Marker-Based and Area-Target-Based User Tracking for Virtual Reconstruction of Cultural Heritage in Mixed Reality

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Abstract. The focus of this paper is the potential of mixed reality (MR) technology for the creation of virtual reconstructions of tangible and intangible cultural heritage. It delves into the key components of immersive and engaging MR experiences. The paper provides insights into the development process of an MR application prototype that virtualises cultural heritage pieces. It covers concept design and implementation, offering a comprehensive understanding of the steps involved. Additionally, it discusses the advantages of tracking approaches for user localisation, specifically marker-based and area-target-based tracking, in the use case of cultural heritage reconstruction. In summary, this paper offers insights into the current state-of-the-art by analysing exemplary projects and the potential of MR technology for virtual reconstruction of cultural heritage sites. With the presentation of an MR prototype and the key development steps involved, the paper contributes to the understanding and utilisation of MR in preserving and presenting our shared cultural heritage.

Keywords: Digital Cultural Heritage · Extended Reality · Digitalisation

1 Introduction

The preservation of cultural heritage and historical information has always been reliant on archival documentation. However, traditional storage and access methods have limitations, like the risk of loss of or damage to physical documents and difficulties in interpreting their content accurately, that increase over time. Fortunately, digitalisation has emerged as a practical solution to these challenges, enabling easier storage, access, and preservation of important archival documents.

As technology advances, new opportunities arise to enhance our engagement with archival documentation. One such technology is mixed reality, which has the potential to revolutionise the way we interpret and interact with historical artefacts long-term. Through MR, we can transform archival documents into immersive experiences that offer deeper insights into historical events and cultural heritage.

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A successor project of the recent EU-funded project AURA[1] explored the digitalisation and MR visualisation of archival documentation from the Archivio Storico[2] of the Teatro del Maggio Musicale Fiorentino[3] in Italy. The project aimed to create an immersive and interactive experience of the historical scenography of Shakespeare's „Othello" tragedy, performed at the theatre in 1937.

This paper delves into the development of a digitalised 3D model and MR visualisation of archival documentation, emphasising the significance of reinterpretation in MR as a means to improve access and preservation of the information contained in these documents. It discusses the technology required to display the augmented scenography correctly on a theatre stage, considering the unique conditions of theatre halls and their suitability for presenting virtual objects in MR. Additionally, the paper will discuss a marker-based and area-target-based tracking approach and find advantages and disadvantages for this use case.

Finally, the paper concludes with a future outlook on the digitalisation of archives and the visualisation of archival documents in MR. By leveraging MR technology, we can engage with historical artefacts in immersive and interactive ways, fostering greater appreciation and understanding of our cultural heritage. The potential for MR to revolutionise access and interaction with archival documentation is immense, and further exploration and development of its applications in this field are crucial.

2 State of the Art

Digitalising and virtualising tangible as well as intangible cultural heritage has been of interest for several years. Different forms of applications that fall on the spectrum of reality and virtuality have explored the potentials of modern technology for the reinterpretation of culture and history and have opened up new ways of engaging users in creative and innovative ways.

On the spectrum of reality-virtuality, environments are categorised based on their level of immersion and interaction. This can range from the real world to virtual environments and everything in between [1]. In augmented reality (AR), just like mixed reality, digital information or models are inserted in the user's field of view to replace or add on top of the existing objects in the real world. This technology has been proven to be of high value for the handling and conservation of Cultural Heritage. In [2] eight trending topics for AR application in the context of Cultural Heritage were disclosed: 3D reconstruction of cultural artefacts, digital heritage, virtual museums, user experience, education, tourism, intangible cultural heritage, and gamification.

Numerous projects have specifically explored these topics in AR and MR. A significant benefit of the technologies is the ability to recreate and visualise ancient structures and artefacts that may no longer exist or are in remote locations. AR and MR technologies enable users to virtually walk through historical sites, interact with virtual exhibits, and experience cultural heritage in previously impossible ways. It enhances the learning

[1] https://aura-project.eu/en/.

[2] https://www.maggiofiorentino.com/archivio-storico/.

[3] https://www.maggiofiorentino.com.

and educational experiences for both students and tourists. Through interactive storytelling and virtual guides, users can delve into the rich history and context of cultural heritage, fostering a deeper understanding and appreciation of our past [3, 4].

To correctly position the augmented content, a form of marker tracking has to be implemented. Generally, it can be distinguished between marker-based and markerless tracking. Marker-based applications rely on visual markers, also known as fiducial markers, like icons, images, QR codes, etc. combined with computer vision recognition algorithms that ensure correct identification. These markers can be recognised by the device's camera stream, allowing for position and orientation calculation relative to the camera or vice versa. In MR, the virtual elements are then rendered in front of or in relation to the marker [5].

Marker-less tracking, on the other hand, involves the recognition and tracking of key feature points within a predefined environment, also called an area target. Unlike marker-based systems, markerless tracking does not require the placement of physical markers. The virtual content can be rendered seamlessly in the environment. However, this form of tracking can require more computational power [5].

One example was the marker-less AR application, developed by Indrawan [6], where a gyroscope was utilised to demonstrate the position of Dewata Nawa Sanga, one of the Hindu gods. Users could learn and understand the properties of Dewata Nawa Sanga by using the gyroscope sensor to identify the deities' coordinates. It also provides informative 3D animations about Dewata Nawa Sanga. After evaluating the application's usefulness, functionality, and impact on users' motivation. 84.8% of the participants found the application very useful and were highly satisfied with its use [6].

In the following, a concept design for an MR application will be described featuring the 3D digitalisation of an archival document, user interface conventions in MR and interaction systems for immersive applications.

3 Concept Design

Upon evaluating the prevailing trends in digitalisation and virtual reconstruction of cultural heritage, the prerequisites for an innovative application were found, and a design concept for an MR application of an augmented scenography piece was formulated.

The application concept will be deployed on a HoloLens. The objective is to create an immersive and interactive experience that allows users to explore and gain knowledge about a specific cultural artefact, primarily focusing on historical scenography documents from the Archivio Storico of the Teatro del Maggio Musicale Fiorentino. In particular, the scenography of Shakespeare's "Othello" tragedy was to be modelled and virtualised in MR on the stage of an opera hall (Fig. 1).

To ensure precise projection of the 3D model on the stage, a form of user tracking is essential. As such, the application should incorporate advanced tracking technology to accurately map the position and orientation of the artefact in real-time. This enables users to observe it from various angles and perspectives, enhancing the overall experience. Hereby two approaches are to be tested, the projection of content through the recognition of an area target and a marker. For area-target-based tracking, the whole room, including the stage, needs to be scanned and can be tracked by the application, whereas marker-based only facilitates one image, QR code or similar figures.

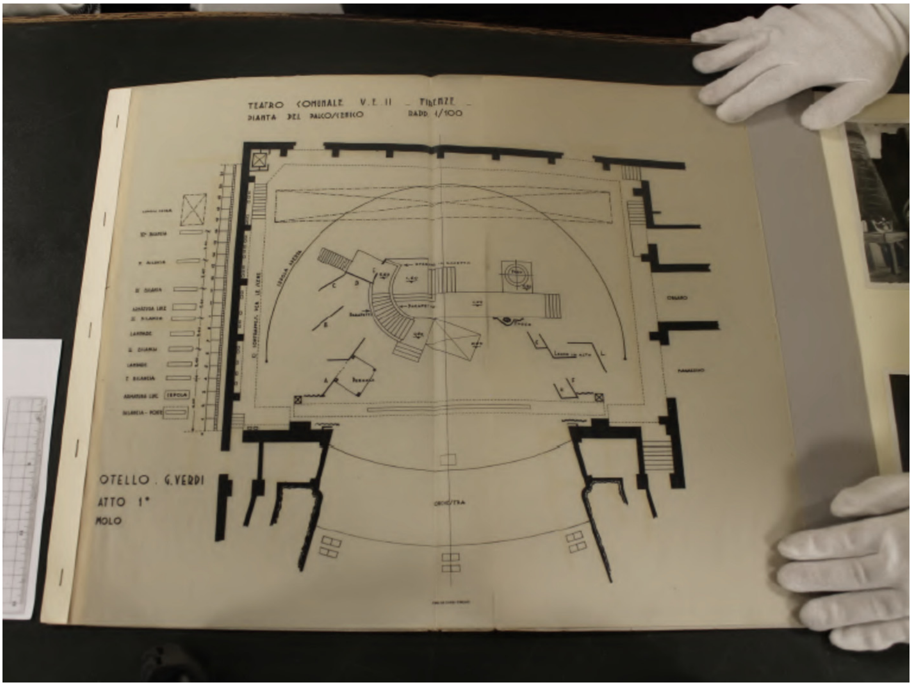

Fig. 1. Scenography document of a scene from "Othello"

Fig. 2. UI and interaction examples for HoloLens [6]

Optimised for the HoloLens 2, the application should take advantage of its implemented hand gestures and offer basic interaction capabilities. Gesture recognition empowers users to engage with the artefact by manipulating it through intuitive hand gestures.

To maximise accessibility, the design should follow a user-centric approach, emphasising usability. The user interface (UI) should be intuitive, facilitating easy navigation and providing clear instructions, adhering to best-practice examples and UI conventions for MR (Fig. 2).

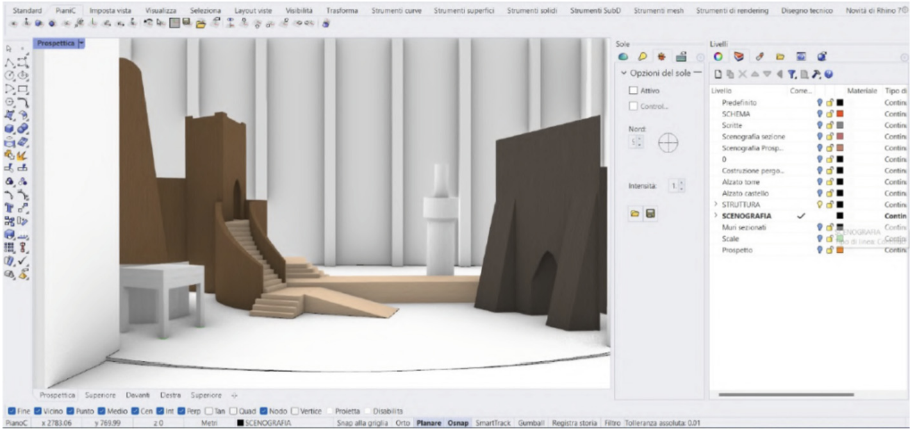

Fig. 3. 3D model of scenography in Rhinoceros

In summary, the application concept aims to deliver a distinct and captivating way for users to immerse themselves in and comprehend cultural heritage pieces. It is intended to offer a unique opportunity to learn about and engage with these cultural artefacts uniquely and memorably.

4 Implementation

Firstly, to implement the concept, the scenography drawings from the archive were detailedly documented. With the 3D modelling software Rhinoceros, a reproduction of the scenography was created (Fig. 3). The original documentation lacked specified information on used materials, colours, and textures. Through observation of photographs, these details were estimated. From the modelling software, the 3D object was exported as a.fbx file and easily imported into the project in the Unity engine, which would be used for further MR development.

During the digitalisation process, the development of the MR application was already started. Unity was chosen not only because of its broad documentation and compatibility with several frameworks but also for the fast and simple deployment process onto the HoloLens device and other MR and VR head-mounted devices, where only slight adjustments have to be made.

The MR functionality was added through the Mixed Reality Toolkit (MRTK), which holds essential features and resources for MR development. After setting the build platform to Universal Windows Platform, seamless deployment to HoloLens was ensured. The scene was adjusted by integrating configuration and components like MixedRealityToolkit, MixedRealityPlayspace, including the main camera, and MixedRealitySceneContent, which serve as the foundation for MR applications.

Following the initial concept design, special care was taken to ensure the UI elements adhered to established conventions and best practices for MR applications. A floating menu was introduced to facilitate intuitive navigation and offer additional interaction options. Employing a consistent visual language, including appropriate colours, fonts, and iconography, the UI elements seamlessly blended into the MR experience without distracting from the main focus—exploration and interaction with the virtualised historical scenography.

To implement user tracking, the tool Vuforia was used, through which the application can utilise the built-in sensors and cameras of the HoloLens device. These sensors capture the user's movements and surroundings, providing valuable input for the tracking system.

During runtime, the application continuously captures and analyses the HoloLens sensor data, feeding it into the Vuforia tracking system. The system then processes this data in real-time. The key feature points from the device's camera stream are continuously analysed for matches with marker data from the Vuforia database. In case a marker target is correctly recognised, virtual objects can be rendered dynamically with accurate alignment to the user's perspective.

This approach was once implemented with an area target, where the hall, including the theatre's stage, was captured. With the help of the Vuforia Area Target Creator app, the hall of the Teatro della Pergola was scanned through a LiDAR scanner. The Teatro della Pergola[4] was chosen because of its accessibility and fitting stage dimension, which adhere to the original stage the "Othello" tragedy was performed on (Fig. 7).

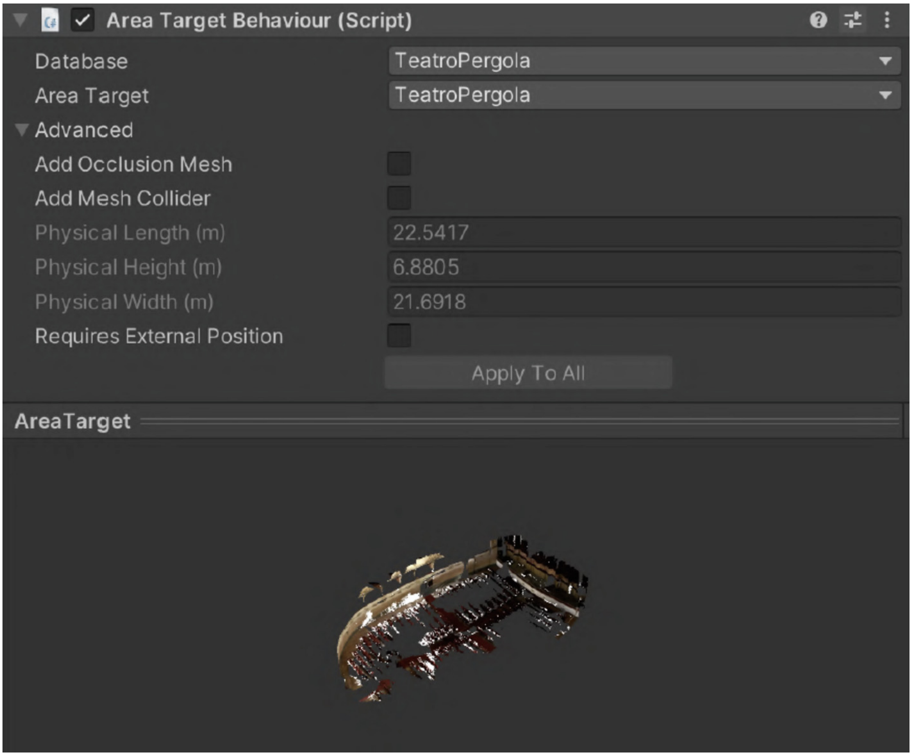

Fig. 4. Vuforia area target in Unity

4 https://www.teatrodellapergola.com.

The area target could then be selected in Unity (Fig. 4), and an event handler implemented the functionality for displaying content once the target was found (Fig. 5). In case the target is no longer within the camera stream, the content will be disabled.

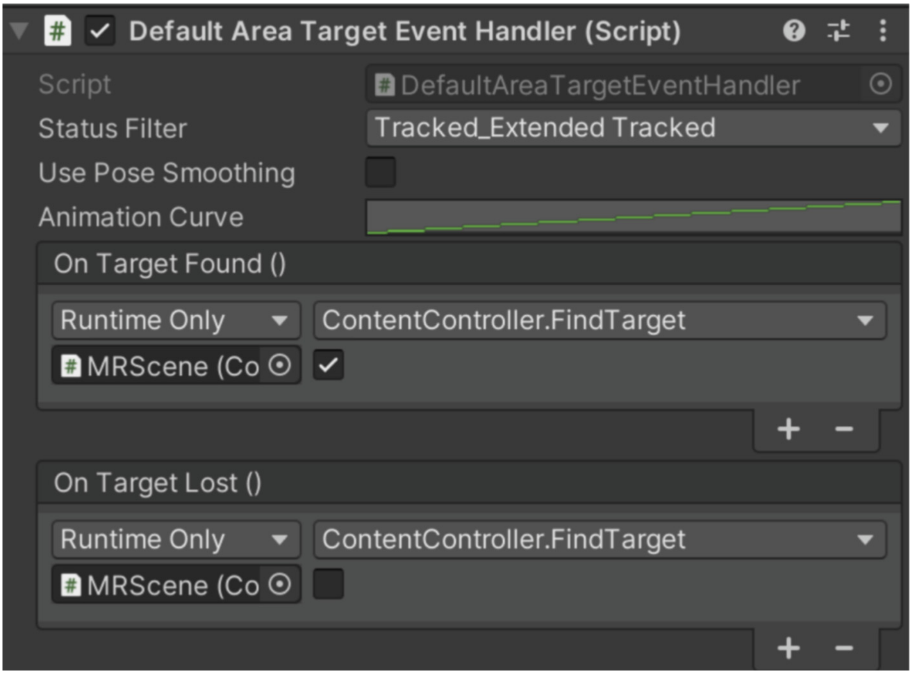

Fig. 5. Area target event handler in Unity

A second approach was implemented using an image marker which can be added by simply configuring an ImageTarget game object from the Vuforia library and inserting the desired image as a.jpg or.png file (Fig. 6).

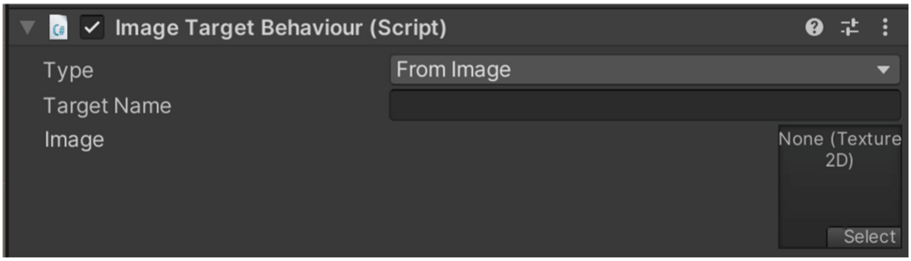

Fig. 6. Vuforia image target in Unity

The original scenography document was chosen as the image marker and uploaded to the Vuforia database. The augmentability was rated five stars out of five by Vuforia, making it very suitable for tracking. The key feature points of the image can be seen in the figure below.

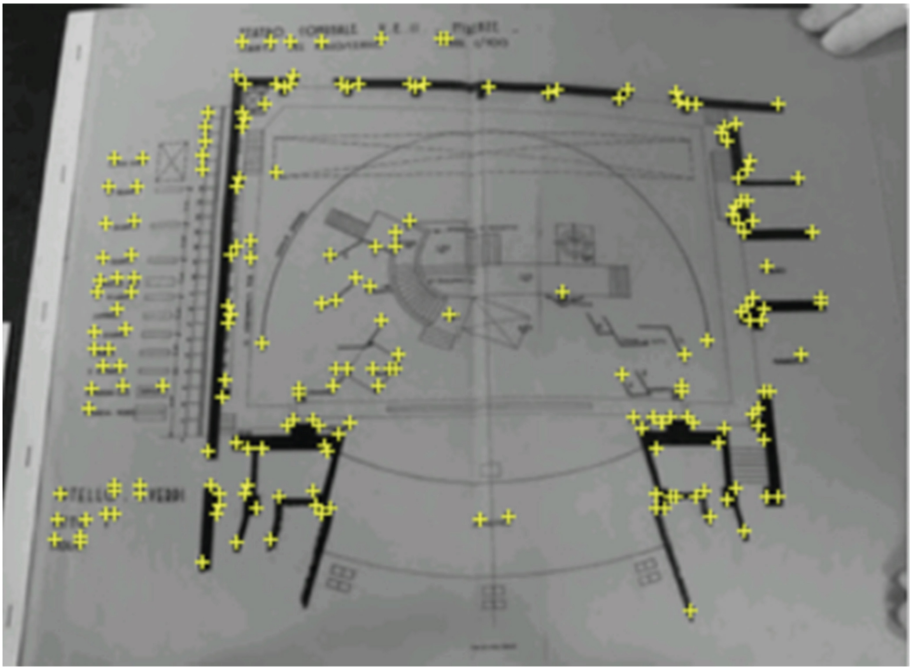

Fig. 7. Feature points of image target in Vuforia database

The resulting MR application visualised a reconstructed scenography from the Archivio Storico in Florence, Italy, enabling users to view and interact with it on a theatre stage (Fig. 8).

5 Discussion

Comparing the two approaches revealed advantages and disadvantages for either version. The advantages of marker-based tracking, through an image marker, were, among others, the reliable and robust tracking performances. Well-chosen markers with many key feature points serve as distinct visual references, allowing for precise alignment of the virtual content with the real world.

Furthermore, high accuracy in tracking the user's position and orientation can be achieved since the markers provide a fixed reference point, enabling accurate spatial registration of virtual objects within the physical space.

Moreover, marker-based tracking is scalable and implementable in various environments and scenarios, making it easy to embed in cultural heritage sites for both small-scale and large-scale applications. In this use case, the marker could simply be placed on the stage or moved to a different space if needed.

However, a disadvantage that became apparent was the overall dependency and presence of markers in the environment. This can limit the freedom of movement for users and may not be suitable for scenarios where markers are not feasible or desirable, such as in outdoor or dynamic environments. This also includes occlusion errors that

Fig. 8. Scenography model in MR application on the stage

occur when markers are partially or completely hidden from the camera's view. Users or objects obstructing the markers can cause temporary tracking disruptions, impacting the user experience.

Markerless tracking, through the use of area targets, provides users more freedom of movement and comes with a different range of benefits but weaknesses as well. Area-target-based methods can perform real-time mapping of the environment, allowing for dynamic interactions with the virtual content. This is particularly advantageous when exploring cultural heritage sites with complex architectural structures.

The tracking and integration of virtual content within the physical space work seamlessly, as it uses the environment itself as a reference, enhancing the sense of realism and immersion of the mixed reality application.

Some disadvantages of the area-target-based approach, however, are the environmental limitations, such as lighting changes or textureless surfaces. In challenging lighting or featureless environments, tracking accuracy may be compromised, which affects the alignment of virtual content. In very unsuitable conditions, the area might not be recognised at all. This can especially be the case in theatre halls that might only be partially lit or do not cover many unique feature points.

Additionally, area targets often involve computationally intensive processes, such as depth sensing, mapping, or point cloud registration. This complexity, also depending on the size of the area, may require more powerful hardware or computational resources, which can impact the overall performance and usability of the mixed reality application on devices like HoloLens. Since Vuforia has limitations on size and scanning time, large theatre halls might be too big to be scanned, making it impossible to use the entire halls as a marker.

Also, inaccurate mapping of the environment can lead to misalignments between virtual and physical objects. These errors can occur when capturing the environment or when handling dynamic scenes and can potentially impact the fidelity and accuracy of the virtual cultural heritage representation.

To sum up, the choice between marker-based and area-target-based tracking depends on the specific requirements of the use case, constraints within the environment, and characteristics of the cultural heritage application. Both approaches have their strengths and limitations, and the suitability of each method should be carefully considered based on the context and goals of the virtual reconstruction application.

6 Conclusion

In conclusion, digitalising and visualising cultural heritage in MR can bring exciting opportunities to explore and experience history. An important part of an MR application is the chosen form of user tracking to ensure accurate alignment and seamless integration of virtual content in the cultural space.

Marker-based tracking provides robustness and accuracy, relying on predefined markers as visual references. Correctly designed makers can lead to precise spatial registration, making it suitable for scenarios where high precision and detailed virtual reconstructions are necessary. On the other hand, markerless tracking utilises the natural features and structure of the environment and uses the whole area as a marker. This approach offers real-time mapping, enhancing dynamic interactions with virtual content and creating more authentic mixed reality experiences.

Both marker-based and area-target-based tracking approaches have their strengths and limitations. Ultimately, the use case and the formulated requirements will determine the better suitable technology.

In the future, improvements through further progress in sensor technologies and machine learning can be expected, leading to enhancements in tracking accuracy, robustness, and overall performance of cultural heritage MR applications and thus making the user experience more immersive.

As the field continues to evolve, researchers and stakeholders need to collaborate and explore innovative solutions for reconstructing and preserving cultural heritage. By leveraging the potential of MR, new dimensions of knowledge, engagement, and appreciation for the shared cultural heritage can be achieved.

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