buildingSMART International (2022)

436-STUDENT Student Research using openBIM

AR-supported Teaching

YexvbAyQ

Entrant details

Role or Job Title on the Project	Projectlead

Employer

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Employer Role	Academic or Research Institution
Are you or your employer a member of buildingSMART?	Yes - Chapter Member

Entry details

Entry Details

By checking this box I understand and acknowledge that this awards program is to assess information about openBIM, and that openBIM is not only about the use of solutions. openBIM is about setting up an environment where every party in a team can work in the optimal way ("how they prefer") without putting limitations on others. It is about freedom to take control over your data and workflows, while keeping that freedom for others as well. Full use of open standards is not mandatory for this mission.	✓
Website	https://arserver.bilab.tuwien.ac.at/projects

Location

Center of Digital Building Processes, TU Wien
Karlsplatz 13/234-01, 1040 Vienna, Austria

Submitting Party and Stakeholder Logos (compiled into one .ppt/pptx file for upload)

PPTX	bSI-Award-2.3-Submitting-... (1.4 MiB download)

Entry Description

The networking of digital solutions in the AEC sector has become increasingly important in recent years. The focus here is on Building Information Modelling (BIM) and the associated Industry Foundation Classes (IFC). BIM forms the basis for further technical developments. The technologies that serve the functional expansion of BIM are labelled under the term "Construction 4.0". These include Augmented Reality (AR), Virtual Reality (VR), robotics, drones, 3D printing, etc.
AR is the extension of the real environment with additional virtual content [1]. AR-capable mobile devices such as smartphones or tablets are used for this purpose. The mobile augmented reality (mAR) thus achieved contrasts with the head-mounted displays (HMDs), which are not yet widespread. Numerous studies have already proved the added value of BIM with AR [2–8]. BIM and AR complement each other in their application, so BIM enables the use of AR already in training. Not only is the learning effect increased, but the students also learn the handling of BIM and this "Construction 4.0" technology.

At first glance, teachers who want to implement AR in their lessons have a wide choice of software solutions. But a closer look reveals that most of them are not suitable. On the one hand, most AR software manufacturers demand financial compensation. BIM authoring software sometimes provides solutions free of charge. However, this can lead to a dependency on software manufacturers through proprietary formats. In addition, longer workflows or programming skills are often required. This leads to a high barrier to entry and use.
In the AR-supported Teaching project, an AR platform of the same name was developed that enables teaching scenes to be created without programming knowledge and based on open standards (IFC). The aim is to lower the hurdles mentioned and make it possible to implement AR in the classroom. For this purpose, the team created three applications (AR editor=Create; AR viewer=View; Website=Manage) functionally separate but interconnected.
With the help of the AR editor, teachers can create AR teaching scenes. Teachers use IFC files, which they import into the AR editor. The teaching scene can then be adapted or extended with annotations, animations, layers and buttons while the IFC remains intact. The AR editor saves the contents of a teaching scene in a database, which improves data access and data up-to-dateness.
The end-user views the created teaching scenes with the AR viewer. Buttons enable self-directed, exploratory learning. The speed is freely selectable, which prevents cognitive overload. The "Live Session" function makes a live connection between AR editor and AR viewer. This allows communication between learners and teachers across spatial barriers. The user of the AR editor can set markers in the live session and expand it with media files (images, videos). An integrated voice and message chat also supports communication.

A web application is used to administer users. This mainly involves defining user roles and assigning groups. Roles regulate which AR-supported Teaching applications a user can use. Teaching scenes are not user-specific but always refer to groups. These are tree-like and can also be created in the web application. It is possible to publish scenes to promote the user base. These appear on the website, can be presented there and can be downloaded by anyone in the AR viewer.

Why does AR-supported Teaching rely on openBIM and other open formats?

- AR-supported Teaching should be freely available to all educational institutions. However, free refers not only to costs (software costs, training costs) but also to a free choice of software. Therefore, the open format IFC is used. This allows the free selection of the BIM authoring software in educational institutions. openBIM file formats also ensure the longevity of data. On the one hand, the BIM models needed for the teaching scene can also be used in the future. On the other hand, this means that ongoing adaptation of the import process in the AR editor is not necessary.
- The file formats used in AR-supported Teaching (IFC, JSON) are also human-readable. Hence, advanced users can develop their own applications that can be used to create more complex teaching scenes. The usage of, e.g., the software Blender can simplify the creation of complex animation sequences. Animation and object are linked using BlenderBIM via GUIDs. The animation data exported from Blender can then be included in the JSON file.
- Modelling for the teaching scene is done in native software. The model information comes exclusively from the IFC. Therefore, modelling for the teaching scene can take place in any buildingSMART-certified software (IFC 2x3, IFC 4). This brings openBIM into the classroom and is a clear, visually easy to view introduction for young, interested pupils/students.

Project team:

- Alexander Gerger
- Konstantin Höbart
- Gabriel Pelikan
- Christian Schranz
- Harald Urban

What stage of completion is the entry content representing?	Testing Stage, Feature Extension

Stakeholder Statements

> University assistant: AR offers two major benefits in teaching. On the one hand, AR enables a clear representation of complicated structures, e.g., reinforcement cages in highly loaded areas. On the other hand, different teaching contents can be displayed and linked centrally in one model.
>
> Student: As a civil engineer, I see the great advantage in the fact that complicated geometries, such as complex reinforcement, are easier to understand. Especially as a first-year student, when you haven't had much experience with spatial thinking, this can be very helpful. I can also imagine that complex detailed connections, such as for a parapet or the connection of a window with all its sealing levels, could be very well represented with AR. Many such things are difficult to grasp as a student if you have never seen them in reality in 3D. I think that can help enormously.
>
> BIM Operations Manager: AR simplifies the perception of spatial dimensions. By placing them in the environment, the viewer has real reference objects and can thus better perceive sizes. This is only possible to a limited extent through the use of VR or 3D models in conventional viewers. AR also makes it possible to display scenes that would otherwise be too small, too large or take too long. This includes, for example, the microscopic structure of materials or a construction process simulation.

Upload a 2 minute video to show the scope of the entry.

MP4	Video AR-supported Teachi... (147.4 MiB download)

Problem Statement

> The networking of digital solutions in the AEC sector has become increasingly important in recent years. The focus here is on Building Information Modelling (BIM) and the associated Industry Foundation Classes (IFC). BIM forms the basis for further digital developments in the AEC sector. The technologies that serve the functional expansion of BIM are labelled under the term "Construction 4.0". These include Augmented Reality (AR), Virtual Reality (VR), robotics, drones, 3D printing, etc.
>
> For example, AR-capable mobile devices such as smartphones or tablets are used for this purpose. The mobile augmented reality (mAR) achieved in this way contrasts with head-mounted displays (HMDs), which are not yet widespread. The added value of BIM with AR has already been proven by numerous studies [2–8]. BIM and AR complement each other in their application, so BIM enables the use of AR already in training.
> Teaching currently relies almost exclusively on two-dimensional representations of mostly three-dimensional problems. This makes interaction with the learning material difficult in some cases. Teachers compensate for this in face-to-face teaching by providing supplementary auditory explanations. If anything is unclear, students can ask questions. However, this component has become more complex since the beginning of the COVID-19 pandemic and the resulting switch to distance learning. Therefore, even greater importance is attached to the clear presentation of illustrations.
>
> Nevertheless, especially first-year students have problems interpreting the two-dimensional representation spatially. However, this interpretation is a core competence of engineers (cf. [9,10]). A plastic imagination is necessary, for example, to understand building details and construction plans. AR can provide support here when used in a targeted manner. AR enables three-dimensional teaching scenes to be projected into the environment and experienced.
> Thus, AR can support teaching, but it can also teach the use of BIM and this "Construction 4.0" technology. However, according to [11], the use of AR is currently low, especially in higher education.
>
> One reason for this is that teachers who want to create AR teaching scenes for their students face problems. The available choice of applications is large, but most drop out after the first viewing: To ensure high-quality AR models, providers demand monetary consideration in the form of subscriptions or one-off payments. However, educational institutions often have a tight budget, so applications with paywalls are ruled out. While an extensive collection of high-quality AR models is available to the paying user, custom

creation is often impossible. Free methods that allow individual creation are often only individual, software-specific solutions. A cumbersome workflow often characterises these solutions, and most require programming skills. In addition, out-of-the-box functions are limited and would have to be integrated independently.
The operational hurdles of implementing AR in the AEC education sector were addressed by [12]. The benefits, which include cost reduction, increased learning efficiency and representation/simulation of complex scenarios, are offset by three challenges:

- Small number of people creating models for AR/VR
- Lack of evaluation studies
- Lack of quality standards

In addition, most AR projects are project solutions. Hence, they are explicitly created for a task or a project. As a result, a person with project or programming knowledge is often required when creating new AR scenes. This situation leads to further problems:

- Independent creation of AR teaching material by teaching staff is not possible or very difficult
- High dependence on external software companies
- Increased costs for individual AR solutions

In AR-supported Teaching, an AR platform of the same name was developed, attempting to solve the problems mentioned. The aim is to provide teachers in the AEC sector with applications that enable the independent creation of AR teaching scenes, independent of software products and without programming knowledge. The use of the open, ISO-standardised Industry Foundation Class (IFC) format, which is already used in the AEC sector, is evident here. Based on this, the team developed an editor and viewer. These should make it possible to create AR teaching scenes and display them on mobile devices. The following goals were defined:

- Open Standards:
  Use of the openBIM standard IFC as data exchange format to ensure a software-independent environment. An additional advantage is the extension of the AR teaching scenes to include alphanumeric data. The aim is not to develop a BIM authoring software but to read and further use the alphanumeric and geometric information contained in an IFC file. Thus, IFC serves as an import format, allowing the teaching scene creator to choose between the available BIM authoring software products freely. In conjunction with the open, also standardised JavaScript Object Notation (JSON) format, advanced users can automate repetitive or more complex activities through their extensions. For example, Blender can be used with the BlenderBIM add-on to create animation sequences.
- Simple usability:
  Development of an environment with simple usability, enabling people without in-depth programming knowledge to create AR teaching scenes and fill them with annotations and animations.
- Open Content:
  Development of a web application for project management and teaching scene presentation. Users can manage AR teaching scenes (versioning), share them and have them commented on and further developed by other users. This will increase the number of freely available AR models in the construction industry.
- Cross-platform:
  The applications developed should be as platform-independent as possible. This refers to the creation of the AR teaching scenes and their viewing. As a first step, it should only be possible to experience the AR models on mobile devices (smartphones and tablets).

Previous efforts and limitations

Numerous software products make it easy to create AR models. An example is ARki, developed by Darf Design [13]. This software provides similar features to those developed in the course of AR-supported Teaching. These features include the import of 3D models and the extension of these with animations, annotations and layers. However, there are two problems. On the one hand, only FBX files (Filmbox) are currently supported, but these only contain animation-related data. This data includes geometries, materials and animation paths. Unfortunately, ARki does not use BIM files (like IFC) and misses out on the advantages of having alphanumeric data alongside geometric data. With a BIM file, a student can grasp, e.g., the material parameters of a wall and whether it is a load-bearing element. Hence, the learners can better understand a teaching scene using BIM files as a basis. The only use of FBX files eliminates this added value of BIM files. On the other hand, a monthly subscription is necessary to create multiple projects. The subscription costs are a significant hurdle in teaching because financial resources are often limited.

But there are already solutions for creating AR models in the context of teaching. ARTutor [14] allows the insertion of virtual 3D models in non-fiction books using mobile devices. The models can be adjusted by gestures or voice commands and users can ask questions in the software. The software searches the text for an answer and outputs it.

Another successful use of AR in education is shown by the project mARble [15], although not in the AEC sector. The project focuses on the implementation of AR in the education of students in the field of forensic medicine. This AR application uses paper markers to project wounds onto learners' bodies. An extension with images, audio, videos and questions and answers is possible. A comparative study between mARble and conventional textbooks found an increased learning effect of the AR application [16].

Companies have also discovered the added value of this immersive technology in training. One of them is the formwork manufacturer Doka. This company created an AR application [17] to display Doka formwork systems projected onto associated two-dimensional plans. This model improves spatial awareness. Another advantage is central data management, which makes it possible to adapt the language, for example, without much extra effort. The application only allows the viewing of predefined scenarios and cannot be extended with user-created models.
Some of the existing AR solutions were developed specifically for teaching. An increased learning effect through the use of AR could be determined. If we look at the AEC sector, the possibility of using AR already exists there as well. However, no application allows the simple creation of AR teaching scenes based on openBIM models.

Research method

AR-supported Teaching is the continuation of a diploma thesis [18] and comprises three applications: AR editor, AR viewer and a web application. These are not stand-alone software products but are linked to each other and only separate the three essential functions: Creating, viewing and administering. The web application supports the administration. It allows the administration of already created teaching scenes and assigning user roles with the help of a predefined, hierarchical role matrix. A distinction is made between 3 types of users:

- User (viewing AR teaching scenes)
- Editor (creation of AR teaching scenes)
- Group Admin (administration of groups, e.g., through role assignment user/editor)

Depending on the role of the user, the application used also varies. For example, a user can and should only use the AR viewer, an editor can also use the AR editor, and a Group Admin has access to the web application. In addition to roles, groups are another possibility for functional separation. They are tree-like, and users can be assigned to a group. Teaching scenes always refer to groups and not to creators. Hence, an editor can create AR scenes for two groups simultaneously, but the viewers of a group can only view specific scenes for them in the AR viewer. If the editor wants his teaching scenes to be visible to all groups, this is possible by publishing the scene. Public projects are visible on the website and can be presented with the help of images and descriptions. In the future, a feedback system and a comment function will help to evaluate and comment on teaching scenes.

With the AR editor, users can create new teaching scenes with the Editor role. Therefore, they use an already created IFC model, whereby only IFC 2x3 is currently supported. The Unity Engine based AR editor has an IFC importer and a project export function. By manipulating and extending IFC models, AR teaching scenes can be created. Additionally, the editor can open existing projects from the server, allowing users to update them or build upon them to create a new project. Therefore, local storage of projects is not required, which simplifies versioning. The import of an IFC file is split into two pipelines:

- Model generation is done with the Unity extension TriLib. This extension allows 3D models to be loaded during the software runtime. TriLib supports numerous data formats, including IFC 2x3, which means that conversion to other file formats is unnecessary.
- The import of non-geometric information is done with IfcOpenShell or the IfcConvert command-line program based on IfcOpenShell. This software is used to create a more retrievable XML file from an IFC file. Although the geometric information is lost, it is already covered by the TriLib import process.

The two import pipelines are linked together at the end of the import process. This is necessary to assign the corresponding alphanumeric data to each geometrically interpreted component. The Globally Unique Identifier (GUID) is used for this purpose, which is attached to each object as a suffix during the TriLib import and is also contained in the XML file. After the import, editing and extension are done in the AR editor. The added data is not integrated into the IFC file but stored separately in a JSON file. The export of the project is needed for backup and consists of the IFC files used in the teaching scene and the JSON file, which contains a list of all IFC elements, annotations, animations, layers and buttons. The media files used are also included. The files are then combined in a folder and transferred to a database (PostgreSQL) using File Transport Protocol over Transport Layer Security (FTPS) and are available to the AR viewer.
The AR viewer is used to view the scenes created in the AR editor. mAR is used. Hence, only a mobile device (tablet or smartphone) with an Android operating system (version 8+), AR core support, and an internet connection are required to download the desired scenes. The mobile device saves the downloaded scenes locally on the device, so no network connection is required for pure viewing. Buttons in the form of buttons are used to control the display. This allows layers to be shown or hidden and animations to be played.

Construction processes can thus be explained and visualised step by step. Flags represent the added annotations in the AR viewer. Tapping on them displays the stored information text or attached media files. The BIM data can be displayed by selecting a component.
These features allow users to explore an AR model in an exploratory and self-directed manner, which is essential for self-learning. The absence of strictly prescribed learning paths by the model's creator leads to a self-selectable speed at which a model is viewed. This prevents cognitive overload caused by too much information at once.
ARCore [19] and the AR Foundation package [20] are used to position the AR teaching scenes. These frameworks enable the placement of virtual models in the real environment using motion tracking and environmental understanding. Currently, the AR viewer is optimised for Android tablets and smartphones.
Additionally, the AR-supported Teaching platform allows live interaction between the AR viewer and AR editor. This feature allows teachers to communicate directly with learners across spatial barriers using an integrated text and voice chat function. Furthermore, teachers can place additional markers during a live session and link them to images and videos.

Paper

Findings/Validation

The development and function of the applications resulting from the project are described in the section above. These are available to educational institutions free of charge and are continuously extended with additional functions. Feedback regarding the usability of the various applications is therefore essential, so usability tests were carried out in parallel with the development to ensure ease of use and generate suggestions for new functions.

As a technology, the Actual System Use of the AR-supported Teaching Platform can be assessed according to the Technology Acceptance Model (TAM). [21] can be assessed. TAM enables a statement of whether a technology is used. This is done based on two input parameters: the perceived usefulness and the perceived ease of use. The latter has already been surveyed in courses at the TU Wien, among other things.

Two standardised questionnaires were used: the System Usability Scale (SUS) for the AR editor and the Handheld Augmented Reality Usability Scale (HARUS). [22] for the AR editor and the Handheld Augmented Reality Usability Scale (HARUS) [23] for the AR viewer. Both allow usability to be assessed on a scale of 0 to 100, with a value of 70 or higher indicating acceptable usability. In the case of the SUS, ten standardised questions on a five-point Likert scale (1 = "Strongly agree" to 5 = "Strongly disagree") are to be answered by the test person. The HARUS consists of 16 standardised questions and a seven-point Likert scale (1 = "Strongly agree" to 7 = "Strongly disagree"). The questions in both scales are alternately scored (positive/negative) to prevent a response bias. It was also possible to provide feedback in the form of free text. Twelve people were interviewed about the AR editor and 15 about the AR viewer. With an average of 78.33 points, the AR editor scored slightly better than the AR viewer with 71.88 points.

The test persons rated the steep learning curve and the fact that hardly any prior knowledge is required to use the AR editor as positive. There is room for improvement in the implementation of functions, which leads to some inconsistencies.

The main problem with the AR viewer was the handling. Not the physical effort involved but the operation of the mobile device while viewing the educational scenes. When using a tablet, both hands are needed to hold the device securely. This results in awkward grip positions when selecting annotations or buttons. To solve this, a hardware-based [18] a hardware-based solution (hand strap for tablet) is preferable to a software-based one. When viewing with smartphones, the size of the screen was more of a problem. The font size of some texts can be adjusted, but the buttons were found to be too small. An adjustment of the Graphical User Interface (GUI) could remedy this. The tests were carried out with an earlier UI version. A corresponding adjustment could increase user-friendliness.

The standardised questions (SUS and HARUS) and the average points achieved per question can be found in the appendix. The Distance to Optimum (DtO) was also calculated for better comprehensibility, reflecting the difference between the maximum achievable score and the score achieved.

The survey of perceived usefulness is to follow soon. The aim is to determine whether learning performance can be increased through the use of AR-supported Teaching. For this purpose, a test will be conducted with two groups. The control group learns a new subject area conventionally with texts. The second group uses the applications developed in the course of AR-supported Teaching. Subsequently, a multiple-choice test will provide information on whether an increased learning effect can be achieved through the use of AR-supported Teaching.

Conclusion/Contributions/Limitations

The AR-supported Teaching project describes the development of an AR platform that bridges the gap between AR and BIM in the context of education. Three applications are necessary: the AR editor, AR viewer and a web application. These allow the creation, viewing and administration of AR teaching scenes. These applications are based on the openBIM principle.

The development of AR-supported Teaching focused on functions for educational institutions and is also available to them free of charge. These mainly include educational institutions in the AEC sector, such as universities and schools for higher technical education. The access threshold was kept low by paying attention to the available infrastructure, for example, through the use of mAR, where no costs are incurred through the use of smartphones or tablets. However, accessibility is not always financially limited but can also depend on other factors. Different educational institutions use different BIM authoring software. This results in a dependency on a proprietary file format. Movement within a vendor-specific software ecosystem is thus necessary. By using openBIM (IFC) and other open standards (JSON), AR-supported Teaching can break this software vendor dependency.

Although the first usability tests are already promising, it can only be determined whether AR-supported Teaching is suitable for education after the second evaluation step. AR-supported Teaching could also become interesting for other educational sectors in the future. To increase the scalability of AR-supported Teaching, the implementation of other open file formats such as OBJ and FBX is being considered. Although the advantage of alphanumeric data is lost, these formats are more common in other disciplines. Nevertheless, there will be teaching fields that will hardly benefit from its use because there is no need for annotated AR models. However, other use cases of AR-supported Teaching have also emerged outside of education. A more detailed description of these can be found under "Use Cases".
In the usability survey, the AR editor achieved an average value of 78.33 points using the SUS, and the AR viewer achieved an average of 71.88 points using the HARUS. The test persons gave feedback and suggestions for features integrated into the new versions of AR editor and AR viewer. The main focus is developing a web version of the AR editor, which is currently only available for Windows. The open-source project "ifc.js" is used for this. This enables a platform-independent creation of AR teaching scenes for creators. In addition, this simplifies the interaction between the AR editor and the web application and creates a more seamless transition.
The dissemination of the AR viewer is to be increased soon by implementing it on other mobile operating systems (e.g., iOS). The mAR used for the AR viewer is only one way of using it, and the screen size of the mobile device limits the immersion that can be experienced. HMDs do not have this problem but are currently too expensive for use in teaching and are therefore hardly used. Further development of AR-supported Teaching on HMDs would be possible in the future.
The number of free AR models is constantly being expanded and existing teaching scenes adapted. By promoting OpenContent, the authors hope to expand the community and subsequently increase the quality of the AR scenes. This results in an improvement in the quality of training both in educational institutions and in companies. The authors, therefore, recommend the promotion of free AR platforms, which build upon open standards (e.g., IFC, JSON).

Example Use

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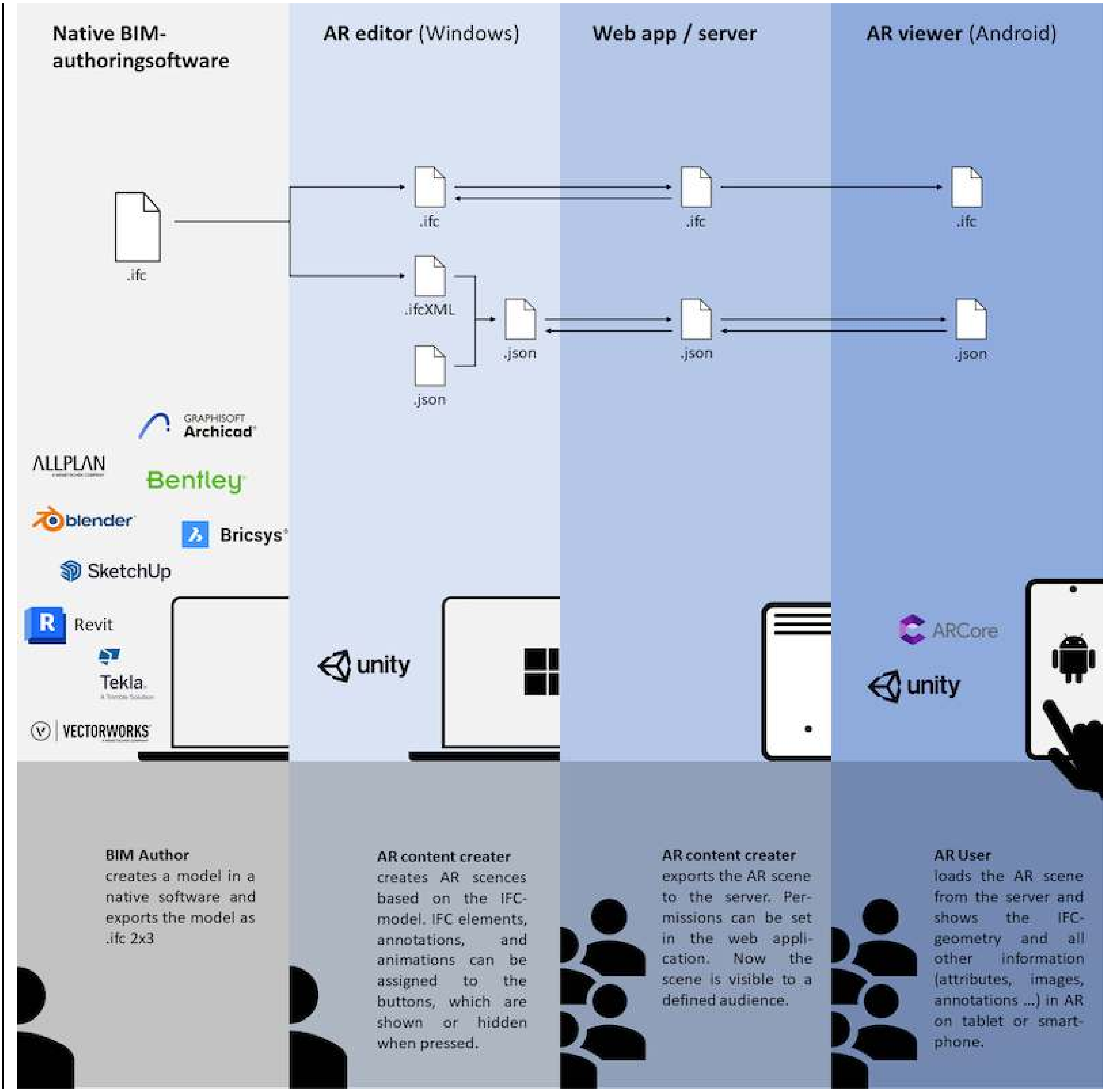
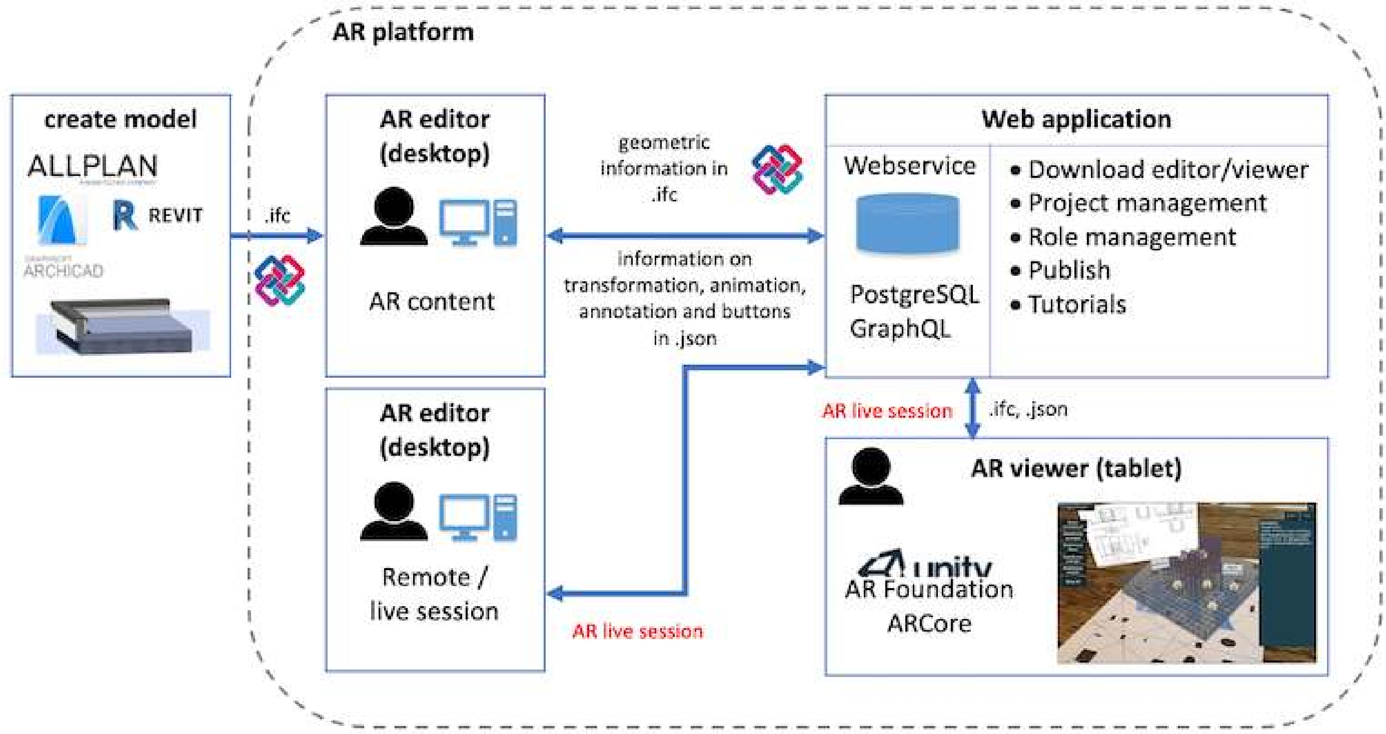
openBIM Evidence

Software Ecosystem Map



Process Maps



openBIM Data Metrics Summary

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Use Cases

BIM Uses were defined on the project | ✓

BIM Uses formed an integral part to how the project was delivered | ✓

I agree to be contacted for more information about the project BIM uses outside of this awards program. | ✓

Documentation on use case(s) as a single file upload

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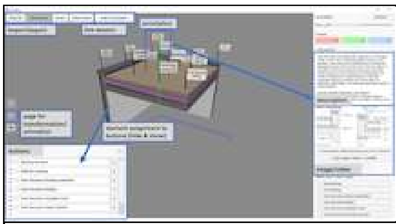
References.pdf 81 KiB



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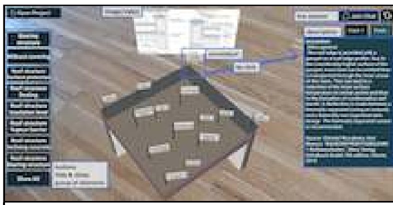

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AR viewer expla... 2.8 MiB

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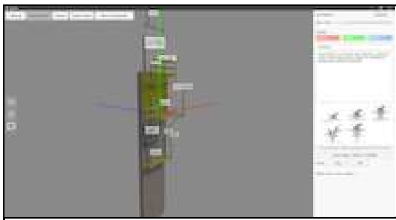

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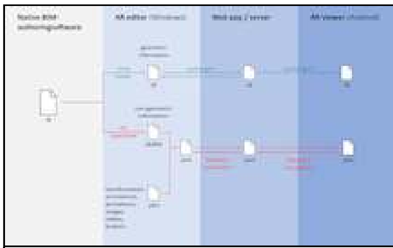

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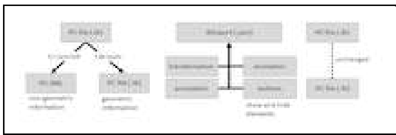

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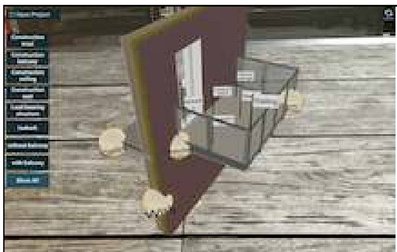

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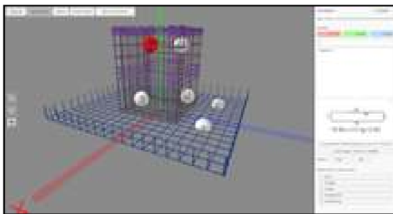
Technical Documentation

Process Map.pdf 222 KiB



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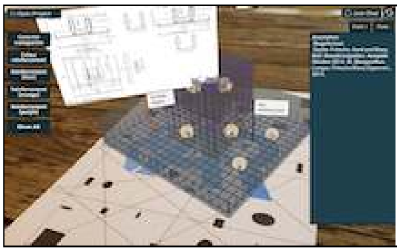

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Student using th... 1.6 MiB

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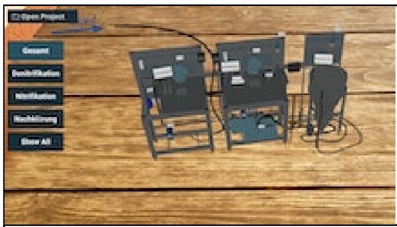
Urban et al 2022 ... 33.2 MiB



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Animation exam... 67.3 MiB

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