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Using photogrammetry and augmented reality in architectural visualization. A mixed reality exhibition of the Otto Wagner Pavilion at the Karlsplatz, Vienna.

OTTO *WAGNER* *APP*

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KURZFASSUNG

Es ist schwierig die Architektur als Gegenstand einer Präsentation in Museen auszustellen. Das generelle Problem bei der Architekturausstellung besteht in einigen Aspekten: wie soll man etwas so umfangreiches und komplexes wie ein Gebäude ausstellen und wie soll man etwas so unfassbar wie Architekturerfahrung verlaufend in Raum und Zeit kommunizieren. Die Hauptfragen der konventionellen Ausstellungstechnik befassen sich sowohl mit der Ausstellung von Objekten in vollem Maß, als auch der Ausstellung von etwas nicht existierendem und wie sind die für die Zukunft vorgeschlagenen Bauwerke zusammen mit dem Umgebungskontext zu präsentieren, oder wie soll man die Designgrundsätze erklären, die meistens für die Besucher unsichtbar sind. Es gibt auch alternative Wege im Vergleich zu den konventionellen Ausstellungstechniken für Präsentation und Darstellung von Geschichten über Architektur und Design. Die vorgeschlagene Lösung für einige der oben erwähnten allgemeinen Probleme ist die Verwendung von der Photogrammetrie Technik und der Augmented Reality (AR).

Das Ziel dieser Arbeit ist es zu zeigen, wie diese zwei Techniken, Augmented Reality und Photogrammetrie zur Verbesserung der Präsentation und zur Erklärung der Architekturarbeit verwendet werden können. Als Case Study wird ein Prototyp der AR Applikation an einem allgemein verbreiteten Multifunktionsgerät präsentiert. Der Inhalt dieses Prototyps basiert auf der Architekturausstellung des Otto Wagner Pavillons am Karlsplatz.

Zum ersten werden ein paar theoretischen Aspekte der AR Technik erläutert und zusammen mit einigen existierenden Beispielen für Ausstellungszwecke in der Architekturdomäne dargestellt. Zum zweiten wird ein technischer Überblick der Fotogrammetrie und ihre historische Entwicklung dargelegt und zusammen mit einem Beispiel der Videogrammetrie des dreidimensionellen Models vom Karlsplatzpavillon dargestellt. Zum dritten wird die Otto Wagner Biographie präsentiert. Des Weiteren werden seine Werke, Designgrundsätze und die Ausstellung, die dem Vater der Wiener Moderne gewidmet ist, in einer virtuellen Ausstellung gezeigt.

Den Kapiteln mit theoretischem Hintergrund folgen Kapiteln die die Erklärung des Konzepts und Inhalts der gestaltenen AR Ausstellung des Otto Wagner Pavillons enthalten. Der Gesamtprozess der dreidimensionellen Gestaltung und der Test dieser Applikation für ausgewählte Smartphones wird demnächst detailliert beschrieben. Erstens, der Implementierungsteil fokussiert sich auf die Entwicklung der photometrischen dreidimensionellen AR Applikation und ihre Vorteile. Zweitens, um die Verwendungsmöglichkeiten des Photogrammetrieverfahrens zu demonstrieren, wurden drei realen Objekte aus dem Alltag mit unterschiedlicher Komplexität und unterschiedlichem Umfeld analysiert, die die möglichen Implementierungen in einer AR Applikation veranschaulichen. Drittens, werden die Game Engine Programme, im Hinblick auf die technischen Anforderungen und den Grundarbeitsablauf, präsentiert. Letztens, werden die Projektergebnisse zur Otto Wagners Geschichte mittels Augmentation an digitalen Kopien der realen Objekten dargestellt und untersucht. Dies umfasst die Einführungsschritte um einem nicht erfahrenen Benutzer mehr Wissen über Otto Wagner beizubringen und um seine Designgrundsätze in Hinsicht auf die AR Applikation zu verstehen. Dies wird als eine Erweiterung der Architekturausstellung im Otto Wagner Pavillon am Karlsplatz, die derzeit mittels üblicher Methoden präsentiert wird, genutzt.

SCHLÜSSELWÖRTER: VIRTUELLE AUSSTELLUNG, PHOTOGRAMMETRIE, AUGMENTED REALITY, OTTO WAGNER

ABSTRACT

Architecture as an object of presentation that is difficult to exhibit in museums. The general problems of exhibiting architecture entails several issues: how to exhibit something as large and complex as a building, and how to communicate something as elusive as an architectural experience that unfolds in space and time. The major questions of the conventional exhibition techniques are how to exhibit objects in full scale, how to exhibit something non-existent, how to present future designed buildings with the surrounding context, or how to explain the design principles that are mostly invisible for the visitors. There are also alternative ways other than the conventional exhibition techniques for presenting and telling engaging stories about architecture and design. The proposed solution for some of the aforementioned common problems is the usage of photogrammetry and augmented reality (AR) technology.

The objective of this work is to show how the two technologies, Augmented Reality and photogrammetry, can be used to improve the presentation and explanation of architectural works. As a case study, the prototype AR application on a common handhold device is presented. The content of this prototype is based on the architecture exhibition of Otto Wagner´s Karlsplatz Pavilion.

First, some theoretical aspects of the AR technology are presented with several existing examples used for exhibition purposes in the architecture domain. Second, a technical overview of the photogrammetry and its historical development is introduced together with a videogrammetry example of a three-dimensional model of the Karlsplatz Pavilion. Third, a biography of Otto Wagner is described. Furthermore, his work, design principles and exhibition dedicated to "the father of the Viennese modernism" are shown in a virtual exhibition.

The chapters with theoretical background are followed by chapters containing the explanation of the concept and content of the created AR exhibition application for the Otto Wagner Pavilion. The complete process of the three-dimensional assets creation and the test application built for the selected smartphone is described in a more accurate detail. First, the implementation part focuses on the development of the photogrammetrical three-dimensional asset for the AR application. Second, to demonstrate the feasibility of using the photogrammetry method, three real-world objects of different complexities and different environments were analysed, showing the possible implementations in an AR application. Third, the used game engine programmes, focused on the technical requirements and basic workflow, are presented. Lastly, the results of the projects regarding the Otto Wagner story are presented and examined through augmentations on digital copies of real objects. This includes introduction steps to allow a non-experienced user to learn about Otto Wagner and to understand his design principles with the aid of an AR application. This is used as an extension of the architecture exhibition, currently presented through the contemporary methods in Otto Wagner Pavilion at Karlsplatz.

KEY WORDS: VIRTUAL EXHIBITION, PHOTOGRAMMETRY, AUGMENTED REALITY, OTTO WAGNER

CONTENT

INTRODUCTION

An exhibition is a multidisciplinary process of conveying information through visual storytelling and environment. In the art world, curating is a necessary operation that - as the world´s etymological roots attest - “treats“ or “cures“ art, making it visible and even understandable to the audience. It can be assumed that without exhibiting there is very little art. Architecture, on the other hand, already exists in the “real world“, in the public domain, as functional, three-dimensional, material element [Patteeuw et al, 2012]. The architecture object as a result of a design process can be visited, observed and examined in full scale. That is the reason why the traditional architecture exhibition concentrates more to present architect´s working methods, reveal the design evolution and uncover the building story. Some of architecture exhibitions focused only on monographic content often regarding the figure of the architect as an artist. Different type of architecture exhibition is used to present results of architecture competitions. In this type of exhibitions a clear and comprehensible representation of the designs to a non-experienced audience is needed. The architecture exhibition is frequently the way how the results are communicated and translated to a general public.

The medium used for architecture representations are commonly flat two-dimensional photographs, drawings and scaled models, CAD renderings (computer-generated images of the building as it might appear in real life), which communicate aspects of the architecture, but rarely allow visitors to experience its powerful spatial and material quality. Perceiving architecture in front of historical building or inside the Gothic church can be very different experience from standing in an architecture exhibition and reading walls full of descriptions. The common methods divide the exhibited buildings in separate isolated forms of different media. Ordinary audience is often left clueless about the design steps and the architecture itself. Admittedly, architectural drawings, photographs, models or experimental structures in art galleries are often presented as an "art of architecture" and treated as objects of fine art. The other problem is in displaying building in 1:1 scale, imitating architecture, or emphasising the exhibition architecture itself.

There are also other ways how to exhibit and tell engaging stories about architecture and design other than using common exhibition techniques. Innovative methods are needed for architecture exhibition to deliver more ambitious impacts. The solution is offered by presenting objects with explanation powered with modern digital techniques in virtual space where the size of exhibiting objects is not determined by real physical borders of the exhibiting area.

One of the technologies with the ability to achieve exhibiting objects in virtual space with the context to real physical world is Augmented Reality (AR). AR is the integration of digital information with the user's environment in real time. In comparison with virtual reality, which creates a totally artificial environment, the augmented reality uses the existing environment and overlays new information on top of it. This technique has been already used for the art-architecture exhibition. Modern Techniques as AR or VR (i.e. Virtual reality) are nowadays used to deliver a message, to present the charm of designed architecture. It is equally important to reproduce the context, recreate the design ideas and the design process. The mixed exhibition created from AR technology and common exhibition methods allow simple synchronisation of building´s visual representation and aligning analogue and digital exhibits to multiple meaningful combinations that provide an effective, intuitive means to help the audience minds integrate diverse forms of exhibitions.

Monographic architecture exhibition focused on the figure of the architect as an artist and a 'creative genius'. The art of architecture exhibition includes an abundance of original models, interior settings, drawings, furniture, photographs, films, tapestries, paintings, sculptures and books designed and written by the architect himself. There are also other options how to solve the absence of the finished article, for example, by creating an exhibition in a building designed by an architect. Same opportunity used the permanent exhibition about Otto Wagner in one of his light urban railway stations in Vienna. The permanent architecture exhibition is dedicated to Otto Koloman Wagner as one of the most significant architects at the turn of the 20th century. His buildings are milestones on the path from historicism to modernism. The magnificent buildings with unique architecture are characterizing the face of the city Vienna. In 2018 it was the 100th anniversary of Wagner´s death and the Vienna Museum presented the complete work of this globally relevant architect. *“Unbelievable, that the last great Otto Wagner exhibition in Vienna was 55 years ago. This inspires to go to the Vienna Museum and to read the sensationally beautiful catalogue. It may be the last chance for many in their lives to get Otto Wagner’s work so well-founded. It should be used.“* [Die Presse, 2018]. The permanent exhibition dedicated to Otto Wagner´s life and work took place in the former light rail Pavilion at Karlsplatz. This former light rail station was built in 1898 and designed by Otto Wagner. The advantage phenomena of exhibiting figure of the architect in one of his buildings and present not just text, models and plans but also part of the architecture in scale 1:1, the building itself makes this small exhibition unique. The permanent exhibition fits in $94m^2$, compared to the anniversary exhibition in 2018, the exhibition space then was more than five times bigger. In this case it would not be possible with usual methods to cover and present the same amount of content on such a small space as the Karlsplatz Pavilion.

The goal of this thesis is to demonstrate how architecture can be represented in exhibition settings today, and present a solution applying modern technologies - AR and digital photogrammetry. These tools create interactive and understandable view of a various visual information such as models, drawings and photos in digital and conventional formats.

After a general introduction the historical background of the architecture exhibition design is given in Chapter 1.

Chapter 2 presents the relevant background of the augmented reality technology and concrete examples of applying AR for exhibition.

Chapter 3 is focused on the topic of photogrammetry. Next to the relevant technological background it presents the historical development of the technology and the examples of photogrammetry technology usage for creating the Karlsplatz Pavilion model.

In Chapter 4 Otto Wagner and his design rules are described. Furthermore, the exhibitions dedicated to Otto Wagner are shown.

Chapter 5 presents the building process of the application with the content focused on the virtual architecture exhibition of Otto Wagner. The concept and content of the presentation is followed with the workflow description used to create the final exhibition. Selected scenario demonstrates the possibilities for the visualisation and presentation of the architecture in AR. The case study applies 3D survey techniques, digital photogrammetry to collect and create digital 3D assets of Otto Wagner’s architecture elements. These are introduced interactively in virtual space due to AR technologies. After presenting all steps needed to create the 3D assets and elements used to build the platform, the single application is demonstrated, and further development is discussed. The story of Otto Wagner´s City Rail will be brought to a new level of experience. Visitors will be no more just silent witnesses of Otto Wagner's phenomena.

1.1 Historical development of architecture exhibition design

The exhibiting design is considerably and simultaneously developed with the improvement of technologies and architecture as an object of exhibition. The current chapter will introduce the development of architecture exhibition with an overview by presenting selected exhibitions relevant to this thesis. Exhibition design dates virtually from early human development, but first became formalized in the "cabinets of curiosity" of the 17th century as people began to travel through the world and displayed their treasures in private collections [@segd].

In the 1767 newly established space was the Salon de Paris, shown in Aubin's aquarelle. Various objects were exhibited alongside each other, including history paintings, portraits, landscapes, portrait busts, and stucco models for large sculptures. Exhibited objects were displayed hierarchically, depending on size. The Salon exhibitions were mentioned in periodicals to attract attention of wider audience to visit this exhibition event.

One of the first public exhibitions for the "common people" were organized at the Louvre in 1792, as a Museum of the French Republic. Paintings, furniture and other art objects taken from the aristocracy were placed on public display. It was also the first time when the owner of the collection was the Republic, the nation, and no longer an individual owner. Hubert Locher describes how exhibitions were increasingly regarded as narratives, in which the meanings of single, autonomous works of art were placed within an overall context: "Shortly after 1800, Friedrich Schlegel, the German philosopher and theorist of art and literature used the term "exhibition" in the context of a museum presentation. While in Paris, he visited Louvre to see the displayed works that Napoleon had looted, especially in Italy. Schlegel described his experience for German readers interested in art in a journal that he edited. In the light of a series of the most important canonical paintings he observed that each arrangement of a series of paintings in an exhibition presented the viewer with a new "body" and that such presentation entailed a new concept" [Locher, 2002].

During the 19th century, national gallery exhibitions and world fairs were held across Europe and in the United States. The history of putting architecture on display in the modern era has been informed by several interrelated traditions, ranging from late 18th century landscape architecture and garden design. These theorized the choreography of objects in spaces of experience, to display the progress and nationalism that characterized the industrial fairs and the national pavilions of world expositions inaugurated by the Great Exhibition of the Works of Industry of all Nations in October 1851 [Carter, 2012].

In the beginning of 20th century the walls in the galleries are getting white colour. Especially in the Vienna Secession exhibition arrangements became increasingly colder from 1903 onward. In 1910, a solo exhibition of the works of Gustav Klimt presented the modern exhibition practice to an international audience.

The Venice Biennale, founded in 1895, played a role in spreading the modern principles and aesthetics practice. In 1927 Ludwig Mies van der Rohe together with architect and designer Lilly Reich, was commissioned by the Association of German Silk manufacturers to create a stand for the German Silk industry in the context of the exhibition "Die Mode der Dame". The result is the "Café Samt & Seide" (Velvet and Silk Cafe) in Berlin, an exhibition stand which also worked as a café at the end of the main hall *(Fig.1)* [@ socks-studio]. Visitors were not only silent observers but also subjects enjoying themselves and exchanging ideas. In the same year as the Silk Café exhibition Mies van der Rohe, on the occasion of the Deutscher Werkbund exhibition, asked 17 European architects (mostly German) to design and construct 21 buildings. Together this formed the Weissenhofsiedlung, advertised as a prototype for the future worker´s housing. Mies created a permanent architecture, which homogeneity became the ultimate symbol of what would be coined as the International Style [Pommer & Otto,1991]. One of first modern international architecture exhibitions was in New York´s Museum of Modern Art (MoMA) organized by Henry-Russell Hitchcock and Philip Johnson in 1932. Exhibition included works of figures such as Le Corbusier, Mies van der Rohe, J.J.P.Oud, Walter Gropius, Frank Loyd Wright and Richard Neutra. Architectural Drawings were framed and models were assembled on pedestals covered with white cloths in order to achieve the transition from art exhibitions to architecture exhibitions as soft as possible *(Fig.2)*. The Exhibition not only served to unify and codify a particular expression of modernism but gave it the wide exposure and institutional backing that helped to establish the true "international style". From 1945 onwards, this type of exhibition was considered as the generally accepted norm. Starting from 1960 new media as video and performance found a place in exhibiting process. The exhibition space also became a subject for discussion increasingly among conceptual artists.

In 1980 director of first independent architecture section in Venice Biennale "The presence of the past" Paolo Portoghesi invited 20 architects from all around the world and organized one of the first international architecture exhibition - Strada Novissima. The exhibition was

Fig.1 *Velvet and Silk Cafe stand design by L.Mies van der Rohe and L.Reich.*

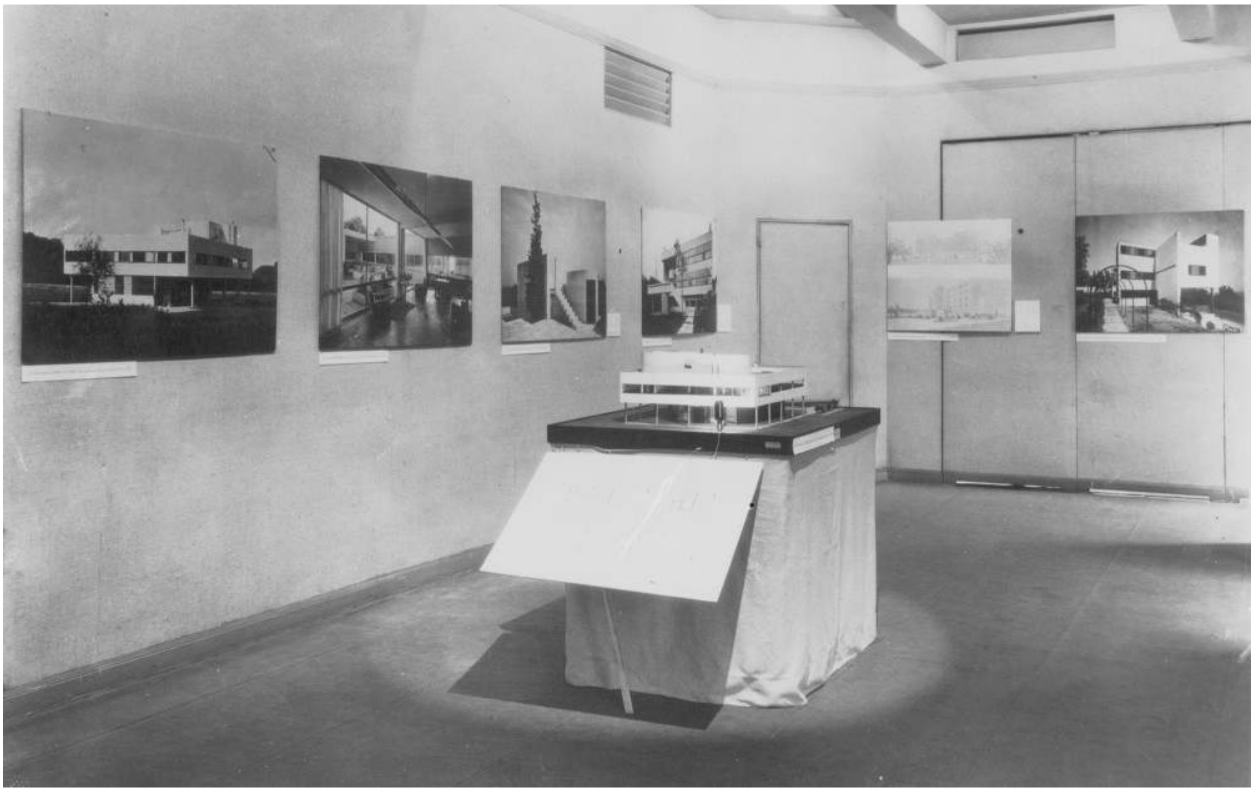


Fig.2 *Architecture exhibition organized by H.R.Hitchcock and P.Johnson in 1932.*

based on the radical ideas "not to show images of architecture, but to show real architecture." The result of this exhibition were series of different façades reflecting the individuality of architecture language. These façades were highly theatrically displayed and produced new and very impressive type of exhibition space *(Fig.3)*. This exhibition was different from the usual exhibition of architecture as it took place in the form of an active collaboration. By using the elements of the street in scale 1:1 and reintroducing it with interior space of the exhibition, addressed Portoghesi the paradox inherent in architecture exhibitions that it is impossible to exhibit a building within a building. What was unique, the presented objects, i.e. façades together with the exhibited space created a real architecture space and not only display. Space of the real scale that could be physically experienced by the visitors. Some photographs captured the interaction between visitors and the façades built in scale 1:1.

1.2 Development of virtual architecture exhibition design

In 1997 an interactive space-viewing device called Digitarama for the Virtual Architecture Show at Tokyo University´s Digital Museum was designed. The device was invented by Takehiko Nagakura. With the movement of the arm, which holds two digital screens, and by rotating the viewer, the view angle is computed and panoramic interior image on a projection screen is displayed. Furthermore, an exterior image appears on a flat panel display *(Fig.4)* [@Nagakura]. The Space Barcoder installation in 1998 from Nagakura used barcode tags pinned on physical architecture models to exhibit architecture. After the laser beam of the reader gun shots, the assigned barcode of the building displays a model in form of computer graphics rendering or video recording of the live space monitor. In 2000 the 7th edition of Architecture Biennale was focusing on the subject of globalisation. The idea of confronting people with migration, war and natural disasters was presented exclusively via videos and cinematic projections. This example of fusion between modern digital technology and the architectural discussion proposed the future trends of exhibiting. The Architecture Biennale can be seen as "a survey of architectural experimentation, how we imagine, represent and display that life." In 2006 a low-cost interactive space browser for three-dimensional architecture designs was developed by Takehiko Nagakura and Jun Oishi *(Fig.5)*. *"Moving of light-weight LCD panel on plan drawing of building displays on the LCD panel a three dimensional interior view of the building model as if it were placed on the plan and sectioned at the position where the panel touches the drawing. The key*

Fig.3 *The first independent architecture section of Biennale named Strada Novissima exhibiting façade-elements of the street in scale 1:1.*

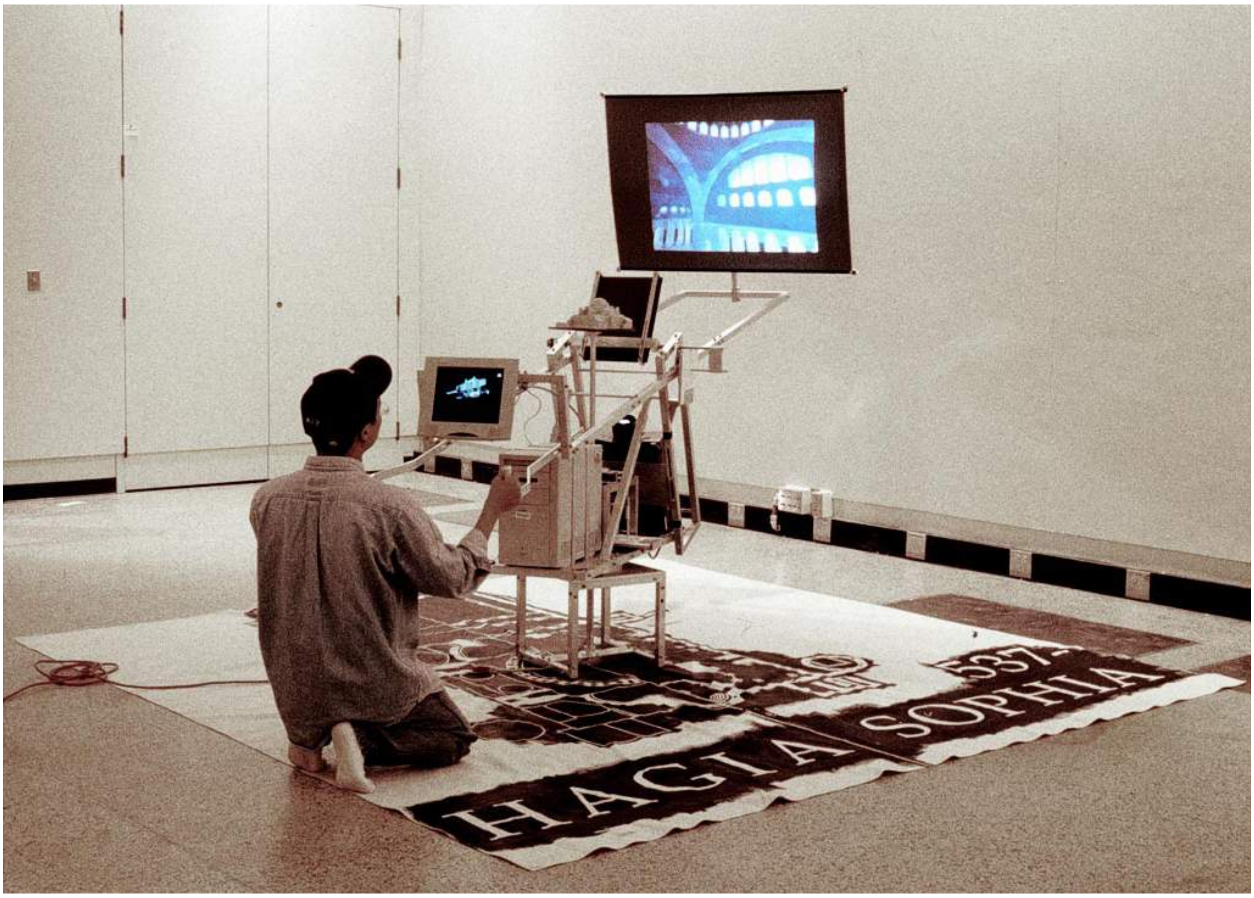


Fig.4 *Digitarama, space-viewing device, invented by T.Nagakura.*

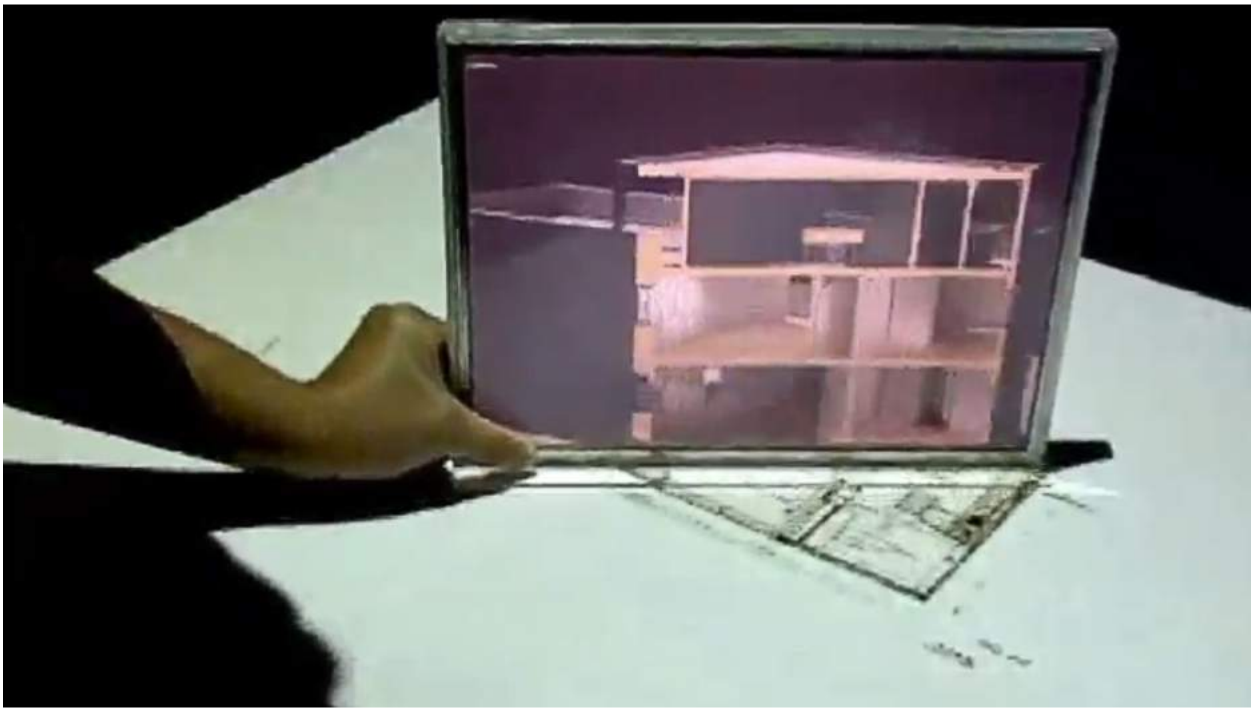


Fig.5 *Deskarama, interactive space browser, invented by T. Nagakura and J.Oishi.*

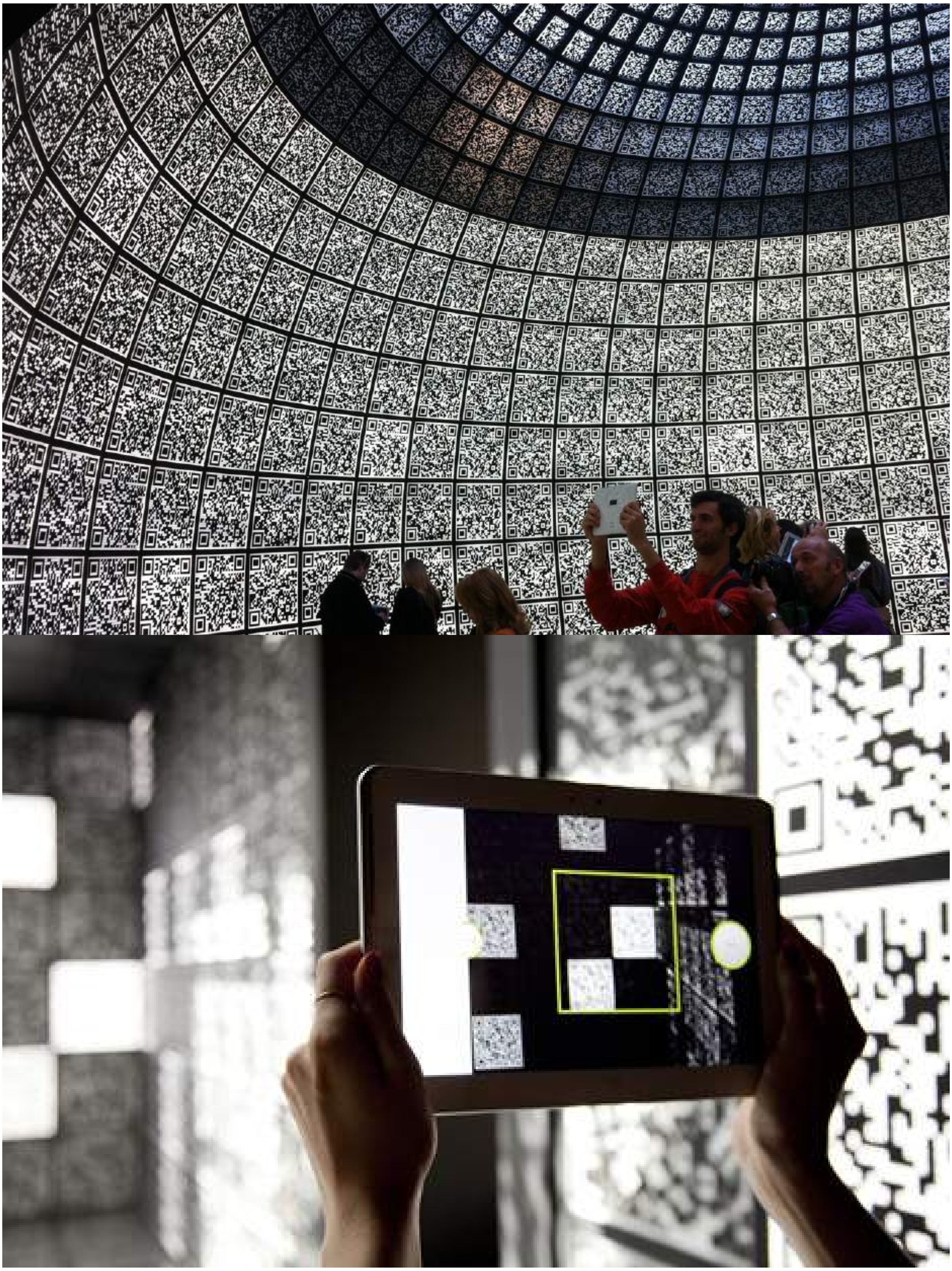


Fig.6 *Visitors in QR code covered Russian Pavilion watching through tablets to get additional information.*

idea was a spatial synchronization of the different architecture representations such as a two dimensional abstraction and photo realistic three dimensional perspective. " [@Nagakura]

In 2012 the architectural Biennale was curated by David Chipperfield and the Russian Pavilion was covered in QR codes, which visitors were able to decode using tablet computers and explore the ideas for the new Russian city. The plans and models of the new Russian science technology centre appear after the visitors look through the tablet *(Fig.6)*. The aim of the exhibition was to find an architecture metaphor for connecting the real and the virtual.

In 2014 the architecture Biennale was curated by Rem Koolhaas and was "hacked" with an app called Project Source Code *(Fig.7)* that allowed to expand the exhibition through augmented reality. "*Blending digital and physical space, the project is deemed to be the first to use augmented reality on live exhibition and also the first time that raw 3D architectural models are treated as exhibition pieces*" [@archinect]. According to the brief for Project Source Code, the single aspect lacking from Koolhaas' thorough world of architectural fundamentals is the realm of digital innovation and evolution- the most important aspect, says project creator Guvenc Ozel. "*Architects seem to be the only artists working in the digital medium that do not share files with their colleagues in the same way that other disciplines do, such as electronic music, digital art and the like*" [@archdaily]. The downloaded app allows the participants to view 3D models of selected projects by pointing their mobile devices at certain images found in the "Elements of Architecture" exhibition. The map accompanying the app serves as a guide and identifies the locations of the images that were used as object trackers for the featured digital models.

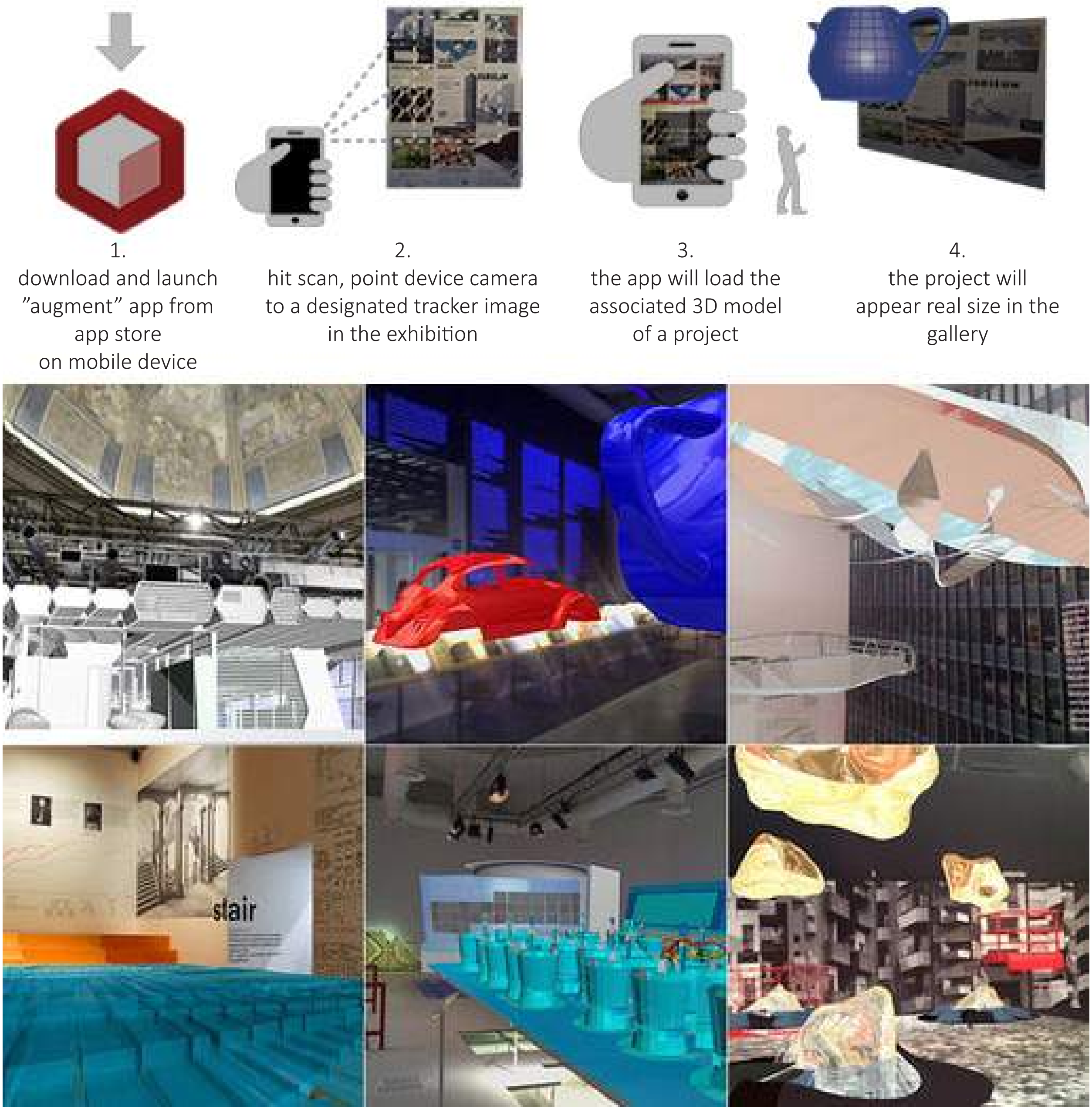


Fig.7 *The Venice Biennale in 2014 with the Project Source Code mobile application that allows to expand the exhibition through augmented reality.*

II. Augumented Reality

Augmented reality (AR) is a view of the real, physical world in which elements are enhanced by computer-generated input. These inputs may range from sound, video, graphics to GPS overlays and more. The first conception of augmented reality occurred in a novel by Frank L Baum written in 1901 in which a set of electronic glasses mapped data onto people. It was called a "character marker" [@interaction-design]. The AR is very often used in the context of Virtual Reality VR and despite some similarities, they are inverse reflections of each other with what they seek to accomplish and deliver for the user. Virtual reality always offers a non-existent, digital recreation of a real life setting and simulate it by computer system, while augmented reality delivers virtual elements as an overlay to the real world. The difference is best illustrated by the reality-virtuality continuum design by Fumio Kishino, Paul Milgram, Haruao Takemura and Akira Utsumi [Milgram & Kishino,1994], the diagram explains the step-by-step transition from a real environment (left) to a complete virtual environment (right). The area between two maximum values called Mixed Reality is characterized by the proportion of reality. Augmented Reality is a part of Mixed Reality and refers to all cases in which the display of a real environment (surrounding world) is augmented with virtual (computer generated) information-image.

The researcher Ronald T. Azuma in his paper "A Survey of Augmented Reality" defined AR system by having three parameters:

- Combines real and virtual
- Interactive in real time
- Registered in 3-D

1. Combines real and virtual: AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space. This is what distinguishes AR from virtual reality that has no view upon the real world.

2. Interactive in real time: Azuma imposes this rule to exclude film animation that is superimposed on an otherwise real scene such as the dinosaurs in Jurassic park. However, this rule also eliminates the yellow first down line marker on American football broadcasts which many hold out as an example of simple AR.

3. Registered in 3-D: This rule is most controvertible, Azuma is imposing it to distinguish AR from simple heads-up displays that simply place data or information in the field of view. Azuma believes that augmented content must contextually interact with the scene that it is imposed upon. This definition disqualifies several applications that many would consider to be in the AR space such as Google Glass [Azuma,1997].

Other term use in context with AR is MARA as a Mobile Augmented Reality Application. A mobile augmented reality application (MARA) is a type of mobile application that incorporates and complements built-in components in a mobile phone and provides a specialized application to deliver reality-based services and functions. A MARA uses the architectural composition of a mobile phone to deliver applications that add value to the physical world through virtual data and services. [@techopedia].

2.1 Historical development

The chapter historical development of Augmented Reality will mainly give overview of mobile AR development. The first augmented reality system was created by computer scientist Ivan Sutherland named "The Sword of Damocles" in 1968 *(Fig.8)*. The device used an optical see-through head-mounted display that is tracked by one of the two different 6DOF trackers: mechanical tracker and an ultrasonic tracker. The limited power of computers at that time caused that only wireframe drawings were displayed to the user. Later in mid 70s the first handhold mobile phone was presented by Motorola and Myron Kruger developed project Videoplace, which combined a projection system and video cameras that produced shadows on the screen. User was able to manipulate and interact with virtual objects in real-time. During the 1980s the biggest area of development for AR related system was focusing on the airplane industry. In the 1992 Tom Caudell and David Mizell coined the term "Augmented Reality" during the work for Boeing. They created a system that allowed an overlay of computer-presented material on top of real world. The aim was to assist workers during an airplane assembling by displaying wire bundle assembly schematics in the see-through HMD *(Fig.9)*. In the early 1990s Louis Rosenbrug developed the first real operational augmented reality system Virtual Figures at the U.S. Air Force Research Laboratory. Virtual Fixtures used two real physical robots, controlled by a full upper-body exoskeleton worn by the user. To create the impressive experience for the user, a unique optics configuration was employed that involved a pair of binocular magnifiers aligned so that the user's view of the robot arms were brought forward so as to appear registered in the exact location of the user's real physical arms. The result was a spatially-registered impressive experience in which the user moved his or her arms, while seeing robot arms in the place where his or her arms should be. The system also employed computer-generated virtual overlays in the form of simulated physical barriers, fields, and guides, designed to assist in the user while performing real physical tasks. Most of significant AR developments in the late 1990s have been made using so called wearable computers. First handhold AR display was created by Rekimoto and Nagao in 1995 and called NaviCam that was connected to a workstation but was outfitted with a forward-facing camera. From the video feed, it could detect color-coded markers in the camera image and display information on video see-through view. This principle can be marked as the first approach of marker-based and mobile AR. One year later Jun Rekimto presented the 2D matrix markers (square-shaped barcodes), one of the first marker systems to allow camera tracking it was a model for future marker-based AR systems *(Fig.10)*. The next step first mobile augmented reality system, the Touring Machine was developed in 1997 by Columbia University. The system used a see-through HMD with GPS and orientation tracking. The Touring Machine *(Fig.11)* consisted from a display attached to the head, backpack holding computer, various sensors and early tablet computer for input. The 3d see-through display attached to the head was equipped with a magnetometer and an inclinometer for viewing direction detection. The handhold display was responsible for input via pen and trackpad. The data was transferred to the computer in the backpack, which was also equipped with a GPS antenna. The GPS data, together with the direction of view data, resulted in the user's exact position, where the names of the buildings of the campus were displayed on the handheld display. In 1998 other backpack wearable computer included GPS, electronic compass and head-mounted display was presented with name "map-in-the-hat" and with main purpose to navigation guidance. Later the project evolved to Tinmith an AR platform used for several AR projects. The Tinmith continued until 2006 and one of the applications known by wider audience AR game ARQuake was built on this platform. The first open-source software platform for AR was released 1999 by Kato and Billinghurst with name ARToolKit. The fact that it was open source allowed possible use for people interested in the manner to experiment with AR

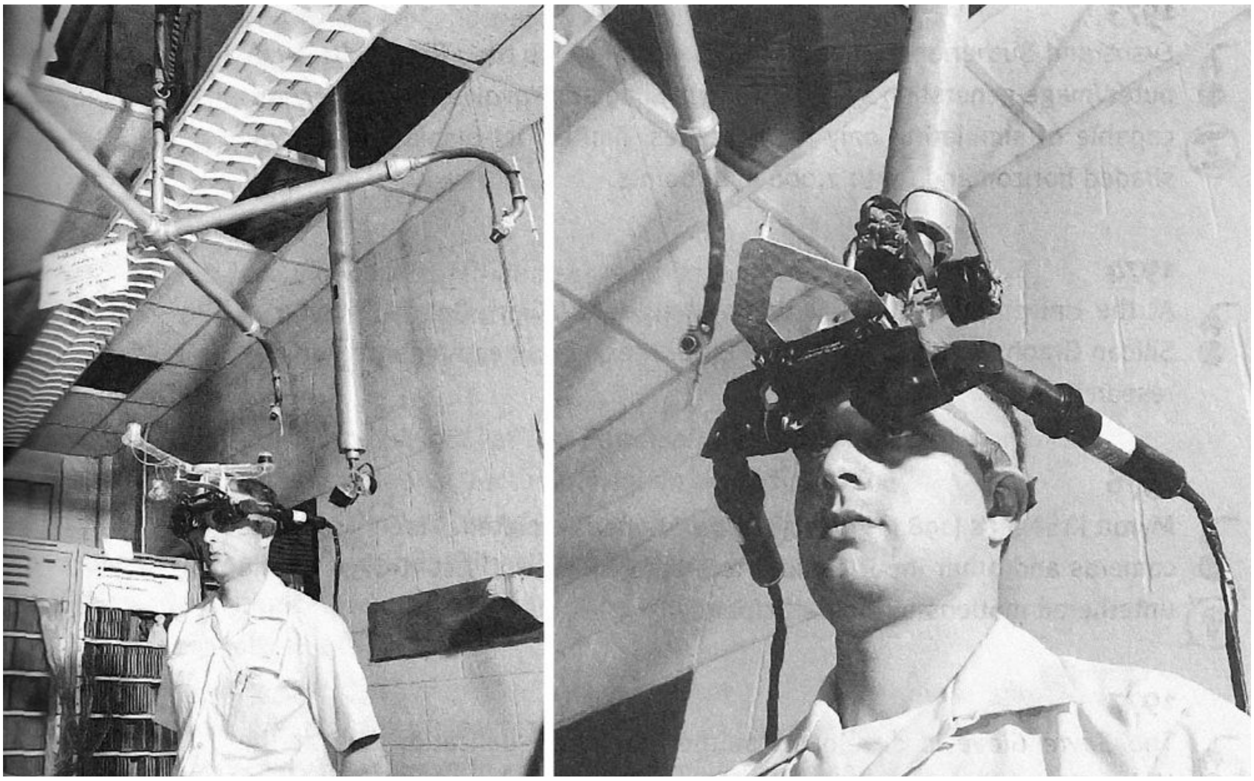


Fig.8 *“The Sword of Damocles” head-mounted display with mechanical head position sensor.*

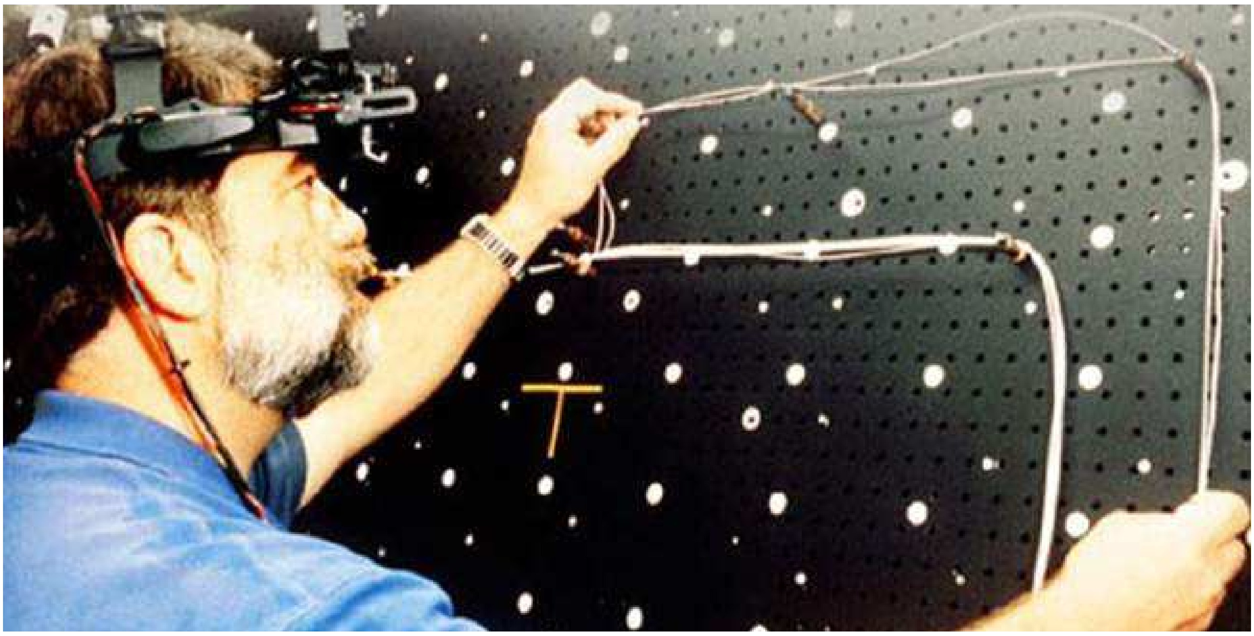


Fig.9 *Boeing´s prototype system displaying wire bundle assembly.*

without a necessity to know the mathematics behind. ARToolKit featured a 3D tracking library using black-and-white fiducial, which could easily be manufactured on the laser printer. ARToolKit was one of the first AR SDKs for mobile, running first on Symbian in 2005, then iOS with the iPhone 3G in 2008 and in 2010 on Android. Currently, it is maintained as an open-source project hosted on GitHub. ARToolKit is a very widely used AR tracking library with over 160K downloads on its public release in 2004 [@ARToolKit]. After 2000 next to the developing of cellular phones start the AR system evolving rapidly. In 2003 Wagner and Schmalstieg presented the first handhold AR system with self tracking running on a "personal digital assistant"(i.e. PDA)- a precursor to today´s smartphones. This has been done implementing ARToolKit as most setup that included a HMD have been designed as a proof-of-concept and do not provide a useable form factor as a PDA would [Wagner & Schmalstieg, 2003]. In 2004 Mathias Möhring present a system for tracking 3D markers on a mobile phone. The result showed a first video see-through augmented reality system on a consumer cellphone. It supports the detection and differentiation of different 3D markers, and correct integration of rendered 3D graphics into the live video stream. Project dealing with the issues of tracking system for outdoor augmented reality enabling accurate, real-time overlays on handhold device was presented by Reitmayr and Drummond in 2006. They give an example how a textured low poly model of the façades in the surrounding of the user could be used as a reference for a vision-based AR system. Their system combines multiple sensors like gyroscope measurements to deal with fast motions, edge-based tracker for accurate localization. Due to different sensors ist was possible to display the result at a frame rate (about 15 FPS) on a mobile device [Reitmayr & Drummond, 2006]. In 2008 AR starts to be used for commercial purposes by different companies and magazines. In the same year PDAs and mobile phone concepts merged into a single segment, giving place to smart phones, which are compact handhold devices that include most of the addressed AR solution hardware. Next to the smartphones, the first usable natural feature tracking in real-time system was introduced [Wagner et al., 2008]. This work became the ancestor of the popular Vuforia toolkit. The other step forward was launching an application that combined GPS and compass data with Wikipedia information. The application was introduced as Wikitude *(Fig.12)* and overlay information on the real-time camera view of an Android smartphone. In 2013 Volkswagen provides a virtual step-by-step repair assistance their app called MARTA (Mobile Agumented Reality Technical Assistance). In 2017 Apple announces ARKit and Google launches ARCore. Improvements in mobile device hardware such as integrated cameras, various types of sensors and good processing power have made the AR system more sophisticated [Huang, et al,2013]. It is estimated that in 2020, AR and VR will create a revenue of 150 billion dollars with

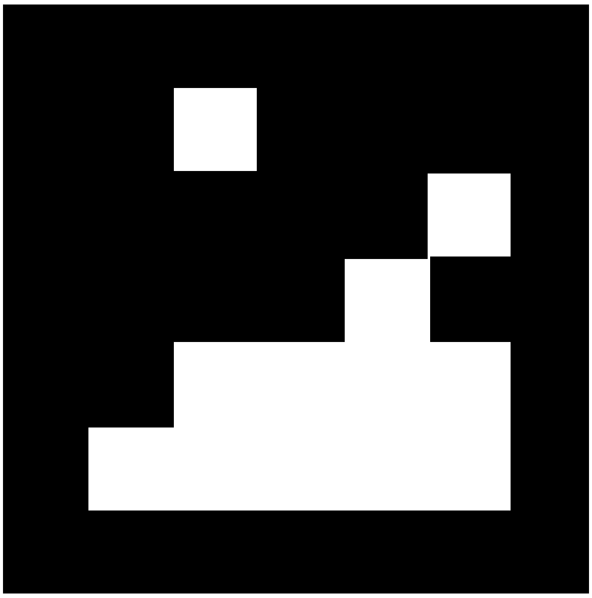


Fig.10 *2D matrix code example.*

Fig.11 *The Touring Machine.*

Fig.12 *Application Wikitude used for the recognition of the Brandenburg Gate.*

more then 11 billion mobile devices connected to the Internet.

Today´s status proved that variety of AR technology applications helps users in their everyday lives. Although the content is created virtually, the result has the same quality, interaction and constant availability that is practiced in every day real life, so the acquiring of the application is very fast.

2.2 Augmented Reality as a exhibiting method

Museography aims to showcase the collections within an exhibition to visitors. These collections do not only contain concrete sources of information, but they also embody the knowledge the creators and museum curators have of the artefacts. In this context, it is considered that AR is an interesting tool that could be used to help visitors understand and appreciate the contents of an exhibition. AR also appears to be a suitable solution to reconcile the digital and real environments, since it visually superimposes information directly onto the exhibit as the user looks at the screen. Over past decades, research has attempted to introduce AR to museums.

One of the first application used to present heritage information to visitors was ARCHEOGUIDE (Augumented Reality based Cultural Heritage On-site GUIDE). The AR based system showed three-dimensional reconstructed virtual models over missing parts of damaged artefacts and buildings in an archaeological site *(Fig.13)*. Using an AR backpack mobile unit, users were capable of visualising virtual reconstructions in loco, seamlessly integrated into the natural field of view. In addition, two more mobile units were adopted: one was based on a tablet PC, and the other was based on a personal data assistant (PDA) [Vlahakis et al., 2002].

In 2006 an educational game-base Virtuoso designed to be played by the museum visitors was presented. The aim of the AR game application was to sort a collection of artworks according to the date they were created. When the users become confused, they can summon a virtual character named Virtuosos [Wagner et al, 2006].

In 2013 the project CHESS (Cultural Heritage Experiences through Socio-personal interactions and Storytelling) aim to enrich museum visits through personalized interactive storytelling *(Fig.14)*. It follows a hybrid, plot-based approach for story authoring and uses personalised information to create customised stories that guide visitors through a museum. It also employs mixed reality and pervasive games techniques, ranging from narrations to augmented reality (AR) on mobile devices. The project aimed to provide four ways to digitally look at exhibits: virtual reconstruction of the original aspect, placement in the original location, visual

Fig.13 *ARCHEOGUIDE - Augmented Reality based Cultural Heritage On-site GUIDE.*

Fig.14 *Project CHESS AR is used to bring augmented colours and stories to art pieces.*

highlighting of interesting details and annotations; and recreation of mythological appearances [Keil et al., 2013]. The authors attempted to evaluate the effect of AR incorporation in a storytelling context in museums. With their test scenarios they were able to prove the technological foundation of their concepts. Two museums participated in the effort, the Acropolis Museum in Greece, and the Cité de l 'Espace in France.

Nowadays there are many concepts of AR application used in many institutions. All the applications bring something new to existing collections and attract wider audiences. Few examples were chosen to present the interesting ways how the AR is applied in presentation.

The Archeological Park Carnuntum is the largest preserved archaeological landscape in Central Europe, where a fully-featured gladiator school site of unprecedented detail is situated. This discovery inspired the creation of a 3D model replica of the school. Even though the site has not excavated, AR technology allows users to see virtually reconstructed city directly on site integrated into the true-to-scale model of Carnuntum, the capital of the Roman province Pannonia Superior. The 3D model is currently used at the Petronell Visitor Center and the AR app is offered by the park as part of their guided tours *(Fig.15)*. An innovative way to showcase the past in very modern setting [@carnutum].

The problem of how to simply and comprehensibly present architecture is solved by the system called Ramalytique design by Takehiko Nagakura *(Fig.16)*. "*The system uses marker-based augmented reality technology to synchronize the viewing angles of all those media. A viewer looks at a scale model through the camera of a tablet computer and can interactively turn on and off various representations overlaid on the live video feed of the model. On a table, the proposed installation displays 3D-printed partial models of elegant country-side villa projects designed and built by Palladio, one of the most famous Renaissance architects in history. Its augmented representation incorporates photogrammetric models sampled through field trips on the building sites as well as drawings left in Palladio's classic canon, The Four Books of Architecture (Fig.17)*"[@cat2.mit.edu].

The ways AR technologies can be applied include expanding and adopting new methods of interaction with their target audience. The augmented reality mobile app development has yet to unearth its true potential.

The main reasons why AR technology is applied for museum exhibitions are:

- attract more visitors
- bring exhibitions to life
- AR is fun and interactive
- AR is readily available and easily accessible
- possibilities to present how things were before
- AR enables the possibility of giving easy and regular updates to maintain interest

Fig.15 *AR application used to present the virtually reconstructed architecture objects.*

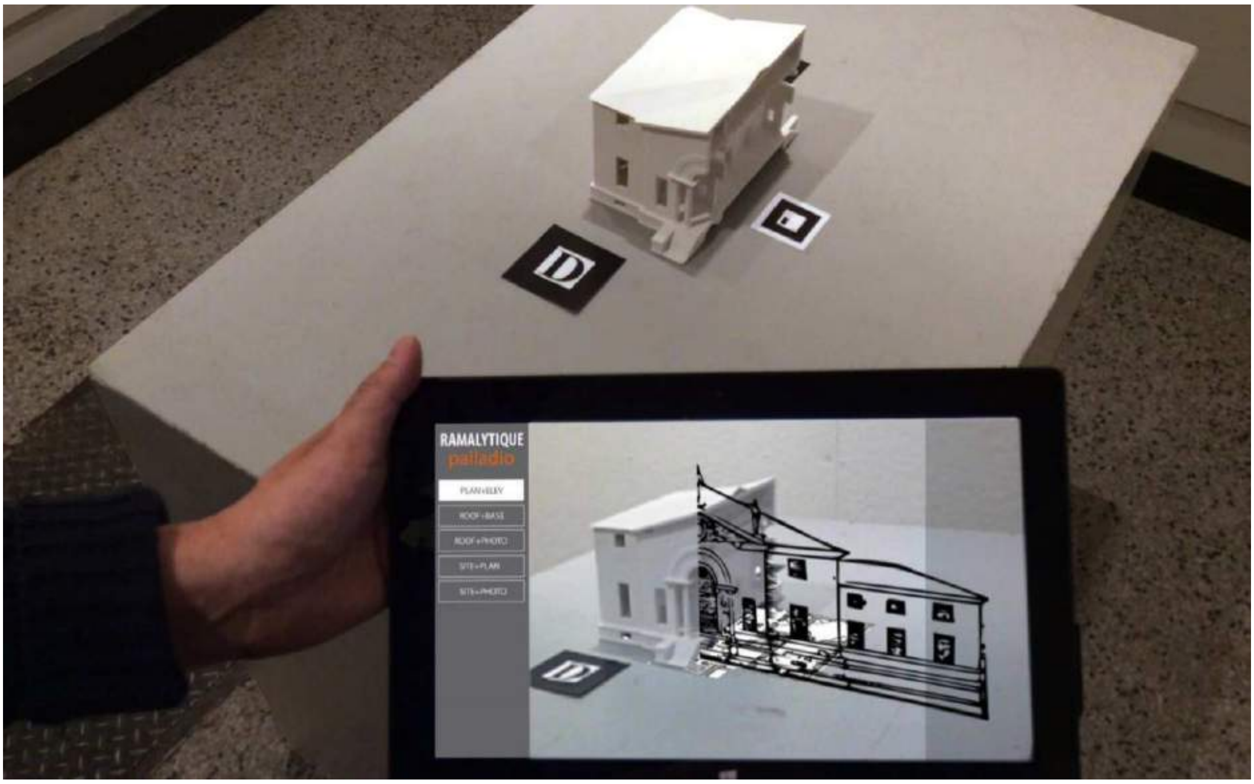


Fig.16 *The Artoolkit binary markers used to augment the content for Palladio´s villa Poiana (Copyright: Nagakura and Sung).*

1. attract more visitors

AR technology is used to attract people and encourage them to visit museums and galleries, this way a completely new experience of learning is offered in a more entertaining form.

The Bone Hall, a vertebrate skeleton exhibition at the Smithsonian's National Museum of Natural History, was unchanged since the 1960s and no longer meets visitor expectations for engagement and interactivity. A mobile app called Skin & Bones was developed to reinvigorate the exhibition with videos, display and AR content. The AR technology had positive influence on the visitor experience and was reflected in an increased exhibition interest [Marques, 2017].

2. bring exhibitions to life

The technology offers to present not just static remains but bring the objects back to life as 3D simulation with many effects.

The National Museum of Singapore presented an installation called Story of the Forest. The exhibition is based on 69 images of Natural History Drawings. The images turned into three-dimensional animations after the visitors use the camera of their phones. The AR technology brings the drawings to life. Audiences can interact with and explore the images in an exciting new way [@nationalmuseum].

3. AR is fun and interactive –

provide play-and- learn experience

Many museums attract families and young visitors by adding little fun and play to their exhibits. By integrating some playful AR elements into family-oriented games, families can play and learn together around a city, a garden, a museum or other locations.

With the AR app called Explore Auch, the city visitors, both young and new, can engage in interactive and rewarding exploration missions together, learn, share and have lots of fun along the way. In short, adding a little AR is an easy way to capture an entire family [@wezit].

4. AR is readily available and easily accessible

5.possibilities to present how things were before

AR gives opportunity to recreate historical events and structures and to see things that have long been gone.

The Carnuntum App is possible to visually access areas that have been buried underground for a thousand years [@carnuntum].

6. AR enables the possibility of giving easy and regular updates to maintain interest

The same real-world exhibition object can be presented in different ways.

Museums have proven to be some of the most exciting testing grounds for augmented reality. The cultural sector is taking major leaps towards embracing new technology, which is coming as a great benefit for those who like to learn about the cultural world around us.

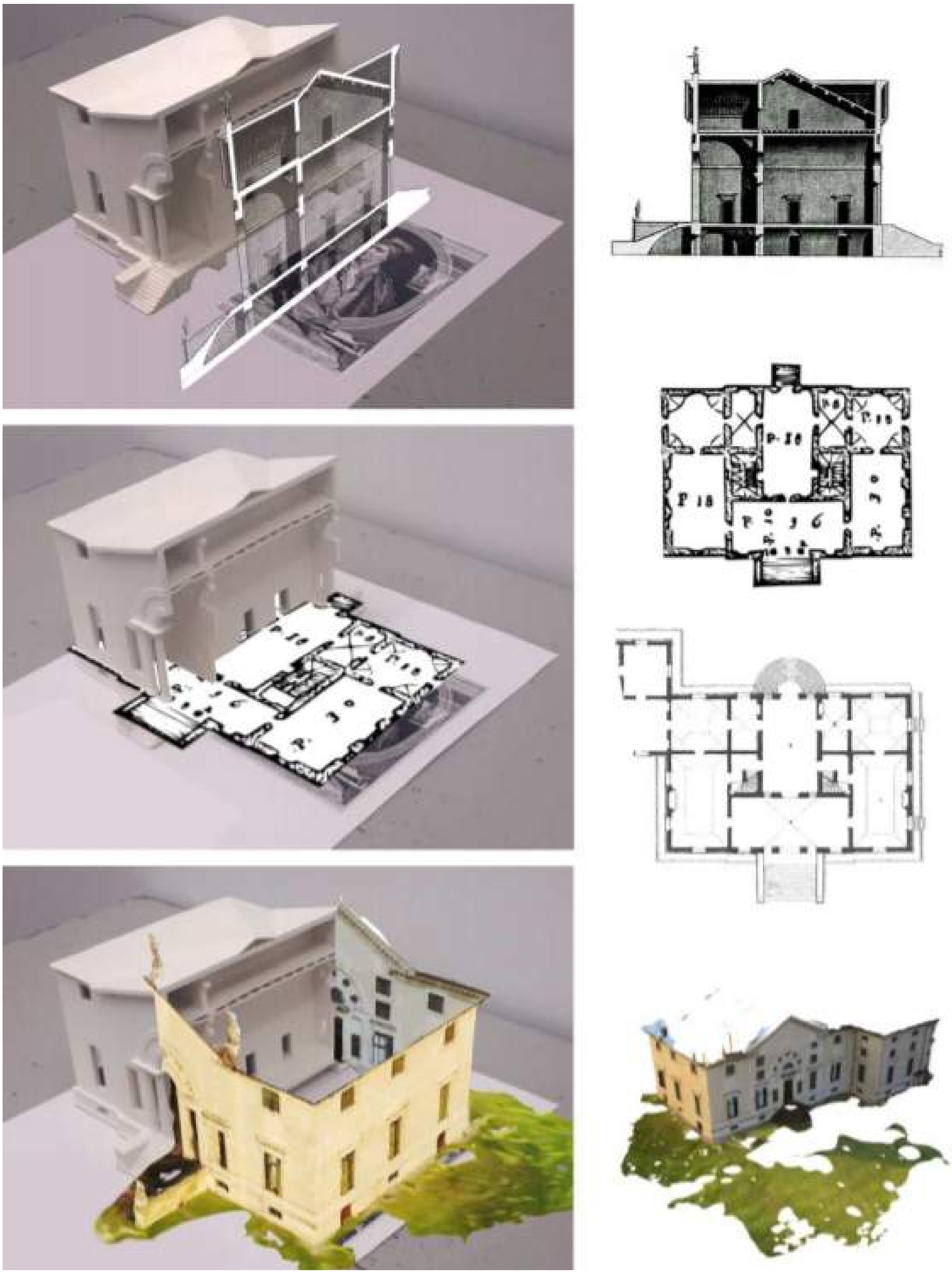


Fig.17 *Ramalytique: Villa Poiana's section (Bertotti Scamozzi, 1796), plan (Palladio's and the recent conditions are switchable), or photogrammetry model aligned to its scale model (Copyright: Nagakura and Sung).*

III. Photogrammetry
Historical development

"Photogrammetry may be defined as the art, science, and technology of obtaining reliable information about physical objects and the environment. This is done through a process of recording, measuring, and interpreting aerial and terrestrial photographs" [@amtmaps].

Photogrammetry is based on descriptive geometry. If we deconstruct the word, we get three Greek words.

Photos = Light

Gramma = Letter – something drawn

Metrein = to measure

Other options is to divide it to two parts: Photo = Pictures + Grammetry = Measurement.

Leonardo da Vinci in 1480 wrote the following: *" Perspective is nothing else than the seeing of an object behind a sheet of glass, smooth and quite transparent, on the surface of which all the things may be marked that are behind this glass. All things transmit their images to the eye by pyramidal lines, and these pyramids are cut by the said glass. The nearer to the eye these are intersected, the smaller the image of their cause will appear "* [Doyle, 1964]. The principles of perspective and projective geometry were the base for developing the photogrammetric theory. In 1759 Johan Heinrich Lambert in the book "Perspectiva Liber" developed the mathematical principles of perspective image using space resection to find a point in space from which a picture is made. These laws and relationships were also basic elements for photogrammetry. In 1837, Jacques Mandé Daguree obtained the first “practical” photograph – photogrammetry using a process called the Daguerretype *(Fig.18)*. In 1849, Frenchman Laussedat who is known as the “father of photogrammetry” was the first person to use terrestrial photographs for the topographic map compilation. In 1858 German architect Meydenabuer used photogrammetry to create plans of the cathedral of Wetzlar *(Fig.19)* and later to measure façades thanks to a phototheodolite: a mix of camera and theodolite. He compiled an archive with the images of the most important architectural monuments in state of Prussia and developed graphical photogrammetric methods for the production plans of building façade. Meydenbauer´s method of map compilation utilised the approach at that time. The photograph was used to map the terrain by intersection. Directions from ground control points were graphically plotted from the imagery. Conventional surveying was used to locate the position of the cameras and a few control points in the scene being photographed.

The development of stereoscopic measurement around the turn of the century was a breakpoint in the history of photogrammetry. “The relationship between projective geometry and photogrammetry was first developed by R. Sturms and Guido Hauck in Germany in 1883.“ In 1893 Cornele B. Adams patented the“ Method of Photogrammetry”. His approach was to obtain two aerial photos from the same captured balloon [Birdseye, 1940]. Adams also invented radial line triangulation in effort to graphically solve the principles in plane table photogrammetry to his balloon imagery.

The time between 1900-1960 is called analogue computation era. For analogue photogrammetry two phases were important- first, stereoscopy was becoming widely used and second it was the development of an airplane. Optical or mechanical instruments were used to reconstruct the 3D geometry from the overlapping images. The main product during this phase was topographic maps. An Austrian developer Scheimpflung came with the theory of the double projector, which offered direct viewing of the projected images he also introduced the concept of radial triangulation and is considered the initiator in aerial photogrammetry since he as first successfully used aerial photographs for practical mapping. In 1901, Dr. Carl Pulfrich, a German physicist, designed the first stereocomparator employing x and y coordinate scales and presented the results at the 73rd Conference of Natural Science and Physicians in Hamburg [Doyle,1964]. This was the first photogrammetry instrument manufactured by Zeiss *(Fig.21)*. In 1908, the first aerial photograph was captured by the Italian captain Cesare Tardivo for the mapping purpose. Later German physicist, designed the first stereocomparator employing x and y coordinates scales it was first manufactured photogrammetric instrument. In 1910, the International Society for Photogrammetry (ISP) was founded in Austria. In 1913 General Dynamics organised the first International Congress for Photogrammetry held in Vienna.

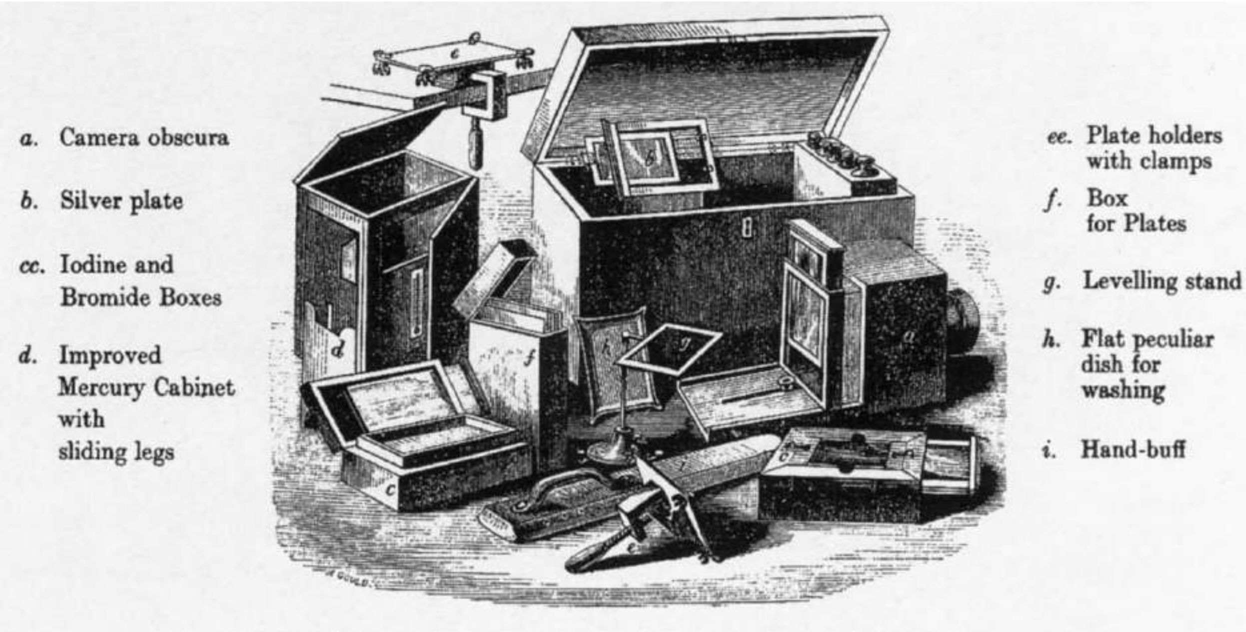


Fig.18 *Jacques Mandé Daguree obtained the first "practical" photograph.*

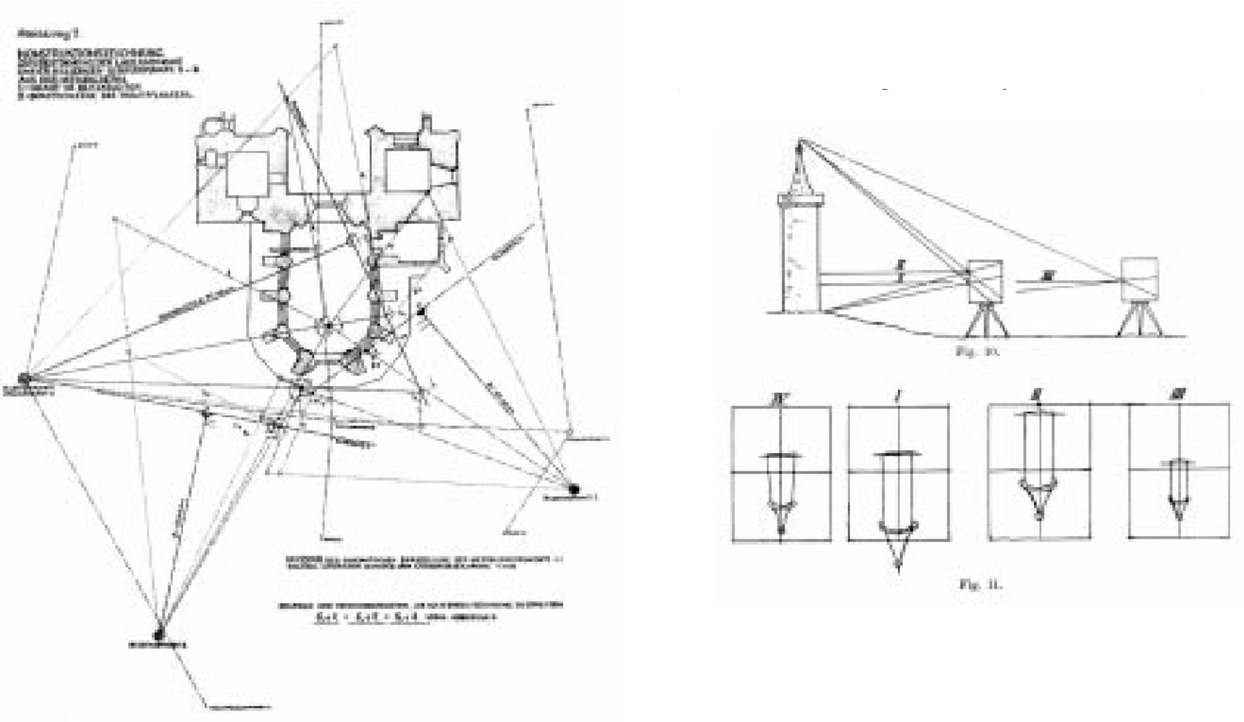


Fig.19 *Meydenbauer's principles of plane-table photogrammetry and the effect of a vertical shift of the camera lens, the position II makes the best use of image format.*

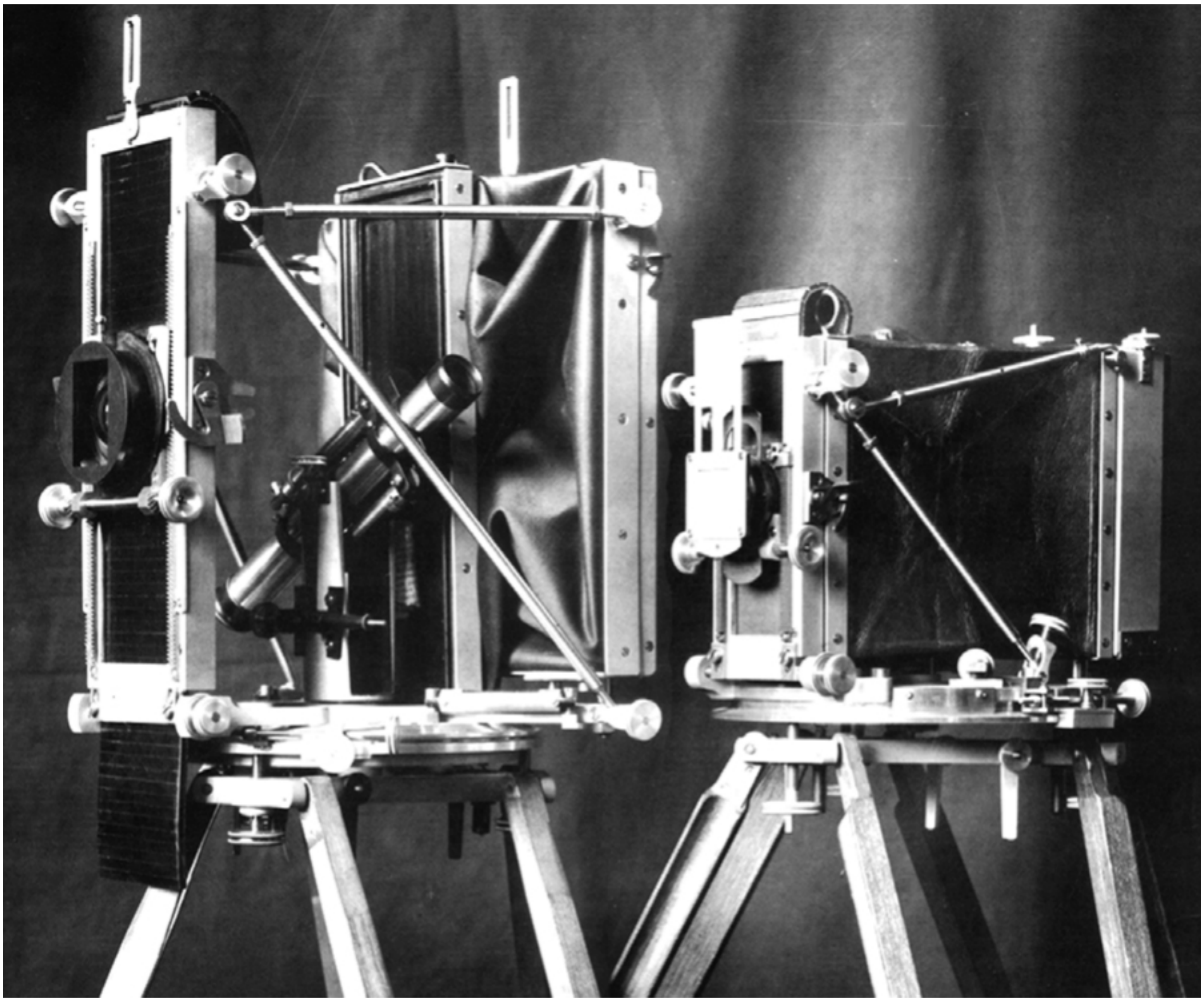


Fig.20 *Metric cameras by Meydenbauer (ca. 1890), left: 30 × 30 cm², right: 20 × 20 cm².*

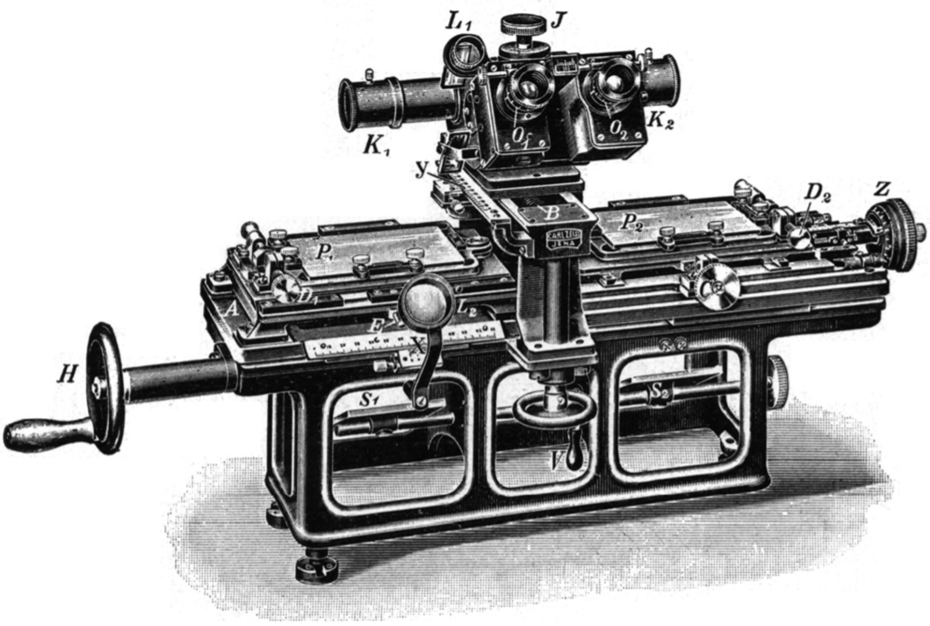


Fig.21 *Pulfrich's stereocomparator (Zeiss, 1901).*

Later in 1924 the projective equations and their differentials were derived, which were fundamental to analytical photogrammetry. Method of relative orientation of stereoplotter makes the process of orientation easier and quicker. This procedure is still in use today. With the new technologies invention of the computers replaces the expensive optical or mechanical components. The resulting devices were digital/analogy hybrids. The outputs were the topographic map but in the digital format DEM (digital elevation map) or digital map.

In 1950 the principles of modern multi-station analytical photogrammetry using matrix notation were developed. Later in the 50s by mathematician Duane Brown new approaches to camera calibration and the mathematical formulation of the bundle adjustment were developed. This involved a simultaneous solution of the exterior orientation parameters of the camera and the coordinates of the survey points along with the interior orientation and systematic radial lens distortion. This algorithm has been used in many different areas of photogrammetry and geodesy. The orientation parameters are the key points related to the photogrammetry approach. There are two main types of these components:

- interior orientation parameters: establish the relationship between the image plane and the projection centre of a camera. The parameters that describe this are the principal distance and the image coordinates of the principal point. In an ideal camera (often described as a pinhole camera) all the light rays from a scene pass through a projection centre and then impinge on the image plane. The vector perpendicular to the image plane pointing to the projection centre originates from the principal point and its length is the principal distance. The coordinates of the principal point are measured in an image based coordinate system. In modern digital cameras the coordinate system is determined by the pixel structure of the imaging chip. In a photogrammetric film camera the coordinate system would be based on the fiducial marks recorded at the corners and midpoints of the sides of the image [@quora].

- exterior orientation parameters:

1. the position and orientation of the camera in a global reference system

2. represents a transformation from the ground coordinate system to the image coordinate system.

3. the reference system is based on coordinates of the perspective centre in the global system and the angle values that define the ratio of the image coordinates in same system. Many photogrammetric cameras are equipped with an onboard Global Positioning System (GPS) and sometimes with an inertial navigation system (INS) or inertial measurement unit (IMU).

Brown with his company became in the 60s the leader in close range photogrammetry. He has been focusing on the refinement of the bundle adjustment for large photogrammetry blocks to include selfcalibration what improved the accuracy and reliability of the photogrammetric adjustment. He recognised that the environment influences the process and by calibrating the camera to extract the camera parameters in environment in which the photography was acquired, the new camera parameters were a better representation than the conventional calibration procedures. Next stage of photogrammetry began with technical development. The first was the addition of retro-reflecting targets which offered significant improvement over conventional photogrammetric targeting, the other was the development of a new bundle adjustment software STARS (Simultaneous Triangulation and Resection Software) that was also able to run on personal computers. The next development was the Close-Range-Camera *(Fig.22)* that utilised the continuously focusable lens. In 1957 Uno Helava developed an analytical plotter which used servocontrol instead of the optical or mechanical construction of previous instruments *(Fig.23)*. The computer was used not only to drive the instrument around the stereomodel but also to digitally transform coordinates between image and the map [Brown, 2005]. In 1964 the first architectural test with the new stereometric camera-system was executed. It was invented by Carl Zeiss.

Digital Photogrammetry is also called softcopy photogrammetry, it is applied to digital images stored on the computer. Since the middle of the 1980s the use of opto-electronic image sensor has increased dramatically. With the development of computers and cameras in the last decades, digital photogrammetry flourished. The first devices able to create digital images were standard video cameras which generated video with resolution of 780x580 pixels and processed in real-time photogrammetry and videogrammetry. The problem with low resolution was later solved in the 1990s with the introduction of scanning cameras that enabled the high-resolution recording of static objects to values 6000x4500 pixels. Next to the development of camera resolution, electronic theodolites were equipped with video camera that enabled the automatic recording of directions to target. Since the 1990 there have been cameras with high resolution ranging from 1000x1000 to 4000x4000 pixels available [Luhmann et al., 2014]. Easily portable still video cameras can store high resolution images directly in the camera *(Fig.24)*. This led to a significant expansion of photogrammetric measurement technology. Online photogrammetric systems *(Fig. 25)* have been increasingly used, in addition to offline systems, both as mobile systems and in stationary configurations. Coded targets enable the full automatisation of identification and assignment of object features and orientation of the image sequence. Photogrammetric techniques combined with pattern projection allowed surface measurement of large objects. Multi-image processing systems are of more importance here. They offer processing of freely chosen image configuration in CAD environment. New software packages provide object reconstruction and creation of virtual 3D models from digital images. Nowadays, software and hardware development allow users to produce photogrammetry models without any deep understanding.

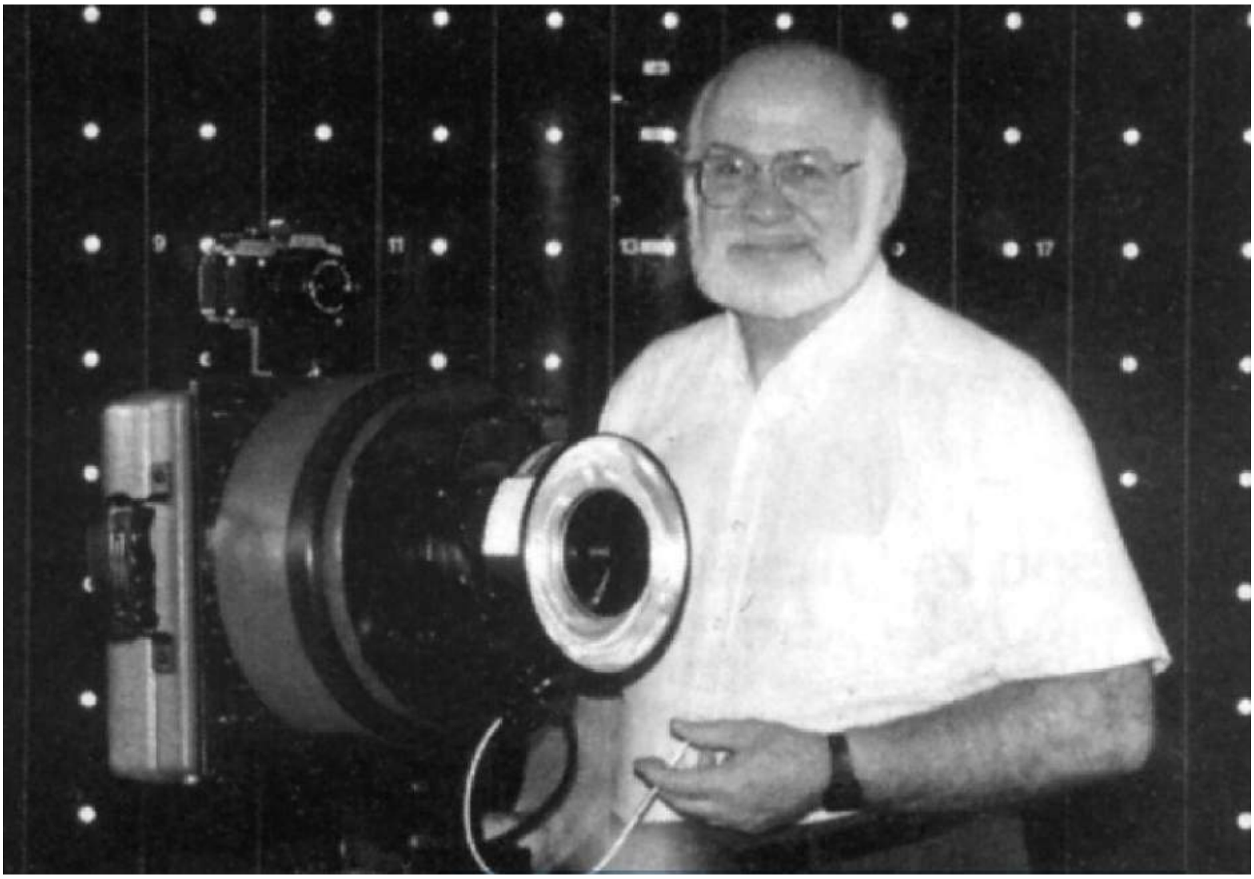


Fig.22 *The CRC-1 camera, part of the "STARS" system developed by GSI.*

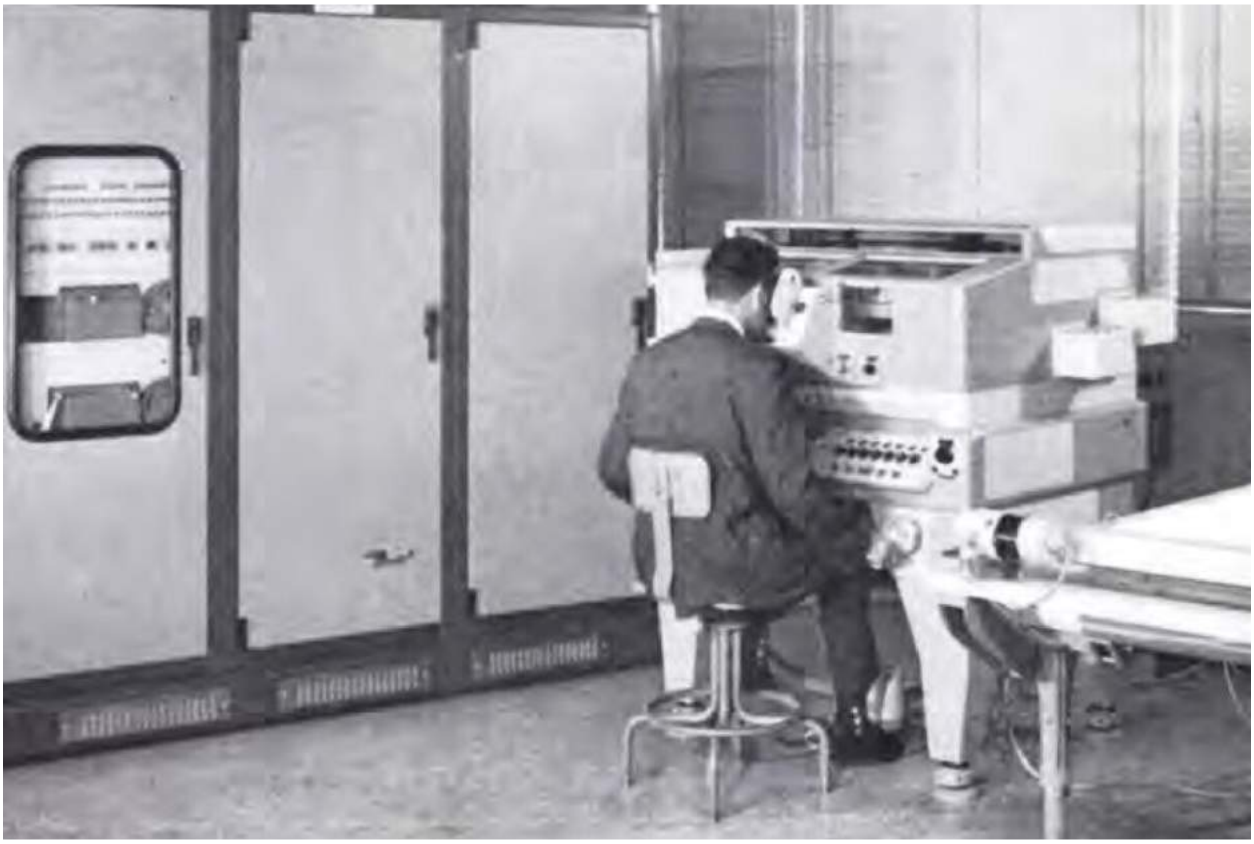


Fig.23 *The first analytical plotter development of the first digital photogrammetric workstations.*

Fig.24 *Still-video camera Kodak DCS 460 (1996).*

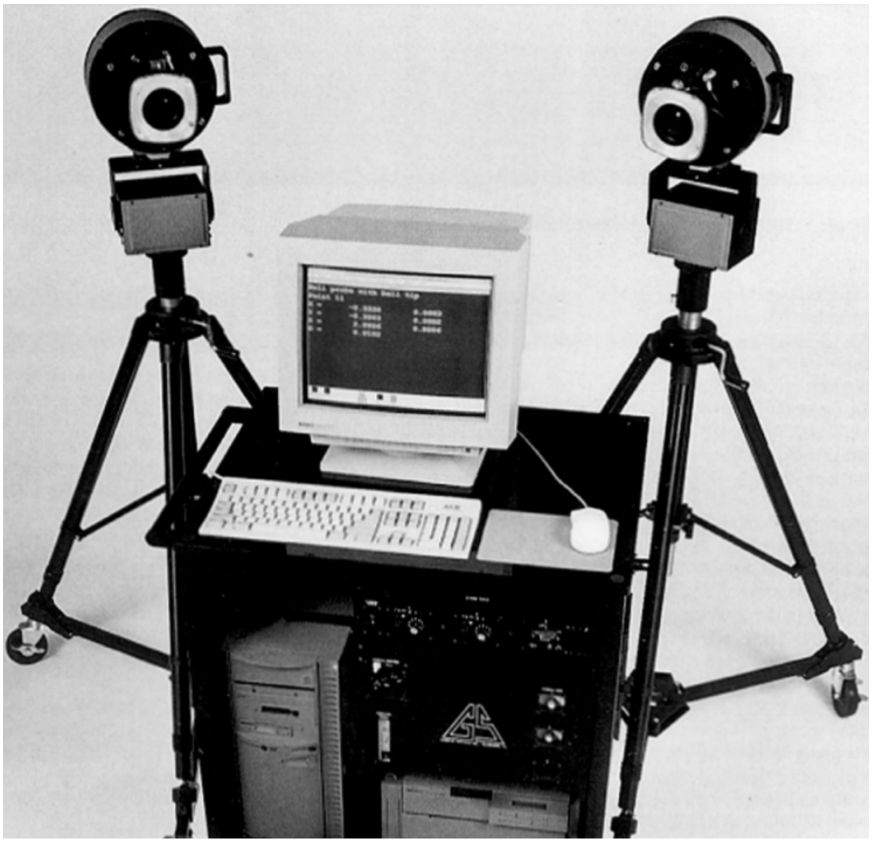


Fig.25 *GSI VSTARS on-line industrial measurement system.*

Photogrammetry is also extremely affordable since the most important piece of equipment – camera, smartphone camera or drone – is affordable. The other important piece is photogrammetry software to create a 3D file of the photographed object. Like many things, photogrammetry software comes in many shapes and sizes. Major software developers have published commercial solutions that are ideal for industrial and engineering applications. On the market there are now more than 10 photogrammetry softwares available that allow translating physical space into a virtual setting.

3.2 Karlsplatz as an object of videogrammetry

Photogrammetry is used in many areas including heritage preservation, architecture, engineering, forensics and accident reconstruction, and medical applications. One of the first steps of preserving our heritage is to document it, what brings on propriety documentation method. Objects of observing are full of fine details and these can not come from photographing that leads to a more powerful documenting method - photogrammetry. This method uses photographs as an input data and makes measurements based on them. With great development of computer science, it is common to use this technique to construct 3D computer model for the observed object. To get a three-dimensional model, it is needed to have at least two images for the same scene from different camera stations that are called stereopair photographs. By applying a data reduction method, the three-dimensional coordinates for the photographed object's points can be computed. Based on the calculated points' co-ordinates, a three-dimensional model will be created.

One of the Otto Wagner works has been selected as a test object, photographed, measured and documented, in order to have well-checked materials. It was also selected to internationally evaluate the results of the analytic photogrammetric process with various cameras, different softwares and with different kinds and amount of control information. The idea of the project belonged to P. Waldhäusl [Waldhäusl, 1991]. The described work was done as part of the contribution to the CIPA (i.e. International Committee for Architectural Photogrammetry) project "Wagner-Pavillon". The building of the former Stadtbahn station with the dimensions 15x8x10m fit perfectly for photogrammetry use. The result has been used as a reference building for testing modern methods of measurement and processing in architectural photogrammetry. For the determination of object control points a 6-station surveying network has been established around the building and the polar coordinates of 44 non-signalised (but well defined in the majority) control points have been measured. The image acquisition was performed with a S-VHS camcorder. The camcorder was inexpensive, portable and offered the ability of on-site quality control. The analogue images were stored on a S-VHS video tape and had to be digitized by a framegrabber. During the image acquisition the shortest focal length (zoom lens) was fixed. To obtain sufficient accuracy in object space with such an imaging device, it is advisable to take as many images as reasonable and to use multiple camera arrangements with convergent rays instead of being restricted to special camera arrangements (e.g. stereopairs).

The photogrammetry system DIPAD (Digital System for Photogrammetry and Architecture Design) [Streilein,1994] was used as a measuring and data processing tool for analysis of the digital image data. The system combines digital photogrammetric methods with the capabilities of CAAD (Computer Aided Architectural Drawing). The photogrammetric processing is performed with a Digital Photogrammetry Station (DIPS), while the architectural processing takes place in a CAAD environment. By customizing the functionality of an existing software package with a true programming interface (AutoCAD) an integration of CAAD and DIPS in the course of the project was achieved *(Fig.26)* [Streilein, 1995]. The rule principle of DIPAD is that a human operator assumes responsibility of the image understanding part (assignment of feature attributes/semantics), while the measurement is automatically handled by the computer *(Fig.27)*.

The user indicates relevant parts of the object by approximating a geometric topology to it. The image sequence from object was generated by person walking with the camera around the object and filming all façades. The distance between the camera and the object was around 15-20m and another sequence from the front façade was taken from an approximate distance of 6m. The reason of taking additional close-up images was an attempt to increase the number of measurable lost details due to the low sensor resolution. From the created video, 38 single frames were digitalised with a framegrabber. The image coordinates measurement was performed with the 3D-FEX routine (three-dimensional feature extraction routine component of DIPAD). It is a semi-automatic measurement routine, where a series of model- and data-driven processes interact to extract geometric information from the digital imagery. Therefore, only relevant features (as defined by the user) are extracted. Redundant or useless information is reduced to a minimum. The three-dimensional position of the object is derived by a simultaneous multi-frame feature extraction, where the object model is reconstructed and used to triangulate the object points from corresponding image points. Linear boundaries - edges of building in architecture photogrammetry - contain more information than vertices. The edges also have a major importance for the object shape description. The 3D-FEX routine takes advantage of this fact by first locating the edges of the features to be measured and then deriving the vertices as intersections of the appropriate lines *(Fig.28)*. The object coordinates of a point detected in two or more images are calculated either by a spatial intersection, by a bundle adjustment or by a bundle adjustment with self-calibration, depending on which model parameters they are treated as a priori known or unknown. The derived object coordinates are then projected into each image and used to restart the image-based feature extraction.

The photogrammetry method using DIPAD software resulted in final three-dimensional geometric and semantic object definition of the Otto Wagner Pavilion in the CAD environment *(Fig.29)*. The architectural object can be represented by the objects points, lines, surfaces or combination of these displaying forms. The format file and CAD environment allow to apply the model for Virtual Reality in terms of visualisation and animation.

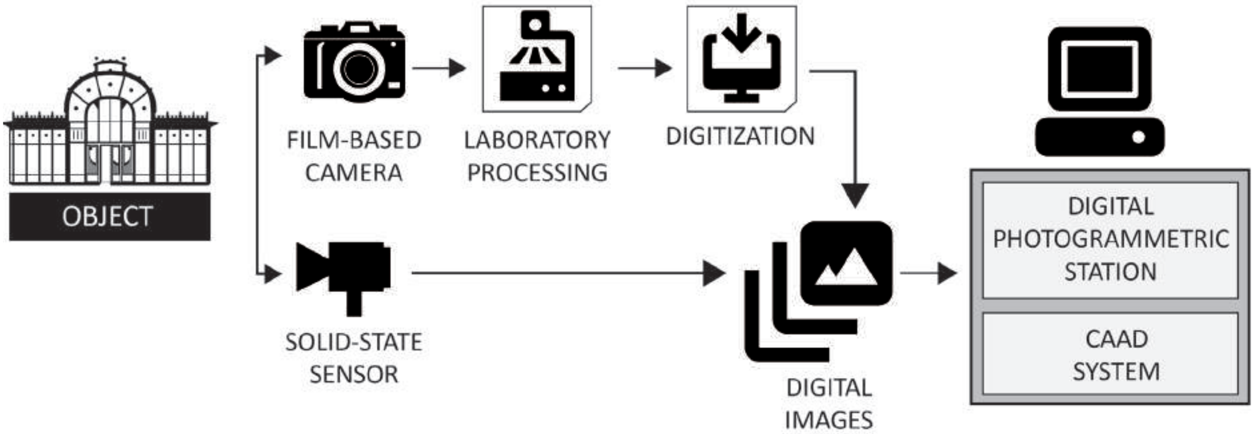


Fig.26 *Architectural photogrammetry workflow with DIPAD.*

Fig.27 *Modelling in the CAAD environment can be entirely monitored in the viewports linked to the model.*

Fig.28 *Performance of 3D-FEX routine of a single feature in three images simultaneously:*

a) images from a sequence

b) initial 3D position of feature from approximate model, projected into image planes

c) final 3D position of feature after 5 iterations, projected into image planes

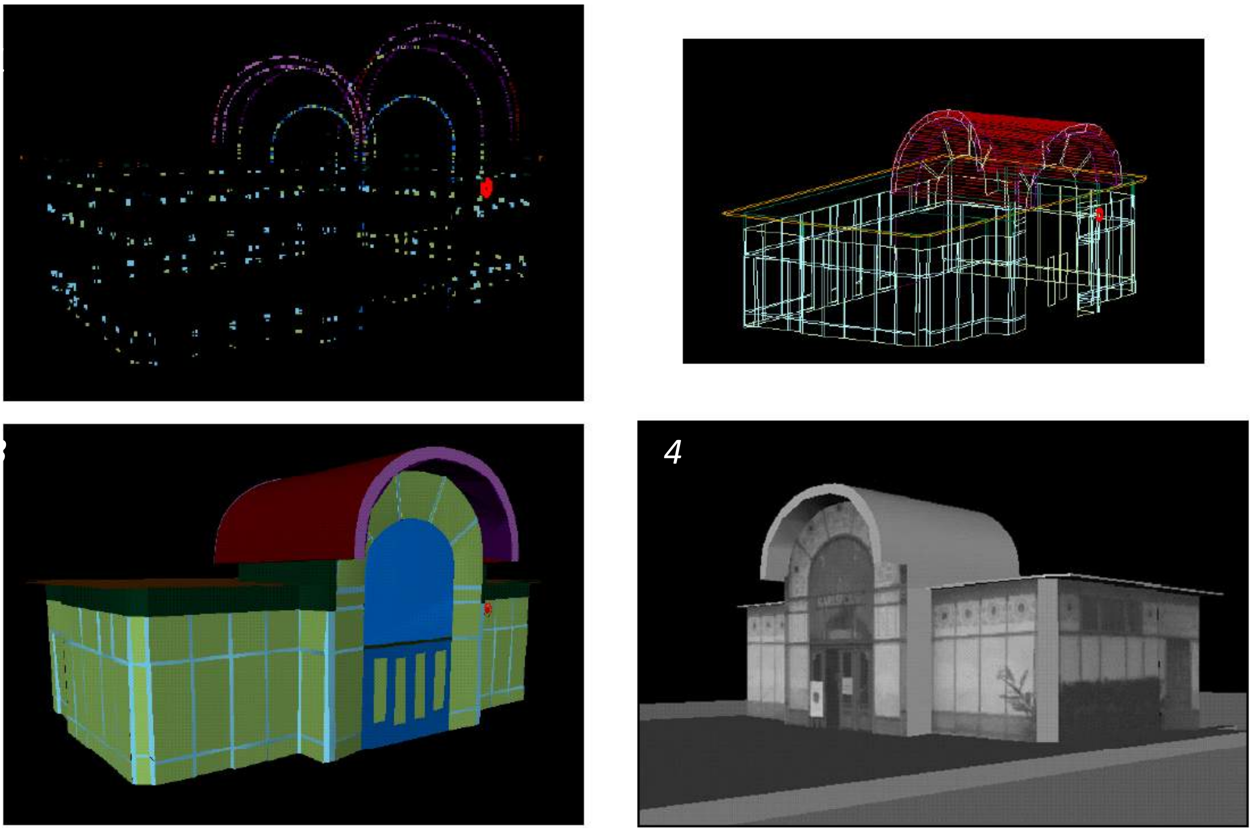


Fig.29 *Photogrammetrically generated CAD-model of O. Wagner-Pavillon:*
1. point model 2. wireframe model 3. surface model 4. texture model

Fig.30 *Photo of Karlsplatz Pavilion (2018).*

3.3 Photogrammetry assets

Due to modern technologies and methods it is possible to document the state of architectural heritage with full and fine details. Digital close-range photogrammetry is a method which allows to document and create textured three-dimensional digital models of existing objects *(Fig.31)*. To create a three-dimensional model many overlapping photos of the object from different camera positions are needed. Taking correct photos for photogrammetry is based on understanding the photogrammetry process. Photogrammetry technique relies on feature detection. First, the software goes through all imported images and detects common points between any pair of overlapping photos. The software detects features in each pair with a significant overlap. Using two dimensional features in a pair of photos, it is possible to detect the location points in 3D space. From all the submitted photos the software creates the accurate camera location. In the next step the geometry reconstruction and texture creation is made based on the camera positions. To avoid software problems with feature matching it is necessary not to have moving objects in the scene during the photo shooting and to have enough overlap between images. Objects made from transparent, translucent, shiny, specular or reflective materials will cause that the matching algorithms will work not correctly, and it will not be possible to create the final object.

3.3.1 Shooting strategy

There are different shooting strategies to achieve a good result - 3D model. The shooting strategies depend on using different equipment, object size, object geometry and accuracy.

The first strategy is used mainly for creating 3D models of characters are based on hundreds of cameras assembled in a spherical or cylindrical construction with flat diffuse light around the object. The size of the object is determined by the size of the studio.

The second strategy is using a camera on a drone, the photo or video acquisition is according to the same shooting rules as for an object on the ground. The difference is that the drone is applied on an object of a large scale.

The third technique consists of using an automatic turntable that spines the object and sets the increments and triggers on a stationary camera. The advantage of the turntable is that the object can be set in any position to shoot all sides and it can also be fully captured. It is recommended to use a single coloured flat background to avoid capturing it and increase the final result quality. It is ideal to use a light box or a light tent that produce no shadows or highlights to achieve the best lighting condition and get the best texture

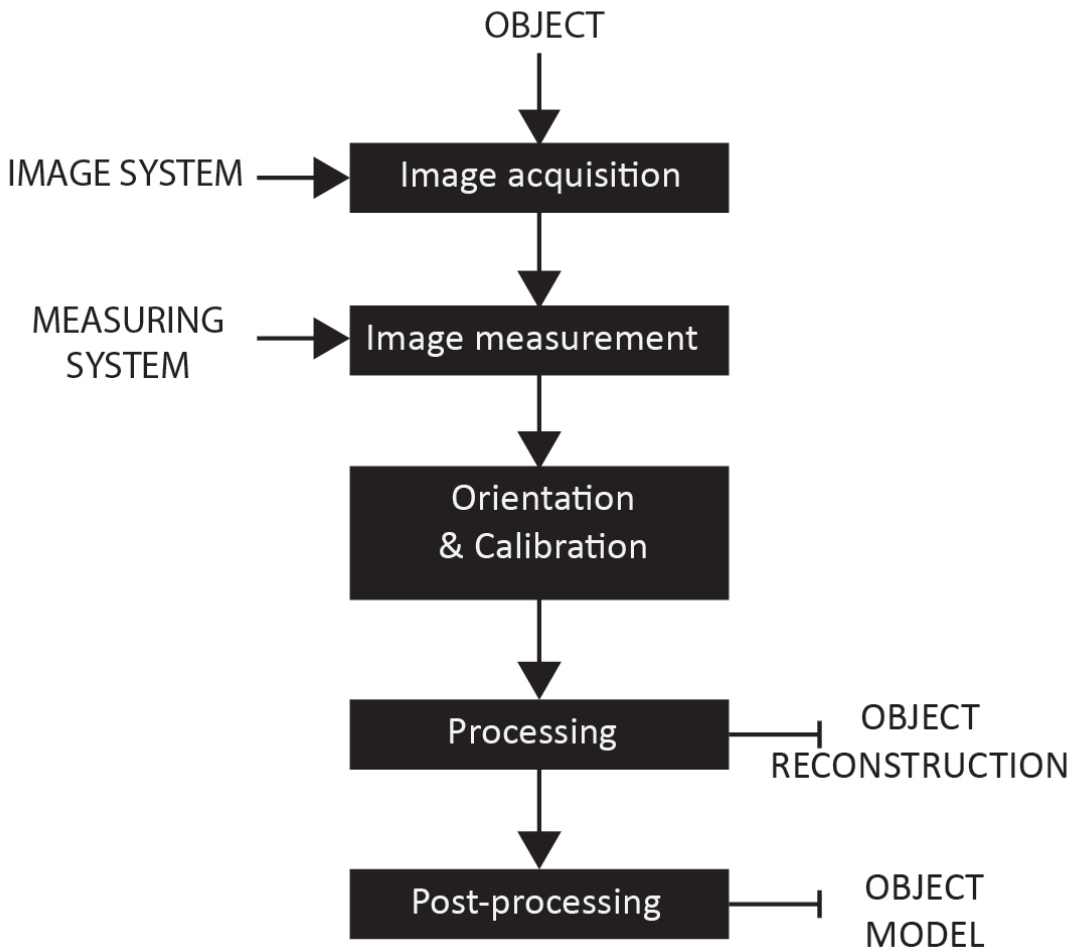


Fig.31 *Photogrammetry process from real object to 3D digital object models.*

quality.

The last strategy consists from moving the camera around the object and shooting full loops of photos *(Fig.32)*. It is recommended to have enough space around the object. For the scanned object up to 3 meters high it is good to have 3-5 meters of available space around. To obtain high quality results, it is recommended to create a loop of photos in increments of 5-15 degrees (10 degrees = 36 images per loop).

At least three types of loops are recommended, based on distance.

First type of photo loops is from distance, where the whole object fits in the image. For better results it is possible to make more loops from different elevation levels. The created images from this loop use the photogrammetry software as “a basic frame”, which will be used during the alignment and depth calculation of the closer-range shots. Panoramic shots should be avoided because they have no parallax changes or depth information that are required for the calculation of the mesh details.

The second loop type is of mid-range and it is closer to the object than the first loop by approximately one half. The mid-range shots are important for the software to connect the far distance loop with the close-range image. The middle range photos should cover all surfaces on the photographed object. Every point on the surface needs to be captured at least with 2-3 images, one perpendicular and two in slight (10-15 degrees) angle to the surface.

The last loop is of close-range and the photos are taken from a close distance from the surface (approximately 50cm). These images are used for creating higher resolution texture. The overlapping rules of photos are the same as for the mid-range loop. That means every shoot needs to be overlapping with the next one by least 60%-80% or preferably even more.

The shape and the curves of the object should be followed during the loop shooting. The picture needs to be perpendicular or in a slight angle in relation to the surface of the object.

3.3.2 Creating three-dimensional model

The process of creating a three-dimensional model starts from the photo acquisition, creating a set of photos and ends with a three-dimensional model of the photographed object *(Fig.33)*. The digital images also brought new methods for the acquisition, archiving and processing. The common image-process workflow begins with the image acquisition and finishes with the intelligent initiation of events. The process of photogrammetry is mostly applied in the range of acquisition of photos, pre-processing and segmentation. Image matching techniques are applied to detect matching object features such as

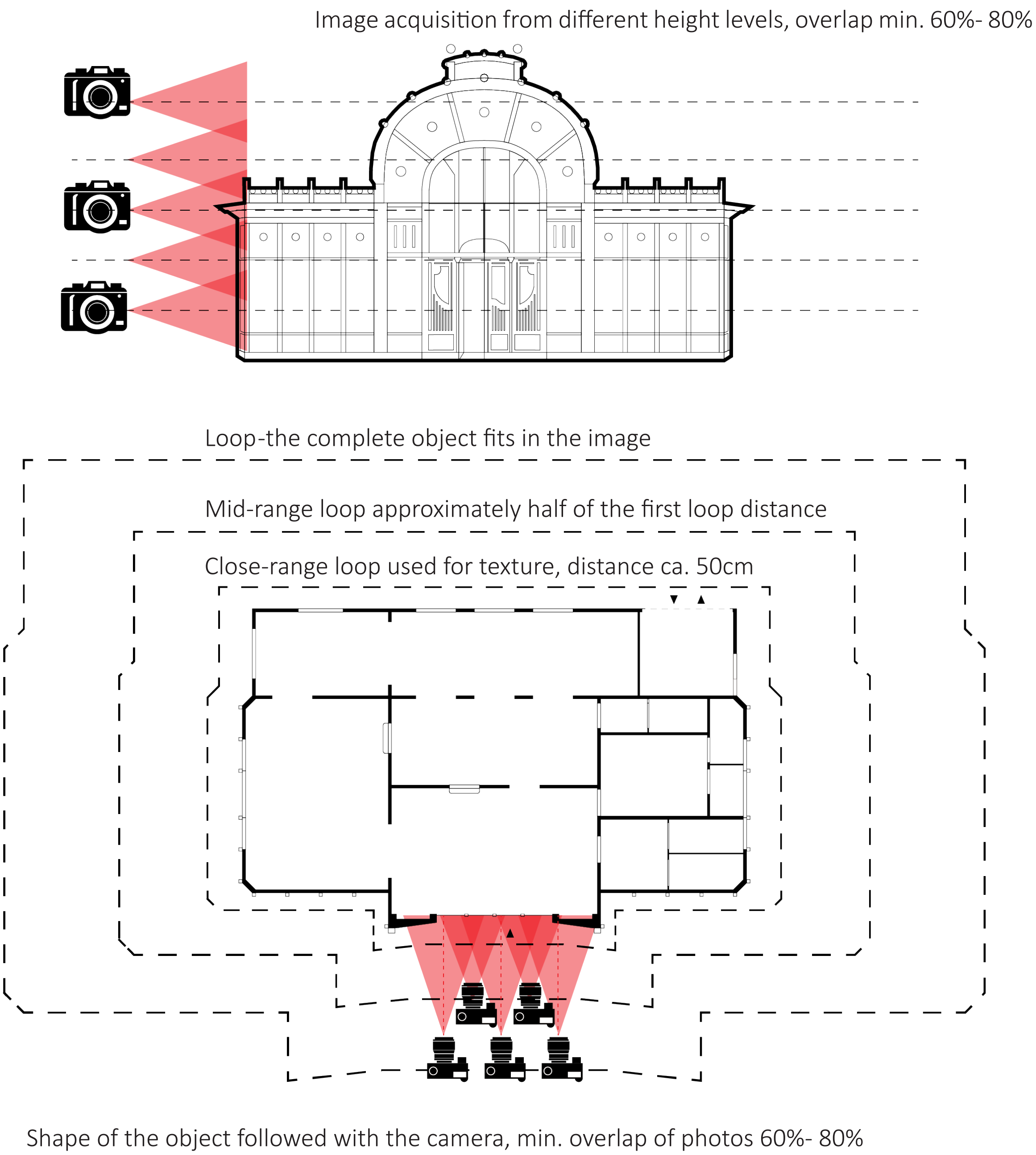


Fig.32 *Photogrammetry strategy applied for Karlsplatz Pavilion.*

points, edges and patterns captured on more than two images of the photographed object. There are few rules that help to avoid problems with the matching process and can be done during the image acquisition.

- The object surface is fixed
- The same illumination, atmospheric effects and media interfaces are present during the acquisition of images
- Diffuse light is used
- The same spectral amount intensities in every image overlay are present

The starting point of image matching process are the input images (video) and the calculation of calibration and orientation parameters. In case of using the smartphone camera the internal orientation parameters are not known but are calculated with a procedure of self-calibration. The digital images used as input are characterised with two important parameters for photogrammetry software.

- Image resolution describes image size as a number of contained pixels typically in length x height. The number of pixels indicates a visual quality of the image and the unit of measure is dot pre inch (dpi).

The higher resolution of the images, the better chance of achieving high accuracy because items can be more precisely located.

The colour depth corresponds to the colour quantity that is possible to register in the image.

Various types of the data formats are used for the digital image: formats that allow to save additional information as image description, colour tables, etc. It is possible to lose information during saving and data compression methods. The most important feature for photogrammetry is the reproducibility of the original source- image.

Second step (pre-processing) is based on image improvement (smoothing, noise reduction and contrast adaptation).

“ *Next step, the feature extraction developed algorithm, is usually called interest operator or point/edge detector. The aim of the interest operator is to extract salient image features, which are distinctive in their neighbourhood and are reproduced in corresponding image in similar way* [Mehravar, 2014].” “*Simultaneously, interest operators supply one or more characteristics, that are later used by the image matching. These operators select any image location that has large gradients in all directions. Edge detectors extract local discontinuities or significant changes in image intensity or texture* [Mehravar, 2014].“ They are used for segmentation operations – extraction of 3D objects and geometrical discontinuities. The establishment of correspondences between features of two or more images is carried out by means of Image Matching techniques. The result of this step depends on the image quality, occlusions and lighting variations.

Measuring conjugate points in two or more images belong to the next step that is the image matching. Finding maximum possible

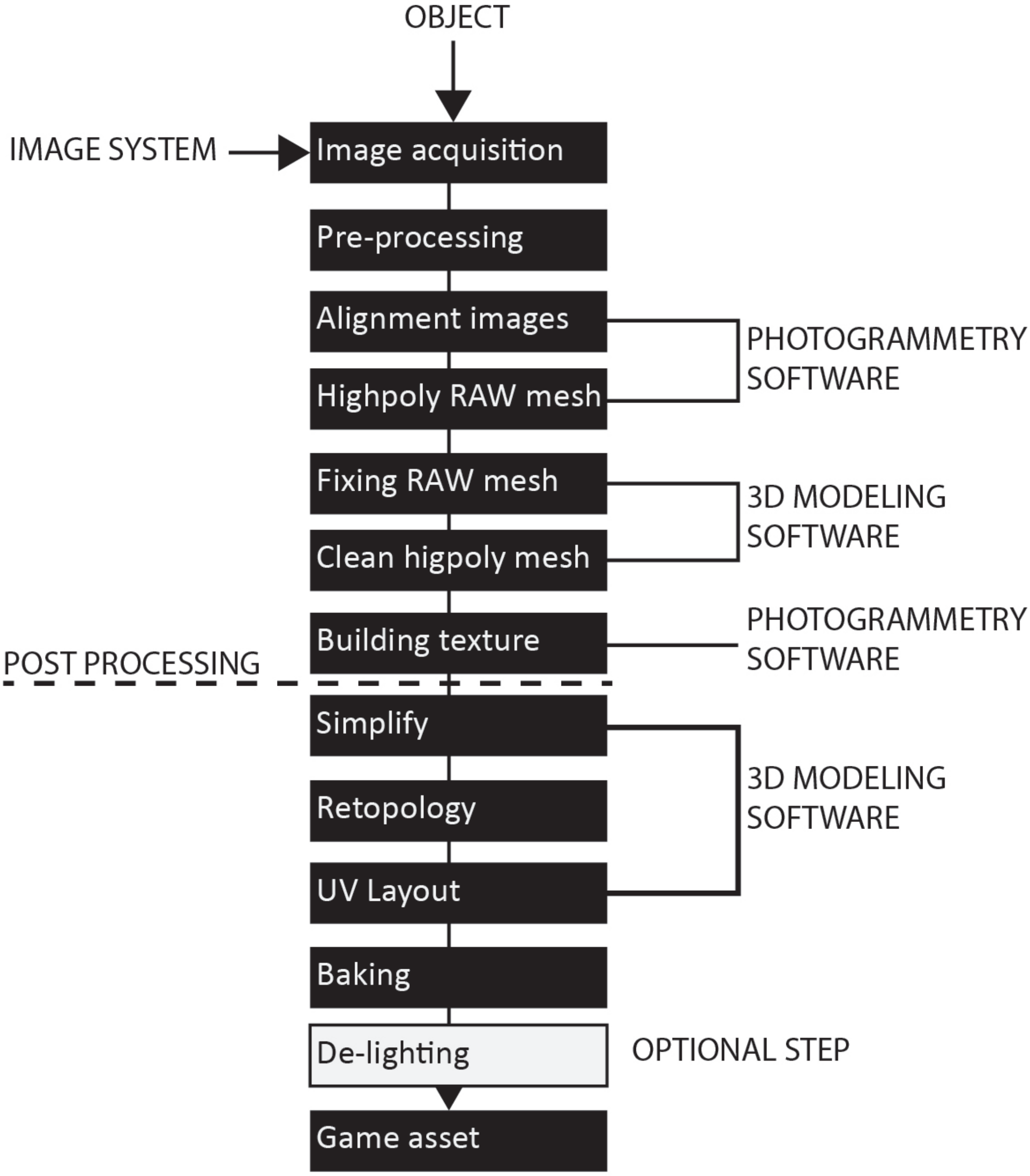


Fig.33 *Process of creating three-dimensional game asset.*

numbers of corresponding entities in all images is used to produce the 3D model. Matching images, pixel by pixel, over the whole overlapping area of images requires an enormous amount of calculations. Moreover, it leads to ambiguity due to a repetitive occurrence of grey values and noise images. To reduce the search space and to minimise mismatches it is possible to apply additional information such as rule or matching knowledge.

Surface reconstruction is the final step and it is based on matching points as well as approximate values of the image position data. This data is used to reconstruct the exact position and orientation of the camera for every acquired image. Based on this reconstruction, the matching points are verified, and their 3D coordinates, geometric elements or vector fields are calculated. After the successful surface generation step, the created model has different displaying options such as wireframe, shaded or textured modality.

In the next step the created 3D models can be textured. The colour images are projected on the geometrical surface based on the internal and external orientation parameters of the inputs. The matching coordinates of the images are computed for each triangle vertex of the surface.

3.3.3 Equipment

Next to choosing the right photogrammetry strategy, another technically important decision to make to achieve the expected result is the equipment and the photogrammetry software.

As a base input data for creating high quality photogrammetry models, the captured images and quality of the images are important. The basic rules for choosing the right digital camera for the best photogrammetry results are:

- high resolution: photos of 8-10 mega pixels or better resolution
- high quality interchangeable lenses: best prime lens (distortion as small as possible)
- camera that allows manual control over settings
- enough data storage memory
- shoots in RAW format and has in-camera histogram
- exceptionally low noise performance with a native ISO 100 or lower

The images need to be as sharp as possible and the depth of the field needs to be as large as possible. High resolution means that fewer photos are required for the reconstruction process. The most common choice is a digital SLR camera.

With the development nowadays it is possible to use a smartphone as a device for high-resolution photogrammetry scan with sub-millimetre resolution *(Fig.34)*. The next important thing is the possibility to save uncompressed photos and provide manual exposure. The exposure needs to be good enough to keep the ISO as low as possible - set to 100 or lower to avoid noise, especially in darker areas, which are not good for the reconstruction software. The shutter speed should be high enough (1/160) to avoid motion blur. To

Fig.34 *Telescopic pole with fixed iPhone 8 used as capturing device in the presented case study.*

reduce a reflection effect from different surfaces the polarize filter can be placed on the camera lens. Since the very early stages of photography, the use of polarizing filters is very common as a way of reducing strong sky luminance and eliminating reflections from glasses or stretches of water [Feininger, 1954]. In close range photogrammetry polarization filters have been used for precise detection of shiny aluminium structures and retro-reflective targets in aerospace industry [Wells et al., 2005].

3.3.4 Software

Nowadays there is a huge offer of a different photogrammetry software. In general, according to the work system, the software can be divided into two groups: locally installed on your computer or other type running on cloud. An advantage of working on cloud is that the process time is not based on strength of your hardware. The software installed on personal hardware gives full control of all the photogrammetry steps during the whole time. *(Fig.35,36)*

3.3.5 Weather condition

For the image acquisition, next to technical support, the weather is the second most important factor. When shooting in outdoor environments, weather has a large impact on the photogrammetry process. Snow and rain are not appropriate weather conditions for photo shooting. The sun produces highlights and strong directional shadows that are difficult to remove from the generated albedo texture. This is a situation that needs to be avoided as it is difficult to have a good exposition with resulting high exposure range. In high-contrast photos, noise tends to appear in strong shadows. Day time without direct illumination, as experienced during sunrise or sunset, is the best shooting condition. Shooting on an overcast day provides a constant indirect illumination and very soft shadows that can be easily removed from the image later. On the other hand, in case of low luminosity, the ISO value should be raised. Stable weather and lighting conditions are important to have consistent pictures for the reconstruction software.

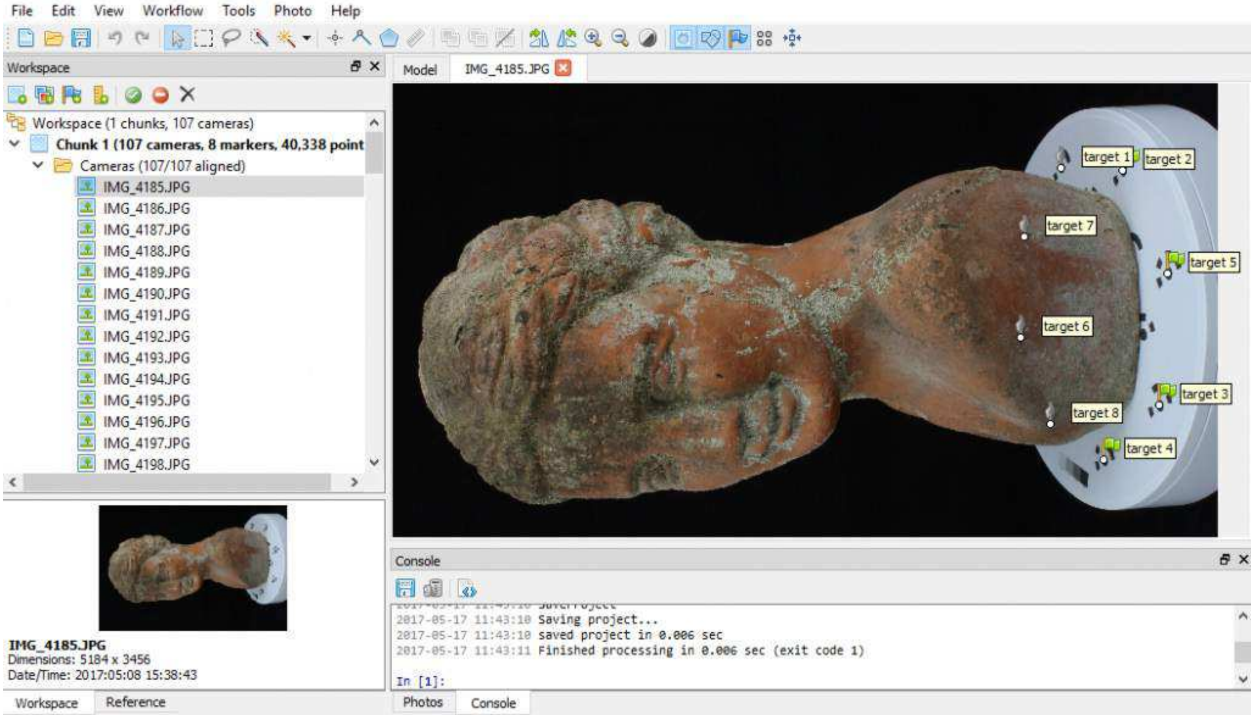


Fig.35 *Interface of the Agisoft Metashape software.*

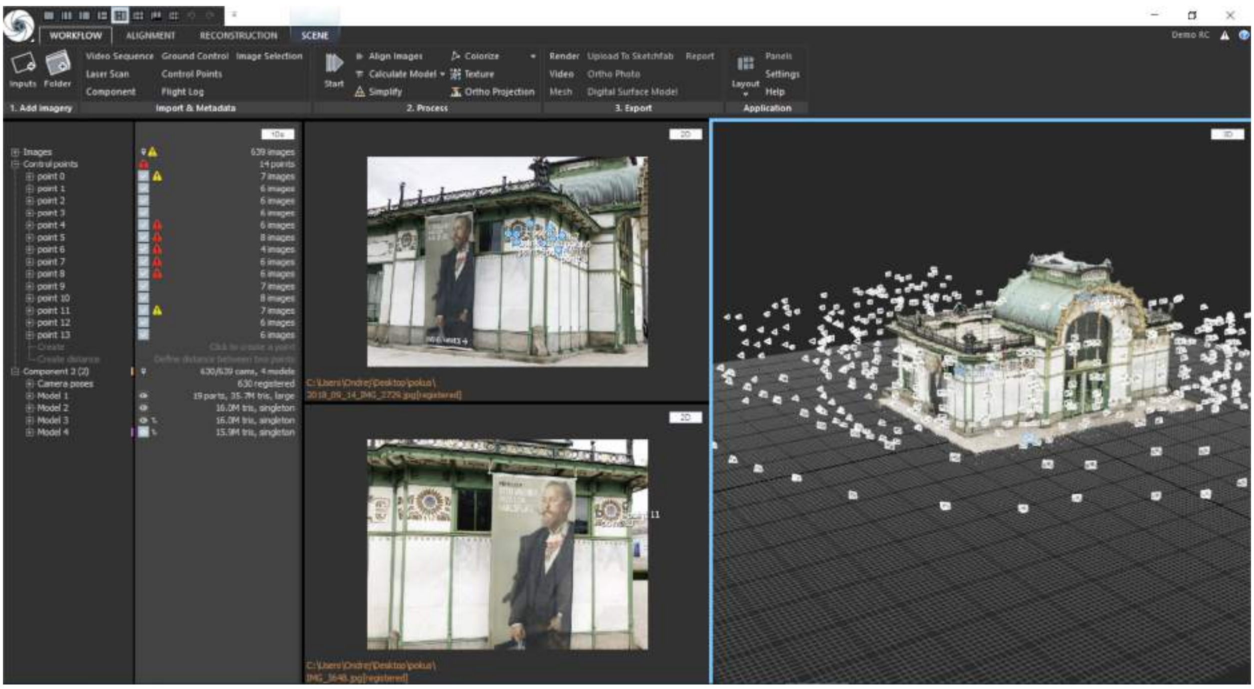


Fig.36 *Interface of the RealityCaptue software with the 3D model of Karlsplatz Pavilion.*

IV. OTTO Kolomann WAGNER
Life and work

Otto Koloman Wagner *(Fig.37)* was born in Penzing near Vienna, Austria, on July 13, 1841 as a son of Simon Rudolf Wagner and Susanne Huber. Wagner´s father died when he was just 5 years old. His early death seemed to be the decisive event in Wagner´s life, which made him continually examine the issue of self-generation. This later became his architectural art. First, he attended the Technical University and trained as a builder on the site to learn all about building. It was Theophil Hansen on whose recommendation Wagner was able to proceed to the Königliche Bauakademie in Berlin in 1860. In 1861-1863 he studied at the Academy of Fine Arts in Vienna. Where he met Sicard and Van der Nüll, architects of the Vienna Opera House, they introduced him to art. "*Wagner´s Modern Architecture is rooted in the school of Sicard and Van de Nüll. The architects, who shared their workload the way Adler and Sullivan did, possessed a subtleness and profundity not surpassed even by Borromini and Guarini, and were this abandoned by the construction industry and its journalistic science of art, right to suicide for one and an early death for the other* " [Graf, 2016].

After he left the Academy, he worked in the studio of Ludwig von Förster, the Ringstrasse architect, where he was given an executive function from the start. Otto Wagner's early commissions were for private houses and office buildings in the Historicizing style, exemplified by the 1867 Villa Epstein in Baden. In 1873 Otto Wagner designed the synagogue in Budapest. "Haus Schottenring 23" (1878) and Villa Wagner (1888) in Vienna-Hütteldorf are also in the historicist "Ringstrasse style". The 15 houses he completed were one of the mainstays of his art converting the experience with his strict mother into architecture and sublimating her sternness. From 1887 they were always on the brink of the intolerable as defined in Vienna – The house Universitätsstrasse 12, strictly conforming to Sullivan´s Wainwright house of the three years later, was promptly labelled ´´suspender house´´ by Vienna´s ever malicious tongues. The house Wienziele 38a (1898), corresponding both in time and form to the Schlesinger and Meyer department store on Chicago´s State Street, outraged the Viennese. 15 years later, Loos and Lux were still reproachfully shaking their heads over it. The three houses, performing a period from Doric-Ionic-Corinthiaca, are the most graceful variations of the primeval maternal dwelling.

In 1890, Wagner self-published the first volume of "Einige Skizzen, Projekte und ausgeführte Bauwerke" ("Some Drafts, Projects, and Executed Buildings"). This and the following volumes issued in 1897, 1906, and 1922 respectively already documented the architect's most important works during his time. Otto Wagner was increasingly fascinated by the new developments in science and technology. Up to 1894 Wagner's architectural practice was fully in the prevalent Neo-Renaissance and Neo-Baroque modes. This can be seen in the private dwelling Rennweg 3 in Vienna from 1889, a Baroque, palace like residence

Fig.37 *The portrait photo of Otto Koloman Wagner.*

with rather conventional decoration. Wagner's 1897-1898 project for an academy of fine arts combined classical planning principles inspired from the Roman imperial fora with an aggressive monumentality; however, the open metallic crown with floral decoration which topped the main building was a distinctly modern element. In his remarkable inaugural lecture, Wagner, who was already in his fifties, declared himself absolutely and without reservation in favour of modern architecture in response to modern needs and condemned all stylistic imitation as false and inappropriate. This inaugural lecture, which epitomized Wagner's philosophy of architecture and design, was published in the following year as a book under the title Moderne Architektur where he expressed his ideas about the role of the architect. His style incorporated the use of new materials and new forms to reflect the fact that society itself was changing. In his textbook, he stated that "new human tasks and views called for a change or reconstitution of existing forms". As a designer, from 1890, Otto Wagner was also responsible for numerous furnishings, lighting, textiles, and utilitarian designs.

The functionalism message that Wagner set forth was that "*Modern art must yield for us modern ideas, forms created for us, which represent our abilities, our acts, and our preferences*" and that "*Objects resulting from modern views ... harmonize perfectly with our surroundings, but copied and imitated objects never do.*" Moreover, Wagner repeated verbatim the famous functionalism principle advocated by the great German architect Gottfried Semper. Wagner's outspoken, strongly rationalist functionalism was indeed more revolutionary than his architecture. He subsequently became an adviser to the Viennese Transport Commission and the Commission for the Regulation of the Danube Canal in matters of art. The motto he had adopted for this project, from Semper's *"Artis sola domina necessitas"* (necessity is the only mistress of art). In 1894 he was commissioned to design the stations of the elevated and underground railroad (Stadtbahn) of Vienna. The stations that he designed at the start were in a rather conventional historicist mode. This, however, changed drastically in later stations he, presumably under the influence of his pupils Josef Hoffmann and Josef Maria Olbrich, both of whom worked for him for several years. Thus, in the later stations, such as the Hofpavillon in Schönbrunn and the Karlsplatz Station, Wagner used the historicist formal vocabulary in a freer and more innovative manner. In his blocks of flats in Vienna, such as Linke Wienzeile 38 and 40 of 1898, Wagner adorned the new materials façades, which were essentially inspired from Renaissance palace architecture, with bold flat ornament, purely Art Nouveau in character. In that year Wagner joined the Vienna Secession, remaining a member until 1905.

After the turn of the century, Wagner started throwing off the Art Nouveau influence. His work in the new mode culminated in Sankt Leopold, the church of the Steinhof Asylum in Penzing outside Vienna, built in 1904-1907. This was a large cruciform edifice with a hemispherical dome raised on a cylindrical drum. There was abundant decoration, but this had been submitted to a linear stylization and was kept within rectangles and squares. Although remotely Byzantinesque in character, it appeared nonhistoricist and very much in the spirit of the work of younger architects such as Josef Maria Olbrich and Peter Behrens. Wagner's masterpiece aesthetically and technically of the time was the Postal Savings Bank in Vienna of 1904-1906, a work characterized by linearity, smoothness, and crispness of design. Wagner conceived this building as a total work of art, using not only the newest materials such as reinforced concrete and aluminium; he also designed the entire interior, which reveals early functionalist tendencies, and used new methods of furniture-making. This building secured Wagner a place among the 20th-century pioneers. Many of his further designs such as that for the Emperor Francis Joseph Municipal Museum, the Technological Museum of Trade and Industry, a new Academy of Fine Arts, the Ministry of War, and the Ministry of Trade were not realised.

Through his 1894 lecture, which was published as a book in numerous editions, Wagner facilitated greatly the reform of architectural practice and the establishment of modern design principles, such as honest use of materials, especially steel; rejection of historicist formal vocabulary; and preference for simplicity and clarity of form. His own work remained tied to tradition much longer, although it became increasingly modern after the turn of the century. Among his works, the Vienna railroad with its stations and the Postal Savings Bank provided exemplary solutions to contemporary and relatively new architectural problems. His theories and teachings, on the other hand, exercised a broad and fruitful influence and found their full realization in the work of subsequent generations. Without his academic work between 1894-1913 which produced the Secession and the School of Wagner's. Without Wagner´s uprooting between 1846 and 1868, the Vienna of 1900 would not have come into existence, incidentally a fact well known friends and enemies a like among his contemporaries.

4.2 Architectural rules, Vienna Stadtbahn

Vienna was just the 5th city with a city railway. The decision to build it helped the city to reach a new identity and a status of modern city. Otto Wagner was responsible for the desig as an adviser to the Transport Commission in Vienna. To understand Otto Wagner's impact on architecture, we need to understand the design rules. As one of the most important figures in early modernist architecture, Wagner believed strongly in stressing the function of architecture as being more important than form or style. This understanding is mainly visible in his designs for the Vienna city railway *(Fig.38)*.

In 1895 Otto Wagner, declared: “*The only possible point of departure for our artistic creation is modern life.*” The best-known Wagner researcher and admirer, Otto Antonio Graf, analysed the complete process of design in the book Baukunst des Eros. “*Fifty years after Ruskin (The Seven Lamps of Architecture, IV, XXI) had declared the decoration of railway stations unbearably absurd, Wagner saw another necessity than to get the passenger off the track as quickly as possible, since he had nothing to do with a railway running in the open country, nor with a promising mountain railway leading over passes and gorges*“ [Graf,1985]. Wagner considered the project an important contribution to the appearance of the city and paid as much attention to the large structural elements, such as bridges and station buildings, as to the small details, such as railings, lamps, signs and inscriptions, realising a total design concept in the construction. “*The history of architecture was not to be ripped, but to be raised to a higher level through the infusion of the constructive dimension. Not a crack in the creative period seemed necessary, but its acceleration, a peak of the compositional process of modernization. New purposes lead to a new animation of the given ancient form and forms. Wagner succeeded in transforming the classic Dorica into a completely new system for 40 km of rail, which also proudly demonstrated its stylistic modernisation from 1894 to 190, without ridiculing the old system of forms.*“ [Graf, 1985]

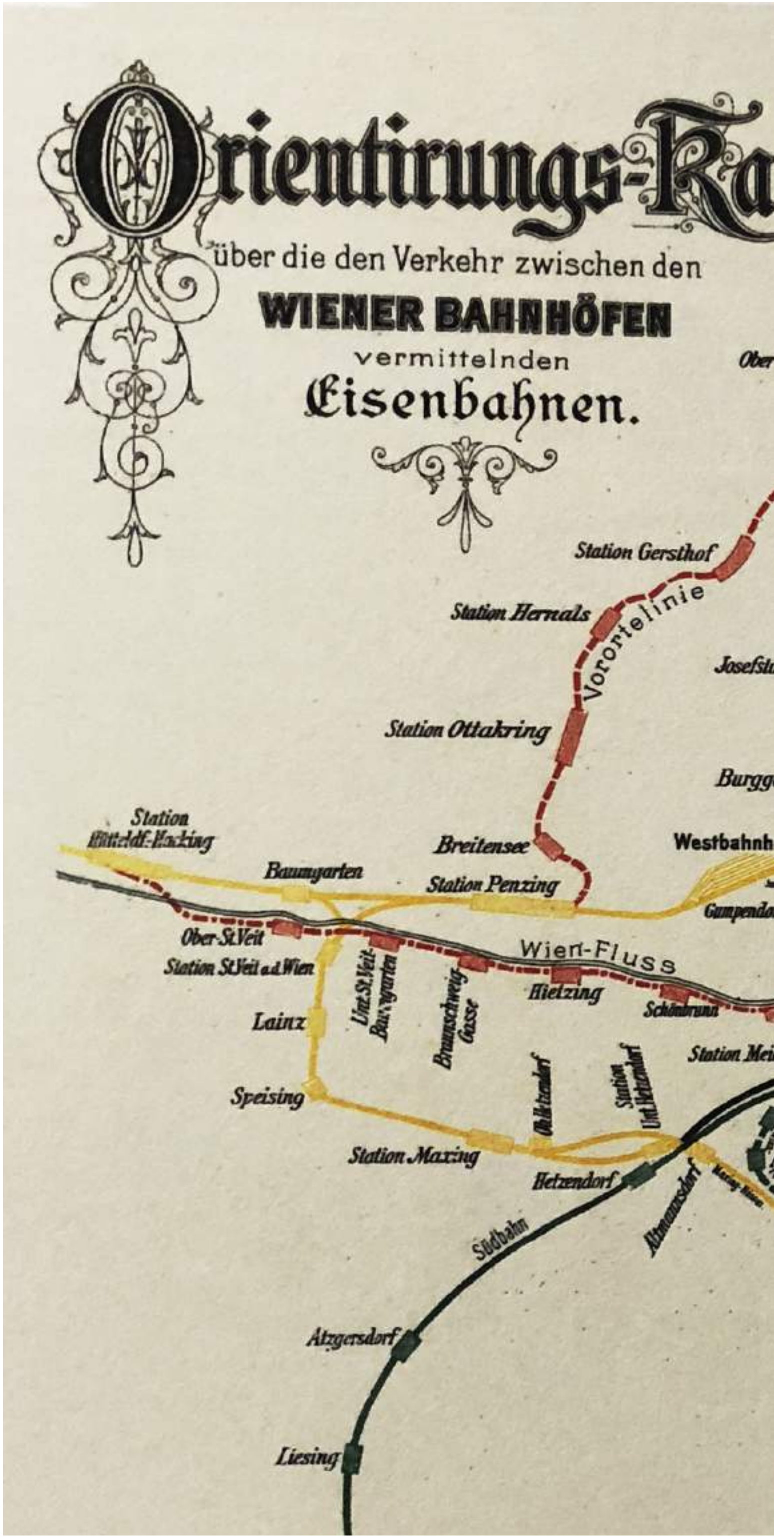


Fig.38 Plan of Vienna City Rail from 1902.

The Doric rules are presented, for example, on the entrances of two-storey railway stations that are marked with Doric columns in the basement. The Doric order is characterised by a plain, unadorned column capital and a column that rests directly on the stylobate of the temple without a base. The Doric entablature includes a frieze composed of trigylphs—vertical plaques with three divisions—and metopes—square spaces for either painted or sculpted decoration *(Fig.39)* [Barletta, 2001]. The Classical Doric temple proportion, 6 × 13 columns, is taken up by numerous temples, e.g. the Temple of Apollo on Delos. A slight variation, with 6 × 12 columns or 5 × 11 intercolumniations occurs as frequently [@hisour]. The Triglyphs and Metopes, the most distinctive and definitive features of the Doric order, are presented along the CityRail stations *(Fig.39)*.

The most known symbol, an unmistakable emblem of the CityRail, one which has remained omnipresent in Vienna to this day is the sunflower railings. In 2017 researching methods uncovered that the familiar known paint green colour was a mid-twentieth century invention. The original colour of the railings and many of the iron components in the station were painted a light ochre or white colour *(Fig.40,Fig.41)*. *"The attentive observer sees all the necessary architectural wisdom at work when he studies the particle of the balustrade attached many kilometres along the railway and the Vienna River: the head from the 12-part division, which closes the stands, expands in the motive frame to the cassette gloriole the 1 + 8 + 16 (12 + 13) forms joined together to connect them with 12 further ones at the corners, which through a small Pelte (small shields) also bring into play the rhodic Pelte, which runs through 34 stations and their viaduct (Fig.39).“* [Graf, 1985] The Doric sequence is present in every piece of the railway in every station from Heiligenstadt to Alserstraße.

4.3 Otto Wagner Pavilion Karlsplatz

From the 36 Vienna subway stations that can be seen, today's eight have been maintained as they were first built by Otto Wagner. Two of the original light City Railway stations are today used as a part of the Wien Museum. One of them was a private station for Franz Joseph, the second pair of particularly fine station buildings can be found on Karlsplatz. Two station buildings on Karlsplatz with the finest and most revolutionary designs allowed Otto Wagner to achieve his goal to create two modern axes of architecture in a city that was becoming one of the most modern cities of its time. These two buildings became one of the most modern monuments of the modern city *(Fig.42)*. Architectural critic and poet Friedrich Achleitner commented on the city railway stations as follows : *“...In these two station buildings Wagner reached a highpoint of his dialectic (in his planning of*

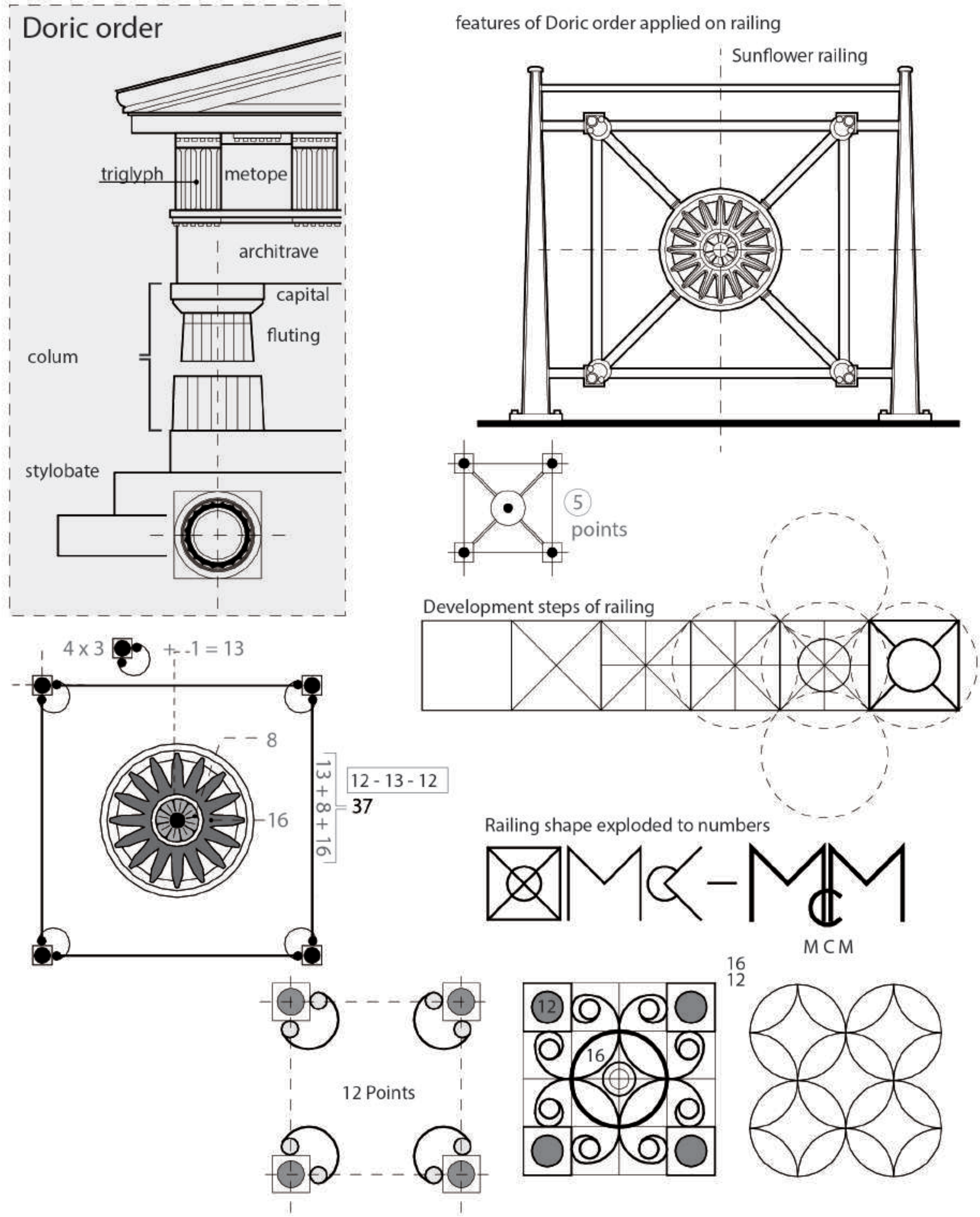


Fig.39 *Doric order and analyse of applying Doric rules on sunflower railing according O.A.Graf.*

the Stadtbahn) between function and poetry, construction and decoration, whereby a severe rationalism engages in competition with an almost Secessionist kind of decoration.“ One of the most quoted Otto Wagner statements *“Karlsplatz is not a square, it is a region“* described the enduring problem of urban development. Karlsplatz was never planned as an urban square but evolved from natural spatial conditions. The completion of the Ringstrasse placed Karlsplatz in the focus of the urban planning. Wagner developed a still fascinated vision of it by endeavouring to place the square in an architectural frame. The location of the station-pavilions provided an easy access for the railway and marked the intersection of the axis of Karlskirche and Akademiestrasse, the street leading to the Ringstrasse *(Fig.43)*. Researcher Otto Antonio Graf analysed the position of the Karlsplatz stations in the book Baukunst des Eros: *“... Wagner has often thought about the Karlsplatz. On the Church axis he saw, on one hand, its five spatial ovals and the eight “tambour windows”, on the other hand, the rhythm of the Musikverein building from Hansen. On the cross-axis of the Technical University he recalled his own proposal for the large pillar and he knew that the greatest moments and monuments should be remembered (beginning with the opera building and ending with Hagia Sophia), ..., from the overlapping of all these ideas the two houses of station from iron, marble and gold were developed ”* [Graf, 1985]. The Karlsplatz station consists from two entrance pavilions of identical design facing each other. Both of them served to accommodate a platform *(Fig.44)*. The pavilions are based on new materials and techniques with a self-supporting system from steel. The steel structures in the entrance halls and ticket stations of the low-level stations were left uncovered, as well as the I-beams were used as window lintels. In addition, the Karlsplatz Pavilions had special cavity walls. The outer sheets were covered with plates of fine white Carrara marble. The upper wall parts are decorated with gilded ornaments made of gold and floral motives such as sunflower rosettes, wreaths and golden plants frieze around the extraordinary copper roof with a characteristic green patina. The initial project foresaw a dome to crown the station, but after the final approbation was given for the square, one of the most important in Vienna, its construction was rejected. The station entrances received more functional treatment as a symbol of modernity.

The interior walls were faced with stucco, supported by rough iron frameworks while the structural scaffolding remained visible. The explanatory text and drawings from Otto Antonio Graf gives a better understanding of the composition and design workflow.

All these structural details and the new methods of wall claddings demonstrated his combination of technical and constructional functionality with high aesthetic criteria and his own progress as an architect from neoclassicism towards modernism. The presence of the ornaments revealed two facts. First, the short floral ornamentation period Wagner went through supported the Secessionist

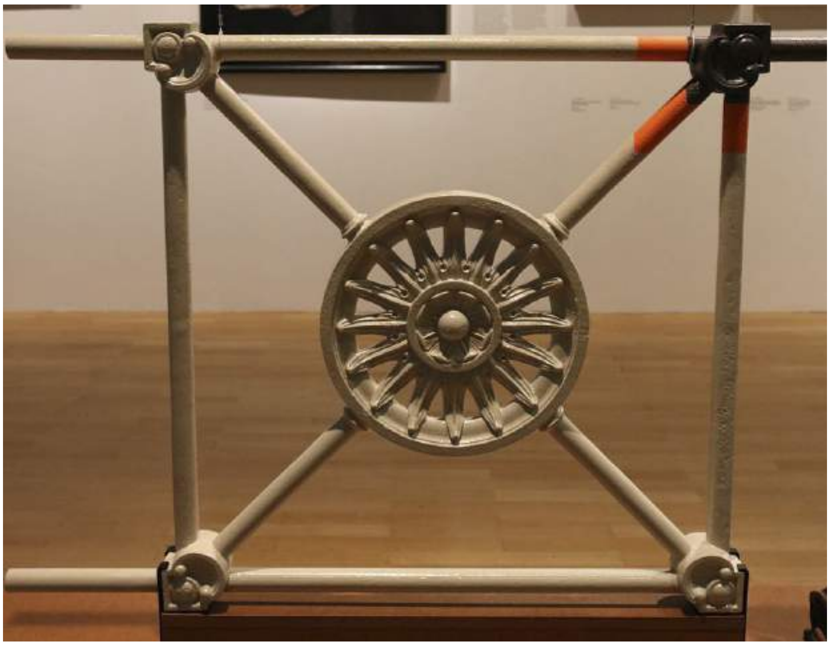


Fig.40 *The original colour of the railing presented on Otto Wagner exhibition in 2018.*

Fig.41 *The original colour next to the current green coloured railing, photo from document Otto Wagner - Visionär der Moderne Doku (2017).*

ideas of the turn of the century. Second, the curvy floral ornamentation created by his student J. M. Olbrich, the founder of the Secession movement, was involved with the details, design and outward appearance of Wagner's buildings. [Haiko et al. ,1992]

With the unparalleled simple and practical design he broke the tradition by insisting on function, material, and structure as the bases of architectural design and created jewel of art nouveau. Still, at this time his style was defined as refined and cool gentleman architecture, which did not hesitate to use fancy details, expensive materials nor perspective effects. Ludwig Hevesi, the hagiographer of incipient Viennese modernism, described the Karlsplatz stations by Otto Wagner as a "*masterpieces in their own way" with "Delicate, light forms of polished, white marble, iron and Secession-green décor* ."

The planning for the underground rail junction in the late sixties and the fact that most of the stations were in bad condition including Karlsplatz, threatened the pavilion with demolition. Protests followed with the motto "*Save Otto Wagner*" *(Fig.48)*. The buildings were moved from the original Akademiestrasse area and reassembled at the new subway site in 1977 *(Fig.49, Fig.50)*. Ironically, because Wagner used a steel frame construction with marble facing, the building could be disassembled and reconstructed. The stations were reassembled two metres higher than their original level after completion of "U-Bahn" construction. This move was a bit unlucky because as a Antonio Graf mentioned, the stations lost the entire depth. The original stations were built lower to allow an unobstructed view of the Karlskirche which was one of the buildings Otto Wagner admired. In in 1979 one of the Karlsplatz Pavilions was affiliated to Wien Museum.

Today, both of the pavilions have lost their original function. Part of the west pavilion is used as an entrance and an exit of a subway. The eastern pavilion, next to Musikverein, transformed into a café. In 1979, the west pavilion was associated with the Vienna museum. Today it is dedicated to documentation and exhibition of Otto Wagner's work and life. It is open from April to October and it belongs to one of the most photographed structures in Vienna. In 2005 it was renovated by the BWM architects that used some of the early photographs as a reference. When comparing original photos, that hang as a part of the exhibition, with the reconstructed state, there can be a lot of differences found. Comparing colour photos to the black and white ones show that the today's interior is not the same people riding the train in the early days were experiencing. According to the photos and original plans it is obvious that some part of interior are gone (the windows where tickets were once sold, tables, ...) The golden embellishments are not present in these early shots of the interior. From the photos it actually looks like only the clock area in main hall had that gold leaf embellishment. As the nowadays research already proofed the wood does not appear to be painted green. The floor

Fig.42 *Main entrance of Karlsplatz station from 1902.*

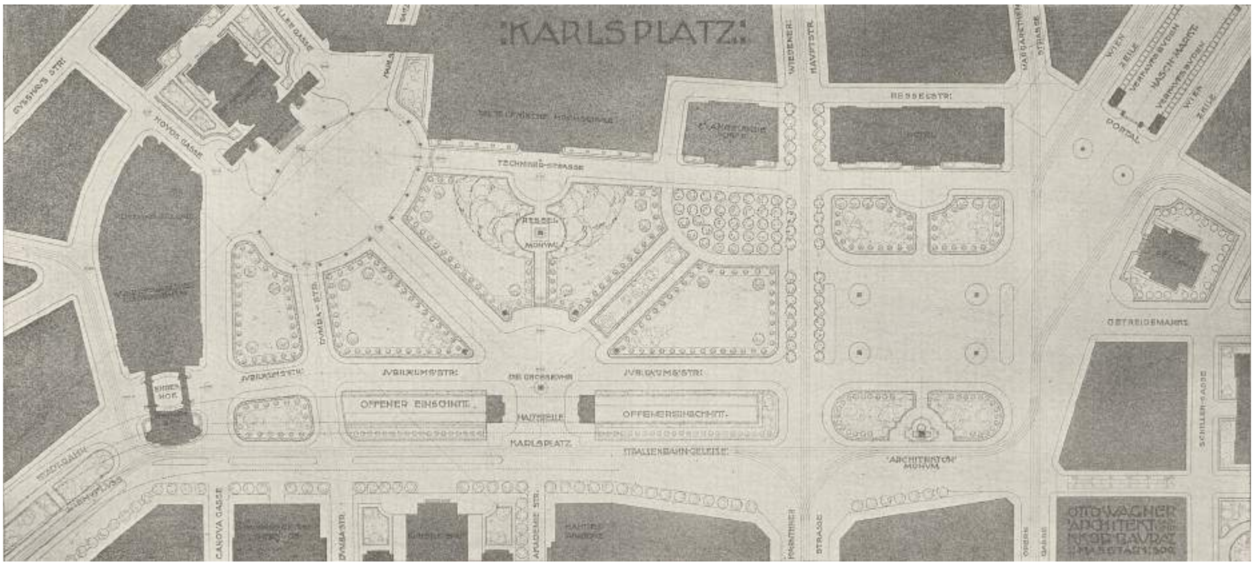


Fig.43 *Otto Wagner's design for the redevelopment of Karlsplatz and the establishment of Emperor Franz Joseph City Museum.*

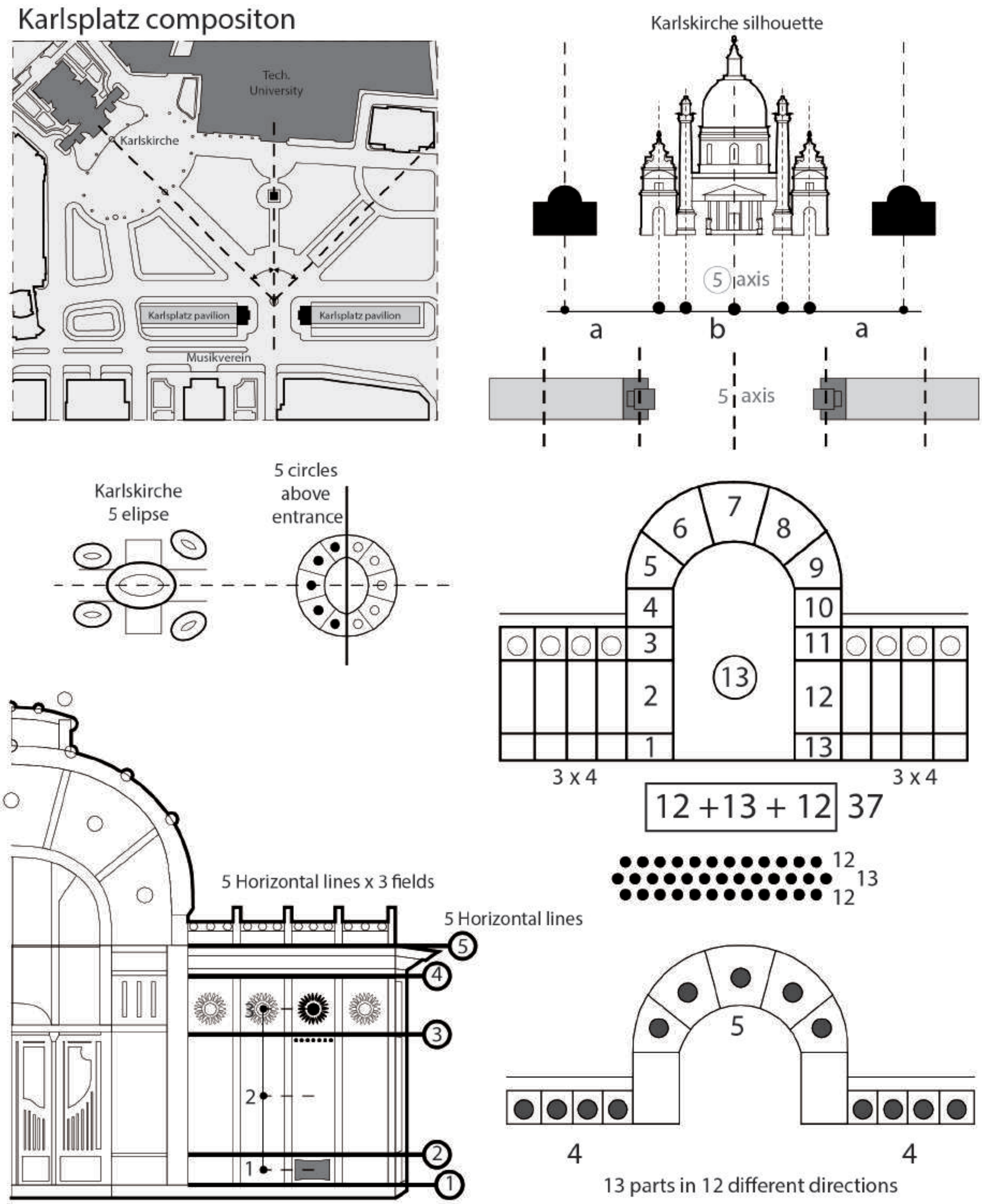


Fig.44 *Doric order applied on the sunflower railings according O.A.Graf.*

Fig.45 *Building the Karlsplatz Pavilions, April 25th 1899.*

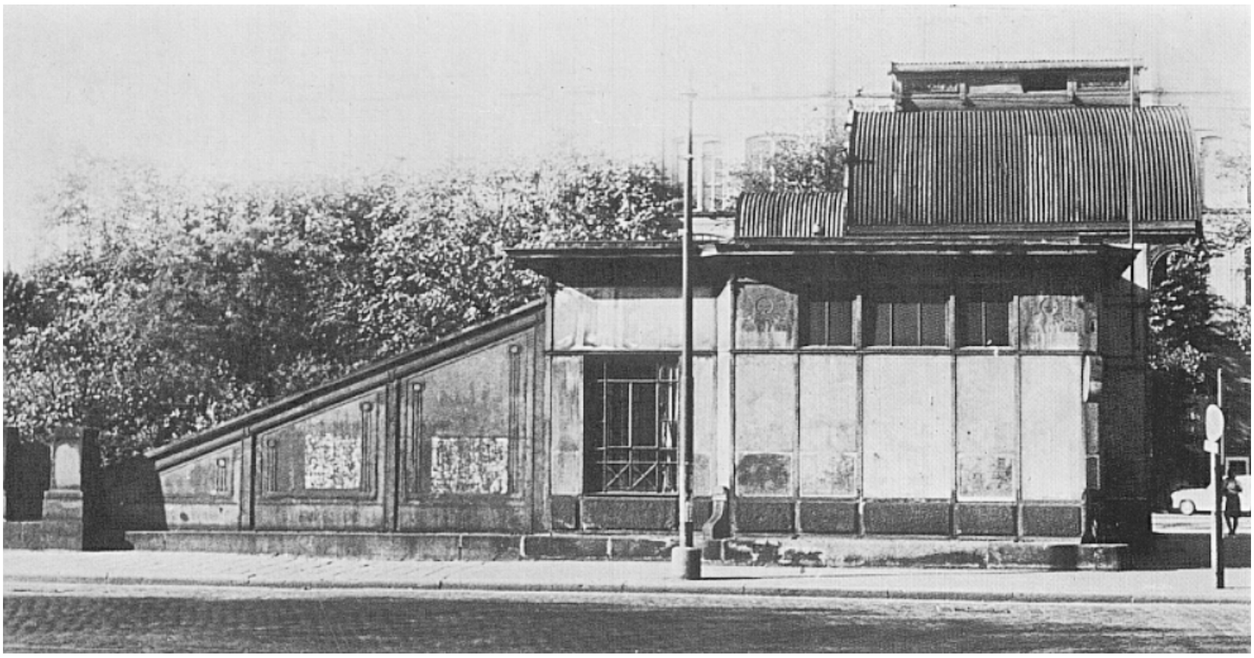


Fig.46 *Side-view on deteriorating Karlsplatz Pavilion in 1960.*

Fig.47 *Photo of vestibule with ticket office, stand and clock, 1900 (part of the permanent exhibition).*

Fig.48 *Demonstration against the demolition of the Pavilions of Stadtbahn station Karlsplatz organised by students of architecture in 1969.*

Fig.49 *Photo of the railway building site from 1969.*

Fig.50 *Karlsplatz Pavilion during reassembling, 1977.*

was probably destroyed during the reassembling. Comparing the photos of the entrance with the actual state it can be noticed that two large bronze cast plaques, informing the passengers of the train direction, and the light over them, are missing.

4.4 Otto Wagner Today

The year 2018 can be marked as a year of Otto Wagner. On the occasion of the one-hundredth anniversary of Wagner´s death, a lot of exhibitions were organised. 2018 was also a year when Vienna was living with modernism. *"Four of the era's chief protagonists died 100 years earlier: Gustav Klimt, Egon Schiele, Otto Wagner and Koloman Moser, all of whom significantly shaped turn-of-the-century Vienna... world-famous Viennese Modernism experienced a watershed moment. Not only due to the deaths in 1918 of Klimt, Schiele, Wagner and Moser, four of the leading lights of what turned out to be the most important era in Austrian cultural, artistic and social history "* [@moderne.wien.info]. On the website moderne.wien.info, created on the occasion of the 100th anniversary, visitors can gather useful information about all the protagonists, exhibitions and plan their own tour. "*Wiener Moderne 2018 will take the form of public exhibitions and events, promoted through national and international campaigns, and unified by a distinctive graphic identity system created by Austrian design studio Seite Zwei. This links a variety of print and digital communications, from banners, posters and programmes to website and outdoor displays of motion graphics (Fig.52, Fig.53) "* [@bpando]. Next to the new website source dedicated to the topic of Vienna Modernism, there were many exhibitions focusing on the topic.

The three main exhibitions were:

Museum MAK, POST-OTTO WAGNER,
30.05.2018 to 30.09.2018

"To mark the 100th anniversary of the death of Otto Wagner (1841–1918) the MAK exhibition POST-OTTO WAGNER: From the Postal Savings Bank to Post-Modernism investigates Wagner's role as the "Father of Modernism" and points out not only the context and the interaction between Wagner and other protagonists of early Modernism, but also the influence his epochal work had on his contemporaries, students, and following generations of architects and designers " [@mak]. The exhibition was accompanied by the 300 pages publication POST-OTTO WAGNER: From the Postal Saving Bank to Post-Modernism. (Curator: Sebastian Hackenschmidt, Curator, MAK Furniture and Woodwork Collection)

Fig.51 *Main entrance of Karlsplatz station, 2018.*

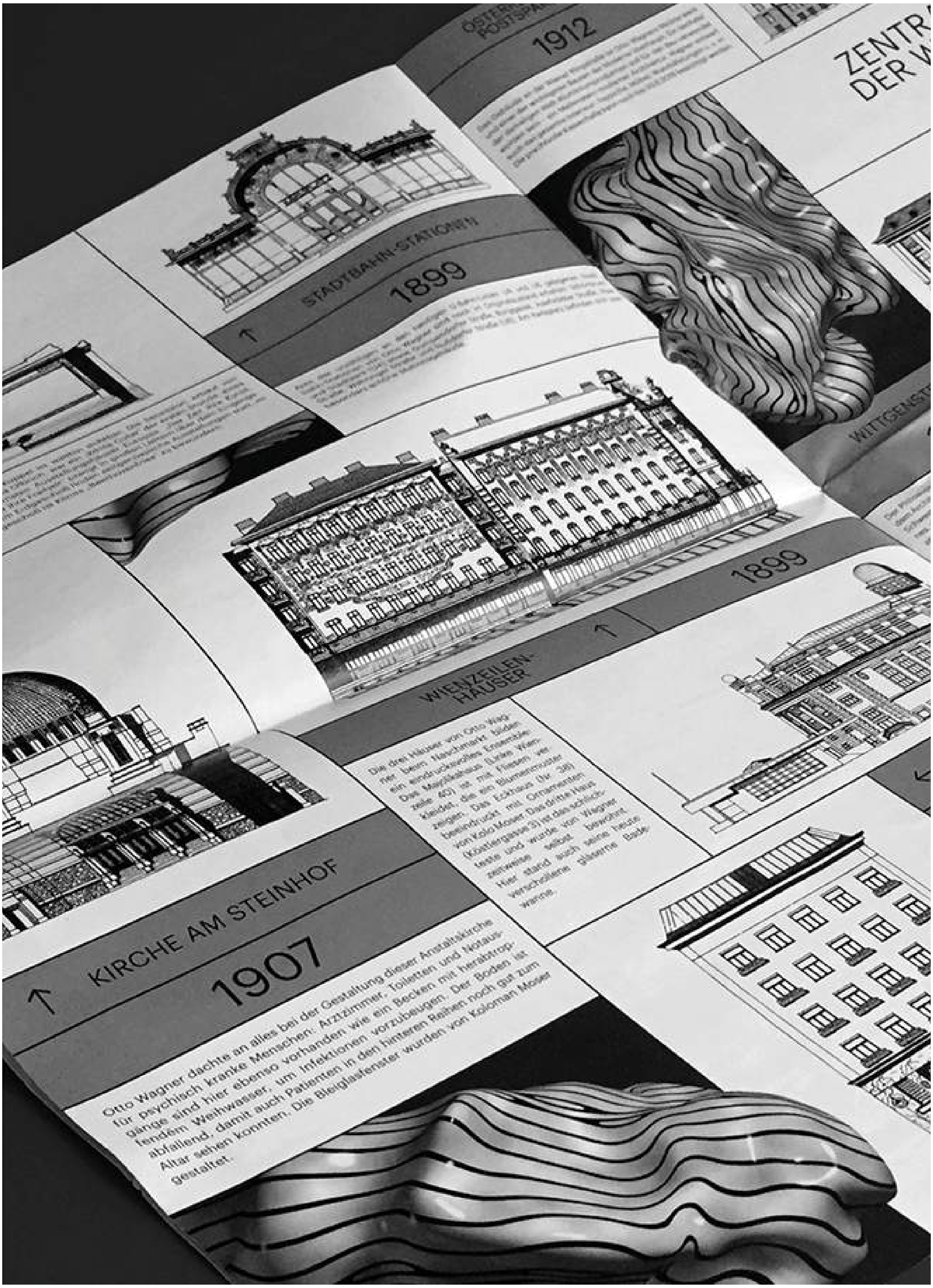


Fig.52 *New graphic identity of Viennese Modernism designed by studio Seite Zwei presented on the occasion of 100th anniversary of the death of the main protagonists.*

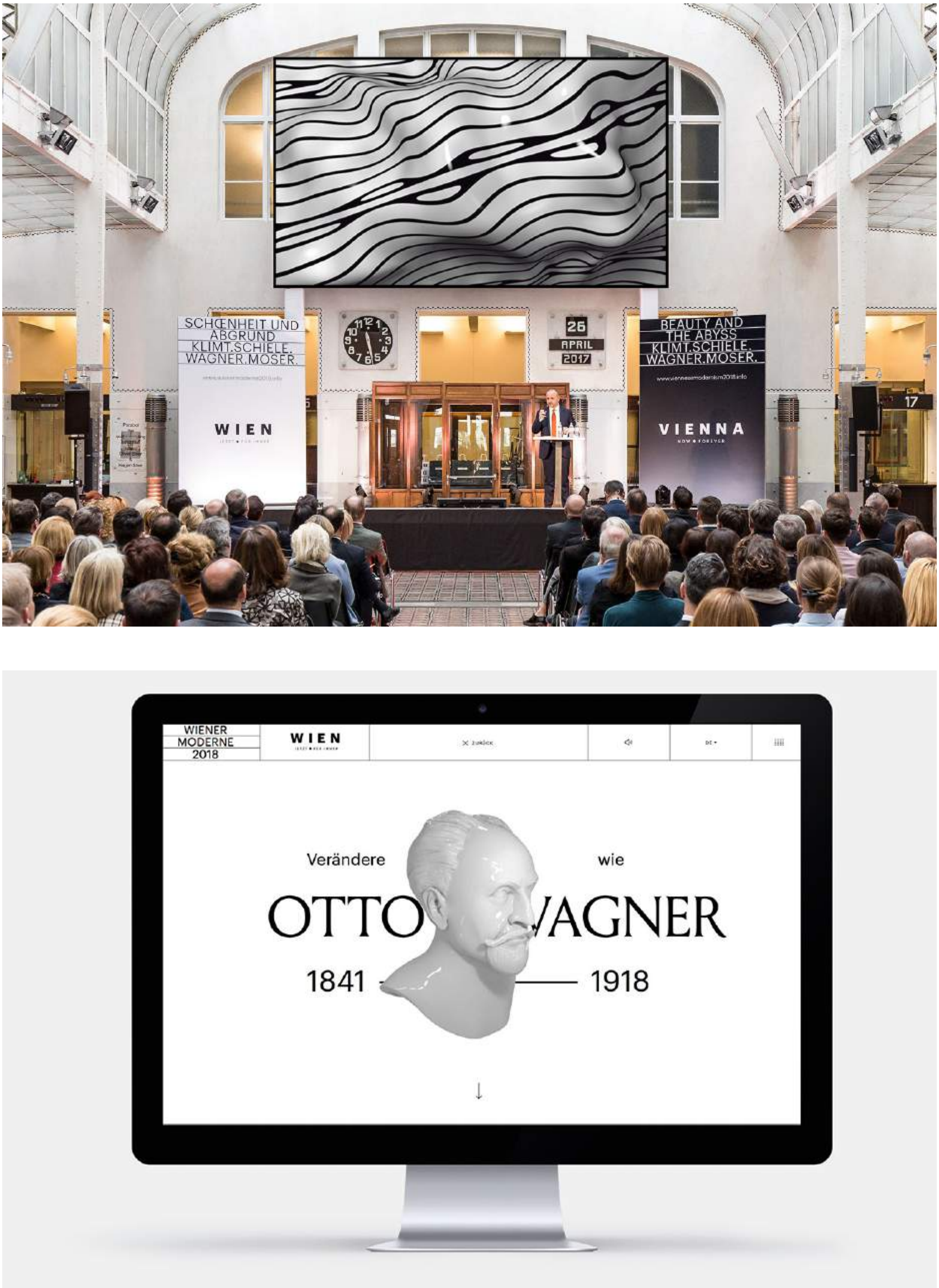


Fig.53 *New graphic identity of Viennese Modernism designed by studio Seite Zwei presented on the occasion of 100th anniversary of the death the main protagonists.*

Hofmobiliendepot (Museum of furniture), Wagner, Hoffmann, Loos und das Möbeldesign der Wiener Moderne , *21.03.2018 to 07.10.2018*

As it was mentioned in the previous chapter, Otto Wagner was an architect that designed his buildings with great attention to detail – including furniture. The exhibition in Möbel Museum was presenting his work. "*... the furniture from Otto Wagner's Post Office Savings Banks ... all these iconic items of furniture herald the dawning of a new era. They stand for revolution and provocation, for a radical break with tradition. And by the end of the nineteenth century this was sorely needed. For all the beauty of the era's art and architecture, the Monarchy was on the inexorable path to collapse* " [@hofmobiliendepot].(Curator: Eva B. Ottilinger *)*

Wien Museum, OTTO WAGNER, *(Fig.54)* *15.03.2018 to 07.10.2018*

The main jubilee exhibition dedicated to Otto Wagner was in Vienna Museum. One of the first exhibitions dedicated to Otto Wagner, called "Das Werk des Architekten", was in 1963. It was curated by Otto Antonia Graf. In 1985 there was an exhibition entitled "Dream and Reality"(Traum und Wirklichkeit) *(Fig.56)* curated by Hans Hollein. It was focusing on the period between 1870 and 1930 and strived to bring all the leaders of Vienna Modernism back to life. More than 622,000 people came to the museum for a taste of Klimt, Schiele, Wagner, Moser. It was the most visited exhibition in the history of Vienna.

This interest remains strong,even beyond 2018. Vienna is still highly interested in the work of Otto Wagner. "*The Wien Museum's prepared comprehensive jubilee exhibition for the one-hundredth anniversary of Wagner's death, and it was the first major exhibition dedicated to this titan of urban architecture in over fifty years. "The exhibition locates Wagner's oeuvre in relation to his companions and opponents, illuminates his artistic, cultural and political environment, and conveys a sense of his international appeal. Exquisite drawings, models, furniture, paintings, and personal belongings vividly relate the story of Wagner's prodigious career. Most of these objects are from Wagner's estate, one of the treasures of the Wien Museum's collection. Several objects will be on view to the public for the first time—an invitation to rediscover this great architect anew*" *(Fig.58,Fig.59)* [@wienmuseum]. The exhibition was accompanied by a richly illustrated publication of 544 pages. In addition to numerous contributions by renowned authors, it contained the first complete inventory of all buildings, projects and designs by Otto Wagner. (Curator: Andreas Nierhaus , Eva- Maria Orosz)

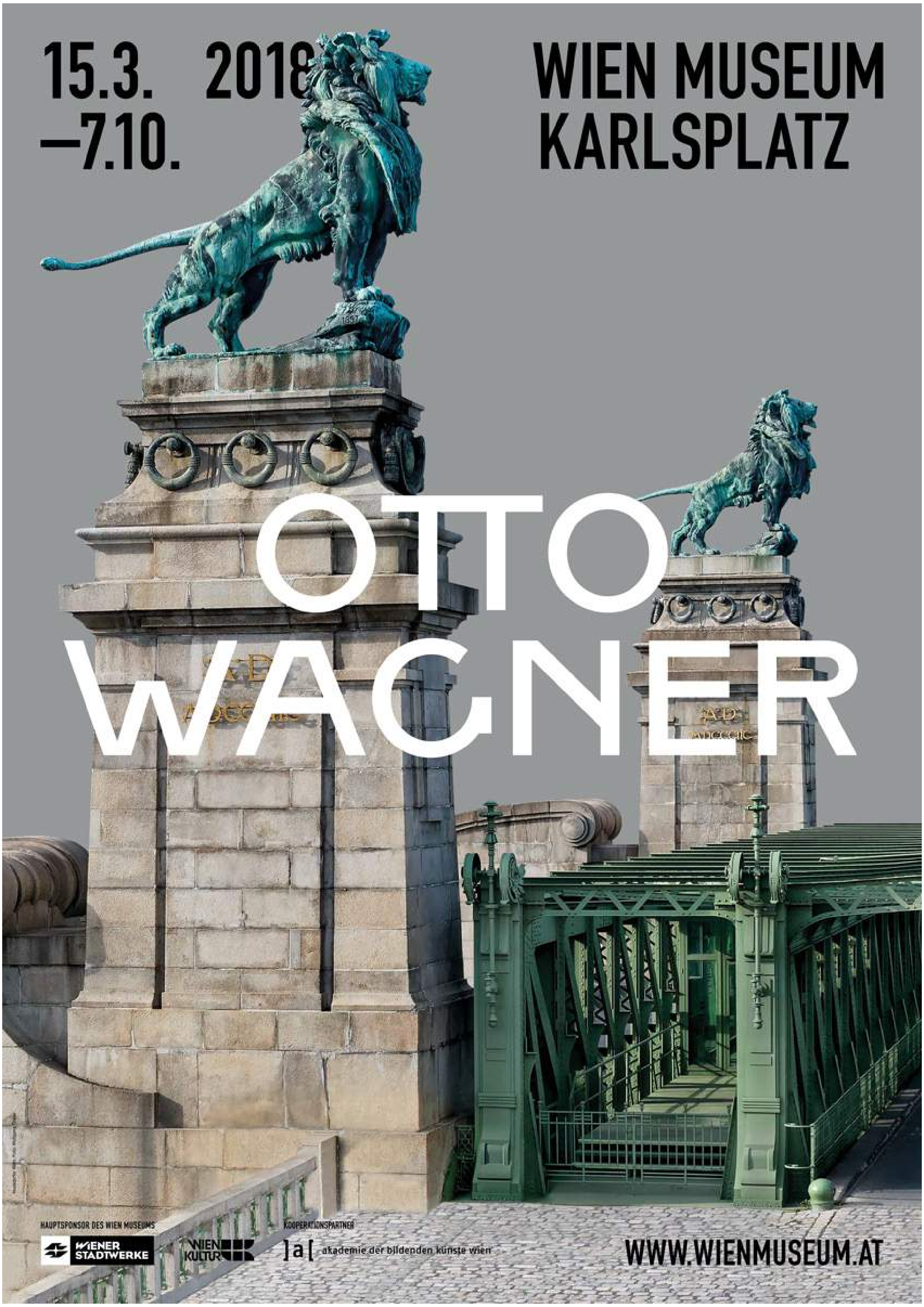


__Fig.54__ Poster inviting on the Otto Wagner exhibition in Vienna Museum, 2018.

Fig.55 *Photos of the permanent exhibition situated in Otto Wagner Pavilion.*

Fig.56 *“Traum und Wirklichkeit”* curated by Hans Hollein presenting the period between 1870 and 1930.

Fig.57 *Photo from Otto Wagner exhibition situated in Vienna Museum, 2018.*

Fig.58 *Photo from Otto Wagner exhibition, installation is focusing on the CityRailway presentation.*

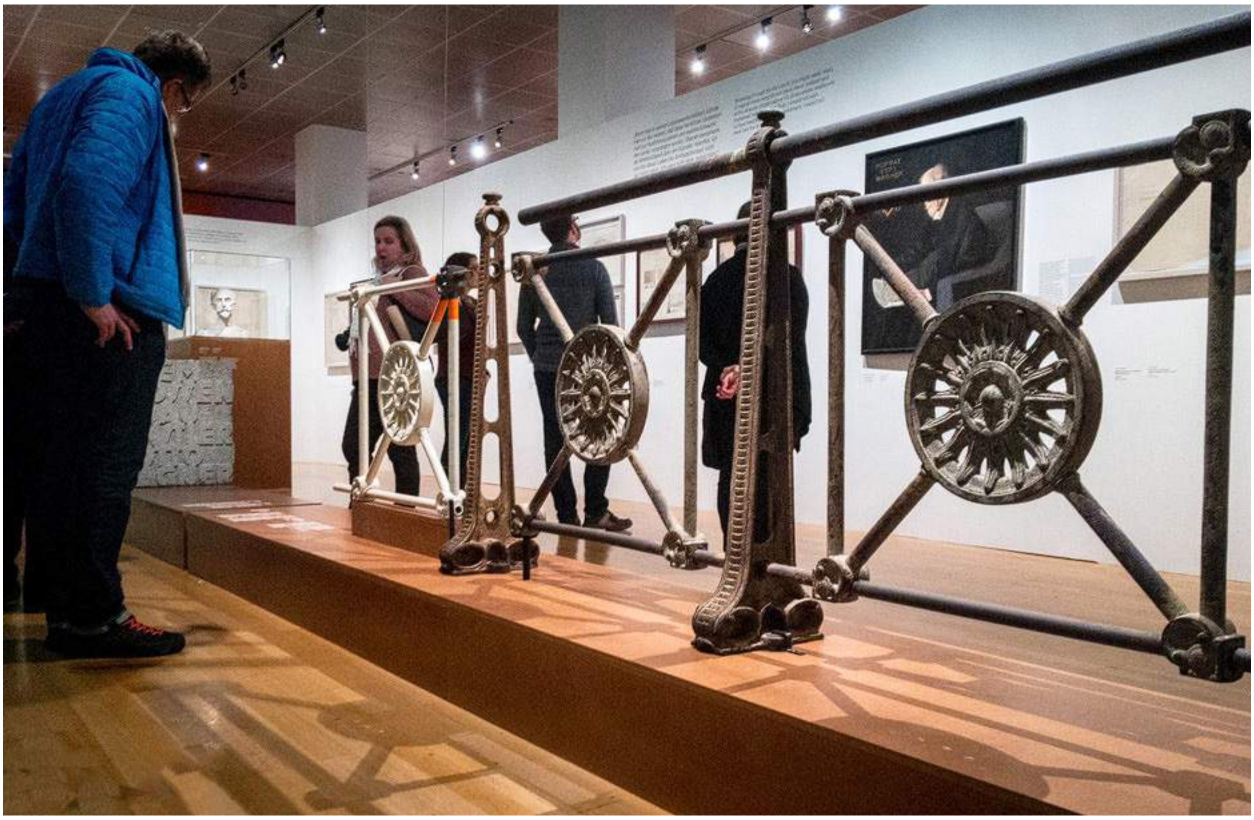


Fig.59 *Photo from Otto Wagner exhibition, installation is presenting the original colour of the railings.*

V. Building an Otto Wagner exhibition APPlication

The permanent Otto Wagner exhibition is situated in the former CityRail station at Karlsplatz. The exhibition is open only from April to October and the presentation content is limited by the size of the pavilion. These all were the motives for creating a virtual exhibition in front of the existing building. Presentation is not bound to opening hours and limited by the exhibition space. Work of Otto Wagner was already the object of many studies and research papers as well presentations, however, it has never been presented in Augmented Reality. An interactive experience of a real-world environment, where all objects are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities - including visual, auditory, haptic, somatosensory, and olfactory [Schueffel, 2017]. This chapter will give an example of how virtual presentation using modern software and hardware can be created. The first part will introduce a content of the presentation based on the previous research, the second part will go through the workflow and all required steps for creating the application.

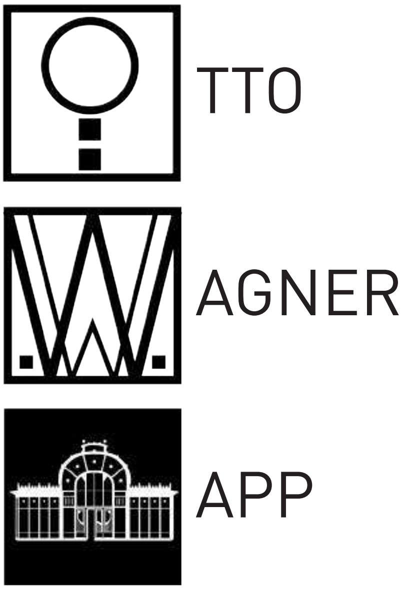


Fig.60 *Icons created for the application.*

5.1 Content

The existing permanent exhibition focuses on the life of Otto Wagner and "*documents the genesis of the most famous designs, including the Church in Steinhof, the K.K. Postsparkassenamt (Post Office Savings Bank), as well as the revolutionary Stadtbahn project (light urban railway) and the* *modern residential buildings. It will also reveal another perspective: Otto Wagner as a radical theorist and polemicist against traditionalism and the cliché of the "idyll". Besides numerous documents, the show includes two models and is not only a fascinating homage to the architect - it also invites the visitor to set off through the city of Vienna and explore his trail* " [@wienmuseum]. This actual content is presented in four rooms of the former railway station. Two of the rooms according to the original plan are former vestibule rooms, one is an exit hall, the second is a former office, all together around 90m^2 large, on which the exhibition is placed. In front of the existing building there is a small square, however, it is big enough for placing the virtual copy of the pavilion in scale 1:1 *(Fig.61)* and allows full-scale virtual exhibition. The square also allows free and safe space for the virtual pavilion visitors to move and enjoy the exhibition. The digital pavilion consists of the main entrance gate identical to the existing one and an interior space. The digital interior space is based on the photos of original state and plans found in books and presented on the existing exhibition. All the differences between the original and the actual state of interior were described in the chapter 4.3 Otto Wagner Karlsplatz Pavilion. For a better comparison of the exhibited content, the same amount of exhibiting space will be used. The digital content will be focused on presenting Otto Wagner's life and the Karlsplatz station. It will be thematically divided into four rooms that are identical to the existing exhibition *(Fig.62)*. Due to virtual form of the presentation most of the presented objects will be interactive what helps to explain Otto Wagner's design ideas better.

1. In the entrance room, which was a former vestibule, the composition axis, relationships and the position of the station in relation to the entire Karlsplatz square will be presented. The presented content is based on further research described in chapter 4.3 Otto Wagner Karlsplatz Pavilion *(Fig.63)*.

2. The next room will be dedicated to Otto Wagner as one of the most significant architects of the turn of the 20th century. The presented sculpture of Otto Wagner's head will be created using photogrammetry methods and will be supplemented with the timeline axis with his most significant works. This part of the presentation will be guided with a voice over and photos of the buildings *(Fig.64)*.

3. The third room focuses on the railing, a notoriously known symbol of the city railway. The composition of the railing that is present in the whole project of the railway will be explained. The model of the railing created with the photogrammetry method is also presented with the results of the last research of the city railways *(Fig.65)*.

4. The last part of the exhibition in the fourth room is the building of the station itself. The created photogrammetry model of the existing state allows to present the analyses of composition, construction and missing parts from the original state *(Fig.66)*.

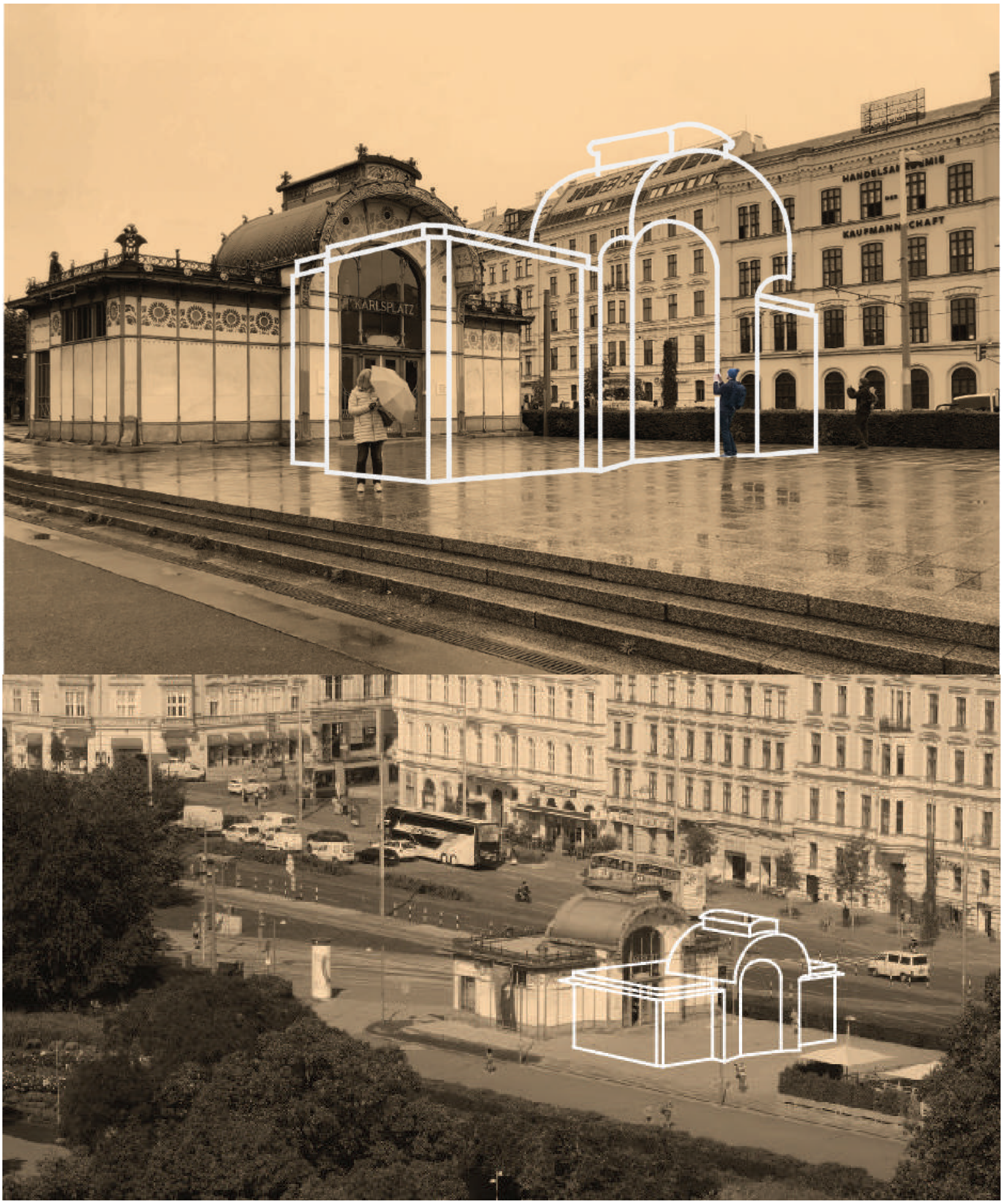
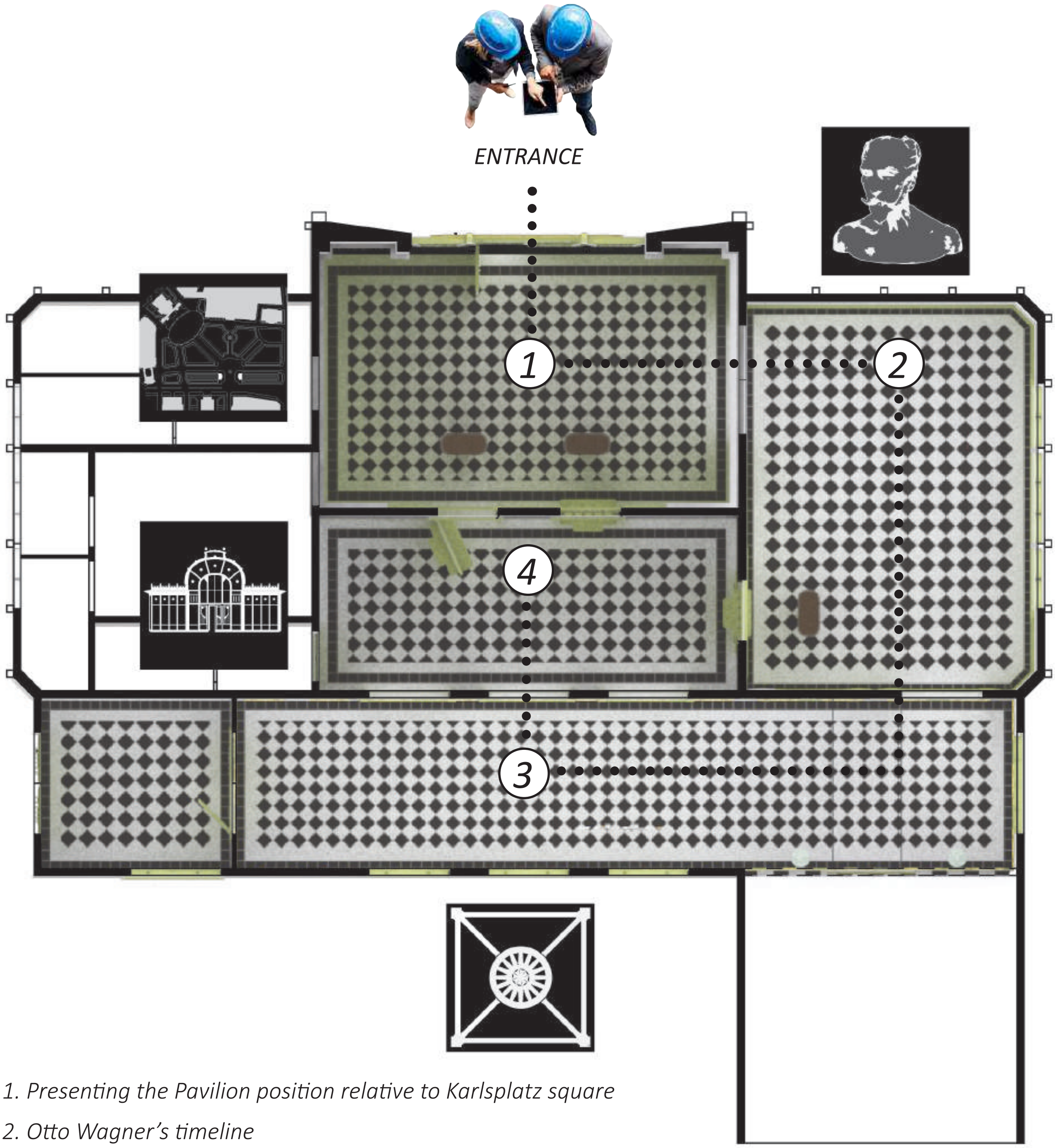


Fig.61 *Square in front of Karlsplatz Pavilion that allows placing virtual copy of the pavilion in scale 1:1.*



1. Presenting the Pavilion position relative to Karlsplatz square
2. Otto Wagner's timeline
3. Railing as a symbol of City Railway
4. Karlsplatz Pavilion

Fig.62 *Floorplan of virtual pavilion created according the original plans from 1902 with the exhibition concept.*

Fig.63 *Presenting the Pavilion position relative to Karlsplatz square. The composition axis, relationships and the position of the station building according to the entire Karlsplatz are presented.*

Fig.64 *Otto Wagner's timeline axis with his most significant works. This part of presentation will be guided with voice over and photos of buildings.*

Fig.65 *Railing as a symbol of City Railway explaining the design and the composition, that is guided through the whole project of the railway. The model of railing was created with photogrammetry method. Results of the last research of the city railways are presented.*

Fig.66 *Photogrammetry model of the existing state allows to present the analyses of composition, construction and missing parts from the original state.*

5.2 Workflow

After the summary of all acquired theoretical knowledge, the creation of the Otto Wagner application can be started. The production process can be divided into two main parts.

The first part consists of three-dimensional assets created with two different methods, and the second part involves setting the agumented reality plugin ARKit in the game engine Unity. The first part provides the application with the main content of the exhibited object. It was created using two different methods. One method involved a manually created three-dimensional model based on photographs and plans, the second group of models are created with a photogrammetry method. The game engine is used in the next part to assign special noises, animation and more interactive options to created 3D assets. All the steps that were executed are described in more accurate detail in the next chapters. *(Fig.67)*

5.3 Technical background

Before creating the final 3D models, it was necessary to test different types of software, equipment and acquisition modalities. The test was performed on the part of the Otto Wagner Pavilion.

In the test study for the created 3D assets, an iPhone 5s device was used for capturing photos. For the final results an iPhone 8 was used. For photogrammetry purpose it is necessary to take a picture as sharp as possible and without any noise. The used iPhone 8 has a 12 Mpx camera with a f/1,8.

The main reason to use an iPhone as a capturing device was the fact that one of the selected objects - the Karlsplatz Pavilion - is complex and has a large scale. In Vienna it is prohibited to use a drone without a special permission. The solution how to create a correct data set with the image loops from different heights was to use a 10m long telescopic building inspection pole *(Fig.68)* [@4kam]. The inspection pole is adjustable to different heights what allows to create photos from different levels. The iPhone 8's dimensions 138,4x67,3x7,3mm and weight 148gram enable an easy installation on the inspection pole using a bicycle phone holder *(Fig.69)*. The weight of the smartphone compared to another camera devices minimizes the pole bending. However, strong wind caused some bending and camera shake that made it difficult to take accurate photos without any blurs.

For the best preprocessing option in order to get better alignment, meshes and textures, it is advised to save the taken photos in RAW format. A RAW file is an uncompressed version of the image file. A camera takes the image data from the sensor,

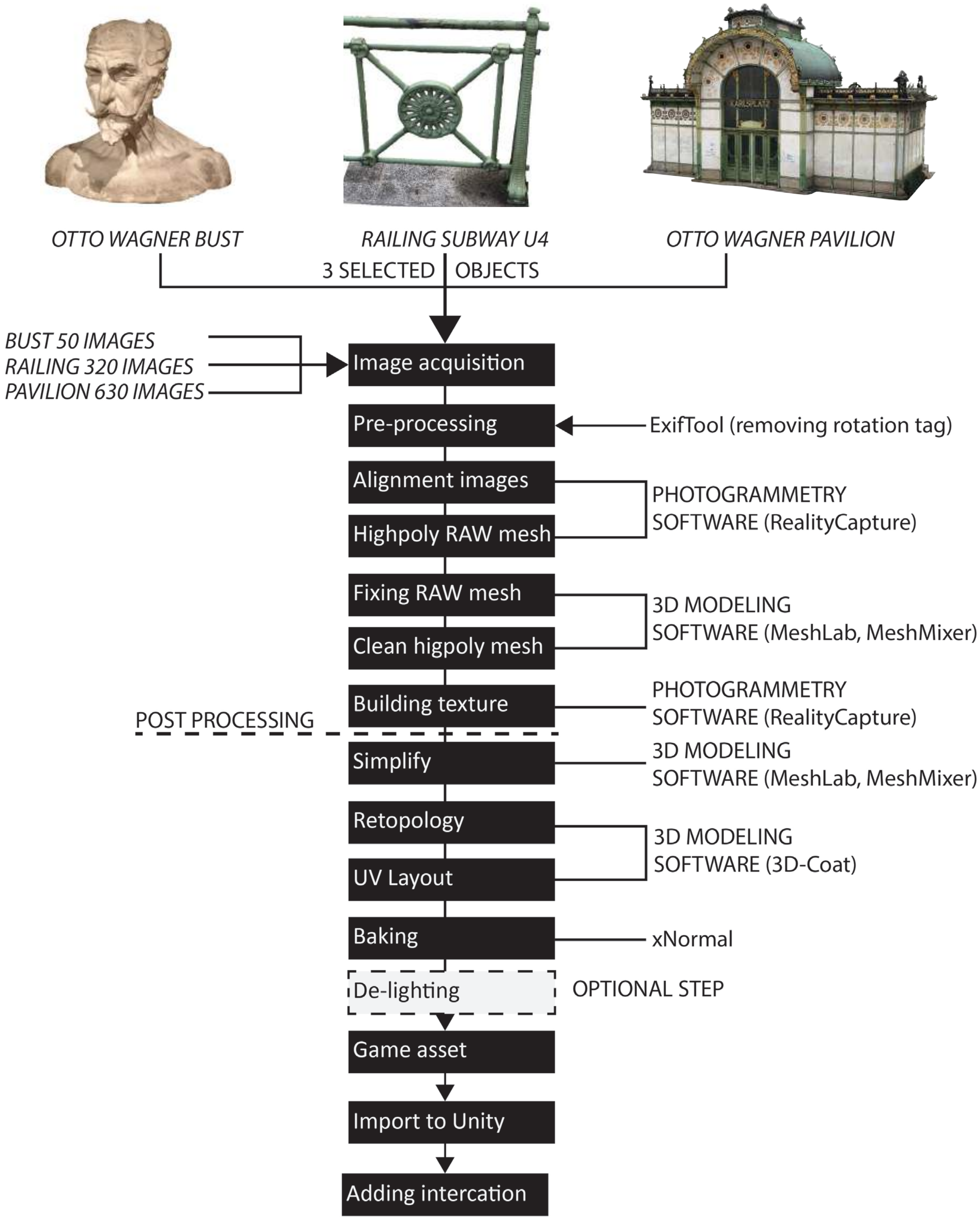


Fig.67 *Workflow of creating the AR application.*

and saves it in an unedited and uncompressed format on the memory card. RAW is normally used with DSLR and other high end cameras. The RAW file contains all the camera's information captured, such as the full dynamic range of the sensor and loads of additional colour information. While a JPEG shot taken with an iPhone 8 is around 4.5MB, a RAW file is 15 MB or more. That is a lot more information for the photogrammetry software. The preprocessing step can help the software with the identification of the details. There are many ways how to preprocess photos. One of the options is to use CameraRAW in Adobe Photoshop. Base improvements are fixing the exposure in light and dark areas, removing the chromatic aberrations and the noise, and sharpening the image. The main rule is not to distort the image in any way, fixing the lens distortions is strictly prohibited. This leads to corrupted data and an incorrect photogrammetry process (result).

Because the stock iOS camera application does not support capturing RAW photos, the data from an iPhone camera is primarily saved in two different formats, HEIF (High Efficiency Image Format) and JPEG (Joint Photographic Expert Group). Format HEIF (.heic file extension), in iOS 11 or later, allows greater file compression. That means that each HEIF picture file takes up less storage space than a standard JPEG image, sometimes up to half of the size per image. While JPEG images are larger, they are also broadly compatible without any conversion for this case study.

Next to the equipment, a photogrammetry software has a direct influence on the final result. Software installed on the personal hardware gives full control of all the photogrammetry steps during the whole time. The computer system used in the presented case study was Lenovo IdeaPad Y510p Black *(i7- 4700MQ CPU processor, 16,0GB of RAM and an 2x NVIDIA GeForce GT750 2GB SLI)*. To avoid problems with the reconstruction process two different software, both working locally on hardware, were tested. The first one was Agisoft Photoscan [@agisoft] (now Agisoft Metashape) *(Fig.33),* the second was RealityCapture [@capturingreality] *(Fig.34)*. As a tested object, a part of the Otto Wagner Pavilion was selected. During the evaluation test both software were set to default settings.

Although RealityCapture (RC) supports just Nvidia graphic cards, while PhototScan is supported also with non-Nvidia GPUs, the PhotoScans capabilities (number of photos processed at once) are more directly limited by the RAM size. The RC software is much more resource-friendly. It works internally very differently and it is better suited for medium-end systems. The speed of RC software is even faster than Autodesk cloud service if the uploading, queue-waiting, processing and downloading time is included. Most photogrammetry tools cannot match the abilities of RC in speed of aligning photos and generating dense point clouds.

The software chosen to generate the assets for the virtual presentation of the Otto Wagner Pavilion was RealityCapture. It offers

Fig.68 *Telescopic pole with fixed iPhone 8 used as capturing device in the presented case study.*

a demo version for testing without exporting possibilities. For the case study the "promo" license was selected. It can be used for a maximum of 3 months and a maximum of 2500 imported images per project. Different types of data can be imported to create a 3D model with a high-resolution texture. Images, videos, laser scans, UAV or synchronized camera rigs are supported as well as various combinations of this data. It is possible to export the created final mesh into different file formats (*.obj, *.ply, *.fbx, *.dae, etc.). There is also an option for direct export of the resulting model to Sketchfab with an appropriate automatic optimization of mesh and texture. The RC software can also clean up unnecessary noise or busy surroundings, fix and decimate the result. To obtain good results, the default software settings and the automation process are sufficient, in case correct data was imported. The RC also offers a full control of all the photogrammetry steps. This will be closer described in the next chapter.

5.4 Result of the photogrammetry process

Three objects of different scale, shape and placed in different environment conditions were selected and documented with the photogrammetry method.

The three selected objects were:

- the bust of Otto Wagner
- the sunflower railing
- the Otto Wagner Pavilion

From the selected objects, 3D assets for the virtual presentation were created. All the three objects were captured with the iPhone 8 camera and the data was processed with the CapturingReality software. For each investigated object it was required to set a specific exposure and focus values. The acquisition method followed the basic rules described in chapter 3.3 Photogrammetry assets.

Fig.69 *In case study used capturing device iPhone 8 assembled on the inspection pole and remotely controlled with iPhone 5 using the CameraPlus application.*

5.4.1 Bust of Otto Wagner

The first captured object was a plaster bust of Otto Wagner exhibited in Vienna museum during the exhibition dedicated to the 100th anniversary of his death. The bust was created in 1917 by an Austrian sculptor Gustinus Amborsi. He sculpted the bust of Otto Wagner in the last years of his life and incorporated the shadow of approaching death [Lang,1995]. There were two material versions of the bust created. One is made out of bronze with dimensions 52x53x33cm. The other bust, which was exhibited, was from white plaster with similar dimensions [@digital.belvedere]. For photogrammetry purposes the plaster material is more convenient because it does not produce any reflections. The main difficulties were caused during the data acquisition by the lighting condition. The object, as a part of the exhibition, was spotlighted from the top with different light sources. Strong light caused sharp shadows, which caused the bottom and one of the side parts to be hidden. The second bigger issue was that the bust was covered with a safe glass box that produced a number of reflections of the surroundings on every image *(Fig.70)*. The polarization filter lens was used to avoid the reflections. The applied filter was ZOMEi 37MM CPL Lens Filter for iPhone. "*Circular Polarizing Filter (CPL) is great for removing unwanted reflections from non-metallic surfaces such as glass or water. Professional High Definition: PHD Lens reduces glass flare & ghosting caused by reflections*" [@ zomei] *(Fig.71,Fig.72)*.

Two different methods were used for the data acquisition - video and photos.

First method includes taking a video around the object employing a professional application called FilMiC Pro [@filmicpro] that allows to set up a frame rate (20 frames per second), ISO and the resolution size (4K 2160p). The application also allows to create video without any sound what decreases the size and saves memory space. The used version of RC (version 1.0.3.5681) does not support importing video data. This feature is available in the new version of RC. In the next step, the created video was downloaded to the computer and the frames were extracted with Adobe After Effects. The number of frames imposed for the software depends on the object dimensions, video length and background noise. The total amount of extracted pictures is reduced during the frame extraction in Adobe After Effects. The output used for the photogrammetry software was 206 frames - JPEG images with resolution 2160x3840pixels. The software was not able to align the images and create dens point-cloud. The inputs after image alignment were grouped in many different components containing a small amount of images. As a result, sparse and sliced point-clouds were created. This was caused by the environment with many light sources and a glass cover producing reflections *(Fig.70)*. Because of this, the number of feature points on the images that the software detects was reduced. Finding the unique corresponding features of every single image

Fig.70 *Input image with different types of reflections and sharp shadows caused by the glass cover and different direct light sources.*

allows the software to find the correspondences of images between one another in order to perform the reconstruction. The detected features (points of interest) are used as tie points to restore the correspondence between images and determine the created mesh geometry. The extracted frames from video can also lose some information used by the photogrammetry program.

The second method was based on the capturing of 50 photos of the object *(Fig.73)*. There were only 3 full loops from different height levels but from the same distance made for the input photos. The input data had appropriate ISO values and the maximum resolution size possible for the mobile phone. No preprocessing method was applied on the photos. The RC was set to the default settings, which means that the alignment of the images overlap was set to medium. Medium overlap can be set if all the images in a data set have at least 70-80% overlap with the nearest image. This also caused splitting the result into many components. From the input images only 70% were properly aligned in one component. The aligning problem was also caused by another RC default setting - the number of features for alignment. As default, 40,000 features per image are required. Some of the applied images have less feature points due to a problem with image quality. This was caused by reflection and lighting from the back side mentioned above *(Fig.70)*. After alignment in the created point-cloud the unneeded surrounding elements around the investigated object were removed.

The raw high poly mesh model was created from the 70% aligned images. The reflection of the glass cover caused that the photogrammetry software was not able to correctly create mesh from the back side and was auto-filled with the RC software *(Fig.74)*. To create a high quality texture, the triangle count in the raw mesh was reduced to 1.5 millions. The resulted high-poly model was exported as .fbx format with 4K resolution texture in .png format. After the successful export, the poly/count in the RC software was strongly reduced and the low-poly model was exported *(Fig.75, Fig.76)*. The next steps of the process, from the raw models and high resolution texture to the final asset used for the Unity, are described in chapter 5.5 3D modelling.

Fig.71 *iPhone 8 (12 Mpx camera) with assembled reflection reduction lens.*

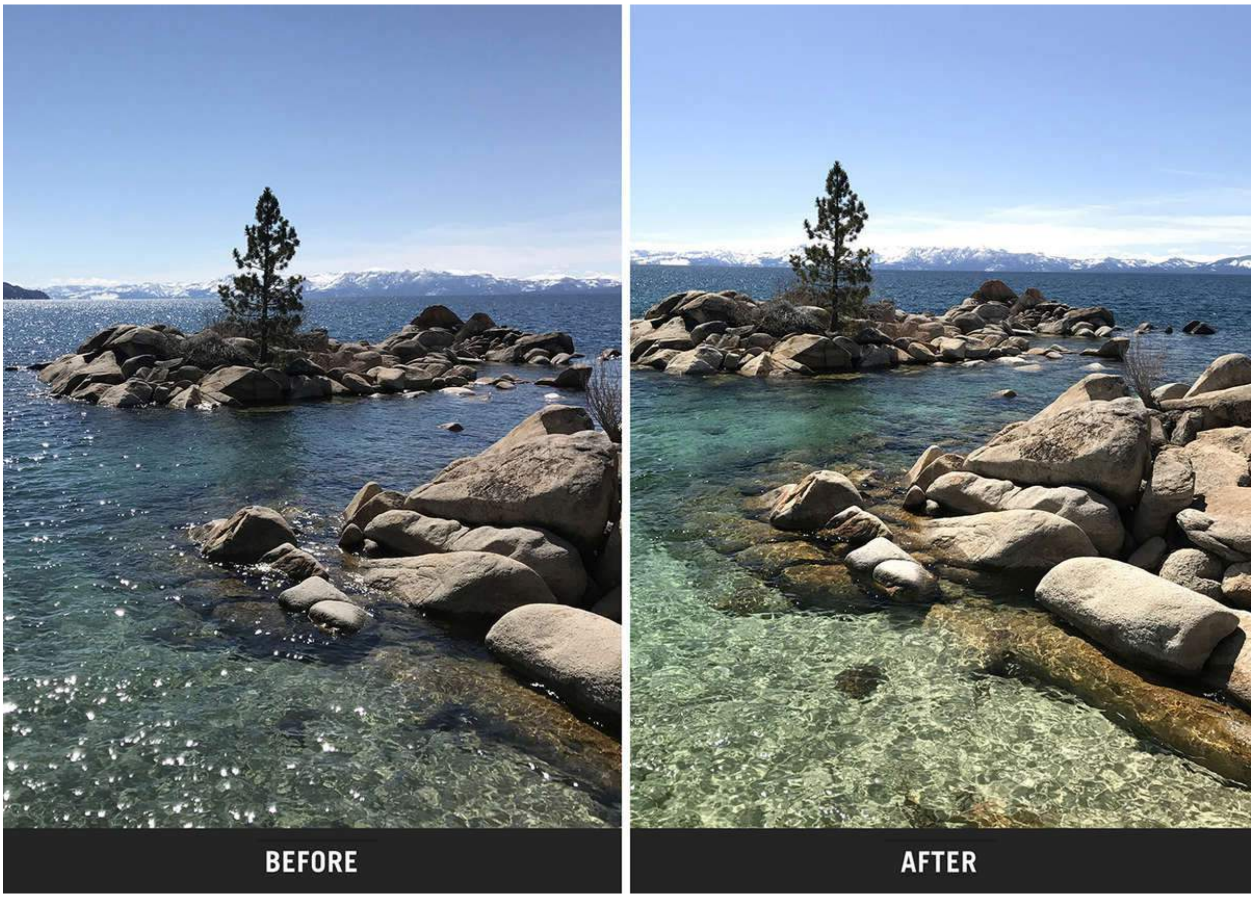


Fig.72 *Example of applying the polarize filter.*

Fig.73 *Input images from one loop used for the photogrammetry software.*

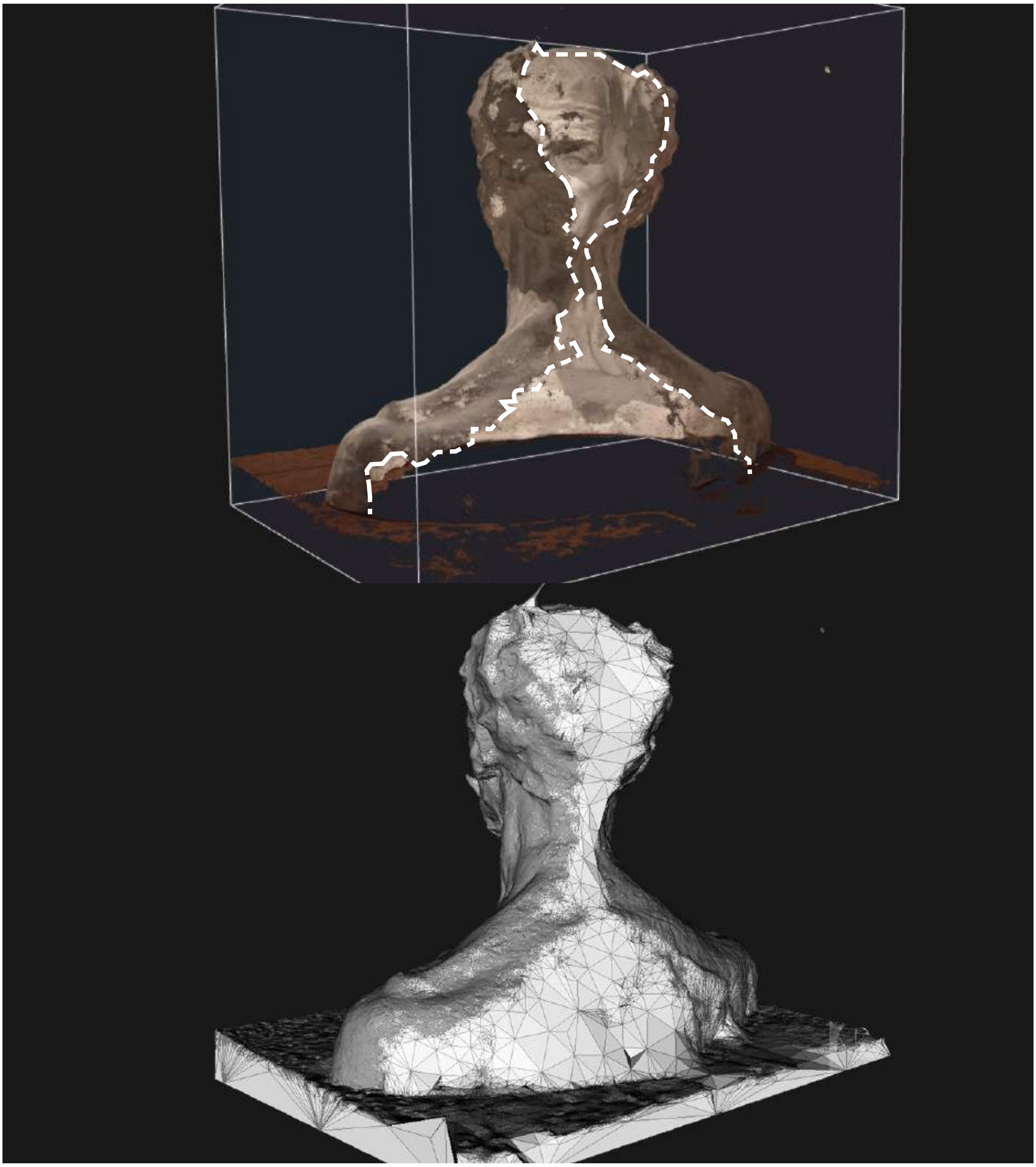


Fig.74 *RAW mesh with a hole in geometry caused by reflection on photos and created auto-filled mesh by RC.*

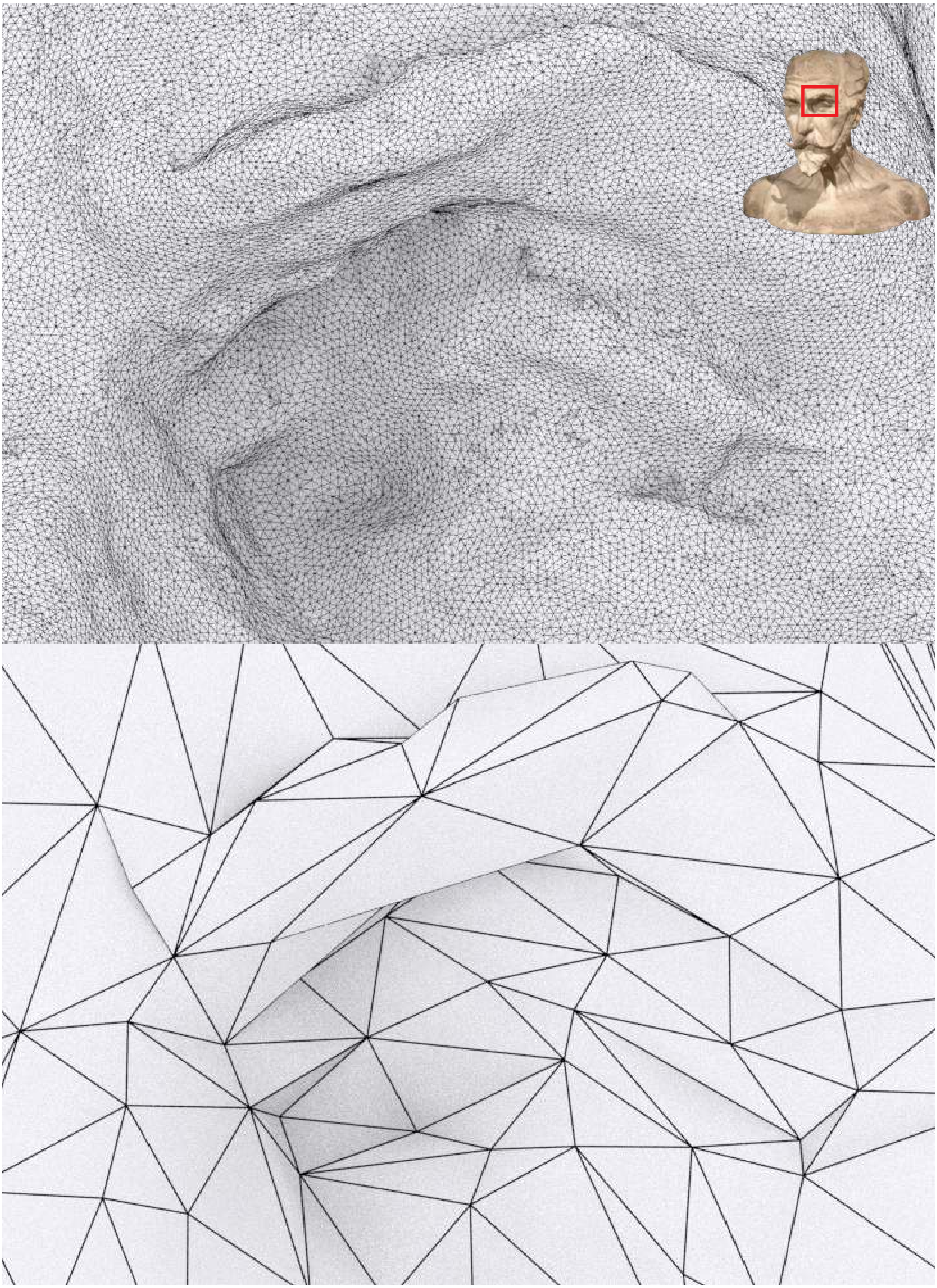
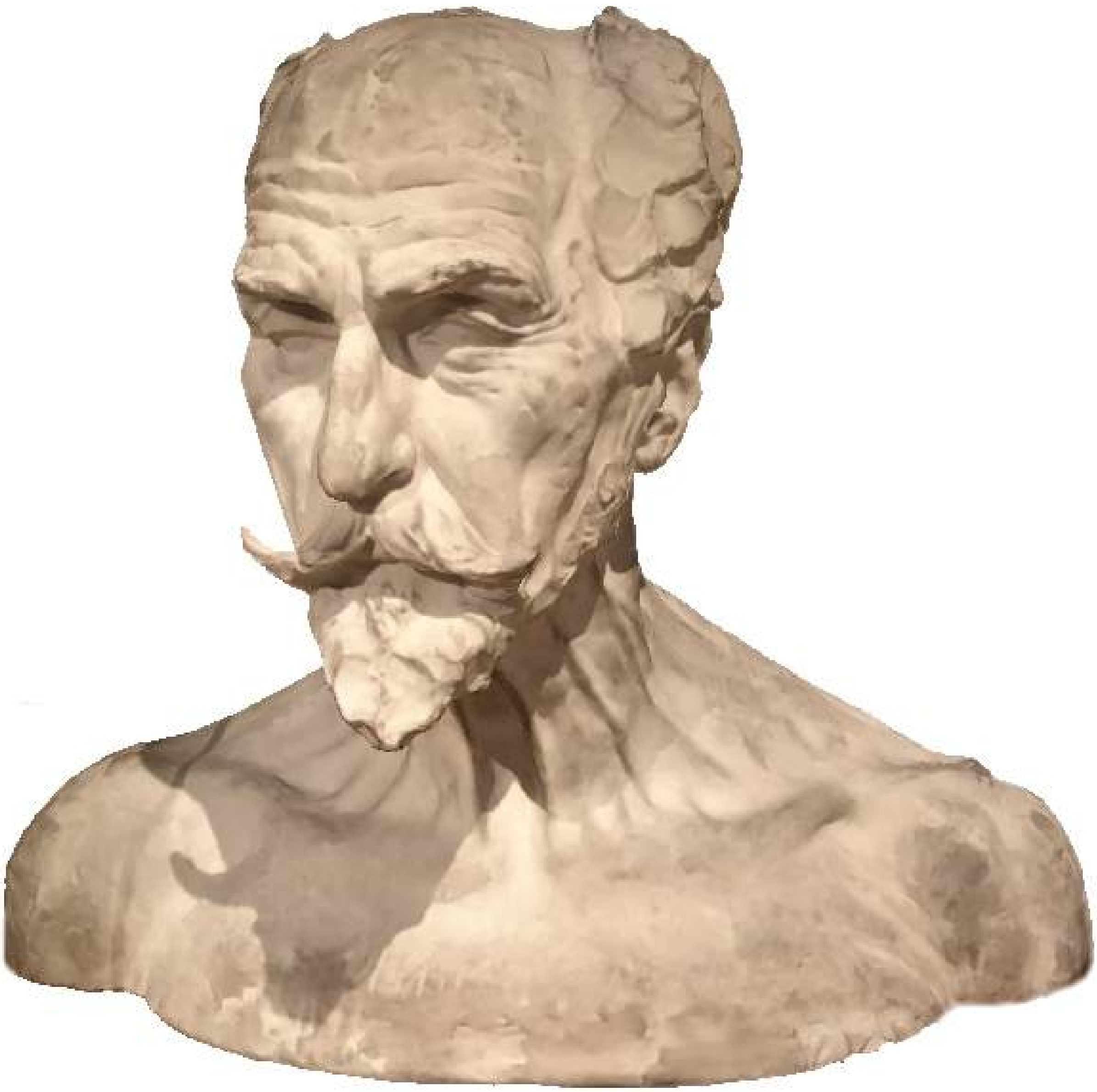


***Fig.75** Polygon density of the same geometry (eye), (above) wireframe RAW high-poly mesh 1.5 million triangles, (down) wireframe low-poly mesh 15 thousand triangles.*



Object	*Bust of Otto Wagner*
Location	*Wien Museum part of exhibition OTTO WAGNER,2018*
Dimensions	*52 x 53 x 33 cm*
Number of photos used	*50 photos (32 aligned)*
Photo resolution /ISO value	3024 x 4032 pixels/ ISO 80
Processing time	*5 min. alignment process/20 min. meshing and texturing*
Raw mesh triangle count	*2.2 millions of polygons reduced to 1.5 millions for texture*
Decimated mesh triangle count	*4.3 thousand of polygons*
Raw texture resolution	*4K*
Baked texture resolution	*4K*
Baked texture type	*normal map, diffuse map*

Fig.76 *The final low-poly mesh with applied 4K resolution texture from high-poly model.*

5.4.2 The sunflower railing

The next selected object was the famous Otto Wagner sunflower railing. "*The railing was made by Firma Wallner & Neubert for the Cityrail. The material used was iron and the dimension of one part was 75cm height and 75cm width*." [@ dorotheum] The selected railing used for the asset was situated on the Stubenbrücke next to the Stadtpark in Vienna (Fig.77). The chosen weather condition was according to the rules mentioned in the chapter 3.3.5 Weather condition. The sunset was selected for the data acquisition. The object was captured on 320 images from loops of different height and distance and few detail shots (Fig.78). The data was imported in the computer in JPEG format with the resolution 4K and preprocessed. Almost all the software available automatically rotate the image depending on the camera rotation. The rotated images are not a problem for modern photogrammetry software, but the vertical photos can be treated as different lens groups. To avoid the potential problem it is recommended to remove rotation EXIF tag with ExifTool or ExiftoolGui. In the next step the data was imported in the RC software. For the railing and the pavilion building objects the default settings were not used. In the RC the grouping by EXIF was adjusted, this can help to avoid an incorrect camera and lens estimation. RealityCapture calculates these parameters from all images in one lens group. Before the alignment process in the RC the value of image overlap can be set to low. The default setting is medium. The low image overlap setting in a small data set helps to avoid splitting the images into many components instead of the one component. The value of the detector sensitivity defines how fine and how many features the RC will try to detect. The commonly used value for the detector sensitivity is medium. After refining all the settings, the alignment process can run. If the data set is correct, 99% of all images align in the first step into one component. When more than one component is created, although the data set is correct, than the alignment process can be run again. The components with a small number of images can be removed. The RC will reuse the features detected in the first step, refine the main component camera placement, and find the right place for the cameras from the first alignment run. If the method does not work properly than manually created control points can be used to help the program recognise the photo location. After the component is created, all the images can be ungrouped, and the alignment process can run again. During the alignment the RC will count all the cameras as different lenses and adjust the small deviations from the different zooms or sensors. The re-projection error can be decreased to 1px, the precision of alignment will increase, and better mesh will be created. 98% of the imported images of the railing were aligned in one component

Fig.77 *Example of input images from different distance loops.*

(Fig.79). Before meshing, the point-cloud can be aligned to the ground and the reconstruction region can be adjusted. The reconstruction region is fitted only around the object, which helps to reduce the meshing time (Fig.80). The meshing is set as default to the Normal detail mode and the RC in this mode calculates the depth maps from 2x down-sampled images. The RC software is able to reconstruct details up to 0,25px. After the mesh producing, the model can be textured and directly uploaded to the SketchFab for web presentation. The final raw mesh is frequently too dens to use in real-time rendering software. Most software will have trouble to work with it. The next step is to decimate mesh, reduce the polygon count and export diffuse map in high resolution (Fig.81). For the export of raw mesh it is recommended to use .obj or .fbx format. To save computer storage, it is recommended to use .ply format. The raw mesh of the Otto Wagner railing was exported with 5.9 millions triangles and 8K resolution texture (Fig.82). The next step includes fixing and sculpting the raw mesh. This part is described in the 5.5 3D modelling process chapter.

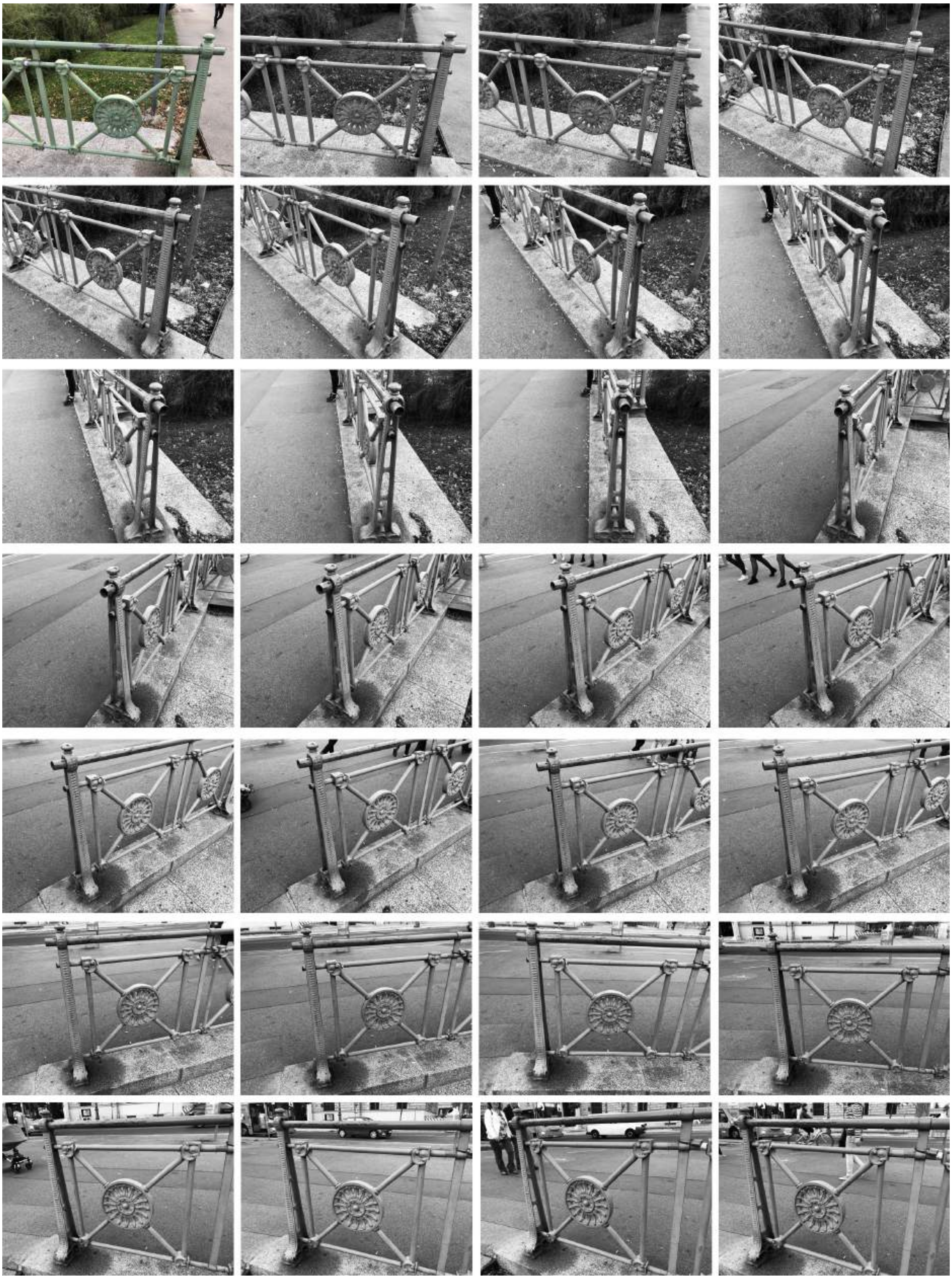


Fig.78 Input images from one loop used for the photogrammetry software.

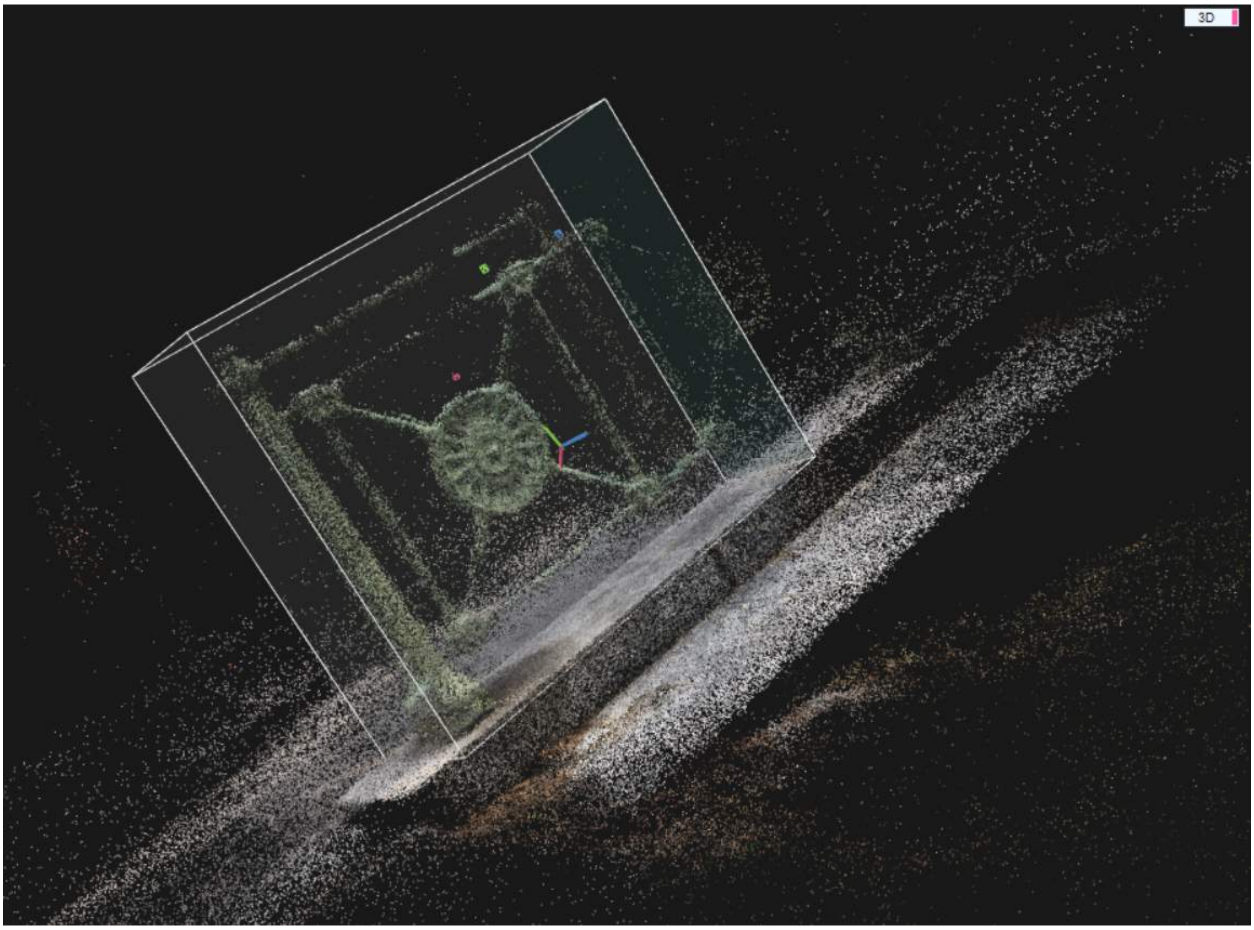


Fig.79 *Point cloud created after image alignment before defining the ground plane and removing unneeded surrounding.*

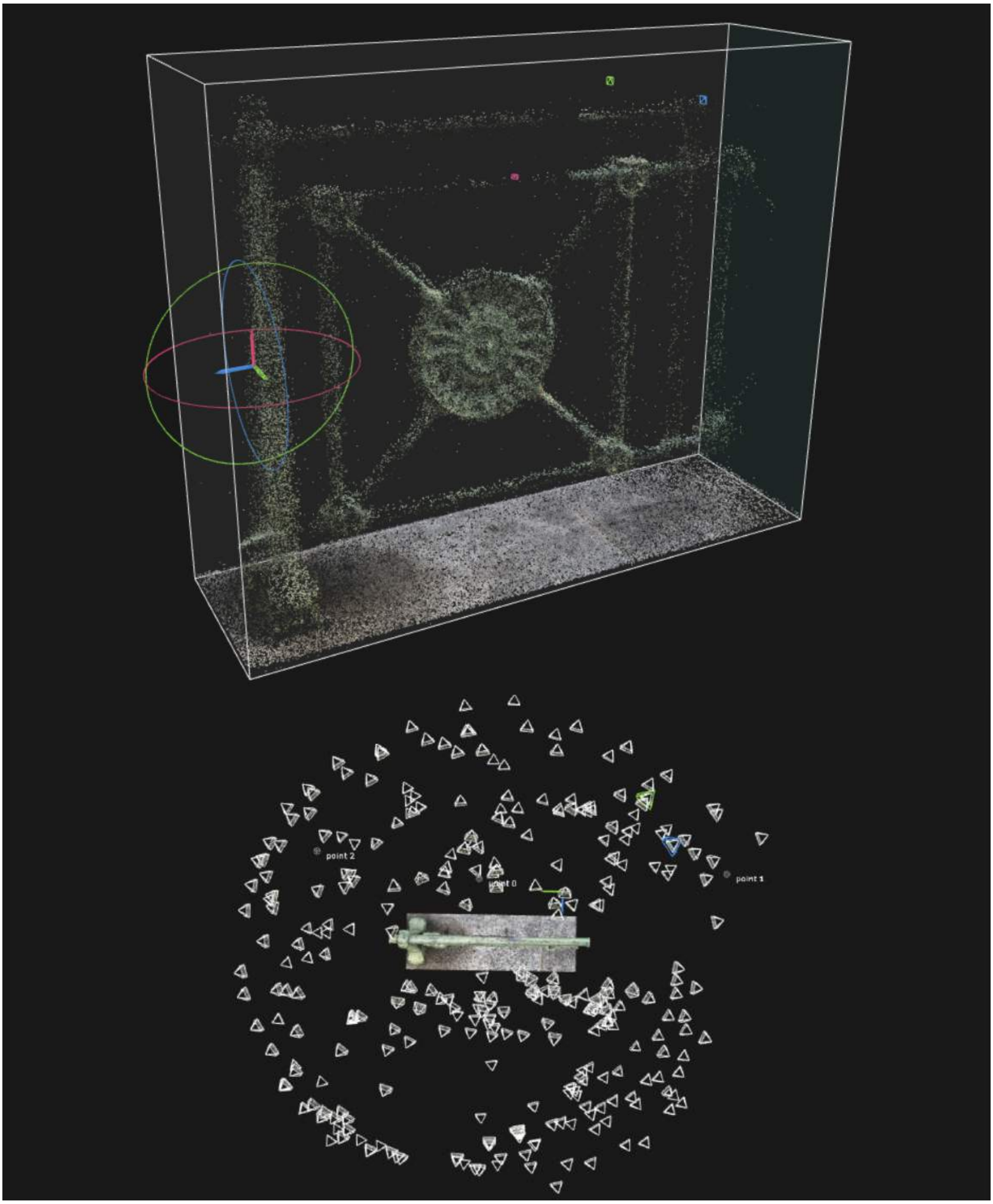


Fig.80 *Point cloud after defining the ground plane and removing unneeded surrounding (above). Top view with all positions of camera during acquisition (down).*

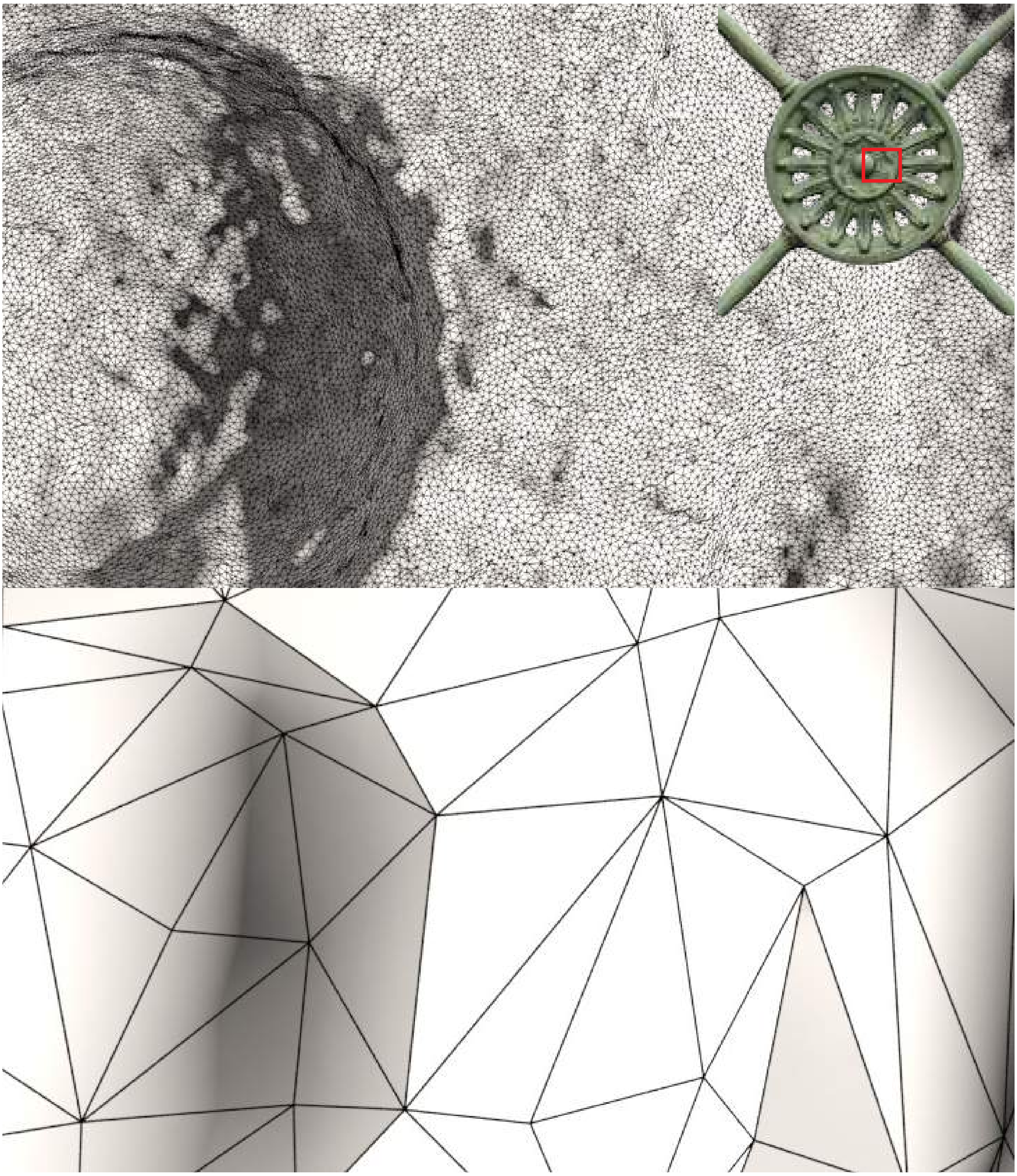


Fig.81 *Polygon density of the same geometry part, (above) wireframe RAW high-poly mesh 5.9 million triangles, (down) wireframe low-poly mesh 12 thousand triangles.*

Object	*Sunflower railing*
Location	*Stubenbrücke, Vienna*
Dimensions	*75 x 75 cm*
Number of photos used	*320 photos (315 aligned)*
Photo resolution /ISO value	3024 x 4032 pixels/ ISO 70
Processing time	*10 min. alignment process/ 90min. meshing/ 30min. texturing*
Raw mesh triangle count	*5.9 millions of polygons*
Decimated mesh triangle count	*12 thousand of polygons*
Raw texture resolution	*8K*
Baked texture resolution	*4K*
Baked texture type	*diffuse- base colour map, normal map, ambient occlusion map, cavity map*

Fig.82 *The final low-poly mesh created by RC with 12 thousand triangles.*

5.4.3 The Otto Wagner Pavilion

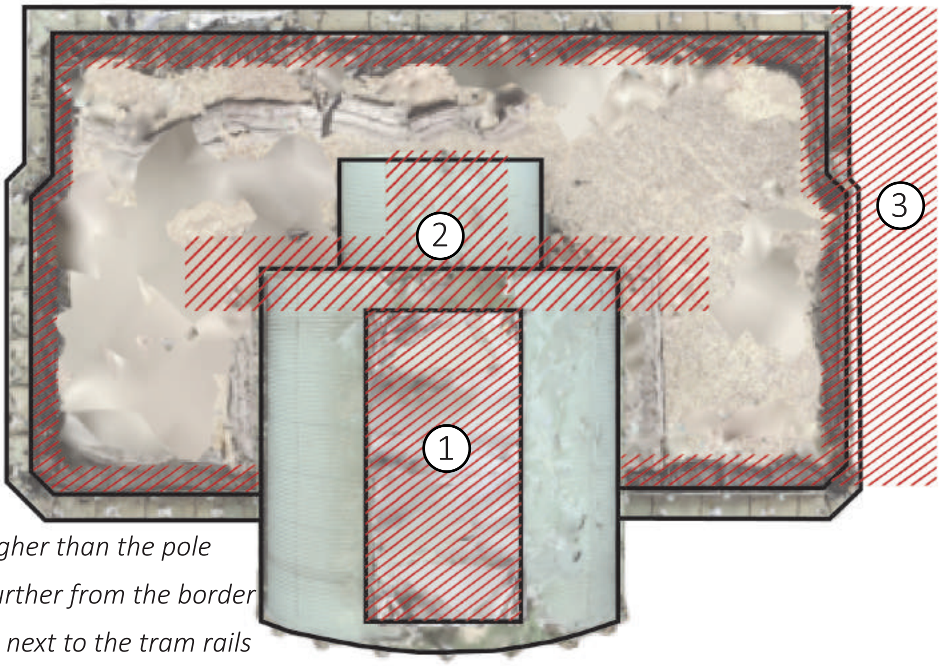
The last selected object documented with the photogrammetry method was the Otto Wagner Pavilion. The former city rail station is a complex object of a large scale with dimensions 15x8x10m. This object is described in more detail in chapter 4.3 Otto Wagner Pavilion Karlsplatz. In Vienna it is not permitted to use a drone without special permission. For creating correct image data of the this complex object, the telescopic inspection pole was used. Three loops were made from different distances and different height levels to capture the object with photos (Fig.83). From one side the object is situated next to the tram rails with the electric wires above. From the tram wires side it was not possible to create photos from all height levels and use the inspection pole (Fig.84). The object itself is higher than the telescopic pole, which caused problems in the data capturing. Parts of the Pavilion roof further from the edge were not possible to document in enough detail. The complexity of the investigated object, environment and used devices do not allow to capture every part of the building (Fig.84).

To have full control of the recording data process, it was necessary to use an application that allows remote control with screen mirroring between two iOS devices. One device is fixed on the inspection pole and serves for capturing the object. The other device is in the user's hands and works as a controller and a display (Fig.85, Fig. 69).

The first input data was created from the video sequence made with a FiLMiC Pro app and FiLMiC Pro Remote extension app. FiLMiC Pro Remote offers powerful wireless control, analytics and clean video monitoring options to expand the functionality of FiLMiC Pro. It took 30 minutes of recording to capture the pavilion with all the details. The used frame rate 20fps will produce data set with 36.000 photos. The three months long RC licence is limited to 2.500 photos per project. To reduce processing time, a number of photos were reduced in Adobe After Effects to 4.000 during the extraction process. It was necessary to go manually through the all 4.000 photos, to remove blurred and not sharp enough images, and to reduce them to final 1.500 images. This step was time-consuming and even with the remote option, the control over the created data was not sufficient. The wireless connection was lost many times, which prolonged the acquisition time. This problem could be solved by using a portable Wi-Fi station.

The second acquisition method includes taking photos employing a professional mobile application Camera Plus and Camera Plus Pro [@globaldelight] that allows remote control and screen mirroring between two iOS devices. One device serves as a camera and the other one acts as a trigger for the

Fig.83 *Input photo taken with the inspection pole.*



1. Parts of the roof higher than the pole

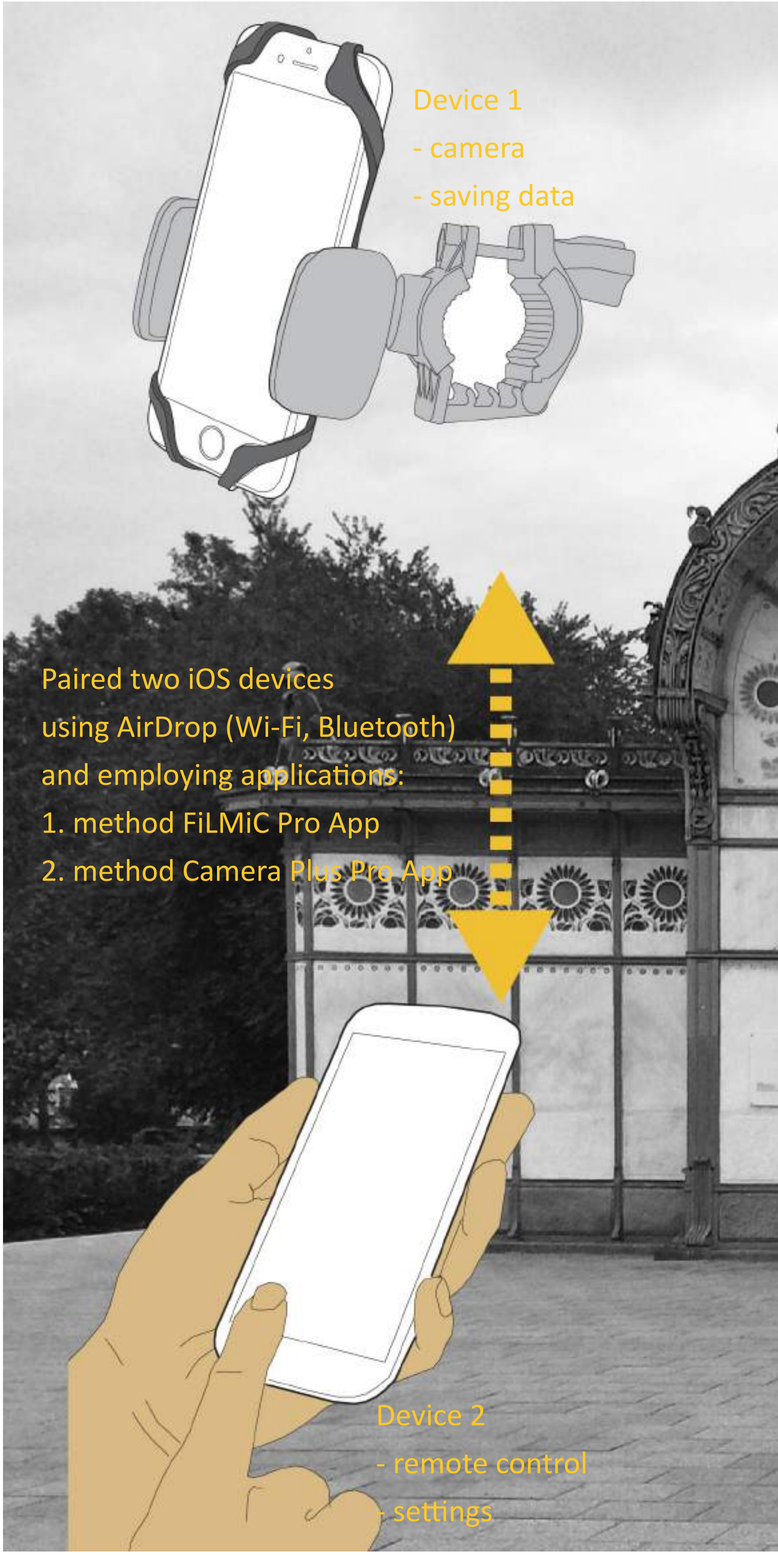
2. Parts of the roof further from the border

3. Part of the pavilion next to the tram rails

Fig.84 *Problematic parts that can not be documented with applied workflow.*

remote controlling (Fig.85). The application does not allow to set a specific ISO value. Furthermore the unstable remote connection does not allow to capture higher parts of the roof. This problems could be solved by employing another application, which supports ISO setting options and allows exporting RAW formats (Camer+2). The unstable connection between devices could be solved by using a portable Wi-Fi station.

For the image shooting, an overcast day was chosen. The data set from all loops consists of 639 photos of high resolution (Fig.87). To help the photogrammetry program align 98% of imported photos the manual control points were adjusted (Fig.86). The pavilion as an object of interest was difficult to capture without any visitors standing in front of the façade (Fig.83). The applied workflow method for preprocessing and producing the high-poly raw model was the same as with the railing object. To achieve better accuracy manually created control points were used (Fig.86). The meshing process ends with 35.7 million triangle mesh that was reduced to the high-poly mesh with 16 million triangles. The next step includes fixing and sculpting the raw mesh. This is closer described in the chapter 5.4 3D modelling process.



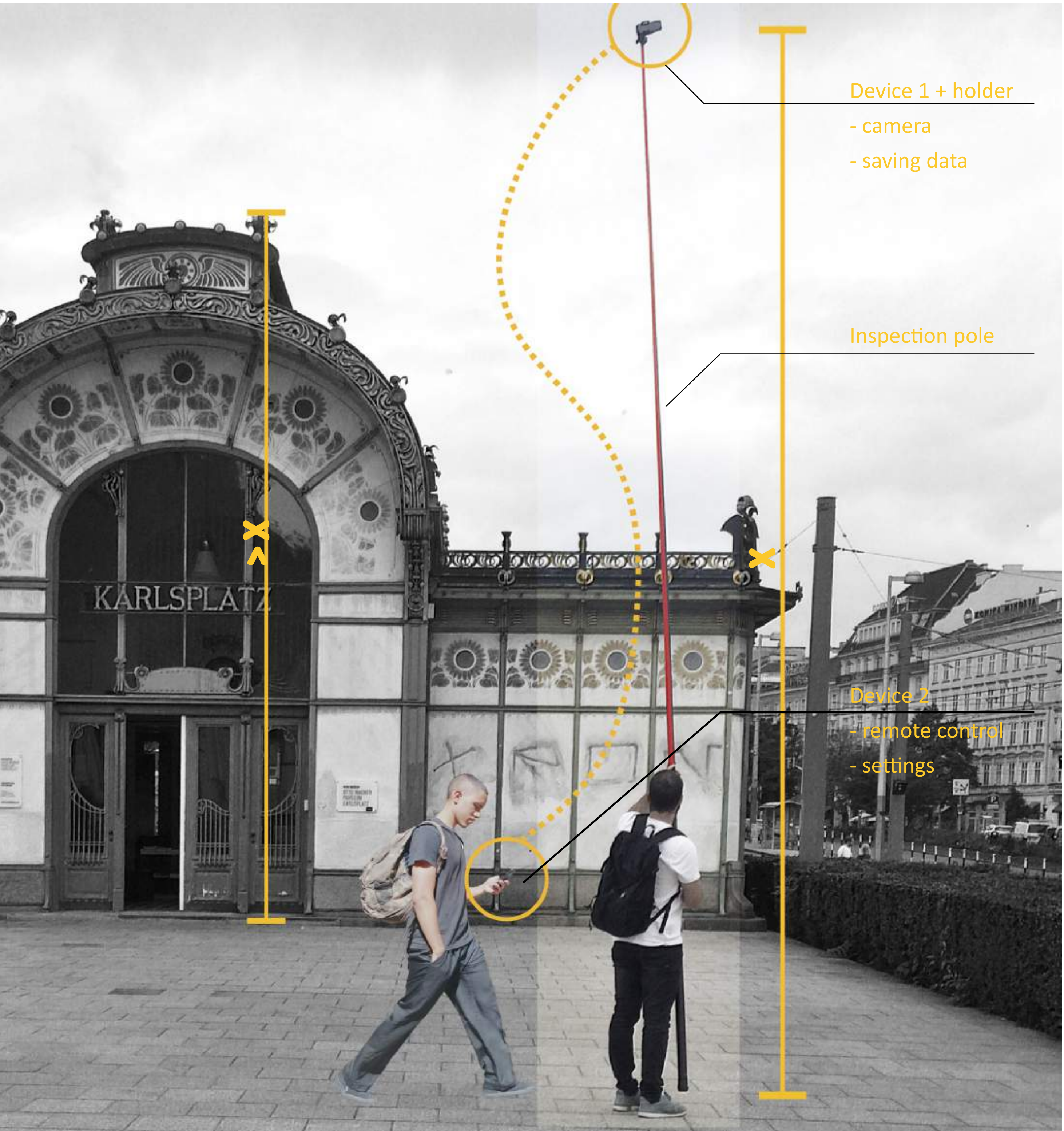


Fig.85 *Workflow with the inspection pole.*

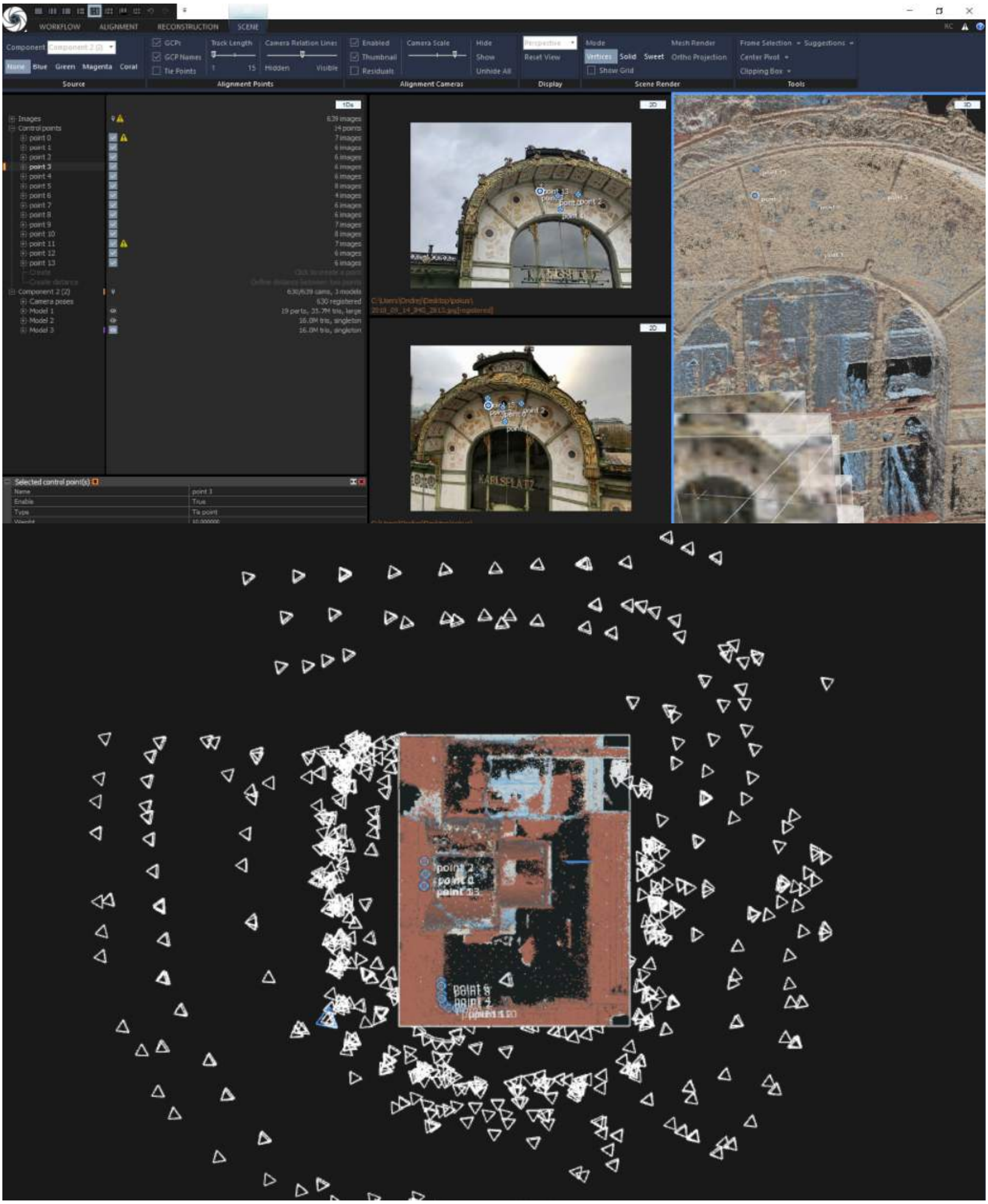


Fig.86 *Point cloud model with manual created control points and top view with the camera acquisition position.*

Object	*Otto Wagner Pavilion*
Location	*Karlsplatz, Vienna*
Dimensions	15 x 8 x 10m
Number of photos used	*639 photos (630 aligned)*
Photo resolution /ISO value	3024 x 4032 pixels/ ISO 60
Processing time	*60 min. alignment process/ 200min. meshing/ 90min. texturing*
Raw mesh triangle count	*35.7 millions of polygons reduce to 16 millions to export texture*
Decimated mesh triangle count	*30 thousand of polygons*
Raw texture resolution	*16K*
Baked texture resolution	*8K*
Baked texture type	*diffuse- base colour map, normal map, ambient occlusion map, cavity map*

Fig.87 *The final exported high-poly mesh created by RC with 16mln triangles and 16K texture.*

5.5 3D modelling process

To create the virtual presentation content for the Otto Wagner Pavilion a set of 3D models were needed. Two groups of 3D models were created. The first group was created using the photogrammetry process, the second group with manual techniques in a 3D modelling software called 3ds Max. The second group was based on old plans, photos and research.

The first group, high-poly models created with photogrammetry method, are not suitable for virtual presentation. The next workflow steps are fixing the raw model and create an optimized model for a mobile application (Fig.88). High-poly raw meshes exported from the RC commonly have problems with non-manifold edges/vertices and holes created during the decimation step. Non-manifold edges are edges of poly-surfaces or meshes that have more than two faces joined into a single edge. The RC software rarely twists the intersected polygons, only the holes must be filled. For the mesh fixing step MeshLab [@meshlab] and MeshMixer [@meshmixer] were selected. Both software are free of charge and offer options to fix the raw mesh. The next step was to sculpt the surface - some mesh areas can be fixed but without transformation. The main idea during the sculpting process is to fix – increase the mesh resolution of large polygons, fix alignment errors and recover missing parts. The original scale, rotation and position of the raw mesh in 3D space has to remain unchanged (Fig.89). The cleaned mesh is imported back to RealityCapture from the reconstruction tab. The cleaned mesh is automatically placed in the exact same position as the raw mesh. The position, orientation and shape differences between the raw mesh and the fixed mesh should not be big for the photogrammetry software to calculate the correct texture. Based on the size of the object, the texture resolution should be generated, for example the texture of the Otto Wagner Pavilion was in resolution 16384x16384 pixels (Fig.90). To improve the texture resolution result, the option in RC (weight in texturing) for cameras from the bigger distance loop is set to small value. This setting helps the final texture to gain more detail from photos taken from a close loop.

In order to be able to display and modify geometric objects within reasonable response times, it is necessary to reduce the amount of data by removing redundant information from raw high-poly triangle meshes. To obtain the appropriate models for a real-time rendering engine the simplification/decimation step was needed. Mesh decimation is a class of algorithms that transforms a given polygonal mesh into another one with fewer faces, edges, and vertices (Fig.91). The complexity of a 3D model has to be adapted to the hardware capabilities.

The quadric edge collapse decimation option in MeshLab was used to produce a low-poly mesh. The decimation process should not run at once as it will cause loosing a lot of details. It is better

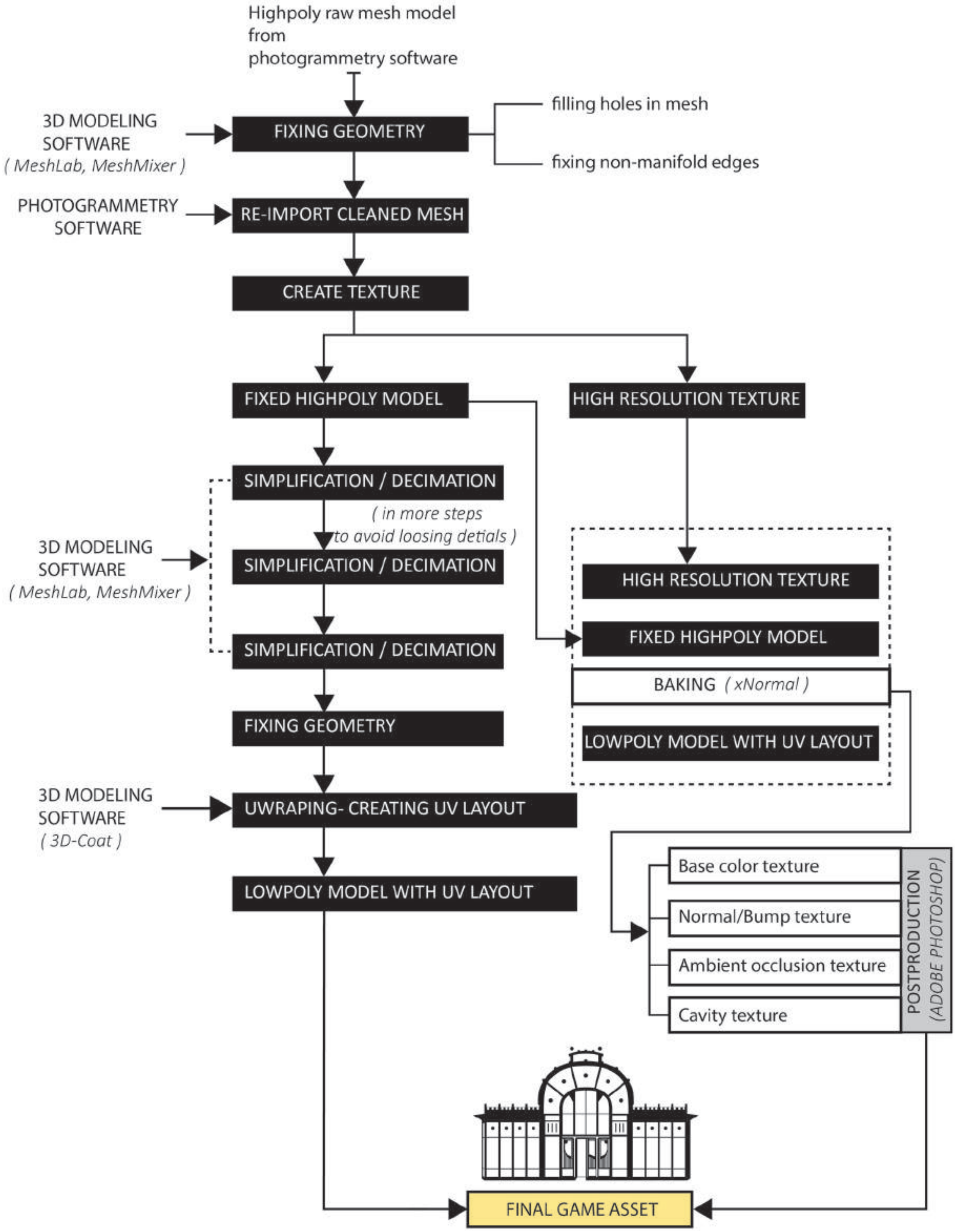


Fig.88 *The 3D modelling workflow diagram.*

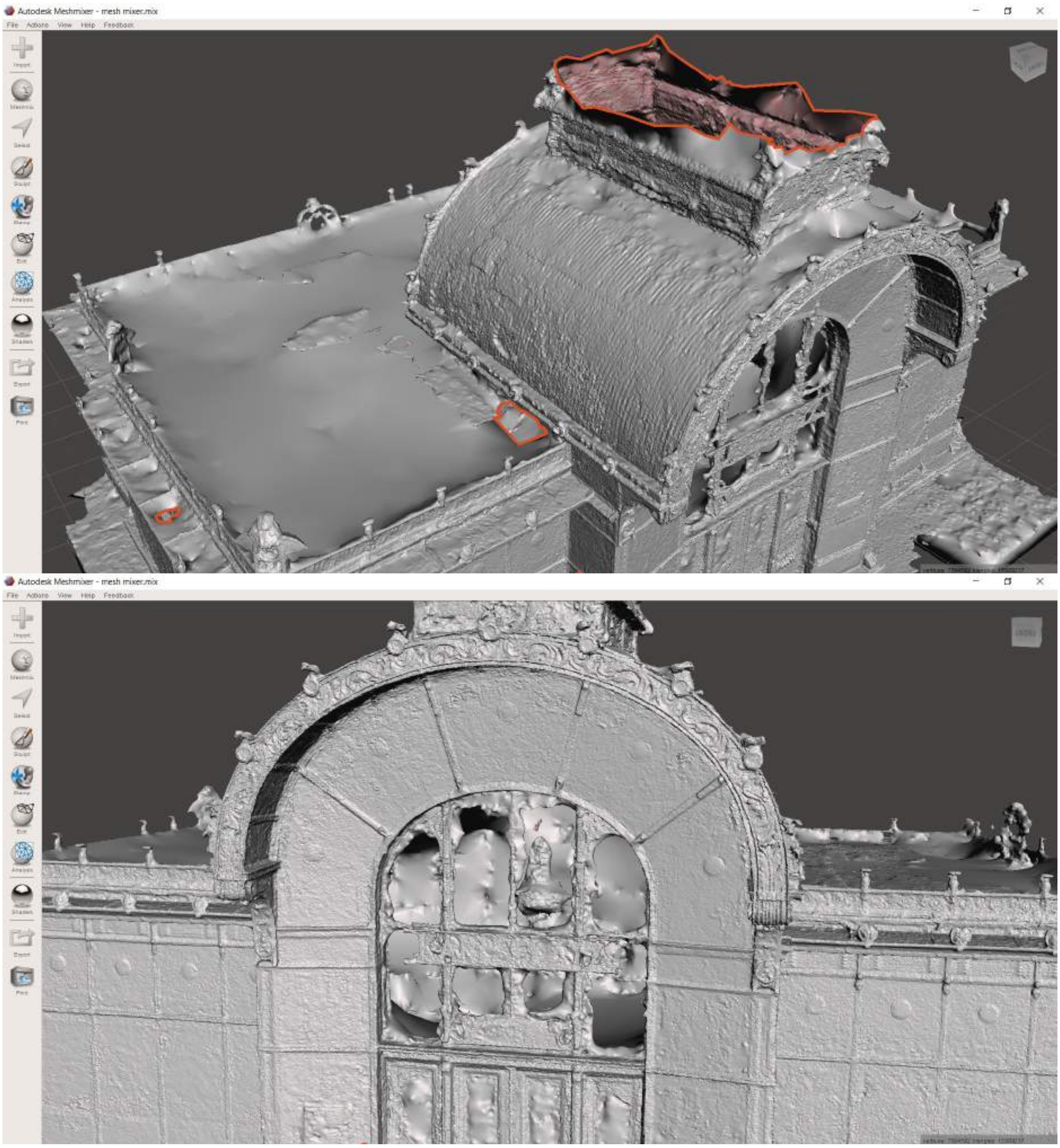


Fig.89 *Fixing RAW mesh (filling holes) in MeshMixer before reimporting to RC and building texture.*

Fig.90 *Fixed high-poly mesh (16 millions polygons) with high-resolution texture (16384 x 16384 pixels) built in RC.*

to do a process of simplification in more steps. MeshLab gives more options to set values for the decimation. All the applied steps for decimating mesh in the case study are described in the next part.

The *Percentage reduction* was set to 0.5. This parameter specifies the desired final size of mesh as a percentage of the initial size.

Next option *Quality threshold* has a selected value of 1. The value needs to be in a range of 0 to 1. The shape of the created optimized model will correspond with the original one more the closer the value gets to 1.

The Preserved Boundary of the Mesh option tries not to affect the mesh boundaries during simplification.

The *Preserve Normal* option tries to avoid face flipping effects and to preserve the original orientation of the surface. The only drawback if enabled is a slight increase in the processing time.

The Preserve Topology option avoids all the collapses that should cause a topology change in the mesh.

The *Optimal position of simplified vertices* insures that each collapsed vertex is placed in the position minimizing the quadric error.

The Planar Simplification option is adding additional simplification constraints that try to preserve the current shape of the triangles. It improves the quality of the shape of the final triangles on perfectly planar portions of the mesh.

The Weighted Simplification uses the Per-Vertex quality as a weighting factor for the simplification. The weight is used as an error amplification value, so a vertex with a high quality value will not be simplified and a portion of the mesh with low quality values will be aggressively simplified.

Post-simplification cleaning is an additional set of steps performed to clean the mesh (Fig.89). The Otto Wagner Pavilion was decimated from a 16 million fixed mesh to a 50 thousand polygon mesh in several steps. In the last step only the selected parts of the mesh without details were extra decimated. The final fixed mesh of the Otto Wagner Pavilion has 30 thousand polygons (Fig.90). The Sunflower railing was decimated from 5.9 million triangles mesh to 15 thousand polygons mesh in more steps.

The high-poly mesh was exported from RC with a high-resolution base texture with all details (Fig.92). Next step was to create the UV map for the optimized low-poly mesh (Fig.93). To create the UV texture coordinates of the decimated mesh. The 3D-Coat [@3dcoat] software was used. UV map is a flat representation of the 3D model. Flattened and mapped topology of the model is also a basis for map baking. UV mapping is the process of translating 3D mesh into 2D information so that the created 2D texture can be wrapped around it. UV space is based on a 0 to 1 grid, with 0.5 as the middle coordinates. UV map consists of the 3D model XYZ coordinates flattened into 2D UVW space. The letters “U” and “V” denote the axes of the 2D texture because “X”, “Y” and “Z” are already used to denote the axes of the 3D object in the model space. Depending on the modeller

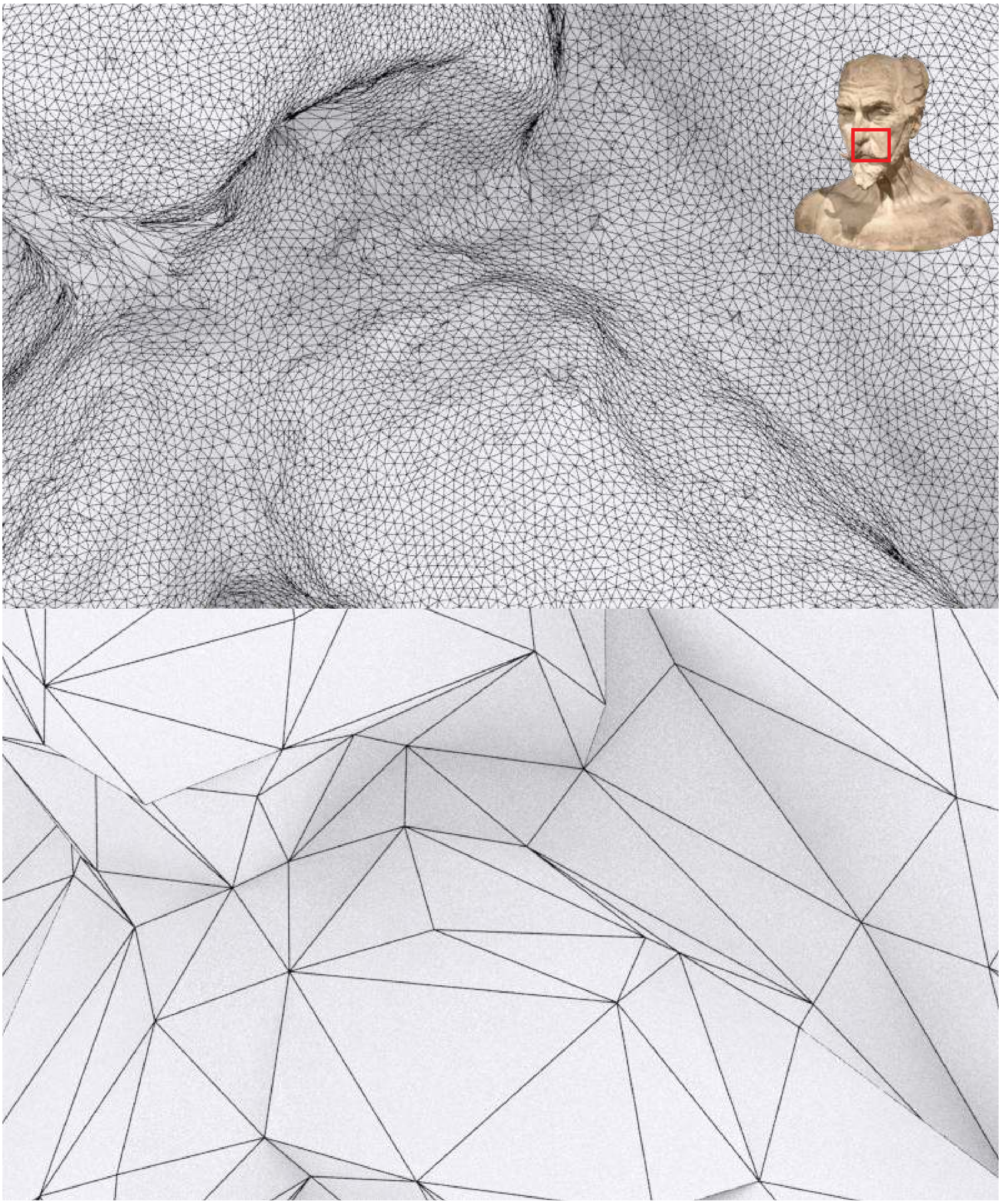
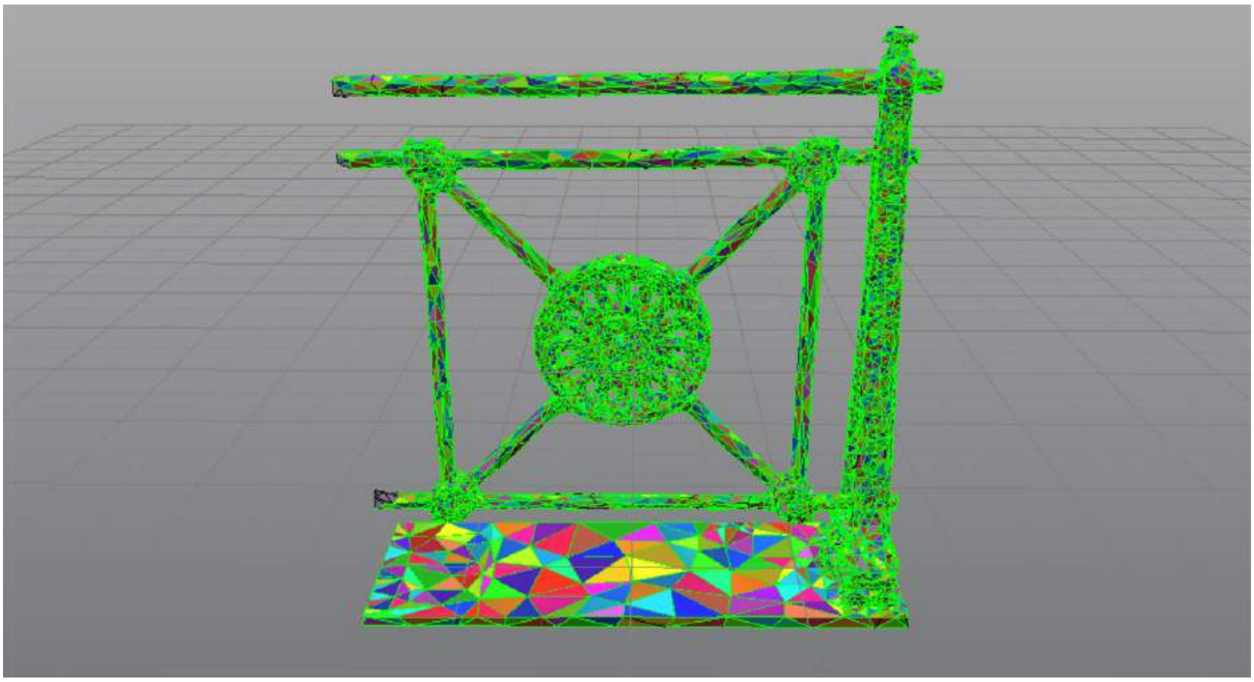


Fig.91 *Polygon density of the Otto Wagner bust (moustache-nose part), (above) wireframe high-poly mesh 1.5 million triangles, (down) wireframe low-poly mesh 4,3 thousand triangles.*



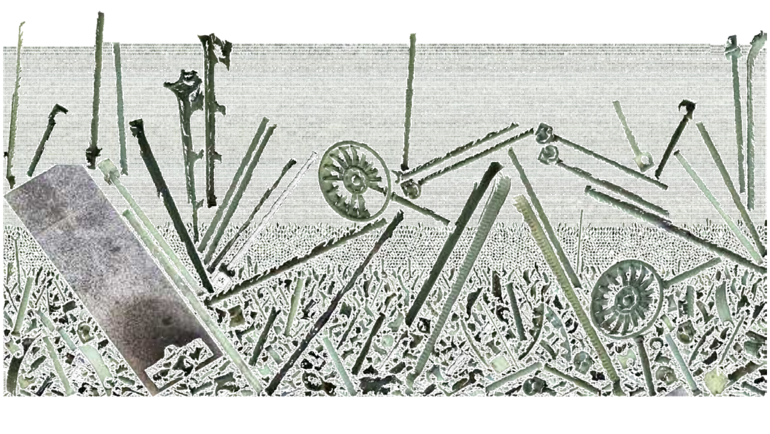


Fig.92 *Example of UV layout and automatically generated map from high-poly mesh by the RC.*

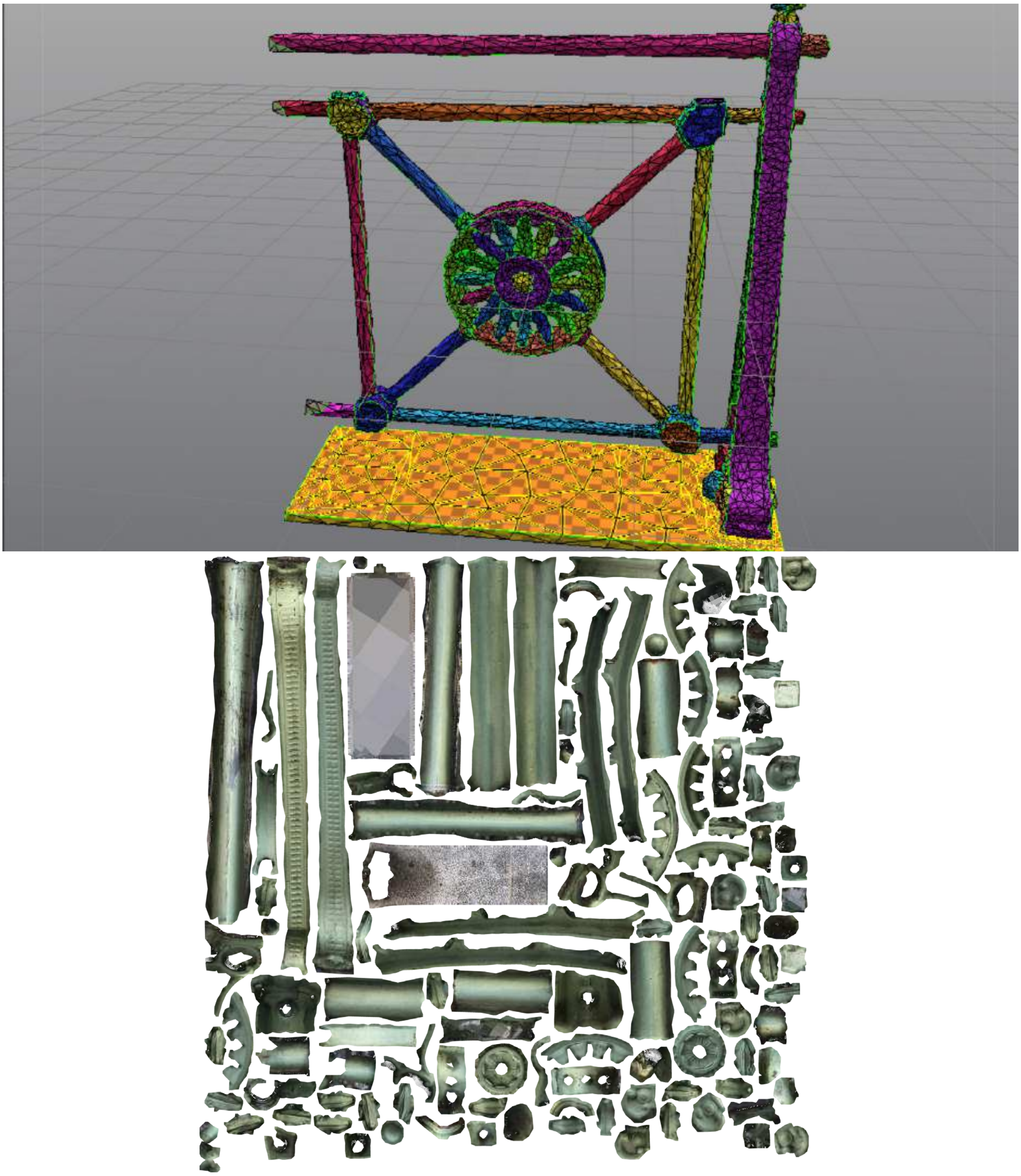


Fig.93 *Example of manually created UV layout in 3D-Coat.*

and the mapper, 3D´s horizontal X-axis equals U in 2D space, vertical Y equals V, and the depth coordinate Z equals W. The depth coordinate ensures that the map is displayed correctly in 3D.

The UV mapping process at its simplest requires three steps: unwrapping the mesh, creating the texture, and applying the texture [Mullen, 2009]. The process of creating a UV map is called UV unwrapping. UV unwrapping is the process of 'unfolding' a mesh so the 2D texture which fits the 3D object can be created. The models need to be UV unwrapped so that real time engines as Unity can perform light information baking. An unavoidable side effect of flattening 3D geometry are seams (Fig.94). A seam is a part of the mesh that had to be split to make it possible to convert the 3D mesh into a 2D UV map. The main idea was to keep seams to a minimum and produce as little distortion to a wireframe as possible. Distortion in terms of UV map is how much the shape and size of the polygons have to change to accommodate the flattening process. The distortion affects the way the details are displayed. The seams were produced to follow hard edges because in these areas they are less noticeable. The generated UVs have a large influence on the quality of the final asset. After the low-poly models were unwrapped the mesh was exported as .obj.

The low-poly mesh is approximately same as the high-poly mesh, however, during the decimation process the low-poly geometry has lost a huge amount of surface details. To compensate for the loss of details the texture baking technique can be applied to keep the level of visual detail from high-poly mesh to the low-poly mesh. Texture baking is the process of transferring details from one model to another (Fig.96). The process aims at generating libraries of texture maps that describe the different qualities of the 3D model surface in a real-time rendering environment scene (materials, texture, colour, lighting, shadows, reflections, etc.). These are memorized and associated with the information describing the 3D model. This procedure - also called Rendering to Texture - precalculates the effects of rendering to generate bitmap images that are expressed in the 2D (UV) system of reference and coherently oriented with the mesh vertices. With this technique, it is not necessary to make rendering calculations for each movement of the model because the realistic result is ensured by associating the maps to the surfaces of the object in (UV) space. This procedure is therefore particularly indicated for applications requiring 3D spatial navigation in real time. The baking tool starts at a certain distance from the model (usually a low-resolution model for game use), and casts rays inwards towards another model (usually a high-resolution sculpt). When a ray intersects the 2nd model, it records the surface detail and saves that into a texture map, using the first model's texture coordinates [@wiki.polycount]. For the baking process xNormal [@xnormal], which is a free software, was selected. After loading a high-resolution mesh, based texture from RC and a low-resolution mesh the ray distance calculator will compute the min/

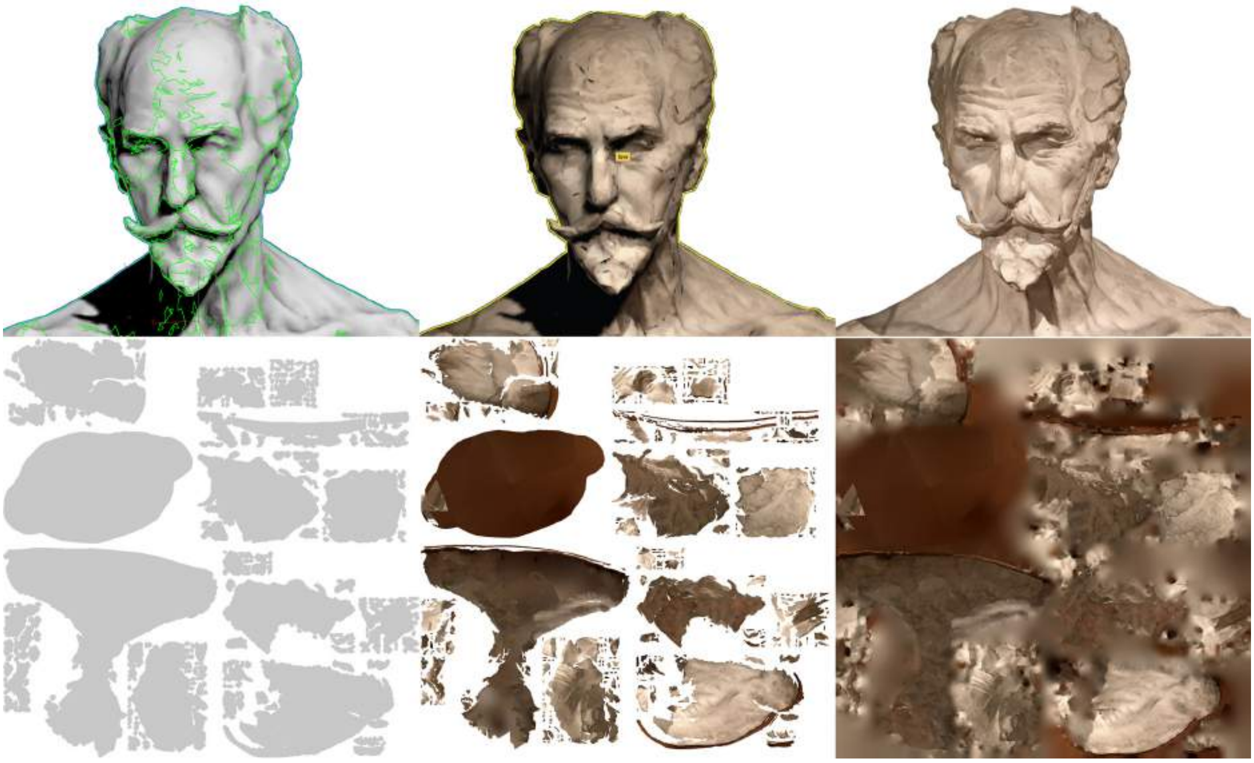
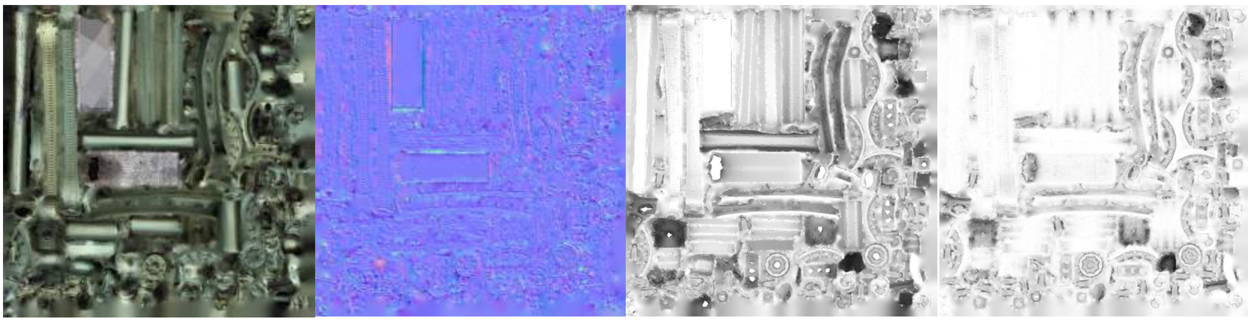


Fig.94 *(from left to right) examples of mesh seams, “hard edges” on geometry and texture adjusted in Photoshop.*



Base colour map *Normal map* *Ambient occlusion map* *Cavity map*

Fig.95 *The different types of generated textures.*

max distance between polygons of low- and high-resolution meshes. If everything is done correctly in the previous steps, the distance value should be really low, around 0.05. In the next step baking setting, texture size, render basket size and anti-aliasing setting can be selected. The normal, base, ambient occlusion and cavity map were generated and exported as a 16bit tiff format (Fig.95).

A normal map is an image that stores a direction at each pixel. These directions are called normals. The red, green and blue channels of the image are used to control the direction of each pixel's normal. A normal map is commonly used to fake high-resolution details on a low-resolution model. Each pixel of the map stores the surface slope of the original high-poly mesh at that point. This creates the illusion of more surface details or better curvature. However, the silhouette of the model does not change [@ wiki.polycount].

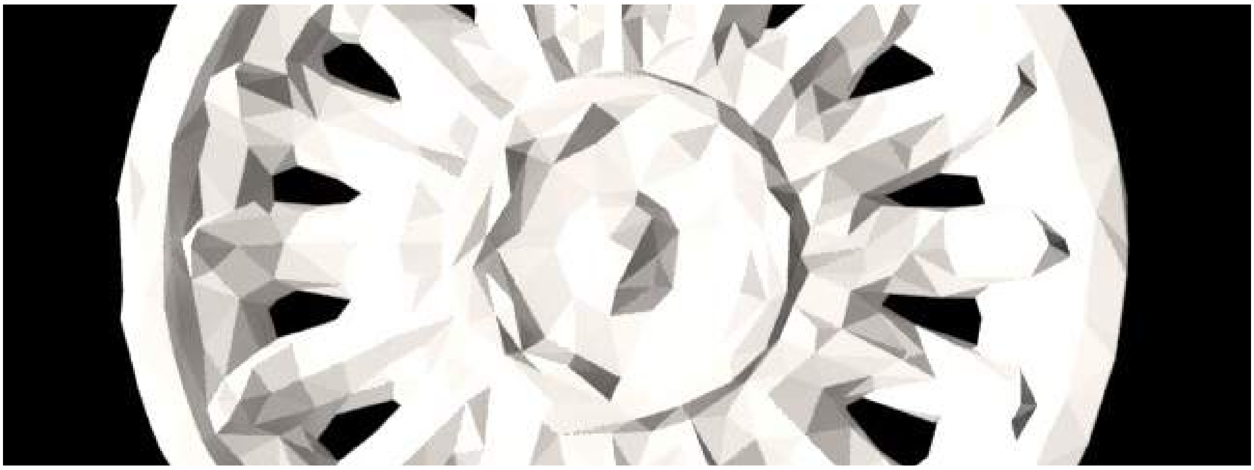
Base colour map (diffuse map) usually means the colour texture. Also called an Albedo map. This map generally only represents the base colours. Adobe Photoshop [@adobe] can be used to remove undesirable parts as graffiti from the façade of Otto Wagner Pavilion (Fig.98). For recovering large areas the Content-Aware Fill and Patch tool were used. All UV islands have extended borders around them. Otherwise black pixel border on a polygon will be visible on close-up render or in a real-time engine. To reduce and avoid black seam edges, the Photoshop plugin filter Flamingpear Solidify C [@flamingpear] was used. The plugin fills 100% image layer and outer edge seams and gives smooth and uniform result.

Ambient occlusion (AO) map creates soft shadowing as if the model was lit without a direct light source like on a cloudy day. AO is usually baked from geometry because it is created using a non-real time ray-casting lighting solution. It can either be stored in a texture or it can be stored in the vertex colours of the model. Typically, the AO map is blended into the metalness or specular map, instead of being stored as a unique texture, because this saves memory [@wiki.polycount].

Cavity map, also called a crevice map, is a texture that stores small-scale ambient occlusion. It is different from a curvature map which stores the convexity/concavity of a mesh. To bake a cavity map, the ambient occlusion with the ray distance is set to a lower value [@ wiki.polycount].

Adobe Photoshop is used to fine-tune the textures and to improve small details, for example, areas where the camera has captured the surface from a high angle. Base colour map, ambient occlusion and cavity map can be joined to one texture to save computing time in real time rendering (Fig.96).

High-poly mesh (5.9 millions polygons)



Low-poly mesh (15 thousand polygons)

Low-poly mesh (15 thousand polygons) with baked high-resolution texture

Fig.96 *Texture baking process.*

5.6 Final 3D assets

The final models selected for the real-time rendering are: The Otto Wagner bust, the Sunflower railing and the Otto Wagner Pavilion. The results are compared and described in Table 1 (Fig.99).

The results could be improved by applying the following steps:

The quality of the data set has the biggest impact on the quality of the final asset. These improvements can be done:

1. capture the object and its surfaces in a more detail way.

2. better filter assembly for reflection reduction

3. objects situated in high density spaces should be documented without the movement of people and cars to increase the number of necessary feature points.

4. photo acquisition of the Otto Wagner bust and railing can be done with more powerful DSLR camera.

5. image output format should be RAW instead of JPEG. RAW format contains all the information the camera captures such as the full dynamic range of the sensor and lots of additional colour information that is used by the photogrammetry software. The RAW photos are more suitable for preprocessing step. The additional free VSCO application [@vsco] or a paid application called Halide [@halide] allow to create and save photos in RAW format.

6. the data set should be pre-process in order to fix exposure, lighten the shadows parts, darken the lighted areas and remove chromatic aberrations.

The final improvements of the 3D models:

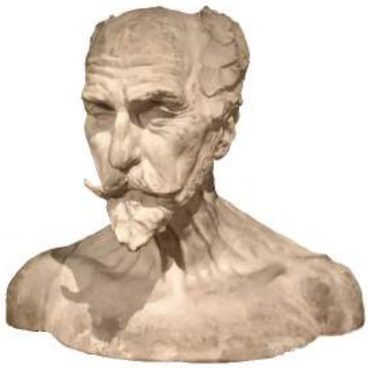
1. using Photoshop (or Unity Unlit) for texture delighting and de-shadowing (removing shadows).

2. materials and map corrections can be done using tools like Marmoset tool bag

The second used group of 3D models was created with manual modelling techniques in 3ds Max. The models are based on the old plans, photos and research. The complete interior environment was based on photos of original state and plans, the differences between the virtual interior and the actual one is described in more detail in chapter 4.3 Otto Wagner Pavilion Karlsplatz. The model of interior is based on photos and original plans so the accuracy cannot be fully verified.

Fig.97 *Final low-poly mesh with applied high resolution texture.*

Fig.98 *Final low-poly mesh with applied high resolution texture (removed graffiti from the wall).*



Object name	Bust of Otto Wagner
Dimension	52 x 53 x 33 cm
Location	Vienna Museum Karlsplatz, exhibition in 2018
Input data:	
Number of images	50 imported - 32 aligned
Size of files	
Image resolution	3024 x 4032 pixels
Output data:	
Raw mesh polygon number	2.2 millions triangles
Processing time	
Highpoly mesh triangle number	1.5 millions triangles
Lowpoly mesh triangle number	4.28 K
Texture	normal map, diffuse map
Texture resolution	4K
Problems	reflection of glass cover, more direct light sources

Fig.99 *Final comparison table of all photogrammetry objects.*

Sunflower railings	Otto Wagner Pavilion
75 x 75 cm	15 x 8 x 10 m
Stubenbrücke, Vienna	Karlsplatz, Vienna
320 imported - 315 aligned	630 imported - 625 aligned
3024 x 4032 pixels	3024 x 4032 pixels
5.9 millions triangles	35.7 millions triangles
5 millions triangles	16 millions triangles
15 K	30K
normal map, diffuse map, cavity map and ambient occlusion 8K	normal map, diffuse map, cavity map and ambient occlusion 16k
moving objects in background	object higher then inspection pole, from one side the tram rails and wires

5.7 Building the AR application

The previous chapter gave an overview on the creating of 3D assets, in order to build a virtual presentation – an AR (Augmented Reality) application. Augmented reality (AR) has many different implementation models and applications, but its primary objective is to provide a rich audio-visual experience. AR works by employing computerised simulation and techniques such as image and speech recognition, animation, head-mounted and hand-held devices and powered display environments to add a virtual display on top of real images and surroundings. To achieve an augmentation, the Augmented Reality system typically consists of :

1. an output device displaying the virtual information (in this case study a mobile phone)
2. a tracking system for determining the position and the orientation of the user
3. a computer processing the necessary data
4. arbitrary input devices for navigation and interaction.

The key challenge for the AR application is to track the user's view position and orientation in real-time, in order to obtain precise alignment between real and virtual objects. The smartphone camera is essential as it delivers the background image for the augmentation and optical information about the surroundings. After the current position of the viewer is detected by the system, the actual content that will be displayed in the real space has to be estimated. A convincing real time AR experience is achieved due to real time rendering that means that the whole process is completed 30 times per second (FPS - frames rendered per second). To create a simpler task for the computing hardware, the optimized, low-poly model, has to be created. There are two main forms of augmented reality applications development, location- and marker-based.

Location-based AR application utilises various mobile devices features monitoring the device position based on assisted global positioning system (GPS), cellular network, camera, compass, accelerometer, etc. No matter what kind of sensor is used, the system has to be able to measure the position and orientation of the camera.

Marker-based AR application works using the device's software to identify patterns (e.g. QR code or plane surface) in the image obtained from its camera. The computer vision algorithms allow to recognise and calculate the spatial relations between the markers and the device's camera. Natural feature tracking relying on CV algorithms does not depend on artificial markers but on the object's surface areas with a high level of local contrast - patterns. Once the current position of the viewer is known by the system, the actual content that will be added to the real world view has to be calculated. The position information of the camera is used in a 3D software that contains all the virtual objects that will be augmented in real space and has a predefined spatial correlation to the real scene.

With the development of technologies, the modern smartphones and tablets fulfil the requirements for displaying AR presentation. These devices are full of different sensors, have a displaying screen and are mobile. According to operating system used there are two main groups of mobile devices: Apple iOS and Google Android. The selected test device for the Otto Wagner Pavilion presentation is the iPhone 8. (*Technical specification: A11 Bionic chip Neural Engine, 12 Megapixel camera and Retina HD display 4.7-inch (diagonal) wide-screen LCD Multi-Touch display with IPS technology and 1334-by-750-pixel resolution at 326 ppi 1400:1 contrast ratio*) [@apple].

Next to the device's operating system, the AR development platform is a determining factor. Two main platforms for an implementation of an interactive 3D visualisation are game engines Unity (Fig.99) and Unreal Engine. These two engines are commonly used for creating computer games, which means the creation of a completely virtual reality environment and a presentation of a fully artificial world. Next to the main use they are also appropriate with different packages for creating AR presentations. Based on a number of tutorials and previous personal experience, the selected game engine type for creating the virtual presentation was Unity. The selected game development environment, providing intuitive tools, helps designing an impressive 3D content. It also provides cross platform publishing and millions of ready-made assets in the asset store. Unity's best asset is that it does a good job at helping to develop mobile game content while being a cross platform with a minimum amount of effort. It also has great documentation, tutorials, and community pages. Unity is an ideal platform for beginners, or creative non-programmes, due to clean and organised user interface, workflow and support of a wide variation of format data assets, such as 2-3D models, textures, animations, etc.

Firstly created digital assets are load into Unity´s project folder, all digital assets could be archived, sorted and from this point used in the Unity editor. In next step the scene can be designed. The scene defines the scenarios and events that the user experiences inside the augmented exhibition- scene. To offer the user a best experience possibility of moving and making his own decisions. The scene will be consist from:

- Starting area after the application start the virtual portal appears.
- Virtual environment of Karlsplatz Pavilion
- Photogrammetric results the results of photogrammetry scanning could be reviewed separately in the virtual interior of Pavilion.
- Assets supplementing the photogrammetry models and offering interaction between user and virtual content.

The possibility to navigate the user through different environments and interact with the content in the scene is the most essential part of the AR application. To achieve this, a user interface

(UI) must be created understandably for the user and offer him the choice of selecting the options based on his own wishes. The Unity editor offers the integrated function of UI creation that offer the developers to create "canavs-objects" such as buttons, text, images and toggles without extra effort. These premade based elements could be placed into the scene and predefine "which event should happen after which element is triggered" [Seifert, 2015].

To build an Augmented Reality application in Unity it is necessary to download and to install a third party plugin from the Unity asset store. Currently there are accessible computer vision-based Augmented Reality SDK that are capable of natural feature tracking and offering plugins for Unity. ARKit (Fig.100), which was introduced in iOS 11, is a framework for an easy creation of augmented reality projects for the iPhone and iPad. The main features of ARKit include:

- TruDepth Camera to detect the position, structure, and expression of the user´s face, all with high accuracy. Making it easy to apply effects in real-time.

- Efficient scene understanding and lighting estimation. ARKit can use the iPhone's camera sensor to estimate the total amount of light in a scene, then apply estimate shading and texture to virtual objects. It works exceptionally well on plane surfaces.

- Visual Intertial Odometry (VIO) to fuse camera sensor data with Core Motion data to track movements without any additional calibration

The newest ARKit 2 came with the iOS12 release and allows a simultaneous agumented reality experience for multiple users. The object detection and tracking compared to ARKit 1.5 extends tracking support to offer full 2D image tracking, so the moveable objects, such as, product boxes or magazines, can be incorporated to the AR experience. ARKit 2 also adds the ability to detect known 3D objects like sculpture, furniture and the vertical planes.

Unity-ARKit-Plugin is a native Unity plugin that extends the functionality of Apple's ARKit SDK to Unity projects for compatible iOS devices. *"It includes ARKit features such as world tracking, pass-through camera rendering, horizontal and vertical plane detection and update, face tracking (requires iPhone X), image anchors, point cloud extraction, light estimation, and hit testing API to Unity developers for their AR projects. This plugin is a preview quality build that will help you get up and running quickly, but the implementation and APIs are subject to change. It contains the plugin sources, example scenes, and components that you may use in your own projects"* [@ blogs. unity3d].

Software requirements:

Unity v2017.4

Apple Xcode 10.0+ with latest iOS SDK that contains ARKit Framework

Apple iOS device that supports ARKit (iPhone 6S or later, iPad (2017) or later) Apple iOS 12+ installed on device

The implementation of the AR features in

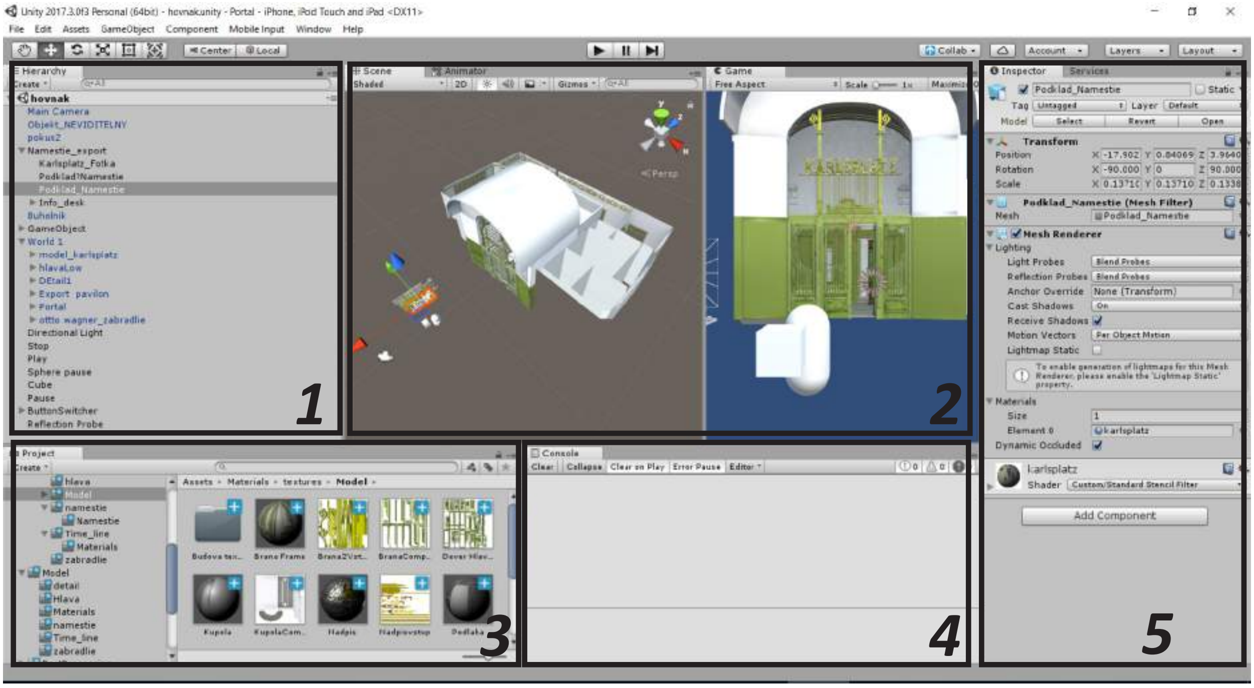


Fig.99 *Screenshot of Unity interface: 1. hierarchy window 2. scene window 3. project window 4. console window 5. inspector window.*

Fig.101 *Lego using ARKit features.*

the case study required computer vision-based tracking which was accomplished by the ARkit plug-in without any further modifications. ARKit uses the built-in camera, powerful processors and motion sensors in iOS devices to track the real world objects and let virtual objects blend in with real environment. It also uses Visual Intertial Odometry (VIO) to accurately track the world around. To place the application content in the real world, an approach based on ground plane detection is used. The plane detection works using the mobile camera. After pointing the camera to the horizontal surface, it shows the surface feature points trying to identify the plane. Once it has enough feature points, it recognises the horizontal surface area. To demonstrate plane detection, the app visualises the estimated shape of each detected ARPlaneAnchor object, and a bounding rectangle for it. On supported devices, ARKit can recognize many types of real-world surfaces, so the application also labels each detected plane with identifying text. The ARSCNView class is a SceneKit view that includes an ARSession object that manages the motion tracking and image processing required to create an augmented reality (AR) experience. An ARSession is the object that handles everything from configuring to running the AR technologies. However, to run a session a session configuration must be provided. The ARWorldTrackingConfiguration class provides high-precision motion tracking and enables features to help placing virtual content in relation to real-world surfaces. To start an AR session, create a session configuration object with the desired options (such as plane detection), then call the run(_:options:) method on the session object of the ARSCNView instance:

```
let configuration=ARWorldTrackingConfiguration()
configuration.planeDetection=[.horizontal,
.vertical] sceneView.session.run(configuration)
```

After the AR session is set up, the SceneKit can be used to place virtual content in the view. When plane detection is enabled, ARKit adds and updates anchors for each detected plane. By default, the ARSCNView class adds an SCNNode object to the SceneKit scene for each anchor. When the added content is as a child of the node corresponding to the anchor, the ARSCNView class automatically moves that content as ARKit refines its estimate of the plane’s position. ARKit continually updates its estimates of each detected plane’s shape and extent. To show the current estimated shape for each plane, this sample app also implements the renderer (_:didUpdate:for:) method, updating the ARSCNPlaneGeometry and SCNPlane objects to reflect the latest information from ARKit [@developer.apple].

5.8 Result

The prototype application for the Augmented Reality presentation for the Karlsplatz Pavilion was built and ran on an iPhone 8. As an inspiration for the application icon motive, the Austrian stamp issued in 1991 on the occasion of the 150th birthday of Otto Wagner was used. After the application is turned on the AR functionality is detected by pointing the device camera on the ground plane. As soon as the plane is recognized, the reference of an existing entrance portal appears on the device screen and it becomes possible to place the object on the ground (Fig.101). In the next step after successful placing, the position of the agumented Otto Wagner Pavilion is fixed and can be visited in full scale. After the user steps in the pavilion through the portal, the complete copy of the original interior environment from 1899 based on photos and original plans appears, and the presentation can begin (Fig.102). The user can see different types of information, text, images, animations and 3D models. During the virtual pavilion walk-through, further interaction for the user is possible through the exhibited objects. The exhibited objects created by applying photogrammetry methods are supplemented by animation, a voice-over guide and pictures (Fig.111). While the user moves and typically rotates around to see all information, the 3D objects are tagged with various icon symbols as voice guide or animation. To find out more about the object, the user can press the icon on the device screen (Fig.120). After pressing, the appearance of the symbol will bring the available content. Depending on the symbol, the content is displayed and overlaid in different ways. This interactive presentation of the exhibits helps the user to understand the design process of the building and the narrative behind the Vienna city rail design better. The final result is more of a demonstration using modern presenting and capturing methods than a full-featured presentation application.

Fig.102 *Placed entrance portal of virtual pavilion in front of the existing Karlspaltz Pavilion.*

Fig.103 *View from inside to outside of the virtual pavilion through the main entrance.*

Fig.104 *Placed virtual entrance on the square in front of the existing Pavilion.*

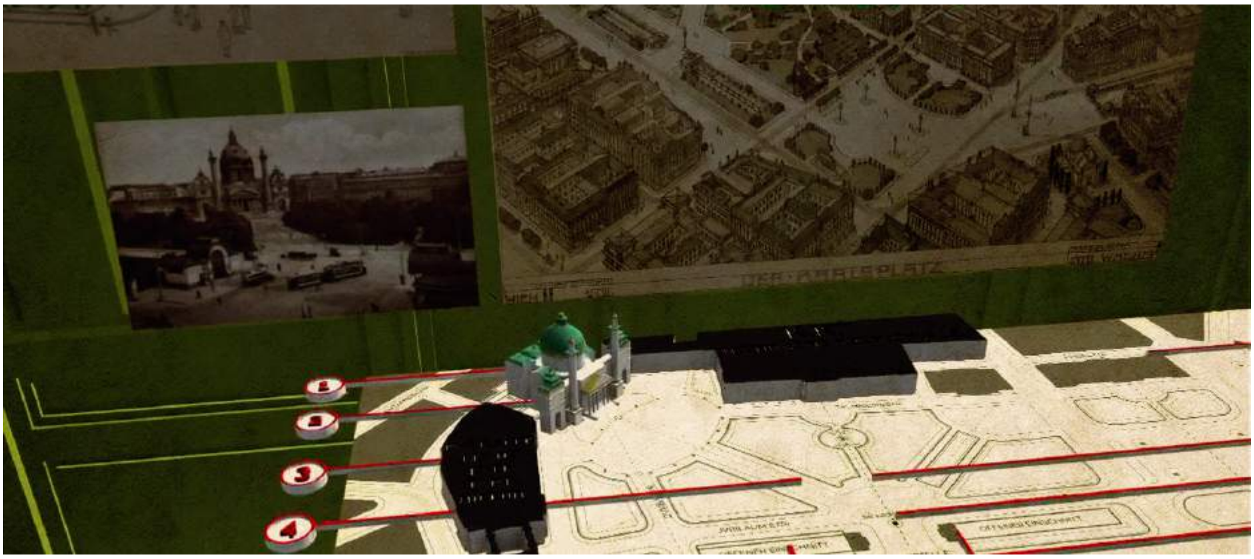


Fig.105 *Presenting the composition of Karlsplatz together with old photographs and drawings.*

Fig.106 *Presenting the composition of Karlsplatz together with old photographs and drawings.*

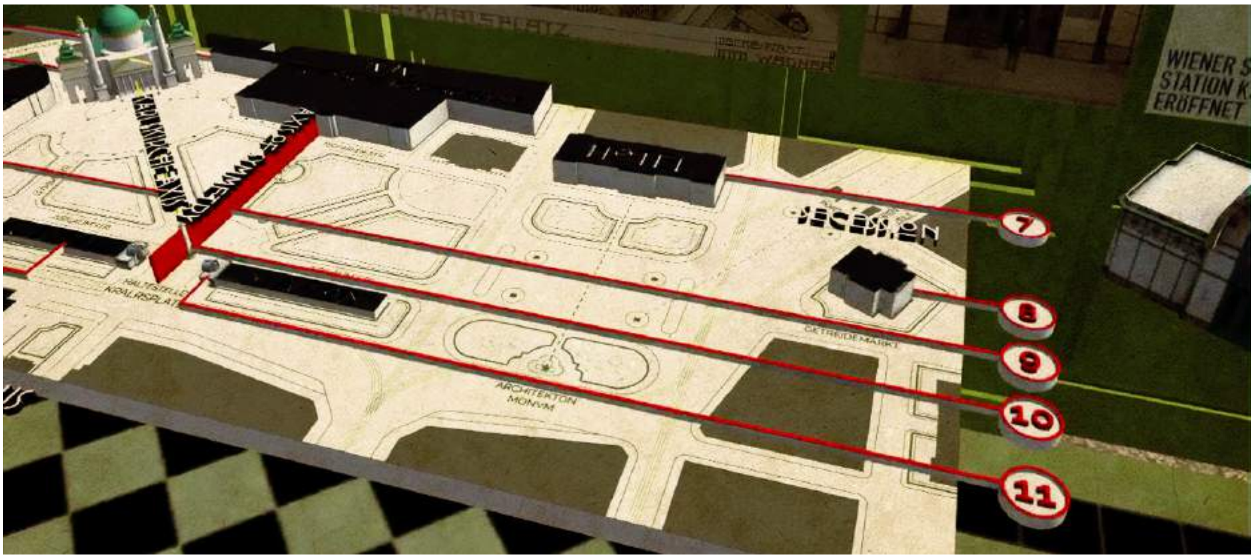


Fig.107 *Presenting the composition of Karlsplatz together with old photographs and drawings.*

Fig.108 *The architect Otto Wagner presented in the second room of the virtual pavilion.*

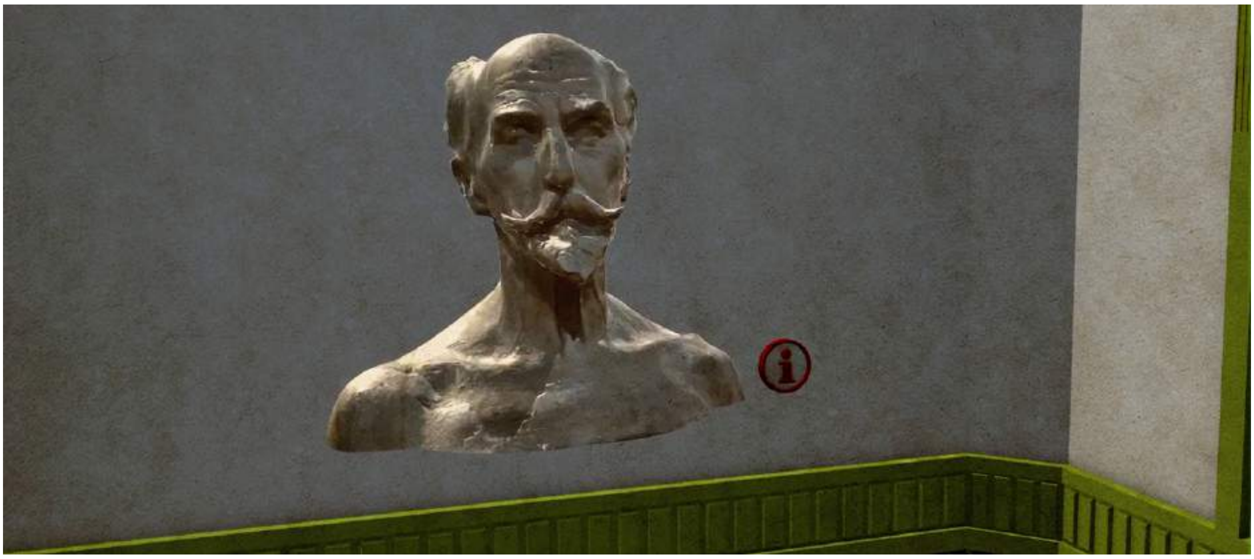


Fig.109 *Part of presentation, the Otto Wagner bust created with photogrammetry method.*

Fig.110 *Otto Wagner bust with timeline that presents his iconic buildings.*

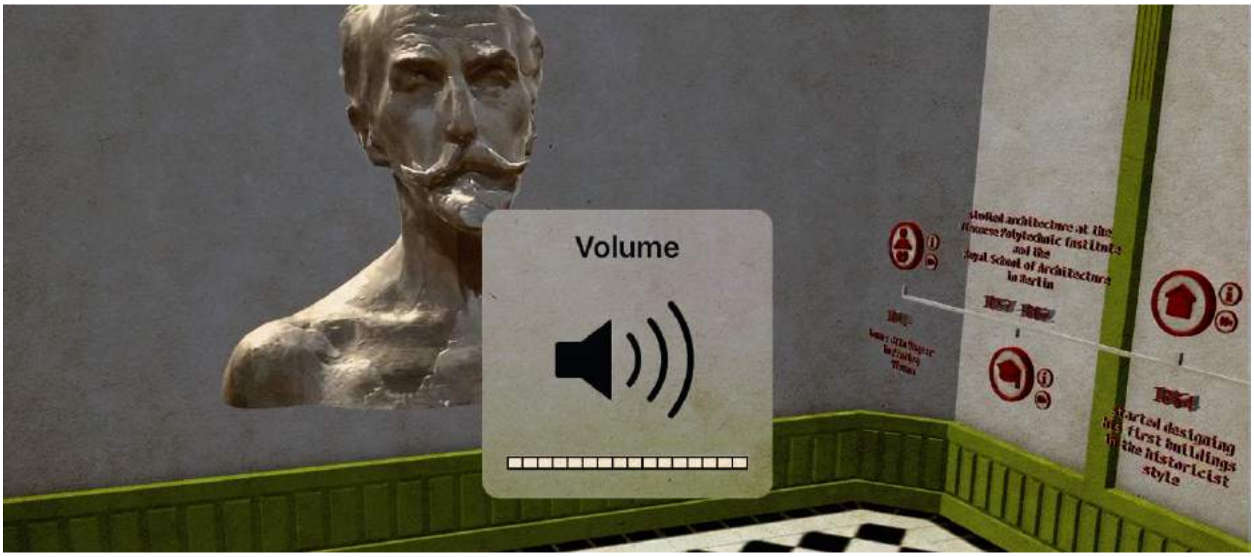


Fig.111 *Otto Wagner's life presentation guided with the voice over.*

Fig.112 *Timeline presenting Otto Wagner's life.*

Fig.113 *The next room of the presentation showing the sunflower railing.*

Fig.114 *The original stairway to platform.*

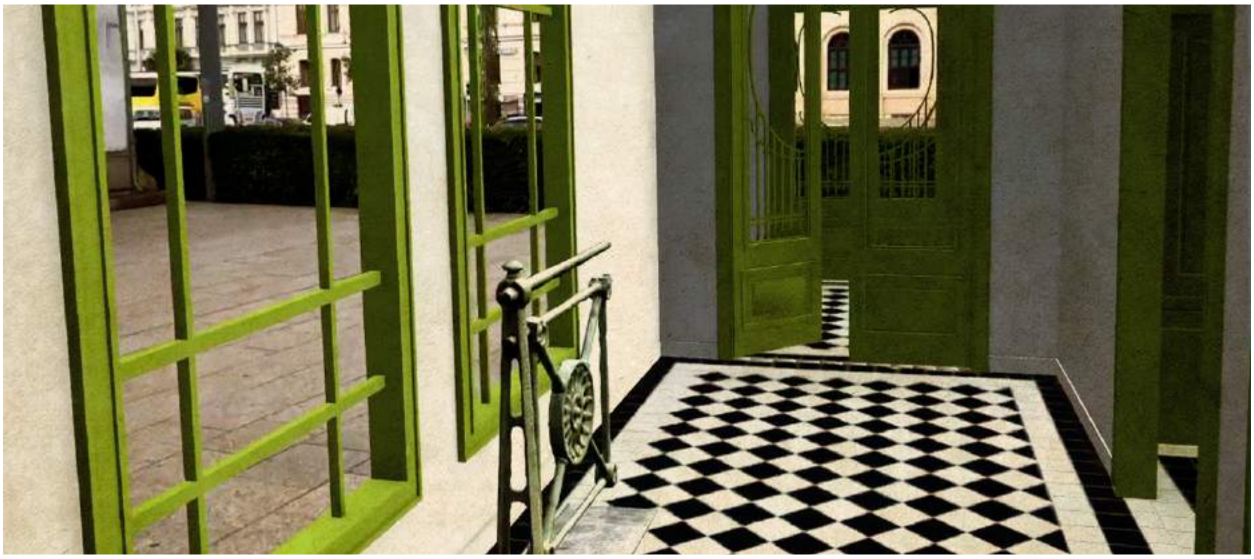


Fig.115 *Hall with the photogrammetry created sunflower railing.*

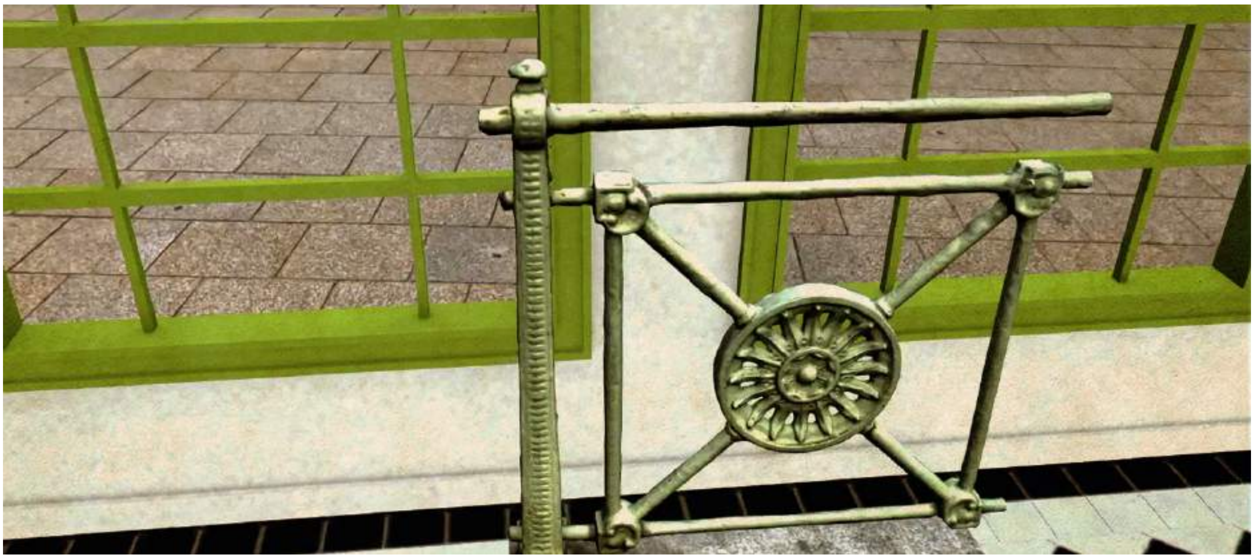


Fig.116 *Sunflower railing in scale 1:1 created with photogrammetry method.*

Fig.117 *Sunflower railing presented in original colour.*

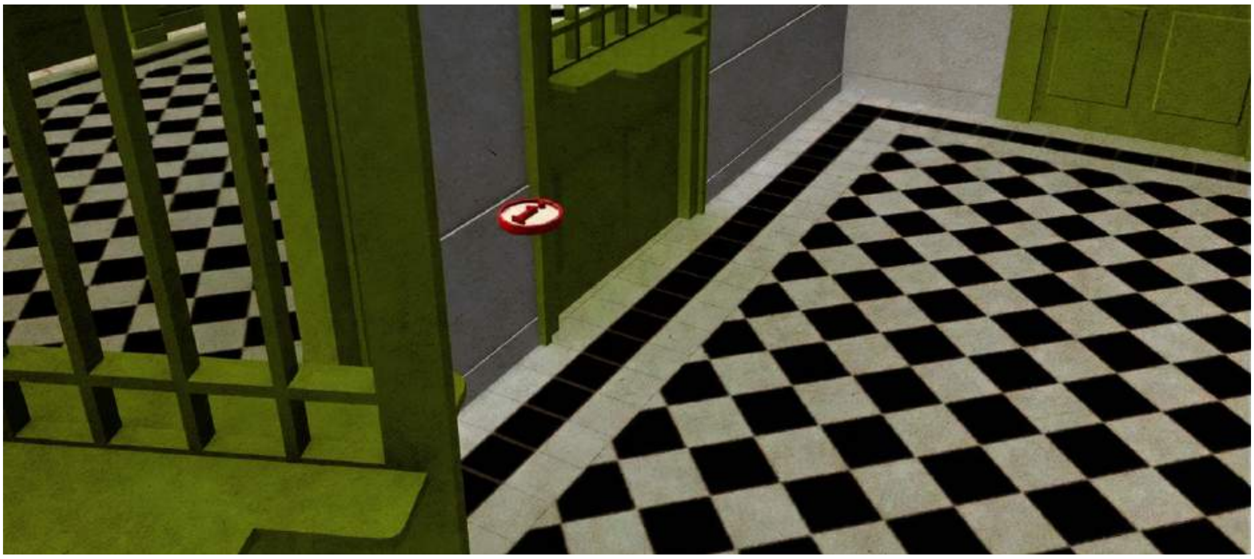


Fig.118 *The last room with the photogrammetry created Karlsplatz Pavilion 3D model.*

Fig.119 *Photogrammetry created model of Karlsplatz Pavilion.*

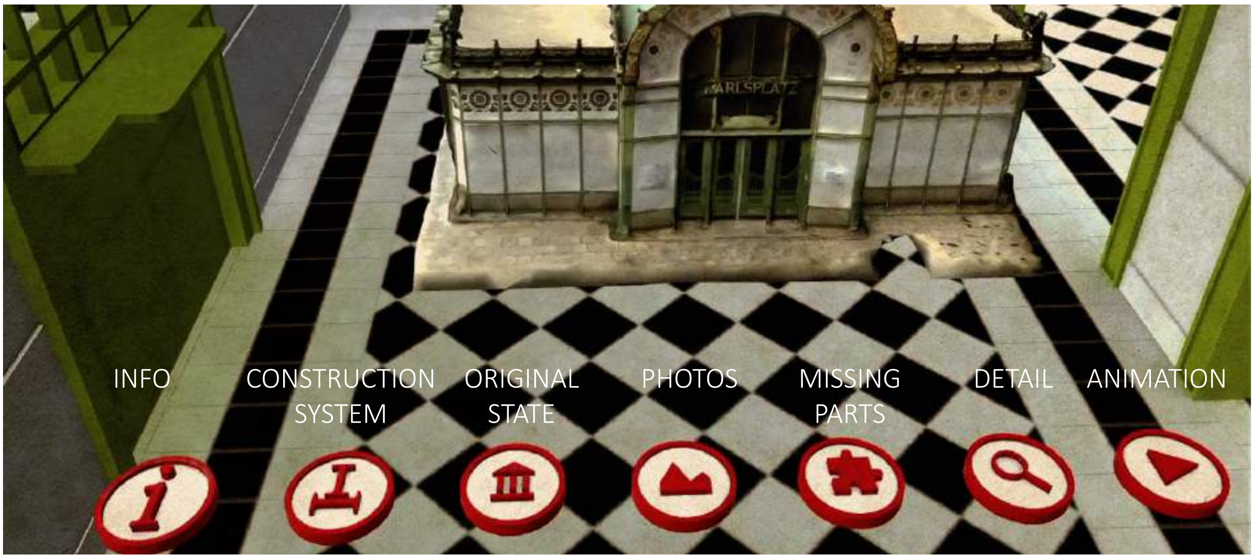


Fig.120 *Buttons with icons used by visitors to interact with the model.*

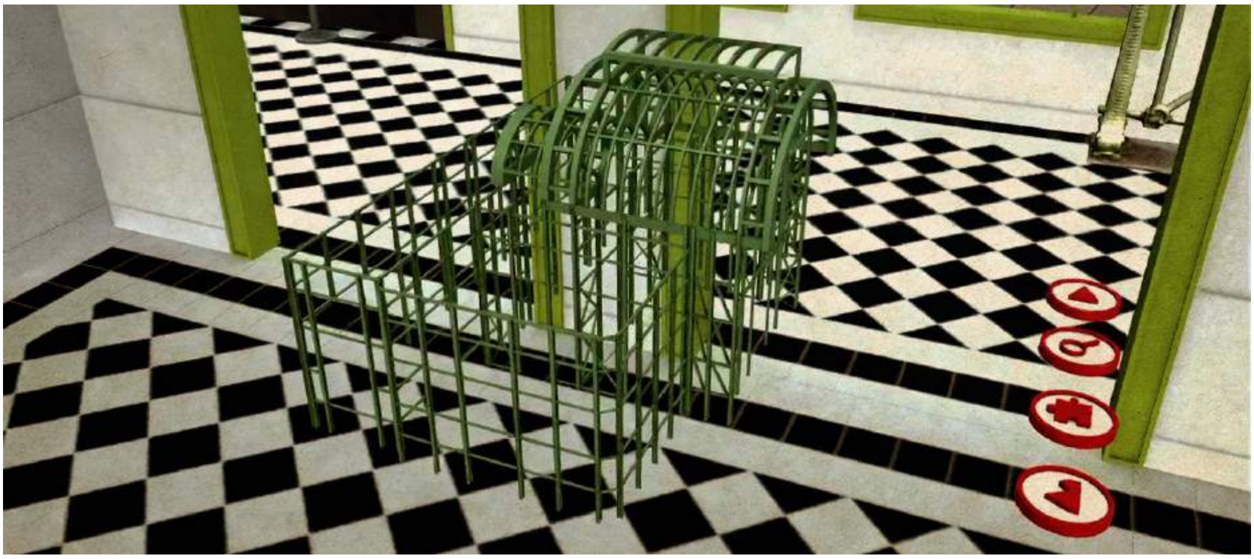


Fig.121 *3D model of the load-bearing system.*

Fig.122 *Original state of Karlsplatz Pavilion is presented.*

Fig.123 *Original state of Karlsplatz Pavilion with the stairway to the platform is presented.*

Fig.124 *Today missing part of Karlsplatz Pavilion and construction system are presented.*

Fig.125 *Original parts, lamps and plaques missing in actual state.*

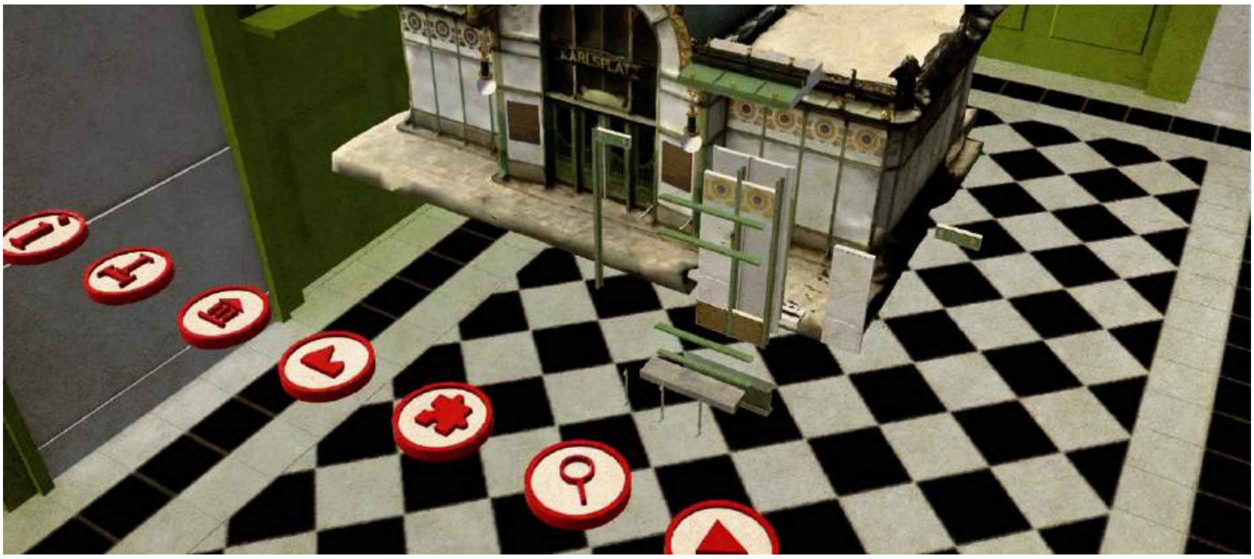


Fig.126 *Wall composition presented in exploded view animation.*

Fig.127 *View from inside to outside of the virtual pavilion through the main entrance.*

Conclusion

For the purpose of an architecture exhibition, representation medium is most commonly used. There are, however, other ways than using common exhibition techniques to display and tell engaging stories about architecture and design. The increasing affordability of smartphones and tablet computers make them widespread among users and offer employing new presenting techniques such as Augmented Reality. An integration of this technology to exhibiting process can create a new layer of knowledge, and can help to understand and further improve the user experience.

The aim of this thesis was to point out the possible solution by creating augmented reality application that presents Otto Wagner's work. The first chapter was devoted to the historical background of architecture exhibition desing as such. The second chapter introduced the augmented reality technology with several examples of its usage. The third chapter dealt with the theory of photogrammetry as well as with practical examples. The fourth chapter analysed the design rules of Otto Wagner and his related works. The fifth chapter then presented the development of the AR application focused on the architecture exhibition of Otto Wagner.

In consonance with the above, the size of exhibiting space is a factor restricting the size of the content. Although the virtual objects are presented in 1:1 scale, compared to the real exhibition objects, they do not need the same size of storage space. Presentation itself is often the final step of understanding the object, the first two are the conversion and research. To keep our heritage, we must think about a method that can document the object in an appropriate way while keeping all the fine details.

In the final application usage the photogrammetry models were demonstrated. In the AR application, the Otto Wagner Pavilion including its inner space is presented in the real scale according to the original condition from 1899. Moreover, the adapted workflow could also improve the way the objects are communicated and understood by inexperienced useres attending the architecture exhibition.

Using a close-range photogrammetry technique for the three selected objects, namely, the Otto Wagner bust, the Sunflower railing and the Otto Wagner Pavilion, prove the following: only with sufficient computer equipment and without the use of a sophisticated camera, the 3D models can be created and the acquired data can be measured. As such, the full information of the original photos is compressed in the results, without having to neglect the fine details.

Although a photogrammetric survey is indeed uncomplicated to perform, if the photogrammetry object and environment fulfil the base specifications (light source, surface material), evaluation of the images could be difficult, the resulted object may not be correctly reconstructed as in the case study. The Otto Wagner bust was covered with a glass box, which created reflections, and as a result the photogrammetric reconstruction software could not extract enough features to recreate the back side of the bust correctly. The results presented in the thesis were also limited by the acquisition possibilities based on the hardware and software used. The problem of the applied workflow and hardware is reflected on the quality of reconstructed 3D model of the Otto Wagner Pavilion. The complexity (object higher than inspection pole and its shape) and the environment (electric wires) do not allow to create complex datasets for the photogrammetry software. The incomplete documentation of the object resulted in some missed parts of the roof and the quality of the created texture. The problems could be solved applying different hardware, for example, a flying drone that would allow to document the object with all the required details. However, using the drone in highly dense areas as the Karlsplatz square could cause other difficulties.

Nevertheless, the use of low-cost equipment combined with base knowledge of the subject matter proved how accessible, simple and practical it is to document an object using the photogrammetry method.

Although the acquisition speed of complex objects is faster compared to the traditional survey techniques, the resulted geometry needs to be optimized for using in further presentation. The simplification and optimization are not yet a full automatic process and are highly time demanding, which causes the traditional modelling techniques to be more effective for simple objects. Next to the future technical development of fully automatic software with preprocessing, the main challenge is to surpass the environment conditions – weather and natural light. These have the main impact on the input data and the final result.

The project of the Otto Wagner application shows how Augmented Reality can change and improve the ways the architecture - monographic architecture shows - can be visualised. The virtual exhibition content demonstrates how AR can combine the created digital models based on the photogrammetry acquisition methods with the possibilities of digital presenting methods (sounds and animations). The application enables the user to experienced the architecture exhibition through the visual and acoustic experience from every angle and uncover the design process. Although the integration of the results into the game engine (Unity) and the development of the AR application is a straightforward process, the creation and the establishment of the project scene require graphic design and computer programming capabilities. Although with the application of plugins such as ARKit and Vuforia generating an AR content is possible with only base knowledge, creating a more complex AR presentation with user interactions could not be finalized, for the designer (architects), quickly without a fundamental knowledge of programming and computer graphics.

AR applications developed for smartphones, however, still have some challenges and limitations to overcome. Some of them include rendering digital data into meaningful graphics and scaling it to fit the perspective of the visual field. It has to work with limited processing power, small amount of computing memory and storage. Next to that, some people may not want to rely on their smartphones with superimposed information. For that reason, wearable devices like augmented reality glasses, will provide users with more convenient and expansive views.

Despite these concerns, there are potentials in the future of the augmented reality-based presentation:

- an augmented reality system can be combined and overlayed with the existing exhibition inside the Otto Wagner Pavilion.

- the AR system can be combined with server-based media content delivery. With this step a huge amount of content in the entire museum space becomes available for an application running on the mobile devices of visitors. A curator will be able to change and select relevant contents for augmented reality-based exhibition. The data from users could be collected and the interest of visitors could be evaluated. This could help the curator with adjusting the exhibition.

- with the photogrammetry acquired model of the Otto Wagner Pavilion as a data base reference for creating object tracking. The combination of the model created using photogrammetry with a computer vision-based AR system that can track real 3D objects might be an opportunity to create a new layer of presentation and explanation on the existing building of the Otto Wagner Pavilion.

The given advantage of this system can create exactly the same impression and experience that was given to people riding the train in 1899.

- the shared AR experience between multiple devices can be created and the interaction between visitors can bring new information, interest and enthusiasm.

- in order to run the application only in front of the pavilion, the GPS data can be used.

- a library of photogrammetry objects can be created and shared between museums and galleries. Such a collection of 3D models could be more accessible for wider audience.

Potential future development for similar kinds of applications can result in possibilities to present not only existing but also non-existent or destroyed objects. Photogrammetry as an accessible technology has a great potential and could be used as a method of documentation needed for cultural heritage preservation. For instance, in the recent case of the Notre Dame fire, a 3D model created by the photogrammetry method could be implemented to document the former structure.

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Fig. 86 Point cloud model with manual created control points and top view with camera acquisition position.
Image by the author....118

Abbreviations

3D	Three Dimensional
AO	Ambient Occlusion
AR	Augmented Reality
CAD	Computer Aided Drawing
CAAD	Computer Aided Architectural Drawing/Design
CHESS	Cultural Heritage Experiences through Socio-personal interactions and Storytelling
CIPA	International Committee for Architectural Photogrammetry
CPL	Circular Polarizing Filter
CV	Computer Vision
DEM	Digital Elevation Map
DIAPAD	Digital System for Photogrammetry and Architecture Design
DOF	Degrees Of Freedom
Dpi	Dot per inch
EXIF	Exchangeable Image File Format
FPS	Frames Per Second
GPS	Global Positioning System
GPU	Graphics Process Unit
GUI	Graphical User Interface
HEIF	High Efficiency Image Format
HMD	Head Mounted Display
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
iOS	iPhone Operating System
JPEG	Joint Photographic Expert Group
LCD	Liquid Crystal Display
MARA	Mobile Augmented Reality Application
MARTA	Mobile Agumented Reality Technical Assistance
MARS	Mobile Agumented Reality System
MoMa	Museum of Modern Art
PDA	Personal Digital Assistant

PHD	Professional High Definition
QR Code	Quick Response Code
RAM	Random-Access Memory
RC	Reality Capture
SLR	Single Lens Reflex
SDK	Software Development Kit
STARS	Simultaneous Triangulation and Resection Software
S-VHS	Super Video Home System
UI	User Interface
VIO	Visual Intertial Odometry
VR	Virtual Reality