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A DECISION SUPPORT SYSTEM PROPOSAL ON THE USAGE OF EXTENDED REALITY SDKS IN AEC DISCIPLINES

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ABSTRACT

Technology is employed in the fields of architecture, engineering, and construction (AEC) for characteristics like producing visual representations and offering assistance during the building phase. Both users and creators of these tools are able to immediately take advantage of the technology's potential as well as create a variety of workarounds for its drawbacks. Both viewpoints will be looked at in this study with regard to mobile extended reality SDKs (software development kit). By excluding the articles that did not provide the relevant information, this research concentrates solely on the papers that discuss the technological aspects of the SDK that were used, the opportunities the SDK offers, and/or the shortcomings of the SDK. The study's main objective is to compare the technological contributions made by the SDKs employed in the scope of the examined literature to the AEC disciplines and to the contexts in which such contributions are made. Through applications in literature research, this study aims to highlight the contributions of mobile extended reality SDKs to the fields of architecture, engineering, and construction. An entry-level developer can use the SDKs in accordance with his work by using the comparison diagrams, produced in this study, to consider the relationships and comparisons between them, as well as to build a framework for what uses should be made in which fields. The technological capabilities and constraints of SDKs have an impact on how research is designed. Making relationality diagrams on the SDK to use and the effects it will have throughout the research phase is also crucial. As a result of the research, SDKs permit flexible uses in a variety of sectors, and their use also financially and logistically supports literature studies.

Keywords: Architecture Engineering Construction (AEC), Decision Support System (DSS), Extended Reality (XR), Mobile Augmented Reality (MAR), Software Development Kit (SDK)

1. INTRODUCTION

Emerging technologies have an impact on design methodologies, production and building procedures, and representational strategies in the discipline of architecture, engineering, and construction (AEC). Despite the potential of augmented reality (AR) in this industry, the experts there have not fully embraced its dynamic notion. Collaboration between various stakeholders is how AR improves work productivity.

Although AR has the potential to enhance real world objects, it also has several restrictions. The quality of characteristics utilized for the model integrated with AR is constrained by and influenced by the software's quality. Solutions can accomplish the goal by being aware of the strengths and weaknesses of the software used in AR applications. At this stage, integrating the use of the software allows for effectiveness due to the use of each software's opportunity in a particular field or the supporting of each software's deficiencies with others. By employing several Software Development Kits (SDKs), more sophisticated AR Applications can be produced. A Software Development Kit (SDK) is a set of tools and libraries for creating programs that are used to create software. Mobile devices are widely available, user-friendly, and reasonably priced, making widespread and democratic adoption of mobile augmented reality applications possible. Due to these characteristics of mobile devices, the article focuses on their development environment, namely SDKs.

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With regards to capabilities like tracking, recognition, and rendering, SDKs vary from one another. The location registration method can essentially divide AR technology into two categories: image-based AR, which recognizes feature points from images, and sensor-based AR, which is recorded by a sensor such a GPS. Marker-based AR and marker-less AR are the two categories that image-based augmented reality falls into, depending on whether specific markers are used. The production of an environmental map and the estimation of the self-position without using the map can both be done simultaneously thanks to Simultaneous Localization and Mapping (SLAM) technology. Here, the camera is the only sensor used by the visual SLAM algorithm. This instrument, which is widely used in robotics engineering, increases the stability of the AR tracking method. Therefore, a markerless AR algorithm is used in the created tele-simulation system [1].

How these settings can be employed in the AEC area, which cases they are used the most, and what potential contributions have been highlighted in the literature are the main study questions. Additional sub-questions include: which SDK can be used effectively in which situations or fields; what kind of usage of SDK does the authors prefer in their research; what are the technological advantages and disadvantages of the SDKs; what opportunities do the SDKs offer in the AEC fields; and which hardware, software, and programming languages are used in conjunction with the SDKs.

By providing answers to these queries, it is possible to identify the SDKs' potential contributions and their limitations to the AEC area. This gives the user looking for "a reasonable program" for "a certain purpose" at the start of their study. The common and dissociating aspects of the SDKs are used in this study by comparing them.

Through applications in related literature, this study aims to highlight the contributions of mobile extended reality SDKs to the fields of architecture, engineering, and construction. It then builds comparison diagrams based on these findings. This approach is crucial for developing a foundation for what kinds of uses go where and for being able to compare and contrast the software development kits that a newbie developer might employ in accordance with his work.

The study's main focus is on the technological contributions made by the SDKs employed in the literature under consideration to the previously listed disciplines as well as the contexts in which such SDKs are applied through flowcharts.

Applications for augmented reality (AR) use a variety of software development kits (SDKs), including ARCore, Vuforia, ARToolKit, ARKit, WikiTude, LayAR, Kudan, FaceSDK, SLARToolKit, FLARToolKit, OsgART, Droid AR, Augment, Aurasma, Metaio, BazAR, D'Fusion, Gamma AR, Tango, Firebase, Estimote Indoor Location SDK, Fologram, Metaio and xBIMToolkit. Some SDKs, such as Tango or Metaio, are excluded from this research because they were taken off the market. Therefore, only Vuforia, Fologram, ARCore, ARKit, ARToolkit, Gamma AR, Kudan AR, and xBIMTools are included in this study.

Vuforia, ARCore, ARKit, and ARToolKit are a few of these SDKs that are often used. Because of characteristics like text and environment recognition, scanning, and object creation, Vuforia is mostly used to recognize many types of visual objects. Motion tracking, environmental recognition, and light estimation are three of ARCore's key capabilities. Light estimation, TrueDepth camera, visual inertial odometry, scene identification, and rendering optimizations are all made possible by ARKit. Single or stereo cameras for position/orientation tracking, tracking of plain black squares, tracking of planar pictures, camera calibration, optical stereo calibration, and support for optical head-mounted displays are some of the unique features of ARToolKit [2]. The most popular program for the creation of AR applications, Unity 3D, is compatible with all four of these SDKs. The emphasis is on the features of software rather than its price or widespread use.

This study is divided into the following sections: an introduction section that includes the problem, hypothesis, aim, and scope; a materials and methods section expressing the methodology by focusing on literature review in the fields of architectural and urban design, construction, and digital fabrication; a section on the technological features and related tools of the SDKs (such as hardware, software, programming languages); a section on the opportunities they offer and the drawbacks of the SDKs; and a section on the results and discussion and finally conclusion section (Figure 1).

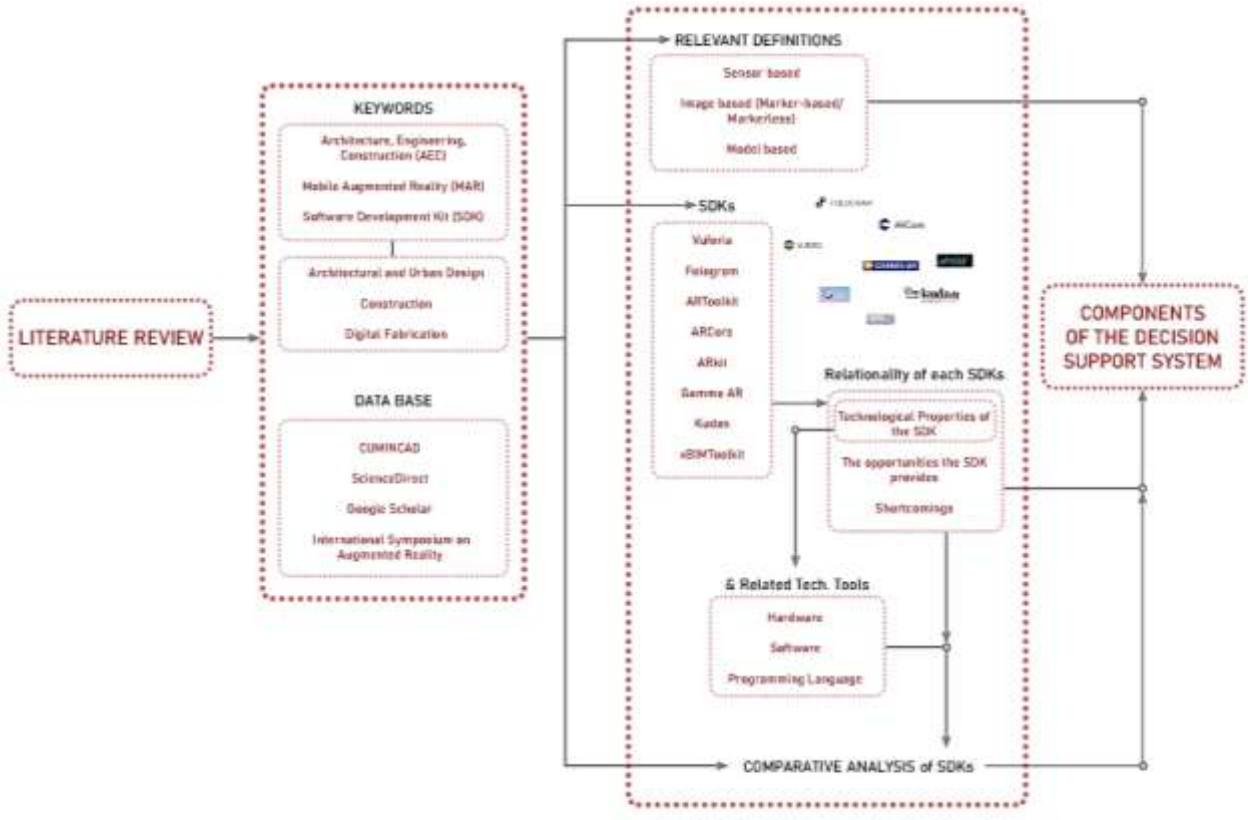

Figure 1. General framework of the study generated by the authors.

2. MATERIALS AND METHODS

This study's methodology focuses on the technological features of the SDKs, as well as associated tools (such as hardware, software, and programming languages), opportunities they present, and the shortcomings of the SDK. Comparative charts make it simple to understand how SDKs relate to AEC fields, software, hardware, programming languages, and technological attributes.

Only the case studies that created AR applications and used them in their studies are examined in the literature review. The research's data source is a collection of publications from the fields of architecture, engineering, and construction that discuss the SDKs used by mobile augmented reality applications.

184 research papers published between 2010-2021 are reviewed on ScienceDirect, International Symposium on Augmented Reality, Google Scholar and Cumincad database is taken from annual conferences of the Association for Computer Aided Design In Architecture (ACADIA) and its sibling organizations in Europe (ECAADE and CAAD Futures), Asia (CAADRIA), the Middle East (ASCAAD), South America (SIGRADI) and International Journal of Automation and Computing

(IJAC). Studies in these indexes contain terms like mobile augmented reality apps, augmented reality SDKs, and augmented reality applications in architecture, engineering, and construction (AEC) (Figure 2).

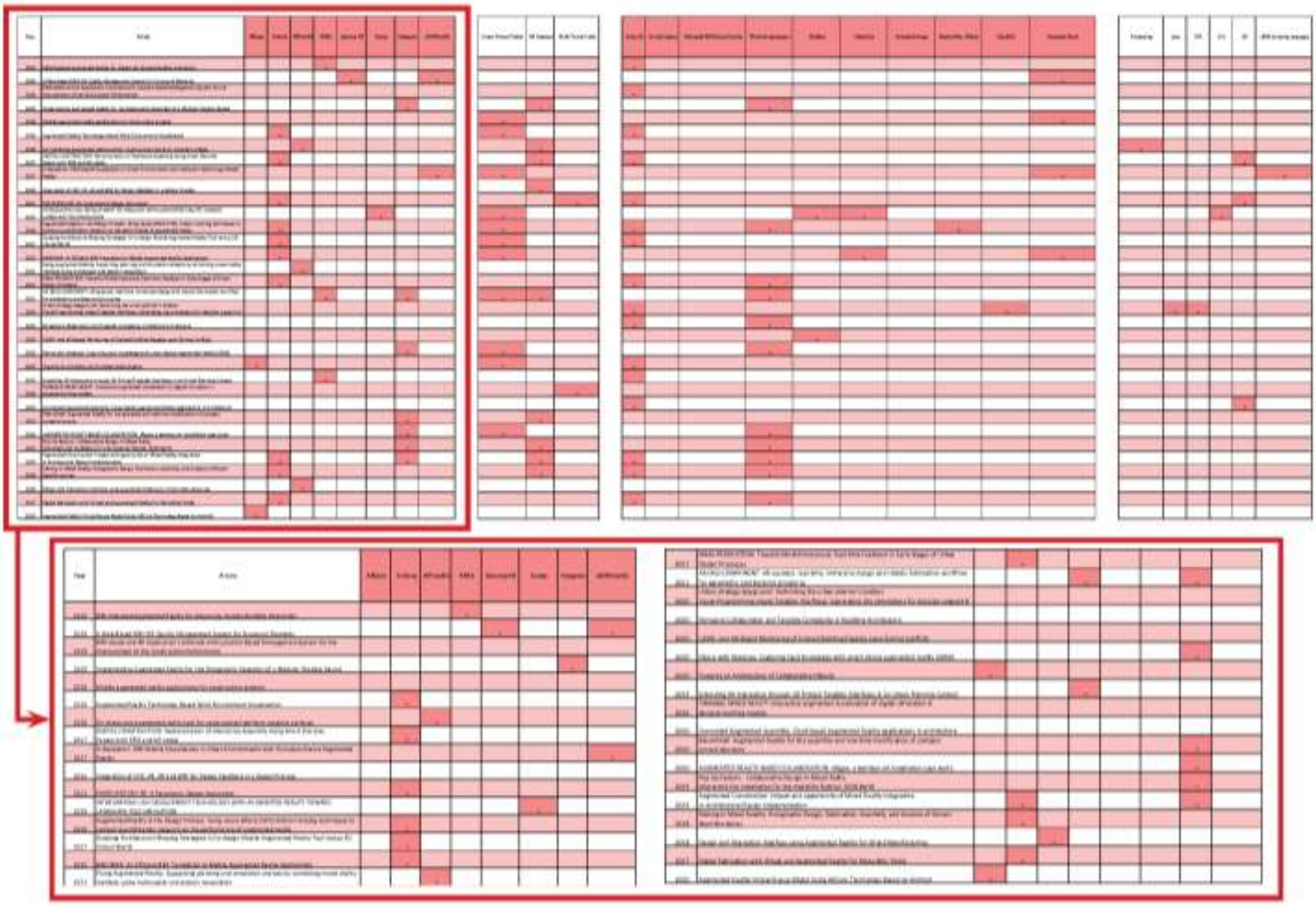

Figure 2. Literature review (filtered & generated by the authors).

In the papers pertaining to this particular field, the SDKs ARCore, Vuforia, ARToolKit, ARKit, Augment, Gamma AR, Kudan, Tango, Firebase, Estimote Indoor Location SDK, Fologram, Metaio Creator, and xBIMToolkit are examined in the first phase of the study. The Metaio Creator SDK is removed by the author because Apple acquired it in 2015 and it is no longer available. Due to their accessibility, Tango, Firebase, and Estimote Indoor Location SDK were also excluded from consideration.

Four categories—BIM/Construction/Building Physics, Architectural Design, Urban Design, and Digital Manufacturing—are used to group the articles. 28 articles on architectural design, urban design, BIM/construction/building physics, and digital manufacturing are reviewed in terms of the technological qualities of the SDKs, the opportunities they present, and the shortcomings of the preferred software (Figure 3).

Figure 3. Outputs of the SDKs in the literature review, generated by the authors.

2.1 Vuforia

This subsection focuses on nine articles that reflect how Vuforia's technological features are used, the benefits it offers, and its shortcomings.

Utilized technological features: According to Yao et al., the tracking technology of the computer vision function keeps the camera in focus. With the help of this technology, it is possible to overlay virtual and physical objects on a single real-time video [1]. In their description of the position tracking function, Abe et al. stress that it does not depend on the type of marker and can identify any marker [2]. Additionally, it features SLAM (Simultaneous Localization and Mapping) function, and the app uses AR markers to determine relative position. As a result, the location is very precise. This SDK is used by Silcock et al. as the computer vision technology tracks and recognizes 3D objects as well as photos in real-time [3]. Additionally, Vuforia permits the use of numerous trackers in the same video scene. The markers can be altered. But they ought to have sharp edges. Researchers might employ paper as virtual buttons with the aid of Vuforia, making the program more interactive. Yao et. al. drive Vuforia SDK again in their next research [4]. Because it enables the assembly of various marker types inside a single Unity 3D environment. Vuforia is run by Gül and provides a library of target objects, object identification, and additional tracking functions [5]. Sun et al. selected Vuforia due to its simplicity of use and widespread adoption [6]. Goepel uses Vuforia with HoloLens and utilizes the feature of depth mapping of this SDK [7]. Jahn and his colleagues use the Vuforia SDK to create a real scale (1:1) model. It enables the physical model to be built continuously without having to go back to the computer [8]. To sum up, utilized technological features of Vuforia is the tracking technology/position tracking, marker technology, it's library, depth mapping and synchronization.

The advantages of the SDK: Yan et al. replicate the wind's movement around a building, giving the designer the data for the early design stage [1]. Using Vuforia SDK, Abe et al. develop a system for synchronizing the physical and digital models [2]. Within the AR environment, Silcock et al. develop tangible and interactive user interfaces [3]. With the use of these user interfaces, users can design different house typologies. On the other hand, Gül develops a program that enables designers to move, rotate, scale, and alter the color of fundamental 3D geometries [5]. Sun et. al. use Unity in real-time, and the massing will change color as soon as the physical site models are modified [6]. For 1:1 scale models, Goepel creates a holographic instructor [7]. According to Jahn et al., 1:1 model construction is aided by dynamic instructions rather than static blueprints [8]. Chaltiel et al. use Vuforia to create an

AR application that highlights how the user's activities affect the structure [9]. Vuforia is applicable to many fields, including digital fabrication, building physics, urban design, and architectural design.

The SDK's shortcomings: In some registrations in the literature, like the study by Abe et al., the registration can result in a system fault. The deep consideration and calculating processes are also criticized in this piece [2]. Silcock claims that this procedure can take a long period [3]. Due to its direct compatibility with HoloLens, Goepel prefers Fologram for holographic instructions in digital fabrication [7]. However, there was no access to the recently developed software Fologram, thus, the author used Vuforia instead. The first issue with Vuforia is the registration issue brought on by the markers. Research takes time to complete. Additionally, using an HMD (head mounted display) with Vuforia is ineffective, and using Fologram in this situation could produce better results.

2.2 Fologram

This section focuses on seven publications that illustrate how Fologram is used technologically, the benefits it offers, and its shortcoming.

Utilized technological attributes: Fologram, according to Kontovourkis et al., enables interaction in the real world by augmenting, superimposing digital results and the digital information that goes with them [10]. Furthermore, this SDK allows the development and control of parametric structures. Another useful technological element of this SDK is its integration with Grasshopper, HoloLens, and smartphones [11-12]. It facilitates coordinated digital building [13]. This SDK is used in the literature because of its simplicity of use, which is another important factor [14]. It enables navigation between the various CAD/CAM phases and acts as a reference during the assembly step [15]. The Fologram SDK recognizes user gestures, screen taps, device position, it has a customizable interface on mobile phones and HoloLens, and the Fologram SDK offers the opportunity to interact with Grasshopper in the AR environment [11]. Fologram's coordinated use with Rhinoceros/Grasshopper is the primary justification for its use.

The SDK's opportunities include the simple ability to assemble sophisticated holographic structures. Construction costs and time are cut out [10]. It provides designers with an easy approach to control the robotics for the creation of manual-unachievable materials through AR, even if they lack specialized computer or programming experience [11]. It uses daylighting metrics [12]. These holographic instructions make it feasible to create anything precisely and quickly. It assists unskilled laborers in the assembly of complex structures [13-15]. Collaborative and creative production is possible [14].

The SDK has a few shortcomings, one of which is that users frequently have to rotate their heads to see all of a visual object in front of them. When live streaming or video recording takes place, there is an error in the way that virtual objects and the real world are superimposed [10]. Holograms and real-time alteration is delayed by a bad internet (Wifi) connection. Because of this, it is occasionally required to restart the device and re-scan a QR code to update the location of construction [11]. To tie the enhanced object to the specified place in a given context, it is necessary to continuously scan the marker [12].

2.3 ARCore

Two articles in the literature express the utilized technological properties of ARCore, the opportunities it provides and its shortcomings are at the focus of this study.

Utilized technology capabilities: ARCore is capable of detecting flat surfaces like floors and tables. By leveraging the facilities on the user's smartphone, in this case an Android device, the virtual object placed on the flat surface is given an anchor that is used to mark the position of the object against the surrounding environment [16]. Another advantage of this SDK is that it operates without any branding or watermarks [17].

The SDK's advantages include the ability to recognize corners, wall borders, horizontal and vertical planes. Virtual items can also be rotated, moved in accordance with the identified planes, and scaled for a closer observation [16]. It enables playing with "Collaborative Objects" in real, augmented and mixed realities [17].

The point cloud technology built into ARCore can detect a variety of textures, but it is difficult to detect monocolors, such as a white color. In the case of a dark room, it is also challenging to detect the horizontal and vertical planes because point clouds cannot detect the texture in such circumstances [16].

2.4 ARKit

Three articles express the utilized technological properties of ARKit, the opportunities it provides and its shortcomings are at the focus of this study.

Utilized technological features: The tracking system and gyroscope feature of ARKit are two of its most important technical features (it corrects orientation through an electronic compass). It enables the superimposition of a BIM model, solves model registration issues, uses tracking and motion sensors to solve tracking issues in dynamic environments, aligns the virtual model with the actual building with the possibility of manual adjustments, and is applicable to both outdoor and some indoor environments [18].

The opportunities this SDK offers: Ashour et. al. develop an application with a wireframe shader. In contrast to opaque shaders, which cause the virtual model to occlude the real-world objects, wireframe shaders shield users from hitting stationary items and oncoming traffic [18]. The user interface shows the GPS accuracy data, compass information, and geographic coordinates. Instant access to built environment-related information is made possible by this application [18]. By filtering out any buildings that were constructed around the same time as the selected building, the interface can represent changes in the physical model [19].

The SDK's shortcomings include GPS's poor accuracy as a result of its registration process. It is particularly inaccurate inside. There is a slight misalignment when moving from an outside situation to an inside environment. The computations for the IMU (inertial measuring unit) contain accumulated inaccuracies [18]. The incorporation of additional tracking methods, such as computer vision and AI (Artificial Intelligence), is this SDK's second limitation [18].

2.5 ARToolKit

Three articles express the utilized technological properties of ARToolKit, the opportunities it provides and its shortcomings are at the focus of this study.

Utilized technological attributes: Camera tracking and calibration should be precise when using the ARToolKit SDK. Otherwise, the real world's augmented guiding lines are shifted. The output results could be impacted by even minor variances and assembly errors in the camera. As a result, using the two-step calibration method offered by the ARToolKit library, each camera was calibrated separately. The majority of AR systems use just one camera. Two cameras work together in the Fazel & Izadi's system to prevent view obstructions, which frequently happen due to user movements or other potential obstacles during construction. Two cameras—one fixed and one portable—make up the capturing equipment [20]. The second camera was a component of an Head Mounted Display (HMD), while the fixed camera was attached to a CPU (in this case, a laptop running AR programs). The proposed tool was marginally quicker than the previously reported robotic fabrication techniques in this research.

The SDK's opportunities: ARToolkit provides novel, viable, and reasonably priced ways to build free-form modular surfaces [20]. Users can draw 2D curves on an existing object and then use straightforward interactions to turn those 2D curves into 3D objects. Users can interact with the designed touch-based interactive gadgets in a natural and simple way [21]. It helps to integrate architectural design with urban planning [22].

The SDK's shortcomings include the necessity of locating the object coordinates because of the use of markers. Small-scale buildings, like those of Fazel and Izadi, can easily use this technique [20]. This approach is rigid and harder to use on a broader scale. Additionally, there is limited support for occlusion [22].

2.6 Gamma AR

In one article, the technological capabilities of Gamma AR are discussed, along with the benefits and shortcomings it present.

The following technological features are used: Gamma AR updates task statuses, enabling input quality assessments on-site, visualizes the BIM Model, directly uses the IFC format, and provides the option to obtain element-specific information by simply clicking on the object. The BIM model is superimposed on the reality on site using this application positioning system's markerless tracking method, which leverages depth sensing. The inspector must select the floor and the room for positioning before selecting two corners of a wall or column in the model to superimpose it on reality. The advantages of this SDK include increased design comprehension, easier information access, effective control, and cost savings. The positioning accuracy issues and the wall model's occlusion of real items are the SDK's limitations [23].

The SDK allows the integration of augmented reality (AR) and building information modeling (BIM) technology [23].

The SDK's shortcomings include the fact that it is challenging to accurately superimpose the pins in order to create an AR experience. Occlusions create difficulties [23].

2.7 Kudan AR

In one article, the technological capabilities of Kudan AR are discussed, along with the benefits and shortcomings they present.

Utilized technological attributes: Kudan uses Simultaneous Localization and Mapping (SLAM)-based markerless AR technology [24].

The system employs the SLAM-based markerless AR algorithm named KUDAN SLAM AR to accomplish the required outdoor review function [24].

2.8 xBIMTools

This study focuses on two papers that represent the technological aspects of xBIMTools that are used, the potential they present, and their advantages and disadvantages.

Utilized technological capabilities: IFC-formatted BIM models can be read, created, and viewed using xBIMTools. Two core libraries of the xBIM toolkit are xBIM Essentials and xBIM Geometry [23]. It has cloud service that extracts the external BIM Model components [25].

The SDK's advantages include its integration of augmented reality (AR) and building information modeling (BIM) technology [23].

The SDK's shortcomings include the fact that it is challenging to accurately superimpose the pins in order to create an AR experience. Occlusions create difficulties [23]. Georeference of the offline data misses [25].

2.1. Comparative diagrams of SDKs

The most widely used SDK in the field of digital manufacturing is called Fologram; other SDKs like ARCore, ARKit, ARToolKit, and Vuforia are also used. Divergent SDKs like Gamma AR, Kudan, xBIMToolKit, Vuforia, and ARToolkit are used in the literature of BIM/Construction and Building Physics domains. While Vuforia, Fologram, and ARKit are mentioned in literature on architectural design, Vuforia and ARKit are also employed in the field of urban design (Figure 4-5).

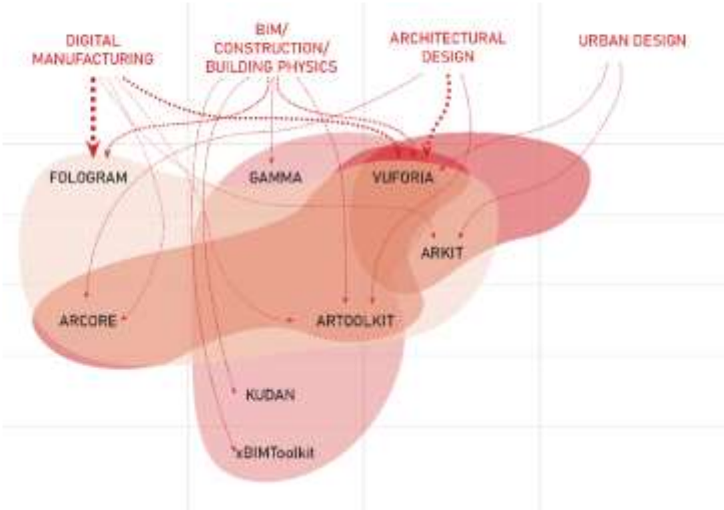

Figure 4. Relationships between the SDKs and AEC Fields generated by the authors.

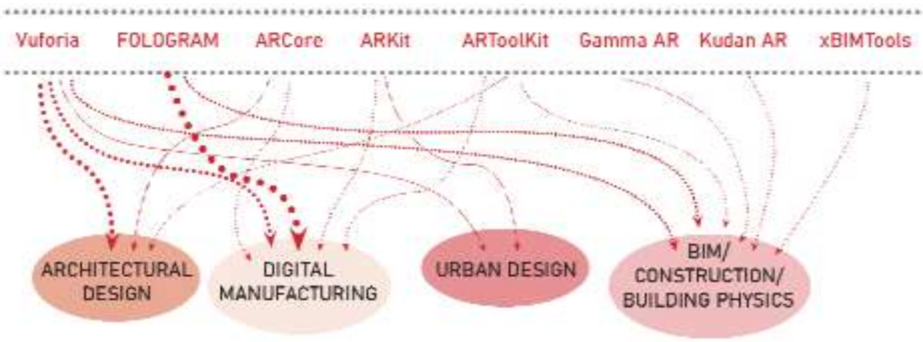

Figure 5. Relationships between the SDKs and AEC Fields generated by the authors.

While Vuforia is driven mostly by Unity 3D, Gamma AR, and xBIMTools which can also be used in conjunction with Autodesk Revit, Fologram is driven by Rhinoceros/Grasshopper (Figure 6).

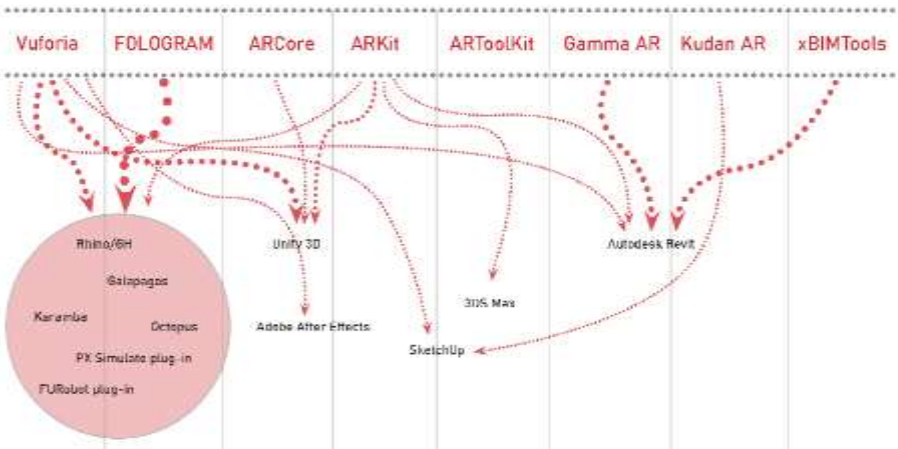

Figure 6. Relationships between the SDKs and software generated by the authors.

While smartphones and tablets are the main hardware runned with most of the SDKs, there are other tools, such as camera, multicopters, UAV camera, bluetooth and wifi enabled microcontroller, RGB Led, 3D printer, 3D scan, paper, robotic arm, smart gloves, multi touch table, head mounted display, kinect (Figure 7).

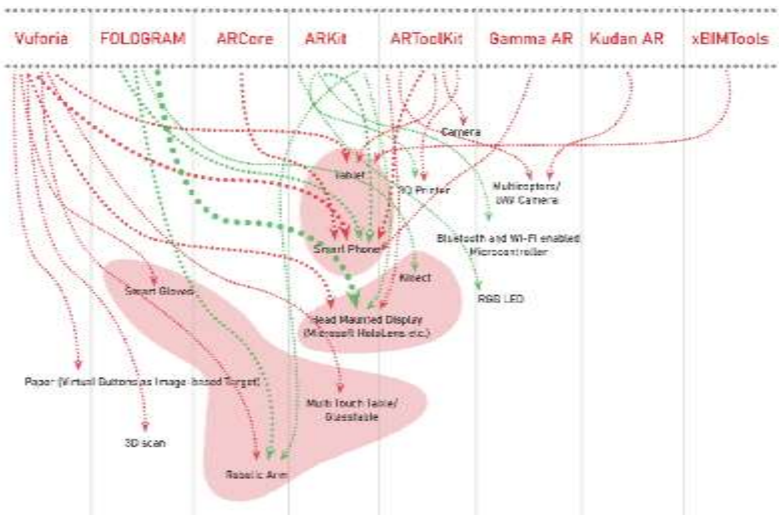

Figure 7. Relationships between the SDKs and hardware generated by the authors.

Due to their predominantly linear usage, the relationships between the SDKs and programming languages like C#, Processing, C++, and xBIM scripting language are weak (Figure 8).

Figure 8. Relationships between the SDKs and programming languages generated by the authors.

Technological properties have a more complex relationship, because mobile devices do not have similar qualities. For instance, ARKit only works with iPhones and thus, uses the TrueDepth Camera capability (Figure 9).

Figure 9. Relationships between the SDKs and technological properties generated by the authors.

3. RESULTS AND DISCUSSION

The tools used in a research affects the design of the research. The way SDKs are used is relevant in augmented reality researches, because SDKs have different functions such as light estimation, true depth camera, tracking planar images, camera calibration, motion and position tracking, environment recognition and simultaneous localization and mapping (SLAM). When developing a research, consideration should be taken in selecting the SDK that will be employed. The goal of this study is to assist the researcher in determining which SDK is required.

In this study, Vuforia is utilized more widely while Fologram, used with Grasshopper is discovered to be the front-runner in the field of digital manufacturing. Kudan, Gamma AR, xBIMToolkit are used especially in the field of Construction and BIM (Building Information Modeling). During ARKit have true depth camera function, tracking of planar images, SLAM and motion/position tracking function; ARToolKit can also track planar images and has besides camera calibration function and ARCore has light estimation and SLAM function except tracking of planar images.

Although in the design field mostly both Vuforia and Unity are used, ARCore and ARToolKit are also utilized in some cases. Fologram is the most widely used SDK and plugin in the realm of digital manufacturing since it integrates with Rhinoceros and Grasshopper easily. In addition, ARKit, ARCore, and Vuforia are used in digital manufacturing.

The development of applications using these SDKs for architectural and urban design, BIM/construction, and digital manufacturing is crucial for the study's next phase because it will allow the testing of SDKs. The sound built into the SDKs may also be employed in navigation systems in the future to aid laypeople.

4. CONCLUSION

The studies in the literature are oriented by the state-of-the-art of mobile AR applications in terms of their potentials and shortcomings. According to the findings, using more mobile application SDKs improves research in a variety of ways. As a result of the research, it is observed that Software Development Kits are useful in a variety of sectors, and studies have shown that using these kits leads in shorter working hours, lower budget, and more accurate outcomes.

This research is constrained by 184 research publications in the AEC industry that use SDKs. These articles do not cover all SDKs, including DeepAR, Wikitude, Easy AR, D'Fusion, and ARMedia. Comparing with other SDKs will require more thorough research.

Artificial intelligence, deep learning and computer vision are required to improve the SDKs. The technological capabilities and shortcomings of SDKs have an impact on how research is designed. For this reason, it's crucial to choose the SDKs based on the area of focus. During the research phase, it's crucial to construct relationship diagrams that show which SDK should be used and what would happen as a result.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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