The Decommunization of the Pyramid in Tirana, the Mausoleum of Enver Hoxha

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The communist regime that governed Albania during 1944-1991 has left considerable architectural remains that are now disappearing according to new urban developments. The project presented here will explore the perception of the monumental heritage of the socialist regime starting from the monument of Piramida. For the first time in Albania, a futuristic and avant-garde architecture was built, too modern and too innovative for the time. Embedded in the urban context of Tirana, the function of this building was being the mausoleum for the chairman of the Communist Party Enver Hoxha, a place of (obligatory) pilgrimage for the citizens of that time. It was designed in 1988 by the dictator's daughter Pranvera Hoxha, his son-in-law Klement Kolaneci, Pirro Vaso, and Vladimir Bregu. This building is raised on platforms and stairs which create a square that looks like a pedestal holding for the Pyramid. According to its architects, the top view goes in harmony with the shape of Mount Dajti. In the years that brought great socio-political changes, it was used as a cultural and social center that over the years has been much neglected and eventually has been transformed as a sort of place of "modern archaeology". For the new generation, the Piramida is something that has always been there, a part of the effective geography, or a contextual horizon, both a foreground and a background in which people feel free to be themselves. From the point of view of the generation that has lived during socialism, the value of the heritage of the dictatorship was unavoidably connected to the memory of the time spent living during the regime. These features contribute to the production of a well-rounded image of the life under the regime in all its facets, and to a better comprehension of post-socialist societies.

Keywords:
Unwanted Heritage, Socialism, Mausoleum, Albania, Digital documentation, Modern archaeology.

CHNT Reference:
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INTRODUCTION

The busts and objects bearing the name of the dictator were not enough for a museum, this time not only to bear his name but to tell the story of the dictator Enver Hoxha through objects, to make his presence once and for all immortal.

Why was this building a pyramid? Was this an idea to give Enver Hoxha the size of a Pharaoh for Albania?

The architect team leader stated that the initial idea was not to make a pyramid. The choice of the pyramid is related to three motifs, starting from the antiquity of the nation's history with the tombs, although it was clear that there would be no grave. Because a nationalist ideology is often constructed based upon people's understanding of their past for ideological purposes and quite often adaptive.

Looking at the Pyramid, especially from above, it is possible to have a beret that it goes in harmony with the form of Dajti Mountain [Kolaneci 2014] (Fig.1) which resides at the back of the structure and on both sides; the clear intent of the socialist dictatorship achievements in modernizing the country and bringing progress to the Albanian society.

Then, the idea was to create a constant contagious space with the whole environment. Almost all public buildings had been definitively adapted to new functions in the new regime; the Pyramid remained probably the only public structure of the communist period in the capital that did not have a clear future.

A few know that this was a NATO Headquarter, one of the main centers for the Balkan, this happened during the war of Kosovo in 1999. It has been a fantastic musical scene for Jazz concerts, a place for fairs events and with long series of functionality. This building explains in the most effective way our transition politics in the last 30 years. It is been part of the emotions of Albanians and it will be in further years.

To further emphasize the distance of the ‘new’ Piramida from the regime, in 2006 the right-wing government decided to nominate the International Cultural Centre after the iconic figure of Albanian anti-communism and gulag survivor, Pjetër Arbnori [Iacono and Këlliçi 2016].

It was in its own innovative architecture, with a strong presence. In its language, it is possible to read the intention of astonishing the visitors. Tirana was a new town, the symbol of the evolution from a simple, difficult, agrarian past [Constantine and Chekrezi 1919] to the new concept of industrial society and modernity. So wrong, at that time the idea of modernity was the Communism in the interpretation of Enver Hoxha and later on of his family, one of the most abnormal regimes around Europe mixing the ideals from the dictatorship of the proletariat with some local/vernacular nationalism [Galaxy and Watkinson 2006] and the cult of personality that isolated Albania from the whole world.

The whole city was going to be transformed into a new urban pattern, to host the people moving from the countryside, but also to disseminate the concepts of communism even through the language of architecture. The intervention from the Italian domination was suitable for this will, while the new housing was proposing an “equal for all” solution that soon would have revealed its limits and issues [Islami et al. 2018].

The pyramid was built in three years by the socialist government immediately after the death of the Albanian dictator, who passed away in April 1986 and was inaugurated in October 1988. It was to be the epicenter of the memory of the dictator Enver Hoxha, as his museum itself that had lasted only four years. But not for many years, as the fall of Communism in Albania could not be delayed. But would this building fall with him?

LOCATION

Tirana has experienced successive developments under the impacts of different regimes. It has served as a mean of expressing political visions and ideologies. With the political and economic transformations in the past decades, the role of Tirana’s city center needed to be transformed: From a single community serving land to serve the public in a multi-functional manner. The importance of the Pyramid in Tirana has played a fundamental role and is one of the main elements of the "Dëshmorët e Kombit" boulevard as a clear example of a political power representative monumentalization.

By focusing on the practice of monument under a dictatorship, we do not mean to suggest that other political types, such as capitalist democracies, do not actively seek to control the past. Rather, we would argue that there exists a continuum. Governments at one end of the scale may routinely manipulate and will often distort the monumental record.

It is impossible to imagine Tirana without it. All this time, it played a multifunction role such as a place for fairs, festivals and public/private events.

This was a reason why the project did not have restored or preserved, it was not properly administered, and special parts were maintained and other parts were falling apart. The depreciation of these parts made its prestige drop too.

A lot of damages are caused to this very special construction, and it is already of crucial importance that any retraining interventions that will be made, to not lose the volumetric identity and the spatial role that this integrated building within Boulevard has. The entire area where the Pyramid lies along with its parks is about 30,000 m^2, in the central area of the city, and this has been the motive that has always been at the forefront for its exploitation and the disappearance of a very important part of the history of architecture and for the history of building engineering and urban planning in Albania. This made it possible to create protests from every citizen who responded to the call for its preservation, making it difficult for us to connect to the dictator, but to link it with other objects of symbolic sentiment.

SYMBOLISM AND THE HISTORY

Looking from above the Pyramid has the shape of an Eagle, becoming somehow the main symbol of Albania. A. Shkreli, an Albanian architect, has said that a French critic has made an analysis of the Pyramid, which he referred to as a post-utopian architecture that arises at a moment when the purpose it had, had died, not just the dictator himself, but the ideology [Shkreli and Tempull 2017].

The object is amortized with the carrara (Fig. 2), an imported marble from Italy, which made the Pyramid brilliant not only during the day but also at night. This material has an internal gloss that reflects every kind of light. By using a combination of marble and glass, the classic and modern are unified in rendering the monumental building more open to space and evoking the transparency. This marble was removed when it was thought to transform it into a theater [Klosi and Lame 2011]. This brought on the surface the concrete structure, the main material used in the 80s Brutalist Architecture in Albania. This structure is made of latex-based mortar, a material characterized by appreciable hydro-isolation properties.

Furthermore, inside it contained the focal point of the museum, a marble statue of a seated Hoxha in the center of a round hall. The museum had neither a proper entrance nor a ticket counter. The hall opened immediately in front of the visitor with Hoxha's statue in the center (Fig.3). The Pyramid was topped by the most significant communist symbol: by a red star to surmount the outer extremity of the building (Figs. 4 and 5), which has also now been removed. The Pyramid's interior was once quite luxurious and multi-functional. The building's interior floors were designed as mezzanines on different levels, creating an amphitheaters square look.

The 3D digital modeling of this building is a very interesting challenge to show the heritage from the communist period and also a great way to understand and present its special shape and functional aspects as a mystical land shrouded with memories to demonstrate the power of the visualization. The geometry and composition come out in their robust presence, as well as the brutalist-monumental intention of presenting a large, strong and surprising architectural context, a sort of focus for the renewed city in real time and how one thing, and how the use of color can make change happen (Fig. 6). But the fact that the shape and the guiding composition cannot be perceived from the ground level is probably a limit of this idea. The visitor moving on the ground level is going to see only "the Pyramid".

In this sense, the 3D digital model is again a great opportunity to inspect the strategy of the Pyramid (Fig.7), including the building itself, transforming the symbolic and gain a better understanding of this architecture that will perform a massive sculpture with the existing main structures being completely preserved (Fig.8). The 3D digital model also provides a way for the space to communicate the message of reality; owing to the fact that the "Pyramid" won't have the same construct in the future.

For the generation that lived during Communism, the values of the heritage of dictatorship were unavoidably connected to the memory of the time spent under the regime (Fig.9). This is because its peculiar shape and plan had become a standing symbol of communism, difficult to adapt to the new democratic regime.

Through all the centuries of their history, the Albanian people have always striven and fought to be united in the fac of any invasion which threatened their freedom and their motherland. This tradition was handed down from generation to generation as a great lesson and legacy, and precisely herein must be sought one of the sources of the vitality of our people, of their ability to withstand the most ferocious and powerful enemies and occupiers and to avoid assimilation by them. [Hoxha 1984:11]

To create a more completed vision about the building, it is very important to ask the opinion of as many people as possible. For this reason, one of the key points in this research is based on a study that includes the point of view about the Pyramid of the group from all ages.

The Pyramid of Tirana is a symbol to our community and it is been a long debate about demolishing it. In regards to architectural laws, a building has to be old in order to have a value but it is not like that. In the last few years, it is thought about the revitalization and the transformation of it. What can this building give us in the future?

THE STATISTIC

From the statistics, most people feel attached or extremely attached to communist monuments, while young people do not feel attached at all. The younger age groups are a little more indifferent when it comes to the memories of the regime. However, while the ages increase, more and more people say that they feel related to this monument. Obviously, the history of the building is associated with the dictatorship, but it is also essential as part of the city of Tirana.

As well, the statistic put in evidence the unwanted heritage and the communist nostalgia that goes in parallel with history and the generation differences seems to be much more significant with the age increasing. The percentage of people associating the Piramida with Tirana decreases the percentage while it is related to the dictator Enver Hoxha as a communism period which is less important for the people. That is why most of the people are against the plans of the demolishment. The majority disagrees and wants to protect it.

The reminiscing makes people to want the protection of the cultural heritage of the dictatorship as part of themselves and not as something horrible, as they used to. It is important to preserve this heritage for the younger and future generations to give them the possibility to understand the older generations, themselves and their society better. This reflects why the communist heritage is a controversial issue and that is why Albanians today disagree on the communist period and what it represented for them [Myhrberg 2011].

THE FUTURE

Tirana in these years is in a period of great transformations, a large number of new projects are renewing the townscape, integrating, most of the time replacing, the previous structure of the town [Various 2017]. This kind of transformations is applied to single buildings as well as to the public spaces [Romano 2012]. In this “liquid” condition there is maybe a chance for the “Pyramid” as a pure object and the city, which the colors will come out everywhere, a mood of change will start transforming the spirit of people [Rama 2012].

Indeed, for its future, a new project of the MVRDV Architects [MVRDV 2018] revealed initial design for Tirana Pyramid in the presence of Prime Minister Edi Rama, Mayor Erion Veliaj, The “Albanian-American Development Foundation” (AADF) and the public.

The 11,800 m^2 former communist monument is set to revitalize and transform the Pyramid of Tirana into a large multifunctional technology education center for young people focused on computer programming, robotics, and startups (Figs.10 and 11). It is said to add volumes and different functions inside. Every function can find its own and to spill out their functions in order to use all the potential by creating these pavilions for the future of the Pyramid.

Assisting the roof, all the way to the top by stairs as a place you can stay and creating destinations into the roof. Flooding the building with the landscape can help to be more attracted to the people.

The project will have finished by June 2019. Also, the project purposes to give the building back to the public and making this ruin into a self-sustaining actor into the urban environment of Tirana.

These days, by maintaining the same structure, we can say that we can keep a part of our history in line with the modern one to open the structure to the public.

The most dedicated area of a city could not only be a museum, but it is also part of the boulevard that wants to show the past, but this environment should be a point to show the future because Albania is a country that wants to leave behind its past. As well, today does exist the boundary between inside and outside of the structure.

Piramida is something that had and always will be there. All these symbols that create the area around are one the part of the privacy for the Pyramid. It is a harmonize space that you cannot see the inside from the outside and this project aims the reverse, to be open to the public, to be transparent to the future and the city.

And that does not mean we should forget, but going smoothly from the past to the modern future.

> *“A people lives happily in the present and future so long as it is aware of its past and the greatness of its ancestors.”*

Heinrich Himmler, 1936, *quoted* in Hassmann (2002:84).

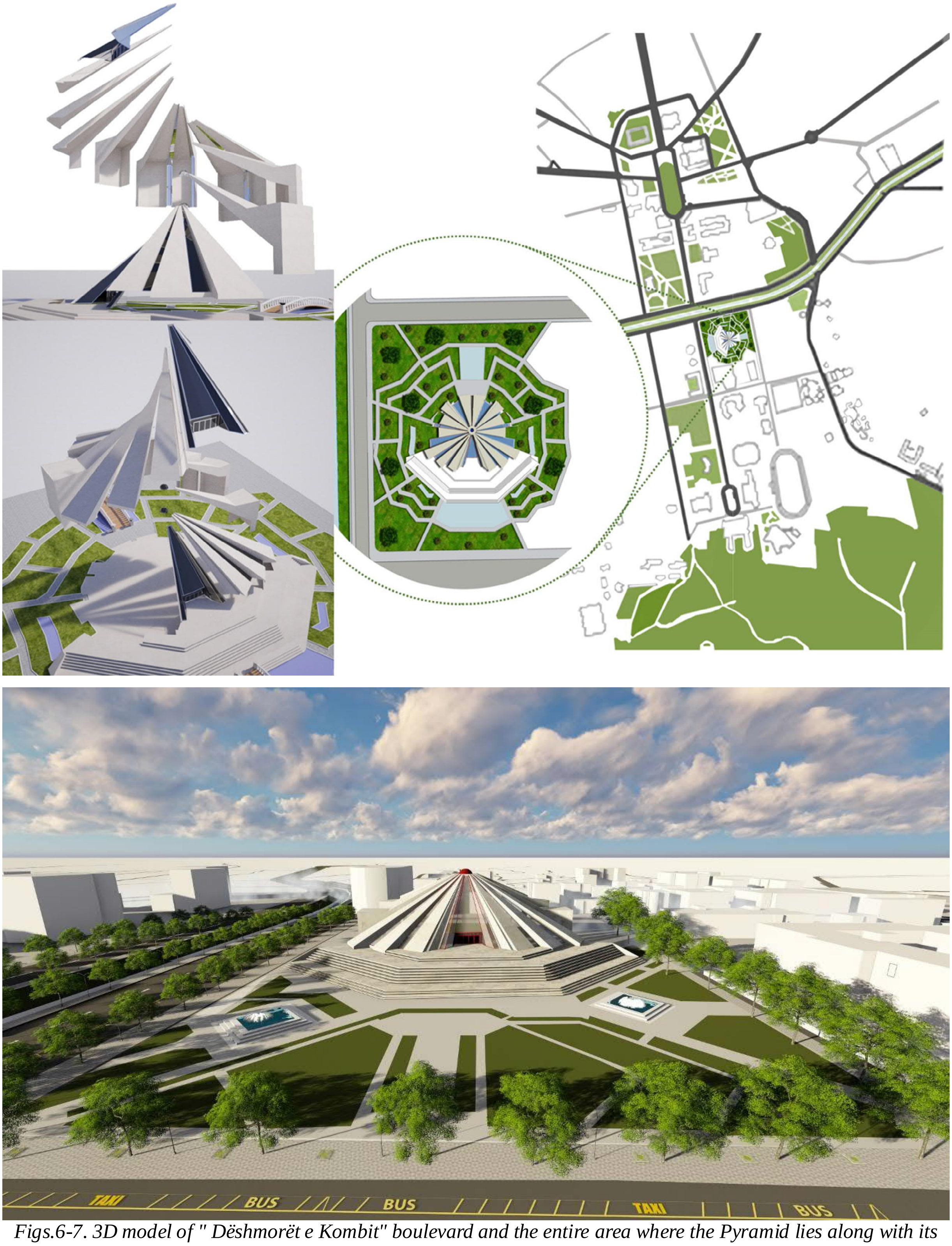
FIGURES

Fig.1. The Pyramid from above that it goes in harmony with the form of Dajti Mountain. (Source: Web)

Fig.2. The Pyramid (Piramida) former museum of Enver Hoxha during its inauguration (Source:Ylli,November 1988)[Iacono and Këlliçi 2015]

Fig.3. Hoxha's statue in the center of the Pyramid. (Source: Wikipedia).

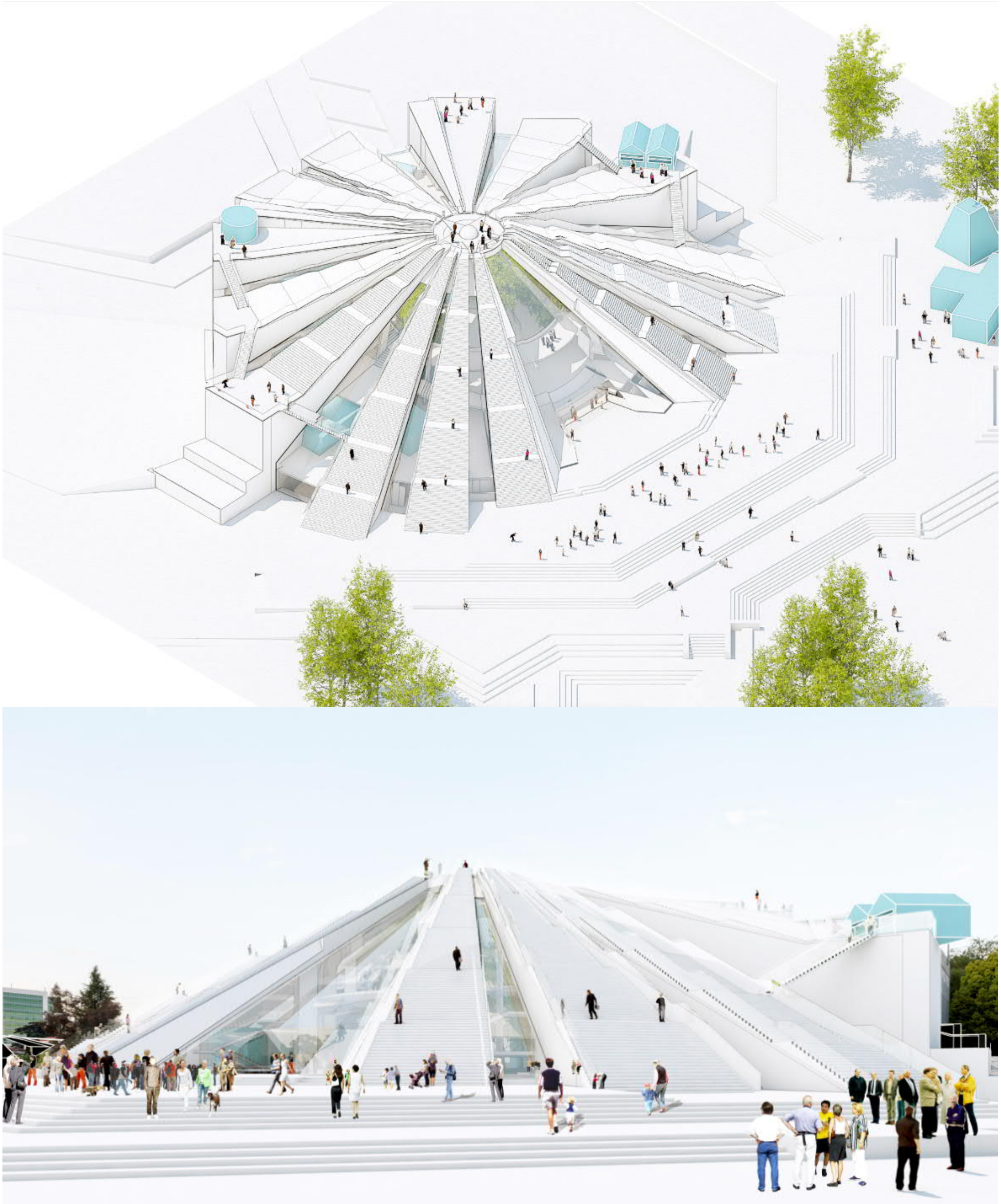
Figs. 4-5 The Pyramid and the most significant communist symbol, a red star. Photo during 1980. (Source: Web)



Figs.6-7. 3D model of " Dëshmorët e Kombit" boulevard and the entire area where the Pyramid lies along with its parks in the central area of the city. (Visualization: J. Demiraj)

Fig.8. 3D Model of the Piramida' as it appears nowadays. (Visualization: J.Demiraj)

Fig.9. A photo was taken under the regime. (Source: Web)



Figs.10-11. Model 3d of the new project of the MVRDV Architects for the transformation of the Pyramid of Tirana into a large multifunctional technology education center for young people. (Source: MVRDV)

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.
Authors are responsible for the contents and copyrights of the illustrations/photographs.

Rosenburg – Rapid State-of-the-art 3D Documentation and Mapping of a Medieval Castle Using Terrestrial Laser Scanning, Unmanned Laser Scanning and Ground Penetrating Radar

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The detailed 3D documentation of medieval castles in heavily accessible topographic settings or partly hidden behind dense vegetation encounters major challenges to conventional topographic, geodetic or photogrammetric surveying. This paper presents a rapid solution for the detailed documentation of the upstanding architecture and remains hidden in the subsurface by combining "terrestrial laser scanning" (TLS) and "unmanned laser scanning" (ULS) with motorized "ground penetrating radar" (GPR). The large medieval castle Rosenburg, Lower Austria situated on a prominent mountain ridge provided a typical situation for a respective case study to present a state-of-the-art solution for fast and efficient high resolution surveying above and below ground. The used terrestrial laser scanner *RIEGL* VZ-400i[1] is able to perform hundreds of automatically registered scans per day. A *RIEGL* VUX-1UAV[2] laser scanner system mounted on the multi-copter RiCOPTER was applied to measure the roof landscape in minutes and supplement the ground-based data acquisition. A motorized multi-antenna GPR system based on a 16-channel MIRA system from *Malå Geoscience AB*, adapted for efficient data acquisition by the *LBI ArchPro*, provides detailed 3D information on subsurface remains like vaults, cisterns, walls of previous buildings up to the remains of garden layouts. The case study exemplifies the latest developments in data acquisition, processing and the combination of such hybrid 3D data sets including the fast and efficient production of 2D maps and plans for heritage management duties.

Key words:

Terrestrial Laser Scanning, Unmanned Laser Scanning, Ground Penetrating Radar, Data Combination.

CHNT Reference:

Wolfgang Neubauer et al. 2018. Rosenburg – Rapid State-of-the-art 3D Documentation and Mapping of a Mediaeval Castle Using Terrestrial Laser Scanning, Unmanned Laser Scanning and Ground Penetrating Radar.

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[1] http://www.riegl.com/nc/products/terrestrial-scanning/produktdetail/product/scanner/48/

[2] http://www.riegl.com/products/unmanned-scanning/riegl-vux-1uav/

INTRODUCTION

Many archaeological or historical sites are defined by both, remains preserved above ground and archaeological remains hidden beneath the ground. The demand for a detailed digital 3D documentation of such sites requires appropriate methods, which allow the highest resolution with correspondingly efficient application procedures [Studnicka et al. 2013; Neubauer 2007; Ullrich et al. 2002].

Typically, the two components of such sites are documented in separate processes focusing on the still standing structures on the one hand and the archaeological remains on the other hand.

In most cases, the work is carried out by different specialized teams and the respective specifications of the survey parameters are defined independently from each other. A detailed and comprehensive combined digital documentation often fails because the survey methods used for the digital recording above and below ground have different resolutions, the corresponding 3D data formats are not directly compatible with each other, or a combined visualization of the complex 3D data sets can only be achieved via detours. In most observed cases no requirements are defined beforehand for the necessary subsequent data combination to derive a complete 3D digital model of the respective site. This is one of the reasons why the full potential of the available three-dimensional documentation cannot be exploited. It is also of particular importance, but still often remains unnoticed, that the complex 3D data sets created by the experts are made accessible in a comprehensible way to ensure that they can also be dynamically used by persons responsible for cultural heritage management or development to derive appropriate products from these data for the respective prevailing issues.

THE CASE STUDY ´ROSENBURG´

The present case study ´Rosenburg´ was defined based on a site, which presents different characteristic challenges for such a digital 3D documentation. The 2.5 ha large medieval castle complex of the Rosenburg in Lower Austria (Fig. 1) approx. 90 km northwest of Vienna, is situated on a rocky ridge overlooking the Kamptal valley. The current castle unites elements from various phases of the Middle Ages.

Fig. 1. Aerial view of the Rosenburg from the East

The castle was built in the 12th century in Romanesque style. Its first documented mention dates back to 1175. Of this small castle of the Goczwin of Rosenberg, only the foundation walls keep remain today. In the 15th century, the Rosenburg was extended to a larger Gothic castle under Kaspar von Roggendorf. The chapel and outer walls of this castle are still preserved today. However, between 1593 and 1597 a large part of the Gothic castle was demolished. The present Renaissance chateau with 13 towers was built in its place. Around 1614 the castle also received a 0.5 ha large tournament ground and 46 arcades. The Rosenburg came to the Hoyos-Sprinzenstein family, which still owns it today, through the marriage of Leopold Karl Graf Hoyos (1657-1699) to Maria Regina Gräfin Sprinzenstein in 1681. Between 1859 and 1875 Ernst Karl von Hoyos-Sprinzenstein restored the Rosenburg Castle, which was threatened by decay, according to the depictions of the palace in the *Topographia Windhagiana* of 1673 (Fig. 2), and made it one of the first castles in Austria to be open to the public. The current owners Petra and Markus Hoyos invoked and supported this case study, which was carried out by the Ludwig Boltzmann Institute for Archaeological Science and Virtual Archaeology (www.archpro.lbg.ac.at) in collaboration with Riegl Laser Measurements GmbH (www.riegl.com) between 2018 and 2019.

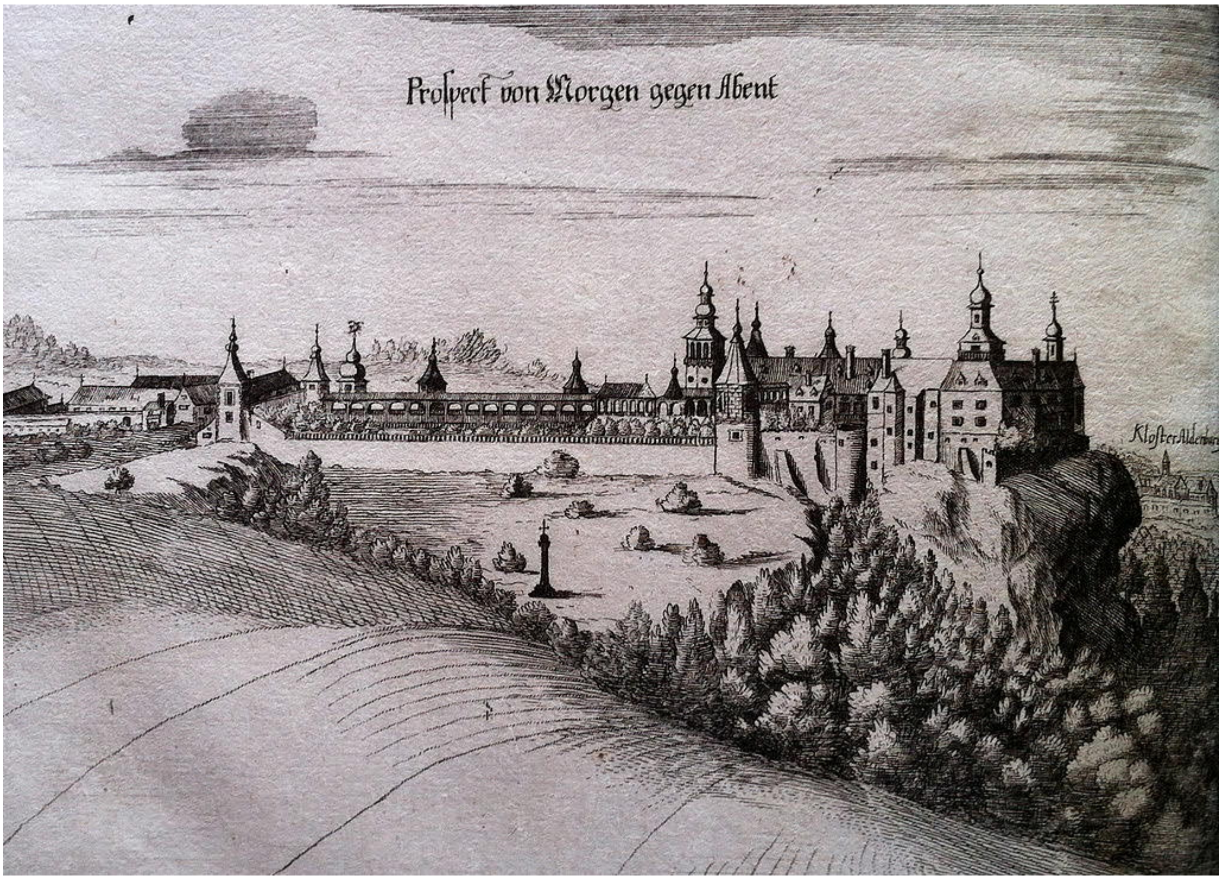


Fig. 2. Rosenburg Castle against the West as depicted in the Topographia Windhagiana, Vienna 1673

The castle complex Rosenburg is not accessible from all directions. The steep rock formations in the direction of the valley are covered with dense forest and the roof landscape is largely invisible from the ground. Larger trees and bushes inside the castle provide further obstructions for the recording process. The wide tournament ground and a comparable large garden terrace facing to the southeast form together an approx. 1 ha large area, accessible to non-invasive geophysical prospection.

The detailed 3D documentation of the standing building structures of such a castle in a heavily accessible topographic setting and partly hidden behind dense vegetation encounters major challenges to conventional topographic, geodetic or photogrammetric surveying. Therefore, an efficient solution for the detailed documentation of the upstanding architecture of the castle and the presumed remains hidden in the subsurface had to be developed.

The objective set for the documentation of the buildings was to obtain a high-resolution point cloud, whereby all trees and bushes were to be removed from the data. In general, two different methods are available for this purpose. On the one hand, a geodetic survey based on terrestrial or airborne laser scanning and on the other hand terrestrial or airborne photogrammetry, for example via image based modeling is applicable. A further objective was to obtain a point cloud already registered/georeferenced in the field, whereby the strategy to be developed for this purpose should be based on a robust workflow.

Due to the various modern disturbances magnetometry could not be applied for the non-invasive prospection of the open areas in the southern part of the castle. “Ground penetrating radar” (GPR) offers the greatest potential for three-dimensional investigation of the subsurface. The choice fell on high-resolution measurements with motorized antenna arrays with medium frequencies and hand-held antennas with low frequencies, resulting in deeper penetration.

The selected approach was based on the combination of state-of-the-art 3D “terrestrial laser scanning” (TLS) and “unmanned laser scanning” (ULS) with motorized high resolution 3D “ground penetrating radar” (GPR). The goal was that all data should finally be visualized and analyzed in a comparable resolution within a single 3D software package. In the following, we would like to explain the technical basics and the methodical steps chosen for the creation of the standardizable solution in more detail. The logistics, work flows and procedures developed for the three combined survey methods are described, which made the efficient and complete documentation of such a complex building possible. Subsequently, the provision of measurement data for the intuitive creation of orthogonal views and sections from the complex 3D data set for facilitating the analyses and further mapping demands will be discussed.

TLS - TERRESTRIAL LASER SCANNING

Data acquisition – logistics, specifications and work flows

For the state-of-the art terrestrial laser scanning, a latest *RIEGL* LMS VZ400i scanner combined with a *Nikon* D-810 (14 mm lens) was selected (Table 1, Fig. 3b). One main objective of the case study was the development of a time efficient and robust scanning work flow ensuring a straight forward automatic registration process and highest accuracy and resolution of the final point cloud.

For the scans the standard scan pattern "Panorama40" with an angular resolution of 0.040° (7 mm @ 10m distance) and five 36 MP photos each was selected. The mean net scanning time per scan position observed is 45 seconds including the shooting time for the 360 degree photographic record. It is necessary to limit the exposure time in order to produce the sharpest possible photos when taking scans and photos simultaneously (depending on the scan pattern and thus the rotational speed of the scanner head). With the scan pattern "Panorama40", this is set to a maximum of 1/200 sec. Since the aperture is fixed at 8 for a large depth of field, the ISO sensitivity of the camera must be readjusted manually or automatically. With these settings, a total duration of less than 80 seconds on average per scan position including the adjustment of the tripod can also be achieved over a longer period of time. The terrestrial scan project consists of 344 individual laser scans collected within one day.

Table 1. Specifications of the terrestrial laser scanning (TLS)

Laser scanner	*RIEGL* VZ-400i
Photo camera	attached Nikon D-810 (14 mm lens)
Field of view of the laser scanner	100° vertical x 360° horizontal
Scan pattern	„Panorama40“
Angular resolution (resolution on the facade)	0.040° (7 mm at 10 m distance)
Measurements / scan	approx. 22.5 millions
Precision	3 mm at 100 m as given in the data sheet
Resolution of a single photograph	36 MP
Time per scan position (inclusive movement)	approx. 80 s

The scan positions themselves are selected so that they are arranged in a chain named ´*scan chain*´ (Fig. 4b). The distance between individual scan positions in the chain is set for the outdoor positions to a mean of 10 meters, about the same distance as to the measured façade (Fig. 3a). Inside the building, the distance of the scan positions in the chain is reduced to a mean of 5 meters. To link individual rooms a scan positions usually is set in the door frame. These relatively small distances make it possible to reduce the scan shadows to a minimum and to guarantee sufficient overlapping areas for the automatic registration of the scan positions to each other. Additional scan positions are inserted in the chain at building corners and passageways to ensure sufficient overlapping of the data for the automatic registration. It is recommended, although not absolutely necessary, to measure control points during the first and last scan of a scan chain. In general, it is recommended to measure a polygon course with a total station ahead of the scan project. The retro-reflecting foils used to mark the control points are finely scanned with the laser scanner. These few but well distributed control points have a high significance for the resulting accuracy of the point cloud.

For the scanning of free-standing buildings, it is recommended to start outdoors scan around the building in a closed loop at the beginning. Afterwards, scanning is done from a building entrance back outdoors. If the scanner has to be restarted - for example after a change of day - the first scan should be taken as close as possible to the last scan position. This enables a direct connection to the chain for the automatic registration process. The scanner position itself normally is changed within 20-30 seconds. This ensures that the data of the built-in “initial measurement unit” (IMU) provides a good approximation of the positioning for the automatic registration even in the case of poor GNSS signal reception.

a)

b)

Fig. 3. a) Two colored laser scans, distance between the scan positions approx. 10 meters; b) RIEGL VZ-400i terrestrial laser scanner combined with a Nikon D-810 digital camera and a GNNS receiver

Automatic registration of the scan positions

In order to prepare the scan data for subsequent registration process, the irregular point cloud is resampled in a first step to a fixed 3D grid - the *´3D voxel data set´* (Fig. 4a). The critical parameters for the automatic registration are the voxel size, the amount of voxels involved and the automatic adaptation to the project. The voxel size can be adjusted manually to the respective scan scenario (Tab. 2), but can also be selected automatically by the algorithm.

Table 2. Typical voxel size and amount of voxels for respective scan scenarios

scan scenario	voxel size	amount of voxels
Indoor small	0.05 m	512
Indoor large	0.10 m	512
Outdoor urban	0.25 m	512
Outdoor non-urban	0.50 m	512

A voxel is only generated if it is occupied by at least three measuring points. Thus it is possible to estimate flat surface pieces in the voxels and to represent them by their center of gravity and normal vector. For each voxel the mean value of the reflectivity, the number of measuring points and a format attribute (line, plane, and volume) are stored.

The following data of the individual scan position are to be used for the registration process:

- GNSS position - not always available (optional with RTK solution)
- orientation from accelerometers and magnetic field sensor (reliable roll and pitch, unreliable yaw)
- position and orientation from IMU data relative to previous scan position
- Barometer if GNSS height was not measured accurately enough

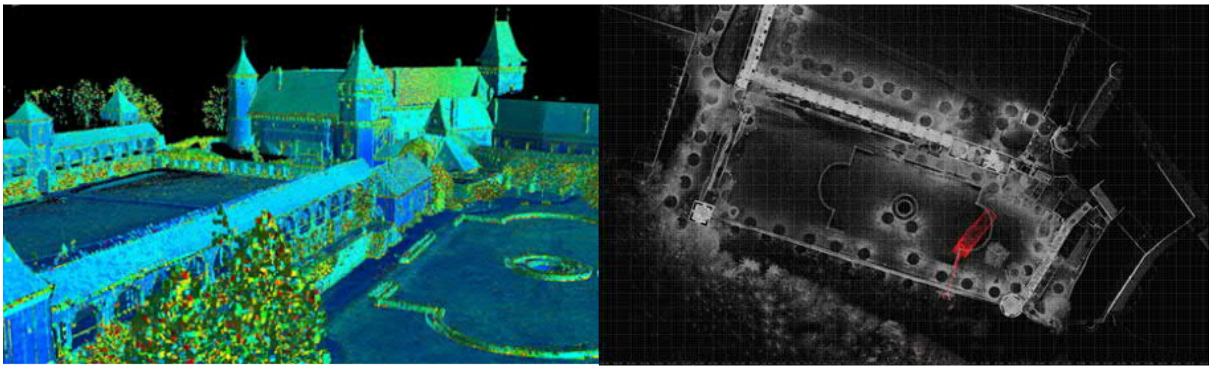
They are combined with reference data from already registered scan positions:

- *´voxelized´* 3D data

The registration process itself then takes place first in the *´spectral range´* known also as *´Phase-Only Matched Filtering´* as presented in [Ullrich 2017]. The following seven-step-workflow has been developed:

- resampling of irregular point cloud on 3D grid yields to “voxelized” 3D data: $v(\mathbf{x})$
- Fourier transformation of $v(\mathbf{x})$: $V(\mathbf{k})$
- same signal but rotated and shifted: $w(\mathbf{x}) = v(\mathbf{Rx+t})$
- Fourier transformation of $w(\mathbf{x})$: $W(\mathbf{k})$
- Fourier Rotation Theorem and Fourier Shift Theorem: $W(\mathbf{k}) = V(\mathbf{Rk}) \exp(i2\pi\, \mathbf{k}^T \mathbf{R}^{-1}\mathbf{t})$
- magnitudes only: $|W(\mathbf{k})| = |V(\mathbf{Rk})|$ → **rotation matrix R**
- for R equal to identity matrix (no rotation): $W'(\mathbf{k}) = V(\mathbf{k}) \exp(i2\pi\, \mathbf{k}^T\, \mathbf{t})$ → **translation vector t**

After this spectral-based registration process has approximated the scans by the order of a voxel size, the extracted planes are used to register the last two scan positions to within a few millimeters of each other.



a) *b)*

Fig. 4. a) Voxel data set of multiple scan positions; b) Resulting point cloud from several scans recorded in a ´scan chain´. The circular features visible in the point cloud indicate the scan positions

This type of reflector-less registration process was initially designed in 2017 and has since been intensively tested in several real scan projects. It is characterized by a very high degree of robustness if the recommendations for the layout of the scan chain and the logistics of the scanning process are followed. Applying this newly developed workflow hundreds of scan positions can be automatically registered. This is a special importance for scan projects like the recording of tunnel systems without ambient light and missing GNSS reception or for example in forests without respective flat areas supporting the automatic registration process.

Multi-station adjustment of scan positions

After the successful registration of all scan positions, small gaps may occur, among other things, if the loop defined by the scan chain is closed. The newly developed algorithm *´Multi Station Adjustment 2´* implemented in the native *RiSCAN PRO* software is recommended in order to compensate for these gaps. This algorithm accomplishes a rigorous adjustment by means of scan data, GNSS measurements and scanner-internal sensor data and all available control points. The average calculation time per scan position is about 20 seconds. Finally, a detailed report is generated automatically.

The scan data can subsequently be checked visually in the 3D view of the resulting voxel data set (Fig. 4a). The standard deviation of the resulting plane estimates from different scans within a voxel is displayed in color. The deviations are usually in the millimeter range. In the project Rosenburg, only four control points were measured with a total station. The multi-station adjustment calculated a standard deviation of 8.7 millimeters for the four reflectors measured by the total station and laser scanner respectively.

ULS – UNMANNED LASER SCANNING

Data acquisition – logistics, specifications and work flows

A *RIEGL* VUX-1 UAV laser scanner (VUX data sheet 2019) on a RiCOPTER UAV (Amon et al, 2016) was used to record the unmanned laser scan data (Table 3). The complete system consists of the laser scanner which is tightly coupled with a high-precision *Applanix* AP20 IMU-GNSS unit for the acquisition of a trajectory with time stamped position and orientation values. For parallel image acquisition two *Sony* Alpha 6000 cameras were used, which are directed obliquely downwards. For processing the trajectory, a GNSS base station was set up, which records a RINEX data stream [Gurtner and Estey 2007] over the time of the recording:

Table 3. Specifications of the unmanned laser scanning (ULS)

Unmanned laser scanner	*RIEGL* VUX-1 UAV
Laser impulse repetition rate	550 kHz
Field of view of the scanner	330 degrees
Scan speed	200 scan lines per second
Precision	5 mm @ 150 m (as given in the data sheet)
IMU-GNSS unit	Applanix AP20
Photo cameras	2 x Sony Alpha 6000
Photo resolution	24.3 MPixel per camera
UAV plattform	*RIEGL* RiCOPTER

After initialization processes, the RiCOPTER (Fig. 5b) executes a pre-programmed flight path for the detailed scan data acquisition. One flight was performed at a flight altitude of 50 meters above ground at a flight speed of approximately 5 m/s. In order to minimize scan shadows on the roof landscape, the flight consisted of several overlapping scan stripes. The flight lasted approximately 30 minutes including the initialization process.

Processing of ULS data

To process the ULS data, the raw data of the IMU GNSS unit and the RiNEX data of the base station are read in the Applanix POSPac software and a resulting high-precision trajectory is created using algorithms known as ´Kinematic Ambiguity Resolution´ [Scherzinger and Hutton 2010].

Based on the time stamps of the trajectory and scan data, the first point clouds are created with an absolute and relative accuracy within the range of a few centimeters. For maximum relative accuracy, the point cloud is further improved with the *RIEGL* software *´RiPRECISION´*. It analyses the corresponding planes between the individual flight strips and uses them to calculate new, improved trajectories, taking into account the local GNSS accuracies. Using the time stamps the images acquired by the *Sony* cameras are also placed along the trajectories and used to colorize the final point cloud (Fig. 5a).

a) *b)*

Fig. 5. a) UAV scan data – true color; b) left: RiCOPTER with RIEGL VUX-SYS laser scanner, right: RIEGL VZ-400i terrestrial laser scanner

GROUND PENETRATING RADAR

Data acquisition – logistics, specifications and work flows

The GPR measurements on the open areas of the Renaissance castle Rosenburg were completed within a single day applying logistics and workflows developed by the LBI ArchPro for large area high-resolution surveys [Trinks et al. 2018]. The tournament ground was examined with a motorized MIRA (**M**ALÅ **I**maging **R**adar **A**rray) system from Malå Geoscience AB adapted by the LBI ArchPro (Fig. 6a). The MIRA GPR system is based on an antenna array consisting of 17 radar antennas (9 transmitter antennas, 8 receiver antennas) with a center frequency of 400 MHz [Trinks et al. 2010]. The antennas are arranged in a box in two rows, which are shifted by half the antenna width (9 transmitter and 8 receiver antennas. Each receiver antenna registers the signal from two adjacent transmitter antennas resulting in a survey resolution of 4 x 8 cm. The MIRA is mounted on the front hydraulic of a communal versatile tractor from Kubota. A Javad RTK-GNNS system (consisting of base and rover) was used to determine the position of the antenna array with an accuracy of ± 2 cm. The data acquisition and navigation was supported by the software LoggerVIS developed by the LBI ArchPro [Sandici et al. 2013].

The garden terrace was scanned initially with the MIRA with a mean penetration depth of 2.2 m and additionally resurveyed to enable deeper penetration with a Pulse EKKO® Pro handheld system from Sensors & Software applying a shielded 250 MHz antenna (Fig. 6b) reaching up to 3.75 m penetration depth. The GNNS data (geographical coordinates, ETRS 1989) are projected by the data recording software into the reference system ETRS89 UTM 33N.

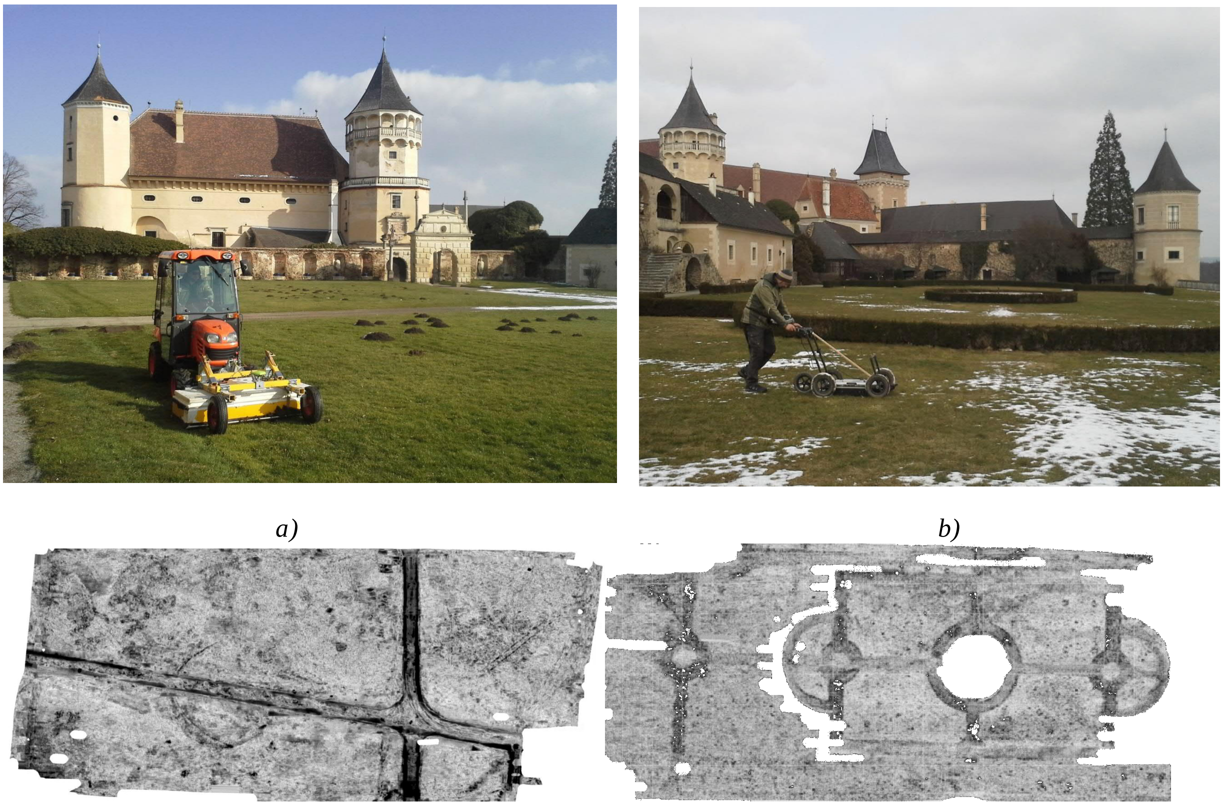


Fig. 6. a) Motorized 16-channel 400 MHz GPR system MIRA mounted on the front hydraulic of a Kubota tractor surveying the tournament ground. b) Hand-held Pulse EKKO Pro 250 MHz GPR system resurveying the deeper layers of the garden terrace. (Photos: LBI ArchPro) Lower row: GPR depth slices of the c) the tournament ground (depth: 0.2 – 0.5 m; area: 0.5 ha); and the d) the garden terrace (depth: 0.2 – 0.4 m, area: ca. 0.5 ha)

Processing and visualization of GPR data

Processing and visualization of the data, both in the field and in post processing, were conducted with the developed software ApRadar developed by the ZAMG and the LBI ArchPro [Trinks et al. 2018]. Several automatic as well as semi-automatic processing algorithms were applied to produce georeferenced and optimized grayscale images. Band-pass frequency filters, time-shift trace corrections, amplitude gain corrections, average-trace removal, outlier detection and noise suppression, as well as envelope-trace computation were performed, before the individual GPR profiles were merged and binned into three-dimensional data volumes. Using selective GPR pulse velocity analyses through hyperbola matching, appropriate values for time-to-depth-conversions were obtained. Subsequently, horizontal amplitude slices, so called GPR depth-slices, were extracted from the 3D data volumes to generate stacks of georeferenced grey-scale TIFF images.

The horizontal depth-slices (Fig. 6c; 6d) were generated in varying thickness [5, 10, 20, 30, 40, 50] cm and the image stacks used for animated image sequences. For further archaeological interpretation and analysis of the data, the resulting stacks of grayscale images derived from the GPR data were imported using the native geodatabase format into the "geographical information system" (GIS) ESRI ArcGIS 10.2. Data segmentation, feature extraction and classification form the basis of the interdisciplinary interpretative mapping process outlining structures of archaeological relevance. Archaeologically relevant anomalies were outlined on the animated image sequences of the depth slices during the interpretative mapping process applying the ArcMap extension *ArchaeoAnalyst* developed by the *LBI ArchPro*. The specially developed extensions overrule ArcMap and enable for the animation of GPR depth-slice mosaics during editing mode.

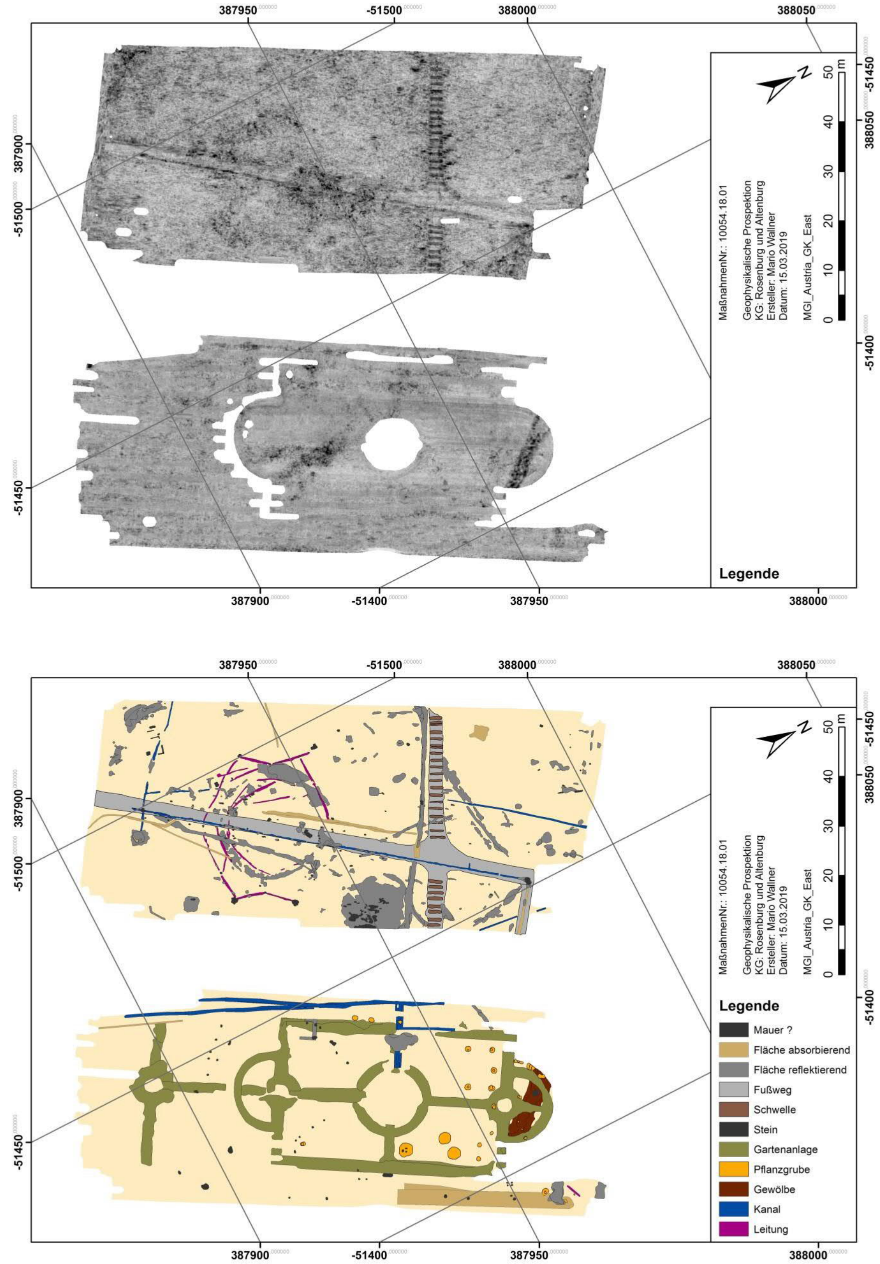


Fig. 7. GPR depth slices of the tournament ground and the garden terrace (depth: 1.4 – 1.6 m, area: ca. 1ha) and archaeological interpretation map

Archaeological Interpretation of the GPR data

The radargram of the tournament ground clearly shows the anomalies caused by the modern road embankments (Fig. 7). In the upper depth range a circular anomaly is noticeable. It is the footprints of a larger tent-like pavilion that has been used over several years for various events. In addition, there are other modern interferences of different installations, which cannot be interpreted in more detail. Due to the high quality of the data, it can be clearly concluded that there are no remains of medieval buildings in the large courtyard. This means that the extension of the castle towards the south did not take place until the construction of the tournament ground.

Under the modern path, which runs almost north-south, massive anomalies can be seen at a depth of approximately 1.4 m to 1.6 m (Fig. 7, dark brown). They lie at regular intervals across the path. However, this is not a disturbance caused by the modern path, but rather an older route for a transport railway, which has been cut into the bedrock. The massive anomalies are caused by the sleepers used to install the rails for this conveyor. It can be traced north up to a quarry located outside the castle. It can be assumed that this transport railway was used in the course of the construction of the garden terrace to procure the material necessary for the embankments.

The radargram of the garden terrace (Fig. 6c; Fig.7, green) clearly shows path embankments of historical gardens which, with a few exceptions, have vanished today. In addition to the paths and pipes for water fountains, the data also clearly show the planting pits for larger trees (Fig. 7, yellow). This planting of larger trees can also be seen in historical illustrations of the gardens, some of which have a different layout compared to the GPR result. Particularly noticeable is an anomaly running almost north-south, which only appears in the deeper layers (> 1.2 m) and widens with increasing depth (Fig. 7, dark red). This is a large vaulted room, accessible from the outside through a narrow entrance below the terrace wall). It has a ventilation shaft which is also clearly visible in the laser scan data (Fig. 8, top). The combination of the vault scanned with the terrestrial laser scanner with the radar data shows a very good correspondence, which clearly shows the potential for the exact definition of cavities in the radar data even at greater depths.

COMBINING TLS, ULS AND GPR DATA SETS

For the comprehensive combination of all data sets the native scanner software *RiSCAN PRO* was extended accordingly to integrate TLS, ULS and GPR data into one view. The developed interface allows for the integration of image stacks as delivered from the GPR prospection. For the direct combination of the data in the same format, an interface to convert the 3D GPR data volume into a point cloud was implemented enabling a straightforward combination for future projects.

In order to register the ULS point cloud on the terrestrial scan data, planes with the corresponding normal vector are extracted. In the subsequent *´Multi Station Adjustment´*, this enables a compensation based on the *´Iterative Closest Point´* algorithm [Dold 2010]. The TLS dataset was recorded and the ULS-based scan data was rigidly shifted. The standard deviation of the residuals from both data sets is 10 mm after registration.

The terrestrial laser data was acquired with the WGS84 geographical coordinates from the GNSS receiver on top of the TLS Scanner, the UAV-laser data had WGS84 geographical coordinates from the used base station and the GPR survey was conducted in WGS84 coordinates in the local UTM zone 33N, thus directly enabling the georeferenced data to be combined in the same coordinate system. The resolution of the GPR data (4 cm x 8 cm x 5 cm) was the coarser than the point clouds from the laser scanning which were adapted accordingly for the combined views. In order to combine datasets of different coordinate systems at their correct geographical position *RIEGL* uses a tool named *´GeoSysManager´*. GeoSysManager is a database tool that allows for the download and the creation of definitions of various coordinate systems along with transformations between their respective data. Accessing these definitions it is possible to calculate the global position of a locally defined dataset allowing it to be placed correctly along with differently referenced datasets. Using that same database it is also possible to further export georeferenced data in various different coordinate systems without the need of additional measured targets to perform the transformation.

The complete project is saved in a new, storage-friendly native format, which can be stored on a server. This allows multiple users to simultaneously extract accurate and detailed information on the castle above and below the surface.

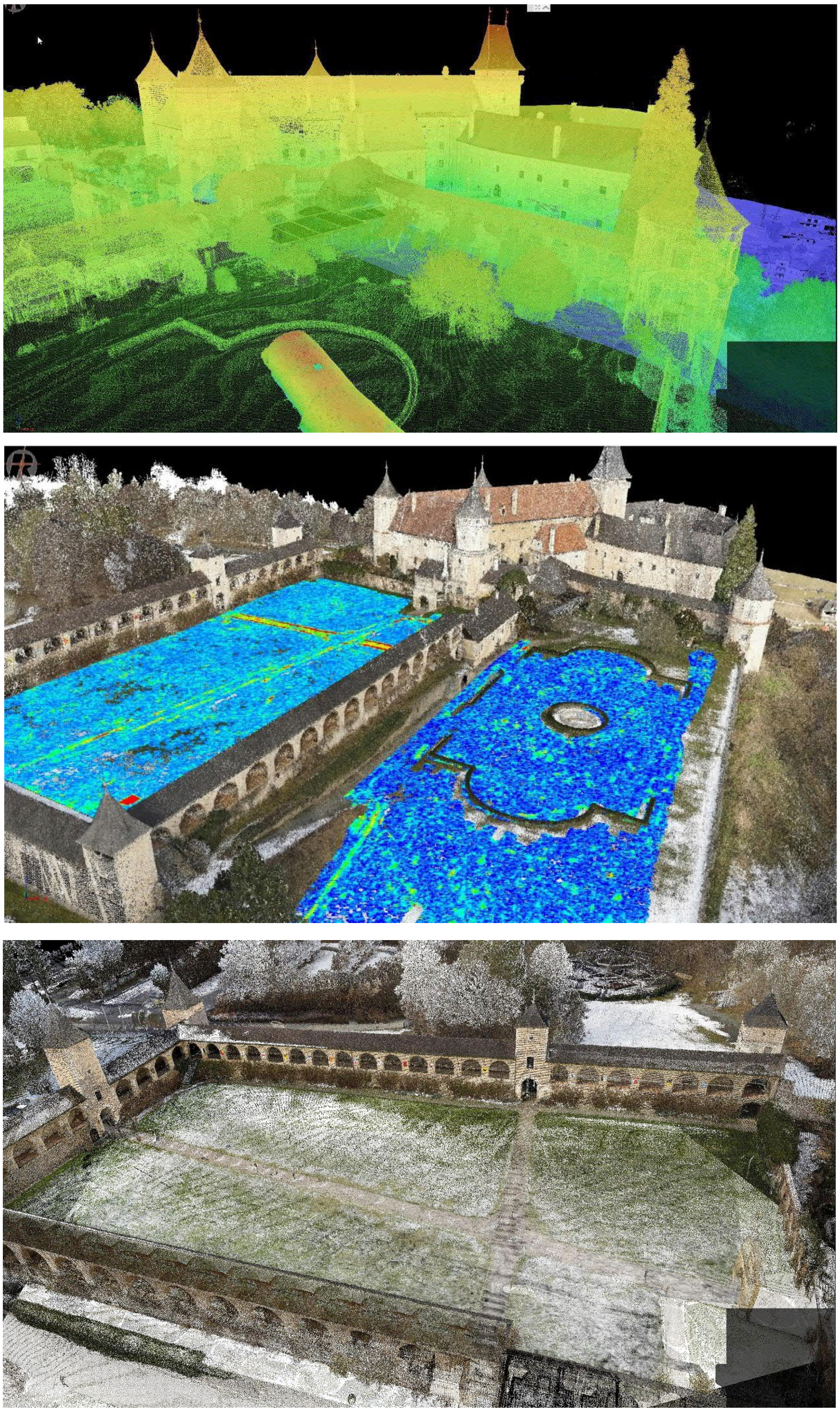


Fig. 8. Combined 3D views of the three datasets. Top: Combination of ULS and TLS datasets focusing on the vaulted chamber underneath the garden terrace. Middle: Combined colored point cloud from the terrestrial and unmanned laser scanning with integrated color coded 3D data volumes derived from the GPR surveys. Bottom: View of the colored point cloud of the tournament ground with GPR depth slice in the depth of 1.4 – 1.5 m below surface depicting the sleepers used to install the rails for the transportation railway

CREATION OF ORTHOGONAL VIEWS AND SECTIONS

A combined laser scanning and GPR project as presented includes dense data from above and below the surface of the investigated site. The point cloud representation of the combined data sets provides a perfect representation of the geometry. The big data contains a lot of information that needs to be comprehensively extracted for further processing or the direct needs of the various users involved in cultural heritage management [Torrejón Valdelomar 2016]. Two-dimensional plans in CAD vector format have long been a common form of comprehensive representation and data exchange among heritage managers, archaeologists, architects etc. The easiest way to create such CAD plans from an existing combined 3D data set of a respective site or historical building(s) is to use an orthogonal view of a point cloud (Fig. 9). This is easy to interpret and can be relatively easily redrawn into a vector graphic. This manual approach has been standard for years but involves expert know how and respective training.

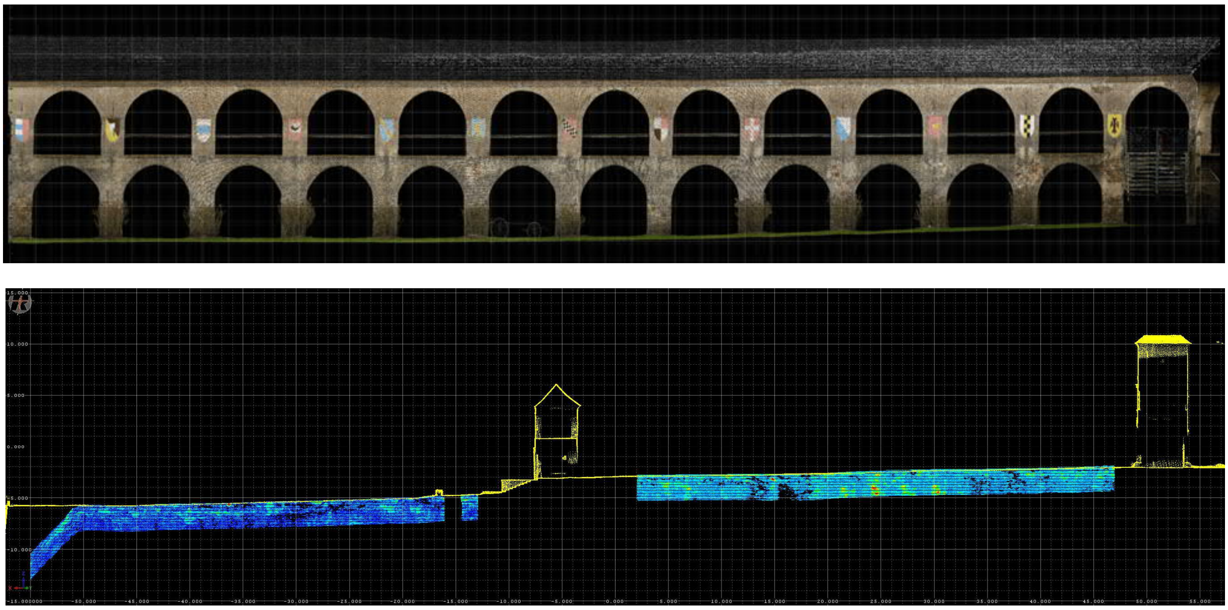


Fig. 9. Orthogonal views and sections from the combined point cloud of multiple scan and GPR data generated by the software RiPano(top) and RiSCAN Pro (bottom)

A solution for the demand for a dynamic and comprehensive creation of appropriate products from these data by non-experts had to be specified. A first implementation focusing solely on the laser scan data is the newly developed software *´RiPANO´*, which enables the export of a complete scan project in such a way that even amateurs can intuitively navigate from the panorama view of one scan position to the next. The browser based intuitive solution [RiPANO 2019] allows for easy data exchange and distribution for the use by non-experts. For each panorama image derived from the respective scan position a depth value is stored for each pixel. The depth information enables the user to set markers at certain points and to capture the respective 3D world coordinates, to measure and export distances or paths. The data format allows for a point cloud to be reconstructed at runtime from the depth values and facilitate the generation of views and sections on demand (Fig. 9). A respective solution for the combined scan and GPR point cloud is provided on expert level by the software RiSCAN PRO (Fig. 9, bottom)

SUMMARY AND CONCLUSIONS

We described a series of workflows and preferred logistics for the fast, efficient and complete 3D recording of archaeological or historical sites above and below the ground surface. The straightforward combination of TLS, ULS and GPR data sets combines surface and volume data in a common coordinate system and facilitates the joint analysis of the 3D digital record. The presented case study, the complex site Rosenburg, exemplifies the challenges and respective solutions found by the interdisciplinary team. An automatic and robust registration method for terrestrial scan positions based on respective logistics and workflows applying the latest terrestrial laser scanner

RIEGL VZ400i are presented. Only the combination of the terrestrial scans with the unmanned aerial scans provides a complete record of the scanned surface. In order to solve the problem of the removal of the disturbing vegetation, the possibility of waveform processing provided by the selected state-of-the-art laser scanners was an essential prerequisite. Laser scanning was preferred to photogrammetric solutions, since on the one hand a faster generation of the point cloud could be achieved [Studnicka et al. 2013]. On the other hand, the accuracy over the entire point cloud is considered constant and < 1 cm and the registered point cloud is georeferenced per se. In contrast, the result of photogrammetry is a priori without scale and with varying accuracy. The power of laser scanning for the recording of surfaces contrasts with the power of photogrammetry for the definition of edges. Through the massive overlapping of scans, the definition of edges is enhanced and comparable with a photogrammetric record from comparable distances.

We present for the first time a standardizable solution for the combined visualization and detailed analysis of laser scan data and high resolution GPR volumetric data sets implemented into a single software product *RiSCAN PRO*. The newly developed and presented software *RiPANO* enables the non-expert handling, distribution and shared analysis of such complex 3D scan data sets. A respective solution for the combined scan and GPR point cloud is currently only available on expert level applying the software *RiSCAN PRO*.

The case study presented and the solutions worked out in response to the challenges encountered show that high-resolution and detailed documentation of archaeological and historical sites is possible in the shortest time without disregarding the quality as measured by the highest accuracy and resolution. This opens up a new window for the efficient digitization of our cultural heritage above and below the surface, which is particularly important for endangered sites, as digitization projects can be started and completed immediately. The improvements to making the data available to non-experts in an appropriate and comprehensible form are of particular importance for their sustainable and dynamic use in the field of Culture Heritage Management as well as in the area of development.

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.
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Digitizing John Ringling's *Wisconsin* Train Car at the John and Mable Ringling Museum of Art in Sarasota, Florida

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The John and Mable Ringling Museum in Sarasota, Florida is home to the private train car of John and Mable Ringling, named the *Wisconsin* after John's home state. This unique train car served as the house on wheels for the tycoon and circus king during his frequent journeys around the United States. Since John was in charge of book the circus and purchasing new acts and equipment across the country, John and Mable found that most of their time was spent in this mobile mansion. In order to expand the accessibility of the train car to the public and to assist curators in 3D printing new train car parts for conservation and replacement. The University of South Florida's Institute for Digital Exploration (USF IDEx) digitized the *Wisconsin* train car using terrestrial laser scanning (TLS) and digital photogrammetry. The completed digital model was uploaded to the 3D model sharing website, Sketchfab, for dissemination to the public, providing access to the interior of the car which is currently closed to museum visitors. Segmented portion of the 3D models were used to create individual 3D models of furniture, parts of which were 3D printed out in real scale and treated in order to resemble to originals made out of wood or metals. The virtual *Wisconsin* also served to provide valuable information and assist in understanding this Gilded Age train car to curators, researchers, and the wider community.

Key words:
Cultural heritage, train, terrestrial laserscanning, photogrammetry, 3D printing.

CHNT Reference:
Davide Tanasi et al. 2018. Digitizing John Ringling's Wisconsin Train Car at the John and Mable Ringling Museum of Art in Sarasota, Florida.

INTRODUCTION

The grand architectural style of the wealthy Gilded Age mansions in the US, with a climax between 1870 and 1900, impacted also the construction of private luxury vehicles, such as train cars. The ownership of such mobile palaces at the time was perceived as the membership of an exclusive club of tycoons and millionaires – a sort of train-set in contrast with the jet-set of the 1950s. This period marks the rise of industrialization which gave way to the growth of a wealthy upper class, which included people like Vanderbilt and Rockefeller, who could afford to build lavish homes for themselves [Shrock 2004; Cravens 2009; McKnight Nichols and Unger 2017; Richardson 2017]. It was during this period that personal rail cars became a status symbol for the rich. Like at their mansions, it was not uncommon for wealthy individuals to host parties and events on the railroad using their private rail cars. Though they did use them for business as well, these rail cars were designed specifically for their owners and decorated in a similar style to that of their mansions [Beebe 1959; Husband 1972; LaHurd 1999]. While ownership of private railcars in the United States did not come to prominence until the Gilded Age, the concept of wealthy and affluent people owning a private railcar, or several, was not a new proposition. Since the 1830s, individuals of status from the United Kingdom owned and rented private railcars to make travel more enjoyable and convenient for them. By the 1840s, American presidents started using private railcars for their frequent travels. President Lincoln had a private rail car for his travels during the Civil War. Lincoln's car even became part of his funeral procession around the United States, making Pullman cars all the more famous [Beebe 1959; Stamp 2013].

These train cars became popular during the 1870s when the Pullman Company began making private railcars for those who could afford such a luxury. Anything a person requested could be integrated into a railcar by the Pullman Company [Beebe 1959]. Unique designs, exclusive patents, tariffs, and the ability to buy out competition allowed

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the Pullman Company to become synonymous with luxury travel on the railroad. Pullman cars were even popular in Europe. It is also important to note that Pullman kept up with the safety standards and regulations, ensuring the Pullmans were the brand known for traveling safety on the rail lines [Beebe 1959; Husband 1972; White 1978]. One such regulation stated that there must be one continuous pathway down the entire length of the car that was cleared of all obstacles in case of an emergency, thus, cars had to be built with one hallway down the length of the car [Beebe 1959].

Even with each Pullman as distinct as their owners, the cars developed relatively similar properties for various reasons, not all of them being related to transportation regulations. There seemed to be a commonality between exterior design in that there was often a platform at the back of the car and the exteriors were painted relatively similarly [White 1978]. Other facets that became popular included heating, plumbing, electricity, and later, air conditioning, as well as full-sized bathtubs, concealed safes, large beds and bedrooms, staterooms, kitchens and dining rooms, and ice closets or refrigerators. These amenities become popular after individuals requested them and the Pullman Company obliged. Other similarities between private rail cars were imported marble and solid silver or gold fixtures, chandeliers, murals or other magnificent works of art, lavish wood panel designs, and fireplaces [Beebe 1959]. The cars were no less than Gilded Age mansions on wheels, complete with all the modern convinces and designs that one could afford. Convoys of serval private railcars for the affluent and their servants was common, and later became relevant to the United States elite who wanted every comfort they had at home to be available to them on the road. These they of convoys included various cars for designated purposes, like eating and sleeping, as well as separate cars for their servants.

By around the 1940s, the ownership of private Pullman railcars was on the decline [Beebe 1959]. The Second World War and, in the 1950s, the beginning of the Eisenhower Highway System caused the railroad to become less prominent than other means of travel, likely the causing further decline to the ownership of private Pullman railcars. While the Pullman Company is notable for its railcars, it would be remiss to not mention that it is also known for its labor strikes in the 1950s over poor working conditions and for being part of the history of the Plessy v. Ferguson United States Supreme Court case which was used to constitutionally justify segregation [White 1978; Stamp 2013].

JOHN RINGLING AND THE WISCONSIN TRAIN CAR

John Ringling was one of the five founders of the Ringling Bros. Circus which first began in Baraboo, Wisconsin in 1884. Eventually, John was put in charge of booking and moving the circus between locations. For this reason, he often traveled around the country, at first by wagon, and in 1890, by railroad. With the railroad, the circus became a national success, rivaling the Barnum and Bailey Circus, which the Ringling Bros. Circus acquired in 1907. John's wealth also allowed him to partake in other businesses, such as land investment, particularly in Sarasota, railroad, and oil. In 1905, John and Mable Ringling were married and bought their first private Pullman rail car, the Wisconsin. In 1926, John built a Gilded Age mansion for him and his wife, Mable, in Sarasota, known as Cà d'Zan [Barry 2014; McCarty 2018]. Due to John and Mable's love of fine art, the Ringling's began collecting pieces from all over the globe, opening a museum of art in 1930 at their Sarasota property. The property and its contents were left to the State of Florida after John's death. In 1948, the American Circus Museum was created on the property. Currently, Ringling property is the John and Mable Ringling Museum of Art which contains the renovated Cà d'Zan to look as it did when John and Mable lived there as well as the art museum, the circus museum, the gardens, and several performing arts centers [De Groft and Weeks 2004].

Fig. 1. Wisconsin train car, side view

John and Mable Ringling traveled frequently—not only for John's work for the circus—but also for pleasure. Since much of their time was spent on the railroad, the Ringlings purchased a private Pullman wooden railcar which they named the Wisconsin (Fig. 1) in honor of the state from which John came [McCarty 2018]. The private railcar was originally built in 1896 and was renovated by the Calumet Shop of the Pullman Company to the Ringlings' specifications in 1905 [The Ringling 2018]. The inside of the car was decorated by Mable to make the mobile home look as extravagant as the era demanded [McCarty 2018]. The Wisconsin was used for parties and as an office for working out contracts for the circus [The Ringling 2015].

The interior of the car contains eight separate rooms, an entryway, a platform with a railing on the back of the car, and the outside is a dark green color with gold lettering and accents, which seems to be a common Pullman Company design. This large sitting room in the back of the car would allow the Ringlings and their guests to overlook the American scenery with the windows which covered three sides of the room. The other rooms served various purposes to allow the Ringlings to live, work, and entertain on the rails. There are two bedrooms – the larger of which served as John's room and, being in the middle of the train, was likely the smoothest ride. Between the two bedrooms sits a bathroom which connected via doors to both bedrooms and the hallway. The Wisconsin has two smaller sitting rooms, which currently house a single bench seat. One is near the front of the car, just behind the kitchen and before the first of two large sitting rooms, and the other is near the rear of the car, connecting to the smaller bedroom and the hallway (Fig. 2). The entire space is decorated lavishly and allowed the Ringlings to travel in style around the continental United States. From the front entrance to the back entrance, excluding the platforms on either end, the car is about 22.6 meters long, or just over 74 feet, and about three meters wide, or just under 10 feet. The individual rooms inside the car range in size, with the smallest room being the entryway, which is about 0.9 meters long and ends at the hallway which runs the length of the train, and the largest being the large sitting room in the back of the car, which is about 5.1 meters long and includes in its width the hallway (Fig. 3).

Fig. 2. Interior of the back large sitting room of the Wisconsin

The Wisconsin railcar served as the Ringlings' mobile mansion until 1916 when they purchased a new railcar – the Jomar – named after the combination of John and Mable's names [McCarty 2018]. The purchase of the Jomar came after the Wisconsin and other wooden rail cars were banned from using tunnels in the New York City as it was a potential fire hazard [Lower 2017]. The Jomar was larger and more magnificently decorated than the Wisconsin and was used by the Ringlings until John's death in 1936 when his nephew inherited the luxury railcar [LaHurd 1999].

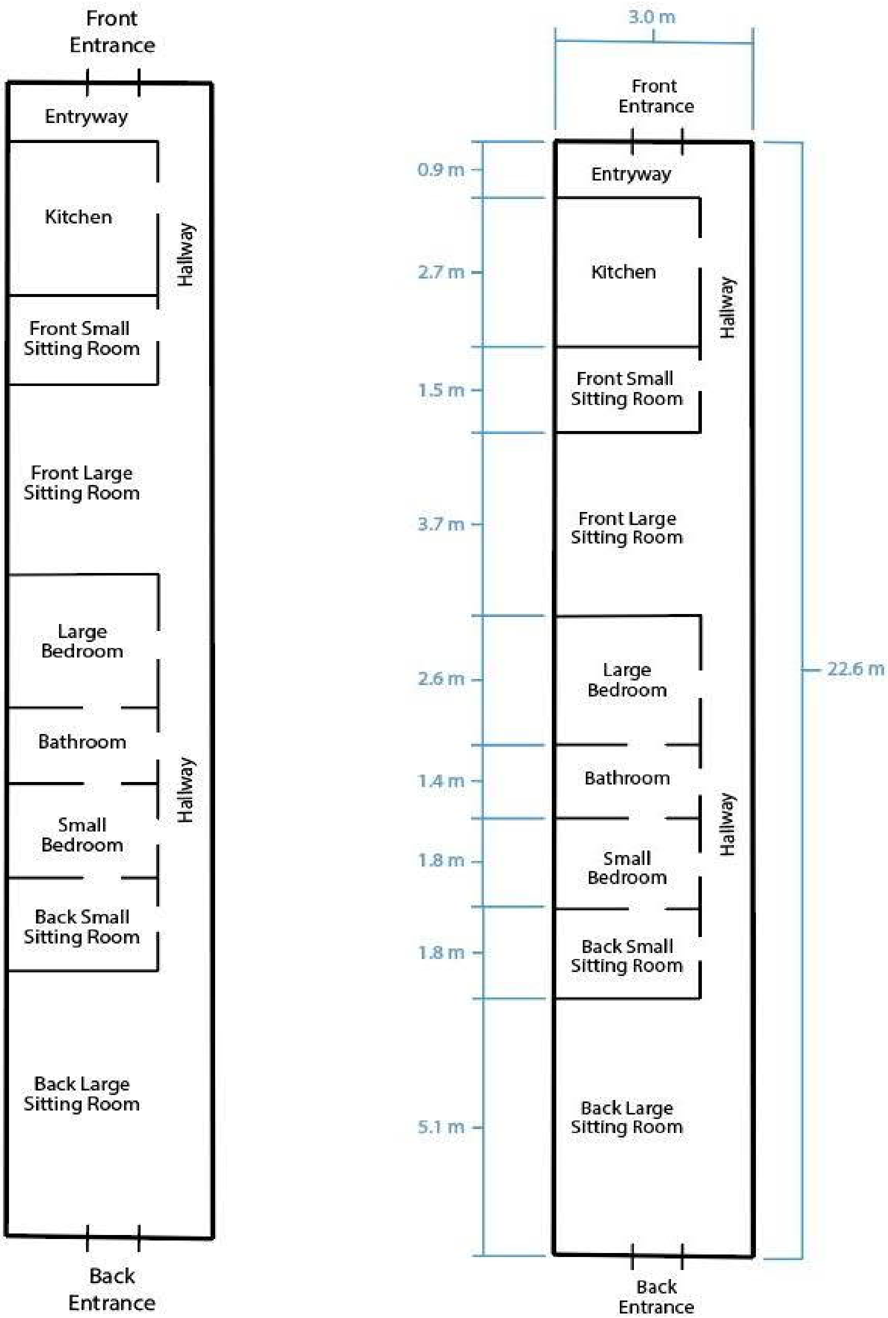

Fig. 3. Schematic layout map of the Wisconsin train car with measurements

After the Jomar was purchased, the Wisconsin was sold to various other railroad companies until 1989 when the railcar became part of the North Carolina Transportation Museum collection in Spenser, North Carolina. In 2003, the North Carolina Transportation Museum Foundation gifted the railcar to the John and Mable Ringling Museum of Art in Sarasota, Florida. At this time, the car no longer looked as it had when John and Mable were using it, as railcars from Pullman were renovated depending on where they were and who owned them. After restoration was completed in 2009, the Wisconsin was opened to the public at the American Circus Museum, housed in the John and Mable Ringling Museum of Art in Sarasota, Florida [Lower 2017; The Ringling 2018]. Today, the decor as been restored by the Ringling Museum to accurately reflect what John, Mable, and their saw inside their mobile home [The Ringling 2015].

The Wisconsin is one of the few surviving wooden Pullman Company private luxury railcars. The Wisconsin has been restored to the period when it was the Ringling's home on wheels, reflecting the unique styles of John and Mable. Although it can be considered a 'controversial heritage', due to its nature of being the luxury vehicle of an early 20th century millionaire, the Wisconsin train car is a unique piece of history, like the Ringling's Cà d'Zan, due to Mable's involvement in its interior design. It is the only surviving example of translation of the fashion of the Gilded Age into a train car. Unfortunately, the Wisconsin's age means that there are several issues with the accessibility and continuing conservation of the car.

THE VIRTUALIZTION OF THE WISCONSIN

In the interest of preserving and researching the Wisconsin and the ability of 3D technologies to enhance current curatorial methods and public access, the "Institute for Digital Exploration" (IDEx)[1] at the University of South Florida used "terrestrial laser scanning" (TLS) and digital photogrammetry to digitize the Wisconsin train car in the spring of 2018, a combination of techniques which have largely proved their potential in the field of Heritage Studies [Lerma 2010; Chapman 2013].

3D SCANNING

IDEx team used two Faro Focus 330x laser scanners to capture 124 scans over a total of three days. Scans were of both the outside and inside of the Wisconsin in order to create a complete and comprehensive digital twin of the train car. There were 84 scans taken on the outside, including the roof, through the use of a cherry picker, and the undercarriage, and 40 scans on the inside (Figs. 4-5).

Fig. 4. Laserscanning data capture in progress laser scanning

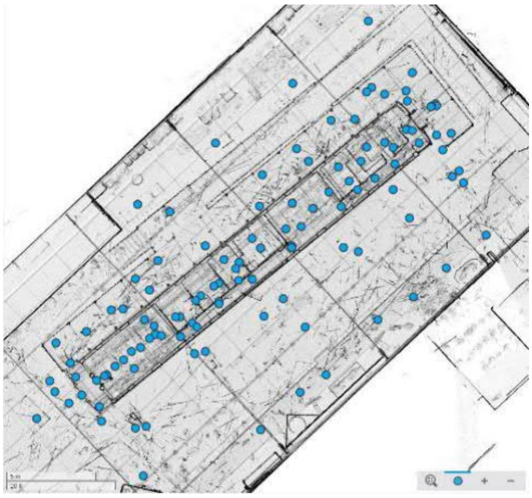

Fig. 5. Overview map generated by Faro Scene showing the placement of each scan

These scanners collect a colored point cloud of the site which is, with the applied setting being accurate within six millimeters. Uniquely textured spheres were set-up and moved intermittently during scanning to facilitate the registration during the processing. Upon the completion of data collection, the scans were processed with Faro Scene 6.2 using settings such colorization and minimal filtering and find spheres function. Registration occurred after all 124 scans were processed, and placed scans in their location, using the spheres placed during scanning. Since the scanning took place over three days, no permanent spheres could be set-up in between days, therefore, the groups created during the importing of the scans were registered together using target-based registration and they were registered manually to connect the individual days. The digital Wisconsin was systematically exported in slices

[1] http://history.usf.edu/idex/index.html

from Faro Scene software as PTS files for analysis. Decimation, when necessary, was carried out using the free software CloudCompare v2.9[2]. The results were very accurate but also rather photorealistic at the same time (Fig. 6).

Fig. 6. Several screenshots of the point cloud from the TLS. Top and Bottom: Outside of the train car. Middle: Inside of the train (right) large front sitting room and (left) top down view of the large back sitting room.

DIGITAL PHOTOGRAMMETRY

While the laser scanning provided geometrically accurate data to create technical drawings and for metrological purpose, the capturing of the train car via digital photogrammetry was necessary in order to achieve a photorealistic 3d model to enhance the experience of a virtual visit. Such technique is becoming increasingly popular among archaeologists and curators in museums for its low costs and high-quality results [Olson 2016].

[2] http://www.cloudcompare.org/

Fig. 7. Screenshots of the digital photogrammetry model of the outside (top and bottom right) and inside (bottom left)

One Canon EOS 5DS camera was used to capture a total of 621 images of two of the largest rooms and the outside. Out of the 621 images, 489 images of two of the largest rooms inside the Wisconsin and 132 of those images were captured of the outside. The images were captured at a resolution of 5792 by 8688. Portable LED lights were used inside the train in order to better capture the images, though the train still remained fairly dim in terms of lighting. The inside and the outside of the car were run as separate models in Agisoft Photoscan Professional 1.4.4. The general workflow was used to create the models. During the alignment of photos and the building of the dense cloud, the accuracy and quality (respectively) were set to high. Upon these two initial steps, the point cloud was manually cleaned to remove stray points. The mesh was created with a high face count. If not otherwise specified, the default settings were used. Upon final inspection, the model was exported as an OBJ (Fig. 7).

DISSEMINATION

For the dissemination and public engagement, it was used on Sketchfab, an online 3D model viewing platform which is freely available to the global public audience[3], where IDEx regularly shares its digital cultural heritage collections[4]. The colored point cloud model was decimated and exported in PLY in order to match the format requirement and models size of Sketchfab and subdivided in 6 individual models: front large sitting room, kitchen, front small sitting room, entryway, back large sitting room and bedroom suite (Fig. 8). The train car can be viewed in its entirety as well as in segmented versions[5]. Sketchfab also allows for a built-in VR experience on mobile devices and on other virtual reality headsets. This means that individuals around the globe will have access to view and visit the Wisconsin regardless of where they are, going around any accessibility issue.

3D MANUFACTURE OF SPARE PARTS

Small parts of the train car and its contents, like wooden elements of furniture and metal parts of the undercarriage, were exported individually for 3D printing [Balletti 2017] in order to create realistic spare parts but also to initiate establishing a little tactile collection, available in the Wisconsin Museum pavilion, for visitors with visual impairments and cognitive disabilities [Franco et al. 2015], but also the general public [Wilson (in press)] (Fig. 9).

[3] https://www.sketchfab.com
[4] https://sketchfab.com/cvast/collections
[5] https://sketchfab.com/cvast/collections/wisconsin-rail-car-ringling-museum-of-art

These individual parts or pieces were cleaned and saved as an OBJ file and were 3D printed in various materials. These 3D prints were also painted to reflect more accurately the original. To achieve both visual and textural similarities to the original materials for this project (here rusted iron and aged wood) a multi-step reproduction process was employed. Materials selection is essential to achieving a similar texture and appearance to the original product. With the cleaned digital meshes and high resolution images as a starting point, the models were scaled and printed on conventional FDM-type 3D printers. They were all printed at 0.12mm layer height and using PLA (Polylactic Acid) filament. The outer shell of the parts were printed at a relatively slow velocity of 40mm/s to reduce mechanical artifacts such as ringing visible as repeated patterns near the edge of parts. After the objects were printed, they underwent a modification process aimed at reproducing realism structured through three main phases: materials selection and part filling, preparation and surface modification, final patina application (Fig. 10).

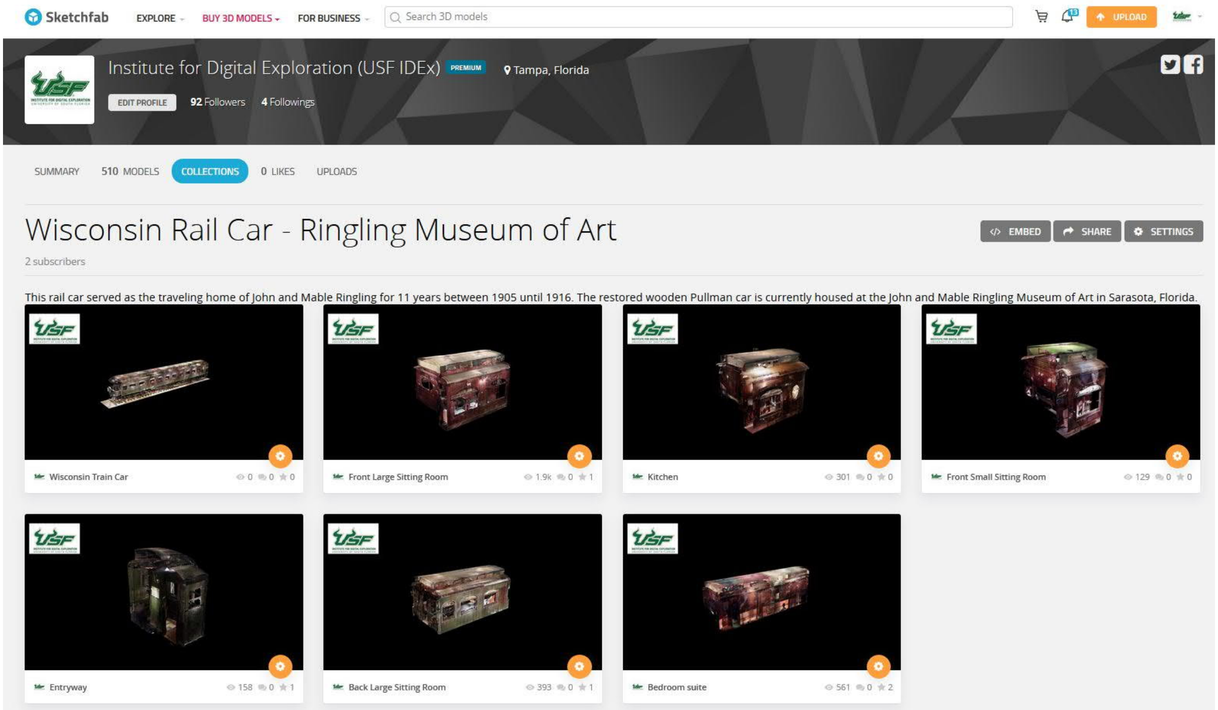

Fig. 8. The Wisconsin rail car Gallery on IDEx's Sketchfab collection

Fig. 9. Left: Part of a chair in the back large sitting room. Right: A hook from the undercarriage of the train.

Fig. 10. Process of 3D printing and painting the part of the chair (top) and the hook (bottom)

MATERIALS SELECTION AND PART FILLING

PLA filament was selected for its low shrinkage and relative hardness compared to ABS polymer contributing to its ability to be worked and sanded. For parts intended to replace wooden components, a wood fiber filled materials were used with up to 25 % (v/v) wood fiber loading. Similarly, bronze and metal particle-filled polymers are available for printing metal simulants. It should be noted that these solids-bearing filaments cause excessive wear on the 3D printer nozzle and typically require the use of a hardened nozzle material to ensure continued extrusion accuracy.

Where possible, all objects are printed with extremely low or zero infill. This permits the filling of the internal void space with density appropriate simulants to match the target weight, density, and balance of the original item. Where possible, a minimum wall thickness of 1.2mm is used which allows surface modification, sanding, and damaging to match original pieces. For parts ranging in the 10-20cm size range, this results in about 95% void volume internal to the part. This void, in turn, is packed with a blend of materials which can be weighed out in advance with volumes measured to ensure the target density is achieved. Highest density filling can be achieved by filling initially with lead shot and backfilling with silica sand (Tab. 1). After that, the overall composite can be infiltrated with low viscosity cyanoacrylate glue which binds strongly with the silica. This density perfectly equates to steels, irons, and cast irons. Using a blend of the different materials below, a very wide and continuous density range can be replicated.

Tab. 1. Densities of various part fillers used in their respective maximum random packing factor

Filler	Typical Density (g/cm^3)	Maximum Packing
Lead Shot (4-5mm)	11.34	64 %
Steel Shot (2-4mm)	7.78	64 %
Silica Sand	1.22	100 %
PLA Plastic	1.25	100 %
Glass Microspheres	0.6	100 %
Expanded Polystyrene Foam	0.05	100 %

PREPARATION AND SURFACE MODIFICATION

Immediately after printing, any support material(s) and structures were removed from the part manually and the parts were given a rough sanding with 100 grit sandpaper. The parts were loaded into a sandblast chamber and blasted with coarse crushed walnut shell media at a pressure of ~60psi (4 bars). This process greatly reduces the visual appearance of 3D printed layer lines and smooths any imperfections resulting from the scanning and printing process. Following this, a further sanding with 600-800 grit paper replicates the natural burnishing and wearing that would occur over time with wooden and metal parts.

In the case of wooden parts, a further treatment is recommended to realistically depict decades of aging, shrinkage, and damage from normal use. These damages mostly commonly come in the form of: visual enhancement of wood grain due to uneven shrinking of the wood, wood destroying organism damage, scratches and abrasions, small wood pore visibility, microcracks, macrocracking, and darkening of the wood. It is important to mimic each of these elements to ensure a realistic part is produced. A rotary tool with a wire brush attachment is used to create a grain-like surface texture. Alternatively, this can also be applied to the digital model but a more sharp appearance is typically realized through manual application. Sharp awls and needles are used to apply much of the rest of the damage with the addition of a rasp near the end of the process to reproduce abrasions. Cleaning with a damp cloth prepares the parts for final treatments

FINAL PATINA APPLICATION

Continuing in the case of wooden parts printed with wood fiber-loaded filament, it is possible to directly stain this material as one would with an actual wooden part. The parts were all stained using commercially available penetrating oil stains. These were applied intentionally unevenly using a crushed paper applicator as 1-2 thin coats and allowed to dry for 2-5 days. Following this, brown and black oil paints were liberally applied and towel wiped with functioned well to fill low lying areas with darker pigment. After a further 5 days of drying, a matte or gloss spray clear coating was applied to protect the surface.

In the case of metallic parts, metallic paints and sprays were used to achieve the bulk of the effect. During the wet painting and application process, coarse salt and metallic powders matching the original object to be imitated are sprinkled on to the surface. The result is the partial embedding of the painted surface with these real metallic species. These metallic particles can be rusted or aged synthetically through the use of corrosion accelerating chemicals thus compressing decades of neglect and corrosion into a matter of hours or days. In addition, oil paints which match the oxide, sulfate, and chloride state of these metal species are painted onto the surface to further enhance the parts where needed. As before, the parts are left to dry for 5 days and then protected with a thin matte finish clear coat. It is possible to also embed further metallic particles into the clearcoat. The final result speak for itself, as the objects have now same weight and appearance of the originals (Fig. 11).

Fig. 11. Photo of several painted 3D prints

TECHNICAL ISSUES AND PRACTICAL SOLUTIONS

The site being open to the public was not of particular concern since visitors cannot enter the inside of the car. One issue discovered after the completion of data collection was that, due to the railcar's need to move when riding the rails, the rail car moved slightly whenever someone inside walked around. Several scans had visible issues within their images that showed a movement of the car which individual scanning technicians could not feel themselves caused the scanner to capture data that was slightly off from the rest. These scans, thankfully, could be saved and used for the most part as there was overlap in scan positions. Parts that aligned with the rest of the train were kept while parts that were slightly skewed within the same scan were removed.

A unique challenge faced with scanning something like a rail car presents itself in the space that one has to maneuver. The Faro Focus scanners can be quite versatile in small spaces, but places like bathtubs, and on top of fabric surfaces, like beds, because a particular issue. Smaller scanners, like the Leica BLK 360, may be able to fit in these smaller locations, however, since the rail car has unique special management, flat surfaces on a higher plane that the rest, like the top bunk in the small bedroom, cannot be easily reached by the scanner and placing the scanner in order to cover these surfaces causes specific challenges. Even places like the kitchen, which for the most part is an open space, has different necessary machinery tightly packed together, so that even the smaller terrestrial laser scanners would have difficulty reaching every area of the space.

Similar to other discussions of 3D datasets is the issue of computing power and dissemination. While this project was small enough to be processed on most of the computers at IDEx, the end product consisted of billions of points, making it necessary to decimate the digital twin for dissemination purposes. The size of the original data is large enough to cause even the most modern computers to have trouble viewing the full Wisconsin 3D file. Dissemination of the data to the broader public would make it necessary to decimate the files as many individuals in the broader public likely do not have the highest level of hardware and older computers, or even newer computer with lesser specifications, would probably have difficulty viewing the full dataset. Even the decimated versions which are available to the public are difficult to view on most mobile devices due to its size. It is likely that the development of new technologies will help lessen the prevalence of these problems in the future.

CLOSING REMARKS AND FUTURE WORKS

The 3D digital versions of the Wisconsin will provide a valuable resource for the future. Not only will researchers and the public be able to view the Wisconsin from anywhere in the world, but it also creates a specific view of the Wisconsin as it was at the time of the digitization. The Sarasota location is at risk for natural disasters like hurricanes due to its bayside location. The fact that cultural heritage, as a physical remnant of past and lost civilizations, has come to us after centuries and in good condition in many cases, despite all the forces that threatened it, does not allow us to take for granted that we will be able to pass it as it is to future generations.

In that case, the virtualization of the Wisconsin will become useful to assist curators to restore the car if it were harmed [Minucciani and Garnero 2017]. This digitization will also provide restoration and curation work with the ability to use 3D printing techniques out of various materials if a part or piece of decor ever needs to be repaired or replaced for any reason. Small or large pieces can be virtually removed from the digital model and 3D printed without harming the car or its part for reproduction like other analogue methods, such as casting [Neumeuller et al. 2015]. Not only will this provide the Ringling Museum to be able to conserve the train car better but also to catalogue how the car may have changed overtime. Continued 3D printing efforts regarding the train car will be employed for the restoration and research of the train as well as to bring the train to the public.

Another important part of the digitization is that the increased accessibility of the Wisconsin. Currently, the public cannot physically enter the Wisconsin; instead they can only look from the outside into the car via the windows. The digital version allows visitors and researchers alike to view the Wisconsin from anywhere in the world and even walk through the rail car using virtual reality methods. This provides the public with the ability to access the inside of the train car digitally which they are currently unable to do. It also provides those who have a disability and may otherwise not be able to experience the Wisconsin with the opportunity to visit the car, allowing for greater accessibility to the public. Researchers and curators will be able to analyze, view, and get a sense of what it was like for the Ringlings and their guests in living, working, and traveling in the Wisconsin without experiencing the constraints which tend to come along with research such as scheduling and travel. The digital Wisconsin also provides perspective visitors and researchers with the ability to better find and evaluate the American Circus Museum and the Ringling Museum as the digital version provides a greater online presence which exposes potentially new individuals to the train car. A digital presence makes the heritage more accessible to those who may not have known about it prior to a physical visit to the Ringling.

One major issue is that the Wisconsin's technical drawings were not inclusive of all parts of the train car, such as the layout. With the 3D digital model, IDEx was able to create an overview map of the train and future users can similarly generate technical drawings in a significantly smaller amount of time than using analogue methods. Technical drawings can also be verified for accuracy since laser scanning provides more accurate measurements than those which have been manually measured [Du et al. 2015]. The measurements taken using this 3D digital Wisconsin can be done with accuracy which may not be possible in real life. Technical drawings can be produced of every area of the Wisconsin, such as the ornate details on the ceiling or the floor plan with furniture, which currently has not been done. These will help researchers and curators to better understand how the Ringlings used the space.

Further dissemination practices will include a clickable map which allows digital visitors to understand better how the train car is laid out. By clicking on a specific area of the map which was generated via the laser scanned point cloud, the digital visitor will be linked with that specific section of the digital Wisconsin. It provides a better context for the individual sections of the digital Wisconsin and allows for integration of a 3D digital exhibit and tour of the historic rail car. Future work on the rail car should include the integration with augmented and virtual reality. As these technologies become more accessible, with decreased cost and greater understanding of programing and using these devices, the integration and ability for the public and researchers to use these technologies will increase.

The Wisconsin train car is a magnificent piece of cultural heritage. Like Gilded Age homes, private rail cars for this elite class of wealthy individuals brings insight to the era and the individuals to whom they belonged. Digitization of these cultural heritage is necessary for the preservation and continued research. The digital Wisconsin increases the ability for preservation, research, and restoration, especially with the incorporation of 3D printing technologies. The increased accessibility for the global public and research is a valuable aspect of the digitization efforts. Continued work on 3D printing and augmented and virtual realities presents a promising future for increased accessibility and research on the Ringlings, their legacy, and the Gilded Age.

The virtualization of a such elaborate vehicle as the Wisconsin and the production of its digital twin is a significant advance for the knowledge of Florida cultural heritage but at the same time it represents a challenge for those scholars called to disseminate properly the results. Without entering in the debate of the best 3D Web Viewer/Platform [Scopigno et al. 2017], in order to fulfill the expectations of the public on the virtual Wisconsin project, it has been decided to prioritize in the future research agenda a Unity-based customized platform for a virtual visit of the mansion, derived from previous experiences [Stanco et al. 2017]. The platform, Virtual Wisconsin, which at this stage is still in the design stage will be web-based, will use visual navigation tools, inspired to the Virtual Ca'd'Zan platform, already produced for the luxurious mansion of John Ringling at Sarasota [Tanasi et al. forthcoming]. From the plan of the train car with a simple point-and-click, users will be able to visualize the 3D models stored in an online server through a customized 3djs-based viewer with the option of choosing between low, medium and high resolution. The platform will also incorporate multimedia contents as text, hyperlinks to external websites, audio and video related with the history of the Wisconsin and the Ringlings and have an embedded VR output in accordance with the current trends in the field of Digital Cultural Heritage [Bekele et al. 2018].

ACKNOWLEDGEMENTS

Authors are grateful to Jarred Wilson and David Berry, namely Associate Registrar and Assistant Director of Academic Affairs at the John and Mable Ringling Museum of Art for the extremely valuable help they provide facilitating the agreement between the University of South Florida's IDEx and the Ringling Museum of Art and for the invaluable help they offered on the field.

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
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