plugins.modalManager.pushModal({
            template: `
        <div style="margin:50px; width: 800px; font-family: poppins">
        <h2 style="text-align: justify">Pick stratigraphic units - help</h2>
        <p>1) Select stratigraphic units typology and units number</p>
        <p>2) Pick units on highlight object of the model</p>
        <p>3) Picked units will appear on the objects center of mass</p>
         
        <p>- Press "Remove selected units" button in order to delete selected unit (object must be selected)</p>
        <p>- Press "Remove all units" button in order to delete ALL units</p>
                 
        <h3 style="text-align: justify">ATTENTION!</h3>
        <p>This tool has no memory and then no save option! Once you finished picking units you can save a screeshot</p>
        </div>`
              })
            },
          onLink_1Click() {
            this.$hub.emit("delete-annotations", {
            ids: this.$utils.getSelectedObjectIds()
              });
            },
          onLink_2Click() {
            this.$hub.emit("clear-annotations")
            },
          },


    props: ["active"],
    watch: {
      active: {
        handler(active) {
          const viewer3D = this.$plugins.viewer3D;
          viewer3D.selectOnClick = !active;
          // viewer3D.highlightOnHover = !active; // To remove the highlight on hover
          if (active) {
            document.body.style.setProperty("cursor", "copy", "important");
            this.pickSubscription = viewer3D.xeokit.cameraControl.on(
              "picked",
              pickResult => {
                if (!this.priority) {
                  return this.$hub.emit('alert', { type: 'warning', message: 'Please select a stratigraphic units typology' });
```

Figure 12. Part of source code related to the *Pick Stratigraphic Units* plugin (the complete code is on the ARK-BIM website).

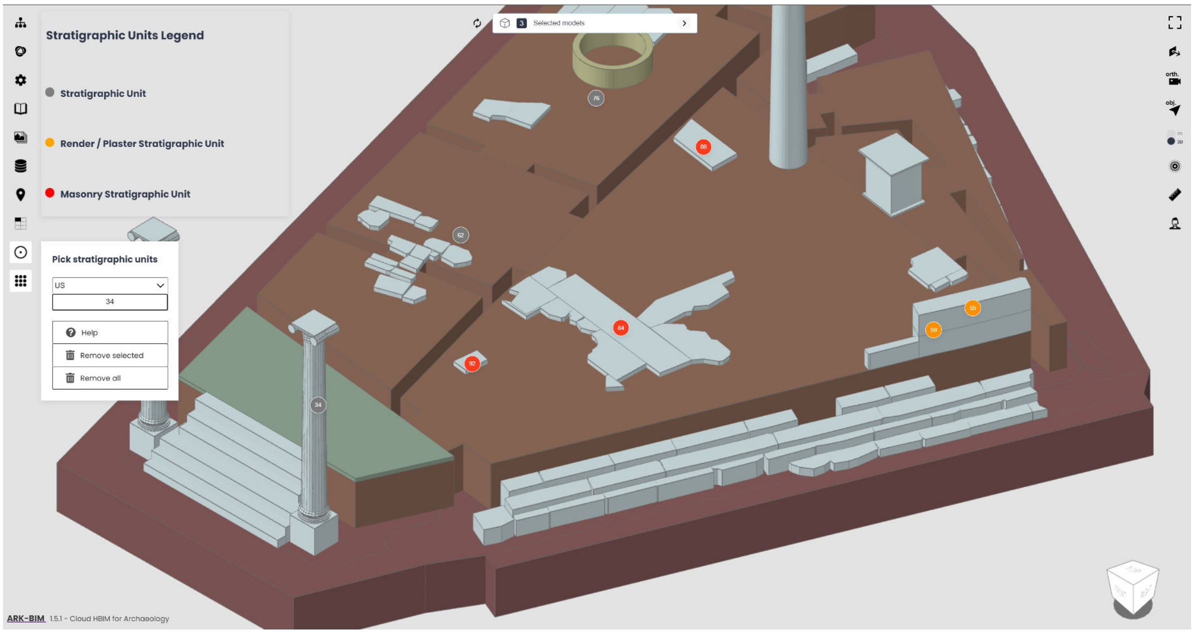


Figure 13. ARK-BIM (version 1.5.1): *Pick Stratigraphic Units* plugin. Sample archaeological stratigraphy picked directly from the sample model. Three classes of units available (US, USM, USR).

Inside ARK-BIM, once units have been picked, the viewer displays alphanumerical annotations within a coloured circle, which will be placed at the object's centre of mass (Figure 13).

Possible notes have been classified in three ways, related to archaeological unit classification [25–27]: simple stratigraphic unit (US-colour grey), refers to ground layers; render stratigraphic units (USR-colour yellow), for render and plaster layers of masonry remains and heritage buildings; masonry stratigraphic units (USM-colour red), for walls and masonry units referring to building archaeology.

In fact, the plugin window was conceived for designating a desired unit identification (e.g., US30; USM54) and then the unit classification using the drop-down menu. Moreover, a conceptual legend can be displayed on the top-left of the environment in order to provide information feedback. This plugin could become fundamental for revisions based on archaeological stratigraphy.

In addition to specific plugin design, the new platform environment was enriched by *informative modal popups* (e.g., for brief text description): *right click* on the 3D space with filtering plugin for IFC types; *edit mode* has been confirmed inside the property tree of objects (no longer available on updated version of the viewer related to free plan).

Plugins can be implemented by embedding custom-tailored source codes into the interface of the viewer (HTML). Their functionalities and languages (VueJS and JavaScript) have to respect the functions, constants and variables of the main viewer. For this reason, custom plugins must respect particular syntax on events references, emitters and listeners and getters (e.g., as regards isolating elements: "get object by type", and so on).

The plugin design was continued by utilizing other open-source programming tools. The early BIMData viewer code was developed using sources shared by XEOLABS [19]: the XEOKIT programming open-source toolkit [18]. XEOKIT is a 3D Web SDK designed for BIM and AEC. This toolkit allows the management of 3D models and interactive actions in a web environment. Despite the fact that XEOKIT supports different file formats, e.g., GLTF, STL, OBJ, and the IFC BIM format with the entire structure is supported, they need to be converted into XKT, the XEOKIT proprietary format.

In this regard, this powerful toolkit has been used for the purpose of including more interactive environments in the ARK-BIM viewer. In fact, two more 3D spaces, useful for archaeology and Heritage assets, have been included as external plugins: the *Hotspot Model* plugin and a *Measurements Centre* plugin.

The *Hotspot Model* plugin (Figures 14–16) was designed using the XEOKIT toolkit in order to enrich the platform with an interactive environment with a hotspot informative model. In this section, the model obtains circular links with information inside; popup labels can display textual data and photographic references, giving a full graphical immersion between 3D models and semantic data. In this regard, archaeological data (textual and graphical) can be shown on related parametric elements. Despite it being included by the XEOLABS developers, it has a fundamental importance inside the global framework of the ARK-BIM platform, and also for further implementation depending on the inclusion of archaeological data. In fact, labels and popup windows can be modified regarding placement, styles and focus on opening (e.g., fly on object). An orthographic projection switch has also been included (perspective and ortho view).

```
window.onclick = function(event) {
  if (event.target == modal) {
    modal.style.display = "none";
  }
};
        const annotations = new AnnotationsPlugin(viewer, {

        markerHTML: "<div class='annotation-marker' style='background-color: {{markerBGColor}};'>{{glyph}}</div>",
        labelHTML: "<div class='annotation-label' style='background-color: {{labelBGColor}};'>\
            <div class='annotation-title'>{{title}}</div>\
            <div class='annotation-desc'>{{description}}</div>\
            </div>",

        values: {
            markerBGColor: "red",
            labelBGColor: "white",
            glyph: "X",
            title: "Untitled",
            description: "No description"
        }

        });

        var prevAnnotationClicked = null;

        annotations.on("markerClicked", (annotation) => {
        annotation.setLabelShown(!annotation.getLabelShown());
        });


        annotations.createAnnotation({

            id: "myAnnotation1",

            worldPos: [7.239, 0.29, -2.47905],

            occludable: true,
            markerShown: true,
            labelShown: false,

            values: {
                glyph: "1",
                title: "Fanum / Sacraria Martis et Opis",
                description: "La Regia serviva per la celebrazione di riti. Come le fonti scritte riportano, si trovavano nell'edificio, due più piccoli santuari (lat. sacrarium) per
                markerBGColor: "white"
```

Figure 14. Part of source code related to the *Hotspot Model* plugin (the complete code is on the ARK-BIM website).

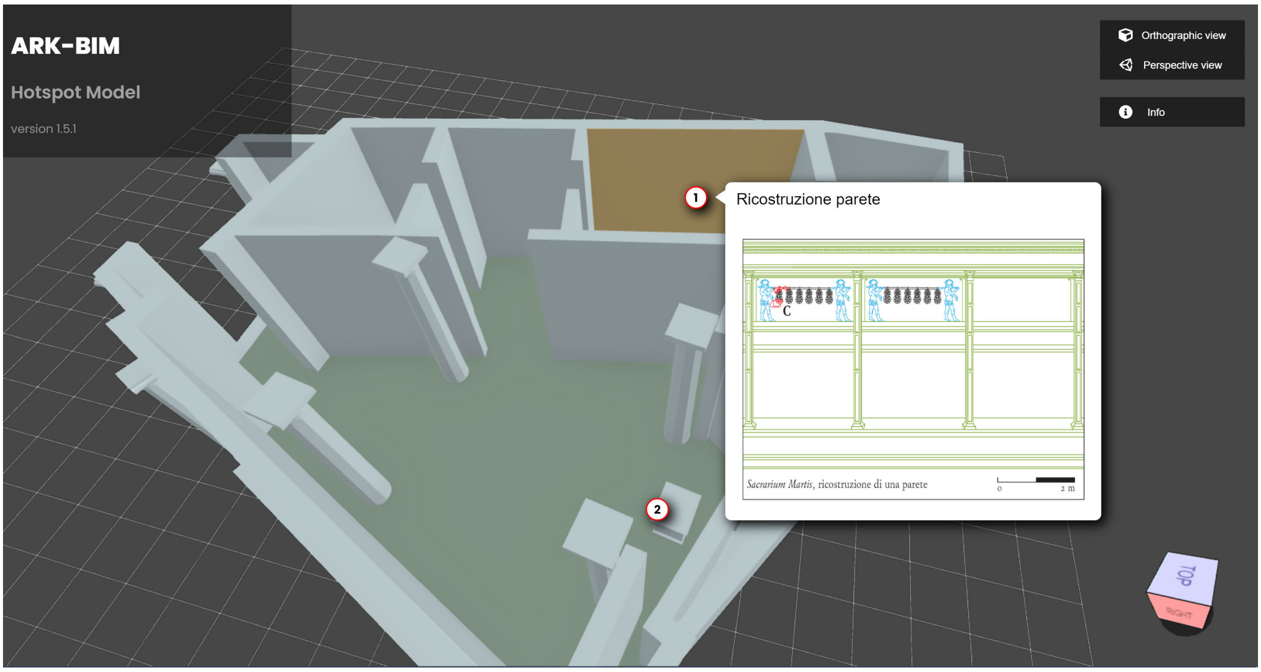


Figure 15. ARK-BIM (version 1.5.1): *Hotspot Model* plugin, sample with an image reference.

As mentioned before, the XEOKIT toolkit was also utilized for developing the *Measurements Centre* plugin. This was designed for picking distances and angles directly on the model (Figures 17–19). A button enables unlocking the measurement process via left clicking on desired distances on the model; the plugin will display a projection of X, Y, Z distances, the default view is in meters and units of measurement can be easily scaled. Hence, the measurement centre has also been implemented with another important tool for picking precise measurements of angles on the model. This plugin has been included, as shown by XEOLABS developers. However, distances and angles have been enabled via dedicated buttons, thus avoiding refreshing the page each time. Thanks to the inclusion of JavaScript Controller Library, distances can then be picked by using different units and scales. This library implementation is now the basis for further development for enriching the *Measurements Centre* plugin. Finally, the orthographic projection switch was included (perspective and ortho view).

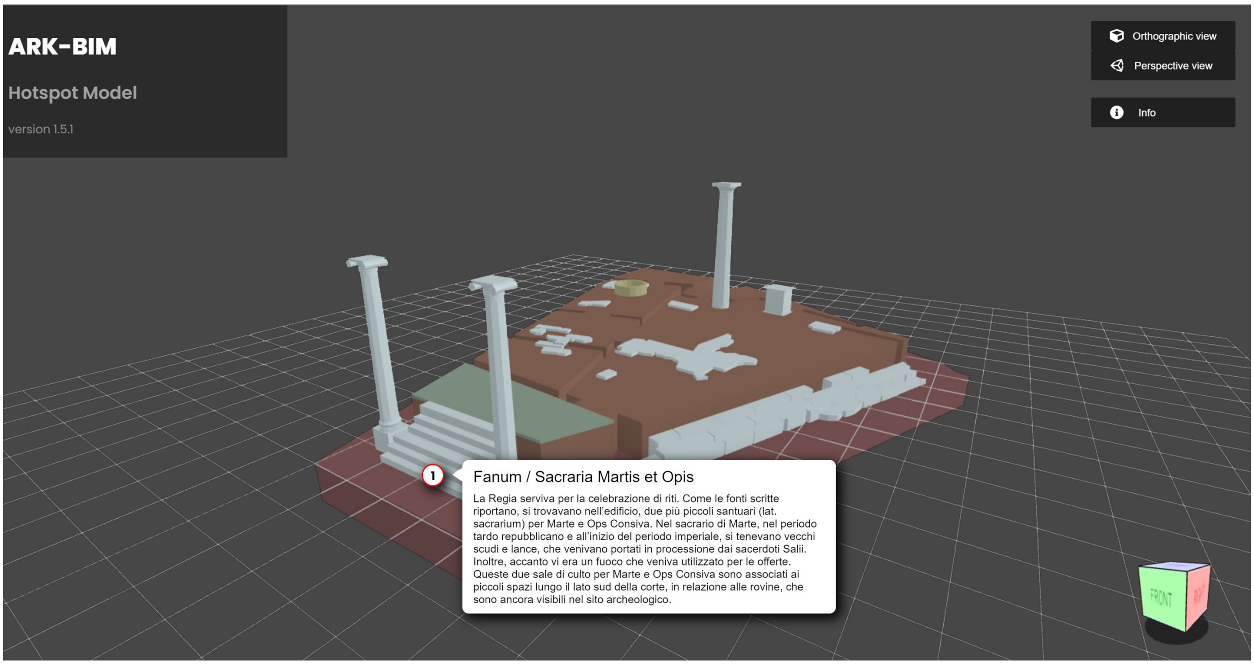


Figure 16. ARK-BIM (version 1.5.1): *Hotspot Model* plugin, sample with textual information.

```
model.on("loaded", function() {
    viewer.cameraFlight.flyTo(model);
});

window.viewer = viewer;
viewer.cameraControl.followPointer = true;

var metrics = new function () {
    this.scale = 1.0;
    this.units = "meters";
}();

var update = function () {
    viewer.scene.metrics.scale = metrics.scale;
    viewer.scene.metrics.units = metrics.units;
    requestAnimationFrame(update);
};

update();


var gui = new dat.GUI({ autoPlace: false });

gui.add(metrics, 'scale', 0.1, 10.0);
gui.add(metrics, 'units', ["meters", "centimeters", "millimeters", "yards", "feet", "inches"]);


var customContainer = document.getElementById('my-gui-container');
customContainer.appendChild(gui.domElement);

    new Mesh(viewer.scene, {
    geometry: new VBOGeometry(viewer.scene, buildGridGeometry({
        size: 55,
        divisions: 25
    })),
    material: new PhongMaterial(viewer.scene, {
        color: [0.0, 0.0, 0.0],
        emissive: [0.3, 0.3, 0.3]
    }),
    position: [10, 0, -15],
    collidable: true
```

Figure 17. Part of source code related to the *Measurements Centre* plugin (the complete code is on the ARK-BIM website).

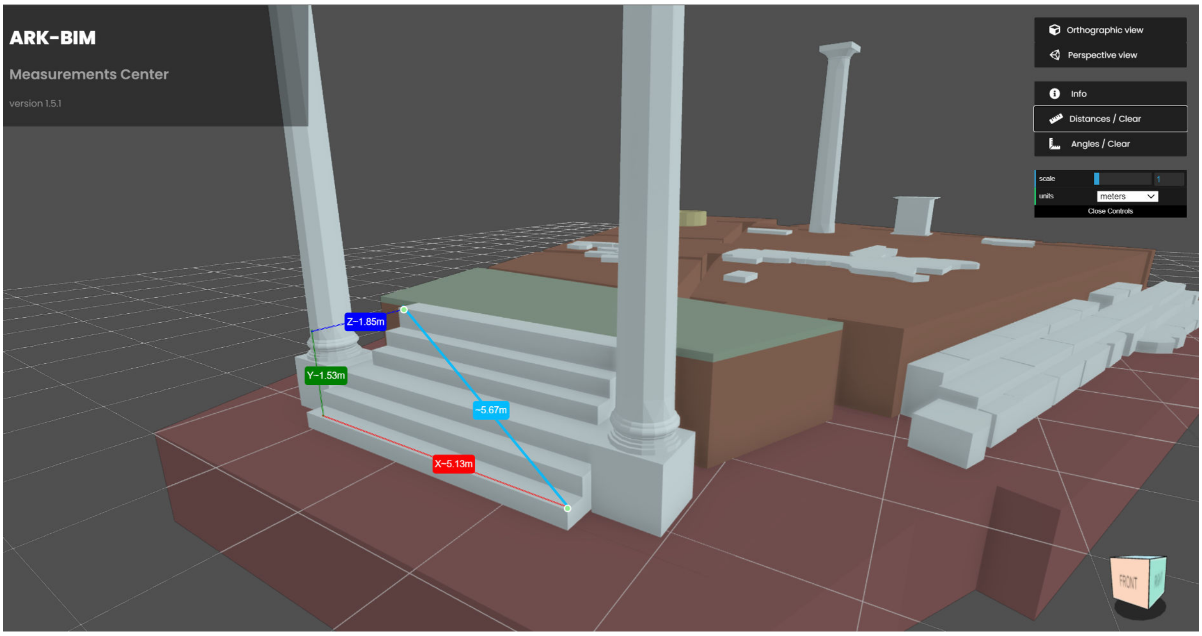


Figure 18. ARK-BIM (version 1.5.1): *Measurement Centre* plugin, X-Y-Z distances on the IFC model.

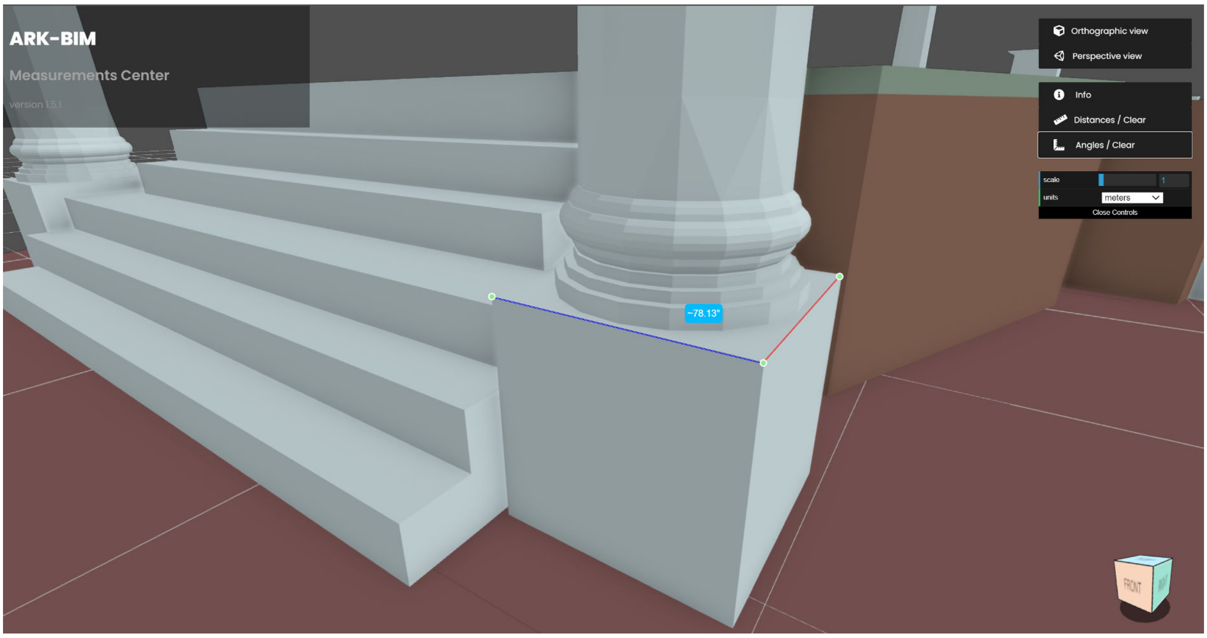


Figure 19. ARK-BIM (version 1.5.1): *Measurement Centre* plugin, sample of angle measurements.

The correct plugin implementation (both VueJS and XEOKIT) ends with the graphical inclusion of buttons on either side of the viewer interface. Plugins can be rendered in three ways: without style; next to the button in a sized window; next to the button in a movable and resizable window.

2.4. Publication of ARK-BIM

After concluding the ARK-BIM development process, the publication of the source code for the platform was necessary. In order to achieve this, a dedicated website was built using Bootstrap, HTML and CSS. A brief description of the ARK-BIM was placed within the website, as well as a brief history of the project and where (and with which tools) the design began. The website is located on the GitHub Pages [28], specifically on: https://ark-bim.github.io (accessed on 20 September 2021) (Figure 20).

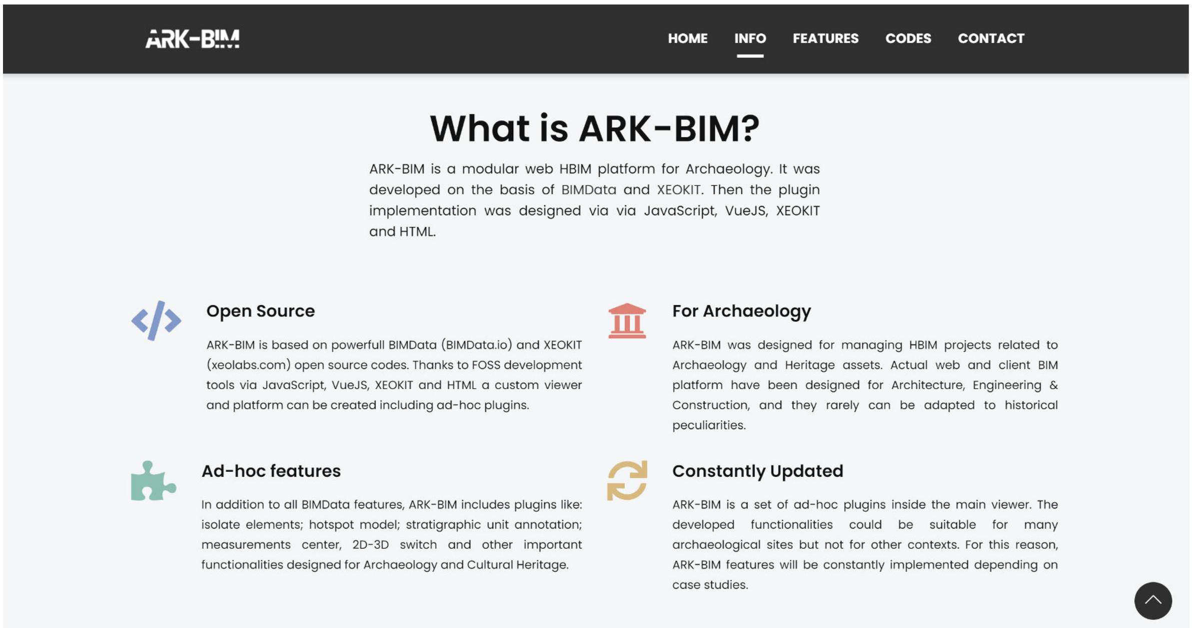


Figure 20. ARK-BIM website. Homepage and platform information with features and main purposes.

ARK-BIM is easily accessible on the website, where information, plugins and source codes are available to be shared and utilized for the purpose of building a personal version of ARK-BIM (Figure 21). Hence, a sample platform (v. 1.5.1) and model (the model presented in this paper) are available here [29]: https://ark-bim.github.io/version1.5.1-sample (accessed on 20 September 2021). In this way, interested members of the community can utilize source codes and provide personal feedback for revisions (Figures 20 and 21).

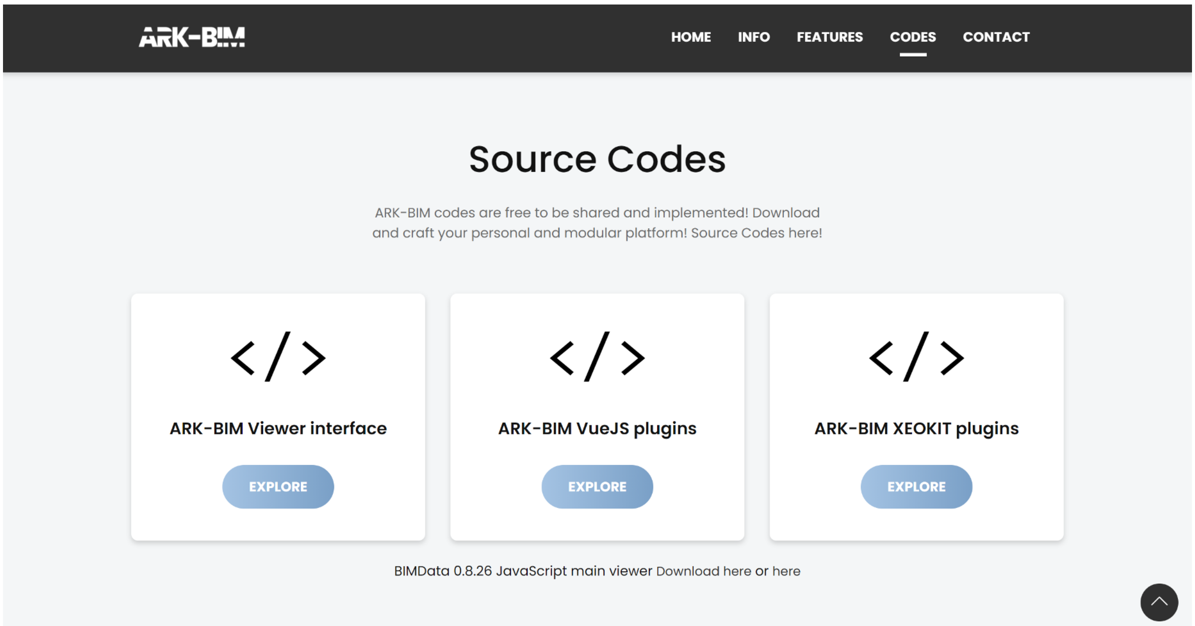


Figure 21. ARK-BIM website. Source code section; codes are free to be shared and utilized.

3. Results

The created modular platform could help in archaeological documentation and analysis. The developed custom-tailored plugins could make a valuable contribution to data exchange and boost data management and revision processes.

The work of the BIMData and XEOLABS developers has been shown to be essential for sharing the source code of important graphical instruments. In this regard, the ARK-BIM platform could be considered a bridge between HBIM archaeological projects and the main account of BIMData (especially for the BCF option).

Revisions and modifications of HBIM data were at the centre of the BIMData and ARK-BIM design; because online data sharing constitutes the final stage of most HBIM projects, revisions and accurate data management and validation are all daily operations that need to be addressed. The BCF option ensures these analyses and guarantees proficient collaborations among professionals, facilitating new revision strategies and relationships.

The new platform can be also be shared through different accessing rules; thanks to the different IFC scopes and accessing rules available via BIMData tokens, the custom platform can be shared, depending on management privileges. In fact, IFC models can be shared by managing different scopes in order to lock or unlock possibilities (e.g., IFC read/write; BCF read/write). Through this filter process, a custom platform can be published in three ways (managing via Postman and tokens): for project managers (in charge of the project for data management, revisions, updates and validations); for active/invited users (revisions and updates); for a large community with a light environment and less specific features [3]. This possibility is fundamental for sharing models and semantic data (object-levels data) depending on users and level of interest, managing access privileges for project teams and other people [30].

ARK-BIM, as for BIMData and other cloud BIM solutions, does not require expensive and specific hardware; only an updated web browser and a low/medium graphic adaptor (GPU) are required. Moreover, these cloud computing solutions offer a democratic approach to data analysis and exchange, drastically reducing costs and releasing users from hardware constraints [30]. At the same time, cloud/server BIM solutions provide real-time and on-demand access, which make it possible to increase productivity and project phases [24]. These are fundamental aspects for increasing accessibility and the ease of analyses. Web solutions and services generate huge benefits for data sharing and exchange, allowing real-time modifications in smart environments [3,31,32].

Being a web-based solution, ARK-BIM is fully compatible with mobile devices (even if not yet optimized). Portability, not only for laptops, is a crucial aspect concerning accessibility of information [33]. Through mobile devices, IFC models and related data become consultable everywhere, thus avoiding the need for institutions and particular instruments, for example, laboratories and dedicated computers [3]. At the same time, first person spaces, such as AR, VR and game-like environments, could boost information access and involvement [34–36]; this aspect could be considered in a future version of ARK-BIM.

In conclusion, thanks to the available source code and web development possibilities, a custom platform has been designed for Heritage and historical assets (Figure 22); archaeological information can be easily consulted and exchanged among project teams and collaborators. ARK-BIM is free to be utilized and implemented by the community. Source codes are available on the official website.

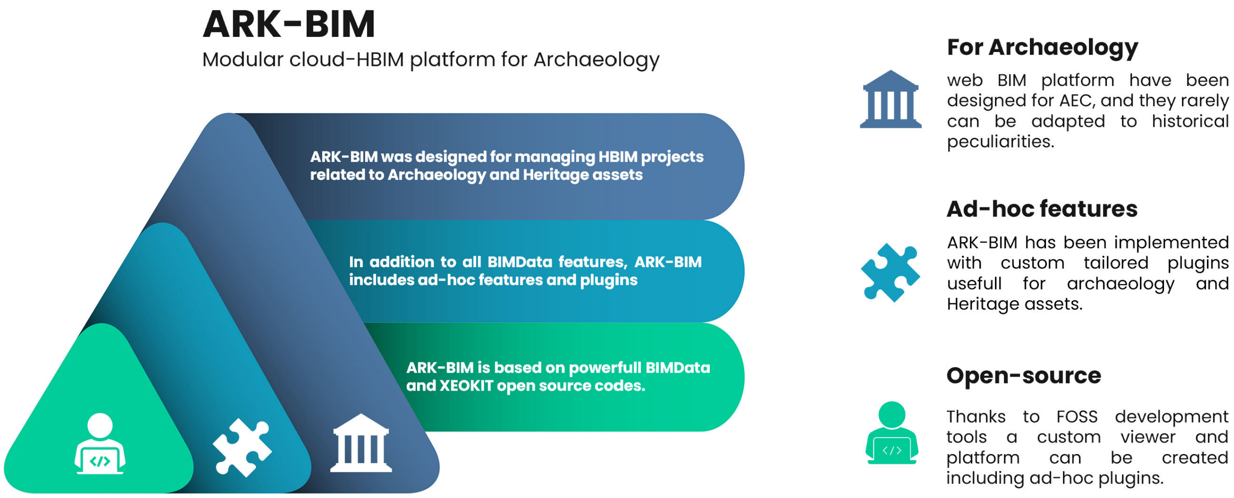


Figure 22. ARK-BIM main features: a modular platform for archaeology, which includes ad-hoc plugins, built with open-source web instruments.

4. Conclusions

ARK-BIM (current version 1.5.1) is a modular cloud platform based on different programming languages that requires constant updating. In fact, the developed functionalities could be suitable for many archaeological sites, but not for other specific contexts. For this reason, features regarding the viewer and plugins can be implemented depending on case studies. In this regard, the Isolate Elements plugin could be implemented with specific attributes: e.g., isolate by tag, materials, metric dimensions and so on.

However, future works could include the creation of a personal cloud and viewer based exclusively on XEOKIT possibilities, disengaging from the BIMData system and creating a proprietary revision centre instead of a BCF option.

Another important feature will be the focus of forthcoming work: the inclusion of high-quality texture, leaning on GLTF file formats (at the moment, IFC format does not support radiometric textures). In this way, an immersive and photographic reference could enrich the model.

ARK-BIM, with its tailor-made plugins, provides valuable support to HBIM project collaborations related to archaeological contexts. It offers the possibility to manage HBIM models and related data in a smart and intuitive web environment; archaeological models and data (resources, properties and databases) can be consulted and revised remotely. Thanks to the BCF option, the real-time IFC properties edit and ad-hoc plugins, a complete suite for archaeological BIM projects is now available. For this reason, this platform changes traditional studies and collaborations regarding archaeology.

ARK-BIM allows the collection of different type of data (from IFC properties to textual information; from reference pictures to databases) in a cloud system and several instrument for investigate them, it avoids data fragmentation derived from traditional archaeological studies (semantic data often disconnected from 3D models) and assists in remote collaborations and data exchange.

Cloud-BIM web development is undoubtedly a growing industry, not only for software but also for research projects. Because online solutions have proven to be essential in these challenging times, cloud-based systems and web platforms are becoming more and more important for ensuring data exchange and interoperability, and they provide a multidisciplinary and open approach. Remote accessibility often provides the only possibility to carry out and update research and analyses (and HBIM revisions and collaborations).

In the future, we could easily see the development of dynamic cloud solutions able to manage (especially from mobile devices) complex and high-quality BIM projects (maybe with texture compatibility), allowing simple on/off functionalities for different users as well as AR/VR switches. In fact, thanks to web development, this new-born platform could be the starting point for developing more and more cloud-based informative solutions applied to archaeology and Heritage assets.

FOSS programming tools and web development possibilities unlocked unthinkable scenarios just a few years ago. ARK-BIM design was made possible thanks to these opportunities. The project idea and design started from a willingness to utilize open and smart instruments of the actual cloud BIM panorama, for the purpose of adapting them to archaeological data. The future of cloud-BIM is certainly ad-hoc web development for specific branches. Nowadays, cloud computing and web programming tools play a crucial role in creating custom-tailored solutions, thus avoiding the adaptation of HBIM data to web apps designed for other purposes.

Author Contributions: Conceptualization, F.D.; methodology, F.D.; software, F.D.; validation, F.D.; formal analysis, F.D.; investigation, F.D.; resources, F.D. and F.R.; data curation, F.D. and F.R.; writing—original draft preparation, F.D.; writing—review and editing, F.R.; visualization, F.D.; supervision, F.R.; project administration, F.R.; funding acquisition, F.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Source codes related to modified viewer and custom plugins are available on the official website of ARK-BIM: https://ark-bim.github.io (accessed on 20 September 2021). A sample platform and model are available on: https://ark-bim.github.io/version1.5.1-sample/ (accessed on 20 September 2021).

Acknowledgments: A heartfelt thanks goes to the BIMData development team for supporting the author regarding viewer modification and plugin design. For the same reason, further thanks goes to the XEOLABS developers. Moreover, this work has been inspired by the guidelines of the International Committee of Architectural Photogrammetry (CIPA), the scientific committee of ICOMOS, concerning Cultural Heritage documentation and preservation through the utilization of open-source solutions for correct data dissemination, an idea also adopted by the GAMHer project, who supported this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Murphy, M.; McGovern, E.; Pavia, S. Historic building information modelling (HBIM). *Struct. Surv.* **2009**, *27*, 311–327. [CrossRef]
2. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling—Adding intelligence to laser and image based surveys of European classical architecture. *ISPRS J. Photogramm. Remote Sens.* **2013**, *76*, 89–102. [CrossRef]
3. Diara, F. Experimental Workflow for the Creation of a non-Conventional Open Source HBIM Platform Integrating Metric Data and Stratigraphic Analysis: The Case Study of the Refectory of Santa Maria di Staffarda Abbey. Ph.D. Thesis, DAD Department, Politecnico di Torino, Turin, Italy, 22 April 2020.
4. Diara, F.; Rinaudo, F. Cloud data sharing and exchange of HBIM projects for archaeology: Possible solutions and proposals. In Proceedings of the Joint International Event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES, Valencia, Spain, 26–28 April 2021; Editorial Universitat Politècnica de València: Valencia, Spain, 2021; pp. 491–494. [CrossRef]
5. BuildingSmart. Available online: https://www.buildingsmart.org/ (accessed on 23 August 2021).
6. BuildingSmart IFC Specifications. Available online: https://technical.buildingsmart.org/standards/ifc/ifcschema-specifications/ (accessed on 23 August 2021).
7. ISO 16739-1. Industry Foundation Classes (IFC) for Data Sharing in the Construction and Facility Management Industries—Part 1: Data Schema, ISO16739-1:2018. Available online: https://www.iso.org/standard/70303.html (accessed on 23 August 2021).
8. ISO/TC 184/SC 4. Industrial Automation Systems and Integration—Product Data Representation and Exchange—Part 21: Implementation Methods: Clear Text Encoding of the Exchange Structure, ISO10303-21:2016. Available online: https://www.iso.org/standard/63141.html (accessed on 23 August 2021).
9. Barazzetti, L.; Banfi, F.; Brumana, R. Historic BIM in the Cloud. In *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection*; Ioannides, M., Fink, E., Moropoulou, A., Hagedorn-Saupe, M., Fresa, A., Liestø, G., Rajcic, V., Grussenmeyer, P., Eds.; Lecture Notes in Computer Science; Springer: Cham, Switzerland, 2016; Volume 10058. [CrossRef]

10. Diara, F.; Rinaudo, F. Open source HBIM for Cultural Heritage: A project proposal. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*; Copernicus GmbH: Göttingen, Germany, 2018; Volume XLII, pp. 303–309. [CrossRef]
11. Diara, F.; Rinaudo, F. Building archaeology documentation and analysis through open source HBIM solutions via NURBS modelling. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*; Copernicus GmbH: Göttingen, Germany, 2020; pp. 1381–1388. [CrossRef]
12. FreeCAD, Parametric Open Source Modeller. Available online: https://www.freecadweb.org/ (accessed on 23 August 2021).
13. Logothetis, S.; Karachaliou, E.; Valari, E.; Stylianidis, E. Open source cloud-based technologies for BIM. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*; Copernicus GmbH: Göttingen, Germany, 2018; Volume XLII-2, pp. 607–614. [CrossRef]
14. Hu, Z.Z.; Zhang, X.Y.; Wang, H.W.; Kassem, M. Improving interoperability between architectural and structural design models: An industry foundation classes-based approach with web-based tools. *Autom. Constr.* **2016**, *66*, 29–42. [CrossRef]
15. Diara, F.; Cavallero, F. From excavation data to HBIM environment and cloud sharing: The case study of *Domus Regia, Sacraria Martis et Opis* (Roman Forum, Rome—Italy). In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*; Copernicus GmbH: Göttingen, Germany, 2021; Volume XLVI-M-1-2021, pp. 207–213. [CrossRef]
16. BIMServer.Center, A BIM Server Web App. Available online: https://bimserver.center/en (accessed on 23 August 2021).
17. BIMServer, Open-Source Server BIM. Available online: https://github.com/opensourceBIM/BIMserver (accessed on 23 August 2021).
18. BIMData, An Open-Source BIM Platform. Available online: https://bimdata.io (accessed on 23 August 2021).
19. XEOKIT, Open-Source Programming Toolkit. Available online: https://xeokit.io (accessed on 23 August 2021).
20. XEOLABS, Developing Graphics Software for Web-based BIM, Engineering and Medicine. Available online: https://XEOLABS.com (accessed on 23 August 2021).
21. ARK-BIM, A Cloud HBIM Platform for Archaeology. Available online: https://ark-bim.github.io (accessed on 23 August 2021).
22. Postman, API Platform for Building and Using APIs. Available online: https://postman.com (accessed on 23 August 2021).
23. Unpkg, Global Content Delivery Network. Available online: https://unpkg.com (accessed on 23 August 2021).
24. Afsari, K.; Eastman, C.M.; Shelden, D.R. Cloud-based BIM data 230 transmission: Current status and challenges. In *ISARC, Proceedings of the International Symposium on Automation and Robotics in Construction, Auburn, AL, USA, 18–21 July 2016*; IAARC Publications: Auburn, AL, USA, 2016; Volume 33, pp. 1073–1080. [CrossRef]
25. Doglioni, F. La ricerca sulle strutture edilizie tra archeologia stratigrafica e restauro architettonico. In *R. Francovich—R. Parenti (a cura di), "Archeologia e Restauro dei Monumenti"*; All'Insegna del Giglio: Sesto Fiorentino, Italy, 1988.
26. Parenti, R. Sulla possibilita di datazione e di classificazione delle murature. In *R. Francovich, R. Parenti (a cura di), Archeologia e Restauro dei Monumenti*; All'Insegna del Giglio Editore: Firenze, Italy, 1988; pp. 280–304.
27. Harris, E.C. *Principles of Archaeological Stratigraphy*; Elsevier: Amsterdam, The Netherlands, 2014.
28. GitHub Pages, Web Sites Designer from GitHub. Available online: https://pages.github.com/ (accessed on 23 August 2021).
29. ARK-BIM Sample Platform and Model. Available online: https://ark-bim.github.io/version1.5.1-sample/ (accessed on 23 August 2021).
30. Lou, J.; Lu, W.; Xue, F. A review of BIM data exchange method in BIM collaboration. In Proceedings of the 25th International Symposium on Advancement of Construction Management and Real Estate (CRIOCM2020), Wuhan, China, 28–30 November 2020. [CrossRef]
31. Redmond, A.; Smith, B. Designing a cloud BIM business process model case study. In *AACE International Transactions, BIM-1265*; AACE Interational: Morgantown, WV, USA, 2013; ISBN 978-1-885517-80-7.
32. Ness, D.; Kim, K.; Xing, K.; Swift, J.; Gelder, J.; Jenkins, A.; Roach, N. A cloud BIM data platform for life cycle management and reuse of building components. In Proceedings of the Conference: Powering the Change to a Circular Economy, Adelaide, Australia, 15–17 November 2017.
33. Balletti, C.; Gottardi, C.; Guerra, C. Geomatics techniques for the enhancement and preservation of Cultural Heritage. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*; Copernicus GmbH: Göttingen, Germany, 2019; pp. 133–140. [CrossRef]
34. Goulding, J.S.; Rahimian, F.P.; Wang, X. Virtual reality-based cloud BIM platform for integrated AEC projects. *J. Inf. Technol. Constr.* **2014**, *19*, 308–325.
35. Banfi, F.; Oreni, D.; Bonini, A.J. The Arch of Peace of Milan and its historic memory: From 3D survey and HBIM to mixed reality (VR-AR). In *Connecting. Drawing for Weaving Relationships, Proceedings of the 42th International Conference of Representation Disciplines Teachers, Reggio Calabria, Italy, 16–18 September 2021*; FrancoAngeli: Milan, Italy, 2020; pp. 1660–1677.
36. Banfi, F.; Brumana, R.; Stanga, C. Extended reality and informative models for the architectural heritage: From scan-to-BIM process to virtual and augmented reality. *Virtual Archaeol. Rev.* **2019**, *10*, 14–30. [CrossRef]