

INTRODUCTION TO THE ARCHITECTURAL CONSERVATION PROJECT FOR THE FACADES OF THE ROYAL PALACE OF STOCKHOLM

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Abstract:

Sweden's foremost architectural monument, the Royal Palace of Stockholm, is now officially the object of a profoundly large architectural heritage conservation project. Such projects are always challenging on many levels, not only because monuments are unique structures, but also because all actions and interventions need to be well justified, optimal, and ultimately acceptable to the public. The project for the conservation of the Royal Palace is estimated to last for the next 22 years and it includes a set of sub-programs, one of which is the "Long-term maintenance of the facades". Focusing on the sub-program for the long-term maintenance of the facades, the authors discuss aspects related to the research that was carried out in order to investigate the structure, to suggest and justify required interventions. Additionally, methods applied to geometrically document the structure are presented here along with reflections on the information management system that will be employed so as to accommodate the documentation needs and information flow for this massive project. The entire case study is presented in conjunction to the ICOMOS "Recommendations for the analysis, conservation and structural restoration of architectural heritage" in an effort to highlight important aspects of the investigation and the decision making process.

1. INTRODUCTION

The Royal Palace of Stockholm, a particularly significant and uniquely well preserved baroque palace, is the legacy of Nicodemus Tessin the Younger, a celebrated architect of his time. After the original palace was destroyed in a fire in late 17th century, and upon the request of King Charles XII, Tessin produced detailed plans for a new palace and, although he dedicated the rest of his life to this work, the Royal Palace was completed long after his death around 1760. Ever since the Royal Palace of Stockholm has been the official residence of the Head of State, it has been the setting of many historic events and currently it houses the offices of the King and the other members of the Royal family, the offices of the Royal Court of Sweden and several museums.

This historic monument has a unique position in the Swedish building tradition and since its completion it has regularly been maintained by its owner, the National Property Board of Sweden. So far, all maintenance programs have aimed to address issues related to the weathering and decay of materials, in a rather conservative fashion. This very practice is the reason for the apparent uniform ageing appearance of the entire building, despite the fact that various parts were completed at different times. However, in 2005, an alarming event, i.e. the detachment and fall of a large piece of the decorative sandstone, became the reason for a series of investigations regarding the condition of the entire Royal Palace. According to the ICOMOS "Recommendations for the analysis, conservation and structural restoration of architectural heritage" [1], safety is the foremost concern for any structure and this event made it evident that the building was no longer safe. The investigation that followed indicated that it was necessary to proceed with the development of a

plan for the “Long-term maintenance and care of the Royal Palace as a whole” and that for the facades it was required to develop a special program, which is now in motion and is entitled "Long-term maintenance of facades", subtitled "Software engineering; investigation, guidelines, pre-planning".

With a special interest to the program developed for the restoration of the facades, this paper discusses aspects related to research and diagnosis in conjunction with the ICOMOS Recommendations. Moreover, a significant part of this paper discusses technical aspects of the project, mainly regarding the processes selected for the geometric documentation of the facades, the properties and the uses of the derived products. Reflections on issues regarding indexing of drawings, information management and scenarios for monitoring the progress of the project are also discussed.

2. RESEARCH AND DIAGNOSIS

The Royal Palace of Stockholm is one of Europe's largest palaces. The palace in numbers is rather impressive i.e. total area is 42,000 m², 1430 rooms, including closets, basements and corridors (about 660 rooms with windows), 972 windows, 28 free standing statues, 717 balustrade pieces, area of total stone facade 9500 m², total quantity of plaster 11,000 m², windows and doors area 7,500 m², total facade area 28,000 m². As already mentioned, the palace has been regularly maintained by its owner, the National Property Board of Sweden. Especially for the facades several programs have been implemented starting from 1814 (only a little more than 50 years after its completion). In particular, it is known that between 1814 and 1844 part of the sculpted stone was replaced. Following, in the early 1900s during another restoration program, extensive restoration work was carried out with replacement of stones and use of oil solutions. Between 1945 and 1970 work has been done for the plaster of the facades. In 1990's another maintenance program involved the conservation of all of the windows and some more stonework.

The ongoing necessity for maintenance work, the alarming event of 2005, which was then followed by more similar incidents, and the realization that the entirety of the various materials of the facades are interdependent, all advocated in favor of a treatment program for the facades as a whole. According to the ICOMOS recommendations, every restoration program should be preceded by a great deal of research, thorough investigation and any remedial measures and interventions must be adequately justified. In particular the ICOMOS recommendations recite a number of principles and guidelines that generally apply for architectural heritage applications and these involve: some general criteria that should be applied, various aspects that should be investigated in order to perform adequate research and make an informed diagnosis, and, finally, some directives and guidelines regarding remedial measures and controls. In the case of the Royal Palace and with particular interest for the facades of the Palace, the ICOMOS recommendations are applied in three stages:

- In 2006 the *Maintenance program* was developed in order to determine actions required for the preservation of the entire palace, and to describe the values and the objectives related to the program. Regarding the facades of the palace, this early study indicated that it was absolutely necessary to take action for the maintenance of the stone of the facades.
- In 2009 a *Preliminary Study* and investigation into the condition of the facades indicated that the maintenance of the stone cannot be done in isolation and that, for a number of reasons (practical, economic, aesthetic, and purely technical) it was necessary to treat the Royal Palace facade as a whole. All its component materials and parts are interdependent. Therefore, the entirety of the facades are to be treated in a progressive frame-work, and the respective program of action has been renamed to "Long-term maintenance of facades", subtitled "Software engineering; investigation, guidelines, pre-planning" [2]. In 2010, the Project Directive was issued by the National Property Board of Sweden in order to officially set the terms for the project and formally declare commence of action.
- Presently, a *Pilot Project* is in motion in order to further investigate practical aspects of the project and deliver guidelines and specifications for the implementation of the full façade work. Some of the objectives of the *Pilot Project* are to seek answers for technical and antiquarian/ideological question posed in the *Preliminary Study* such as the selection of substitute materials, to establish guidelines for stone maintenance and to investigate the implementation of the derived guidelines for a representative section of the façade that holds various types of materials and presents several problems.

The actual implementation of the ICOMOS guidelines and recommendations is a complicated process, mainly because of the plethora of parameters that need to be evaluated, the aspects that need to be investigated and the non-linearity in the decision-making process. A team involved in such a project needs to continuously test, evaluate and update various aspects and processes before a concrete plan for remedial measures can be established. The scheme described in the above enables the project team to establish clear targets, to define the values and the objectives of the program (*Maintenance program*), to perform the required investigation and research, to determine standards, requirements and processes (*Preliminary Study*) and ultimately to implement, evaluate and, if necessary, update the proposed methods for remedy and control (*Pilot Project*).

According to the ICOMOS guidelines, each project of architectural heritage conservation must be handled by a multidisciplinary team that is appropriate for the structure. This project is managed by the National Property Board of Sweden (Statens fastighetsverk), the palace architect, prof. Andreas Heymowski and his firm HOS Arkitekter AB as general consultant, responsible for the historical and architectural investigation and also for the production of drawings. A consulting company, Tyréns, is providing the group with a stone restorer, a design manager and a structural engineer. Norconsult AB, another consultancy, is involved in the project, providing laser scanner data and orthophotos. The team is currently growing with the addition of experts in various fields and with specially skilled staff employed for the first construction site.

Currently, the *Preliminary Study* is the most mature and concrete part of the project. This study, involves many of the major aspects of the ICOMOS Guidelines in terms of a *qualitative assessment* of the structure. Related research was based on historic documents dealing with the construction of the palace, on information regarding past trauma and previous maintenance programs, on knowledge regarding structural modifications and changes of use. Inventory activities have taken place in order to detect, classify and evaluate visible damages (structural damages and irregularities) and decay of materials. It must be noted that, during the *Preliminary Study*, the goal was to detect the most serious problems and to sample different kinds of damages in order to justify the necessity for action rather than to account for each and every problem instance of the entire façade. Interestingly, the palace has never been geometrically documented in its entirety. So, in the absence of reliable information regarding the geometry of the Palace, but also because of the requirement for several tests, the quantitative part of the research i.e. the *investigation of the structural behavior* of the Palace and actual *assessment of structural damage, material decay and the decision* regarding appropriate *remedial measures*, is part of the Pilot Project. In this respect, part of the Pilot Project is dedicated to investigating suitable methods for the survey of the facades and the various assets. With the aim to facilitate, manage and monitor the restoration activities the facades are surveyed with various types of scanners and in a first step elevations and orthophotos are created. Additional research is also carried out in order to select the optimal methods and effectively integrate 3D modeling and 3D printing into the proposed restoration workflow.

According to the Preliminary Study, the preservation of the façade is the preservation of the authentic testimonies from all over the castle's life (authenticity of material) and, therefore, the original stone façade must be identified and preserved to the greatest extent possible. Also, it is important to maintain focus and attention to detail in its architecture (shape integrity) and consequently it cannot be allowed to let the artistic and architecturally significant elements wither to the point that the shape is lost. Where this is the case, and the requirements for authenticity of material and shape integrity come into conflict, in order to preserve the castle's representative function and unparalleled richness of the architectural expression, the form's authenticity and fidelity to Tessin's ideas is more significant. Evidently, in order to preserve the authentic material to the greatest possible extent, such decisions should be made on a case to case basis.

The selection of appropriate substitution materials is another major issue in this case. This is mainly due to the fact that a significant part of the façade is covered with Gotland and Roslag sandstone. The sandstone covers approximately 1/3 of the façade area and the estimated quantity of the material required for the restoration is calculated to approximately 1,000 m³. Unfortunately, the Gotland sandstone is especially difficult to find in such quantities and the same applies for the Roslag sandstone. Concerning the Gotland sandstone the use of similar types of stone is investigated so that the color and the technical properties of the new material be compatible. However, this is found to be impossible because the desired properties for a new material that will be able to withstand weathering, are incompatible. This is because, on one hand, the new materials should behave as Gotland sandstone with regard to thermal expansion and other factors in order to be used on the artistic sculptures, and on the other hand, it should be much more resistant to climate impact.

Therefore, especially for the Gotland stone it is considered that it is replaced by two new materials, one for areas where strength is required and another type of stone for the artistic expression areas. A practice that was applied in the past and may be employed now is the “recycling” of materials from the same façade (Figure 1, left). This practice may be a preferable solution for small and rather protected areas that require replacement.

Regarding the Roslag sandstone, shortage of the original material has led to the selection of several types of stone in order to approximate the richness of color of the original structure. The types of sandstone selected for this purpose are: *Obernkirchener* (gray / yellow-gray), *Warthauer* (greyish-yellow / orange), *Olsbrücken* (red / maroon), *Orsa* (red), *Maulbronn* (purple). Previous experience has shown that during replacing parts of the Roslag sandstone care should be taken so that the result is uniform and no particular color stands out (Figure 1, middle). Another issue is the color differences between the new and old stones. The Swedish tradition involves entering a patina on the new materials in order to decrease the difference between the old and the new and this is a method that will probably be employed in this program.

The Plaster of the facades is found to be at an overall good condition. However, the plaster surface is discolored and the colorization has never been uniform. Also, there are areas where the plaster has been damaged or will be damaged during the replacement of stones (Figure 1, right). According to previous projects it is known that it is especially difficult to repair the plaster and therefore it is considered that the entire plaster cladding is also replaced. As a consequence, the new color that will be used for the plaster is another question, not only because of the current non-uniform color of the façade but also in relation to the history of the Place and the Swedish tradition.

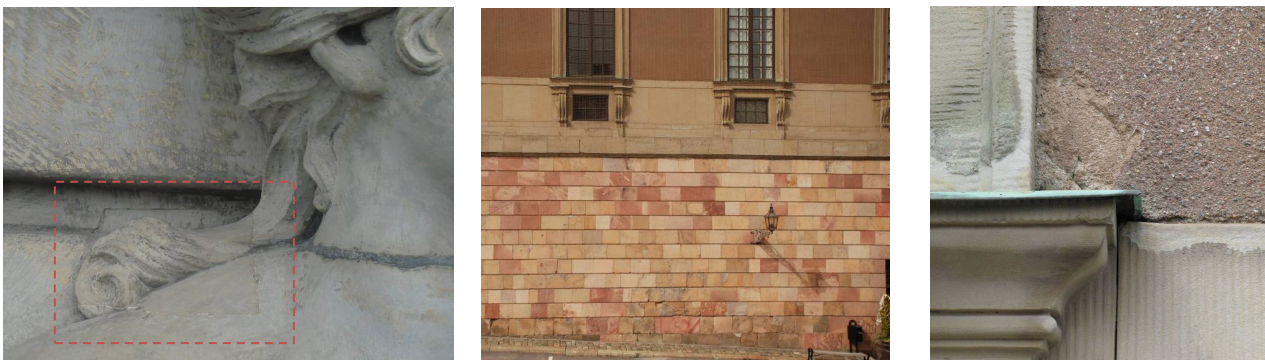


Figure 1: Example of very old and well done replacement on sculpture made of Gotland sandstone (left). Red islands after the replacement of Roslag sandstones with other types of sandstone (middle). Area where the weathered and dirty plaster has been removed and the original (i.e. intended) color is revealed (right)

After the *Pilot Project* is completed, it is expected that several issues will be resolved. For instance:

- Selection of appropriate substitute materials
- Criteria for the choice between the conservation or replacement of pieces
- Non-invasive methods of intervention (modern or traditional)
- Standards and requirements of the geometric documentation process (accuracies, equipment, deliverables)
- Methods for the assessment of the structural behavior of the structure
- Requirements for monitoring applications
- Frequency and nature of documentation processes
- 3D recording, modeling and printing methods
- Quality measures and reports

In order to effectively manage the entire project, the workload has been distributed into 22 phases. In Figure 2, the layout of the 22 annual phases is presented onto the floor-plan drawing of the palace. The 22 phases are classified into 4 groups based on the current schedule. Figure 2 also presents the work area of the 1st phase that was selected as the test area of the pilot project. The image was taken in November 2010, during photogrammetric image data acquisition. The area of phase 1 is the North-East wing of the royal palace, also presented in the floor plan in yellow. Currently the North-East wing is covered with scaffolding, it is a construction site and interventions have commenced. At this stage, the Roslag sandstone of the façade is being removed for conservation. Each piece of stone weighs approximately ¼ of a ton and two people are needed to safely handle each one of the pieces. After the removal of a large part of the Roslag cladding from the North part of the façade, it was evident that the damages are less significant than expected. Therefore, as a test, only half the cladding will be removed entirely, while on the rest only visibly damaged stone will be removed and replaced.

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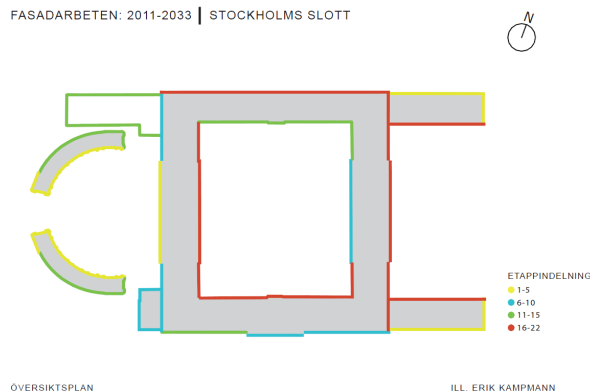


Figure 2: The floor-plan of the palace and the 22 phases of the program divided into 4 groups (left). The North-East wing of the palace, area of the 1st phase - Pilot Project (right).

3. TECHNICAL ASPECTS OF THE PILOT PROJECT

As already mentioned in the above, the Royal Palace has never been geometrically documented in its entirety. The palace had been built for a period of 60 years starting in the late 18th century and several additions were made later in time. The drawings that are found were created by means of topometric methods and are of very low accuracy. Comparisons made with the new drawings indicate differences up to 35 cm. Figure 3 presents the comparison between the old and the new drawings.

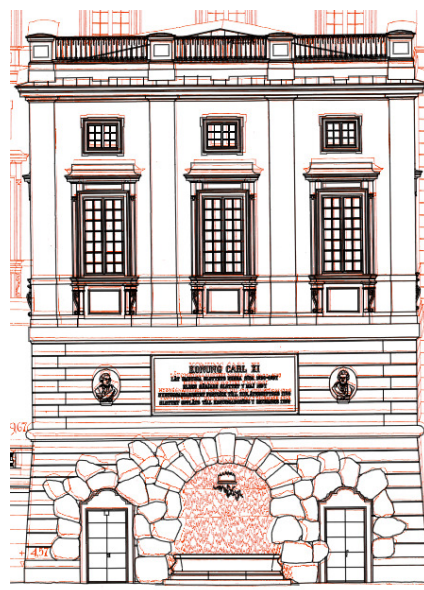


Figure3: Comparison between old (red) and new linedrawings (black). Differences up to 35 cm are detected due to the low accuracy of the initial documentation process

In order to create new detailed drawings for the Royal Palace, the engineers have acquired and used point clouds. For the 1st phase, a small traverse was established in a local reference system and several scans were acquired by means of a time-of-flight laser scanner (a Leica Scanstation). The point cloud registration was initially based on several targets that were surveyed and acquired in the field and later the solution was optimized by means of cloud registrations in order to obtain a closer alignment of the data. In this respect, point clouds acquired for the North and East side and also for the roof were optimally aligned and merged into a single point cloud of c.a. 50 million points. In order to establish a reference system suitable for elevation drawings, the original axes were rotated so that the X-axis be parallel to a line that was fitted onto the horizontal trace of the North facade. After the transformations, new coordinates were derived for the nodes of the traverse and the positions of the targets and these will be used from this point on in order to extend the local geodetic network.

The merged point cloud that was derived was manually cleaned and parsed into smaller drawing files of dxf format for ease of use in AutoCAD. In this way and without the use of a plugin, the architects were able to sequentially insert the pointclouds into AutoCAD and draw lines and details after the point clouds. In Figure 4, an example of a point cloud drawing file is given along with a snapshot of the actual restitution process. As shown in the figure, the partial point cloud drawings were possible to insert into the AutoCAD 2010 environment. In order to save on resources and to be able to insert more point cloud files into a drawing, color information was discarded. Thus, in this mode it was rather efficient to hide and display several point clouds at a time and continuously add features onto the line drawing.

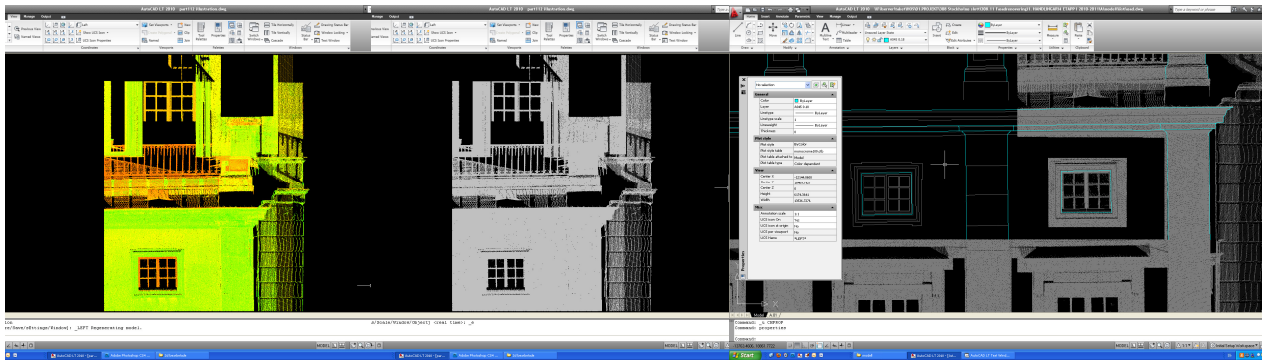


Figure 4: Display of partial point cloud drawings into AutoCAD. On the left, sample of point cloud drawing with intensity information. In the middle, the same drawing after discarding color information. On the right, display of several point cloud parts into a single drawing for restitution.

By employing the method described in the above, it was possible to create accurate drawings in a fast and rather cheap way. However, not all details were visible from the point clouds. For instance, although edges of extruding parts were immediately visible, the edges between the joints of the sandstone pieces were not visible. The missing information was drawn after orthophotos that were created for these facades.

According to the original requirement line-drawings of scale 1:50 should be produced and used for all purposes. This scale is not very demanding in the sense that the desired accuracy of approximately 1cm is rather easy to achieve. Therefore, the use of point clouds for the creation of line drawings was permitted. However, in order to accommodate the requirements of other conservation processes such as inventory, more detailed drawings were required. It was determined that for this purpose, the detail of 1:20 scale was desirable. Given the extent of the surfaces, the amount of detail and the associated cost, it was determined that the deliverable orthophotos could be as accurate as the 1:50 drawings but should display details of a scale of 1:20. In this respect, the delivered orthophotos were produced in a rather unconventional manner i.e. the image acquisition was designed for a deliverable of 1:20 but instead of using targets and geodetically measuring details of the surface, control points were interactively selected from the point clouds. In this respect it was possible to orient numerous images with an overall accuracy that in the end was estimated at 5mm.

The original images were acquired by a full frame Canon camera using a 24 mm lens from a distance of 5m. The pixel size of the original images was estimated to be 1.3 mm while the pixel size of the delivered orthophotos was set at 2.5mm. In order to maintain a favorable base to height ratio and to be able to reconstruct areas that were impossible to acquire while scanning from the ground, the length of base was set

at 2.5m. This configuration resulted in a 1:2 base-to-height ratio and a field of view of 7.5m by 5 m. All photogrammetric processing was performed in the Topcon Image Master software. Camera calibration was also performed by the Image Master Calib module. In Figure 5, a snapshot of the Image Master software is used to present the results of the photogrammetric orientation in terms of residuals and statistics for the selected control points.

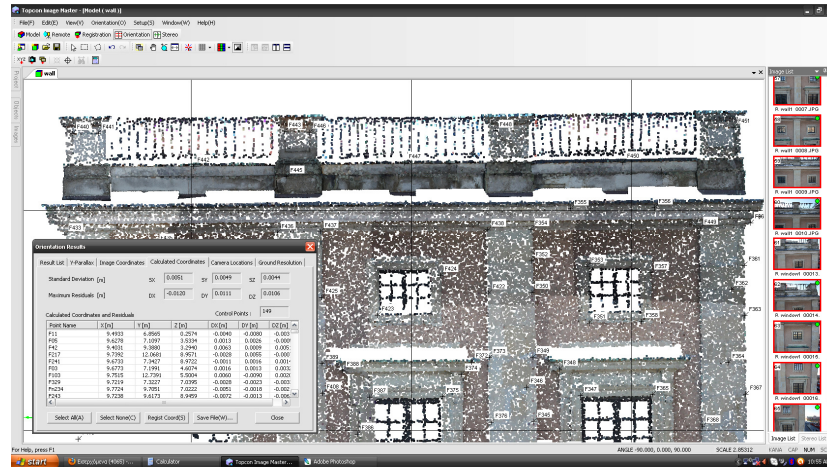


Figure 5: Statistics and residuals after the photogrammetric orientation of images in Image Master software while using control points interactively selected from the original point cloud.

By employing the workflow described in the above, detailed high quality orthophotos were created. For the Norther facade, the delivered orthophoto was a photomosaic comprised of more than 150 images. Respectively, for the Easter facade, a total of 80 images were used. Figure 6 presents examples of the delivered line-drawings and orthophotos.

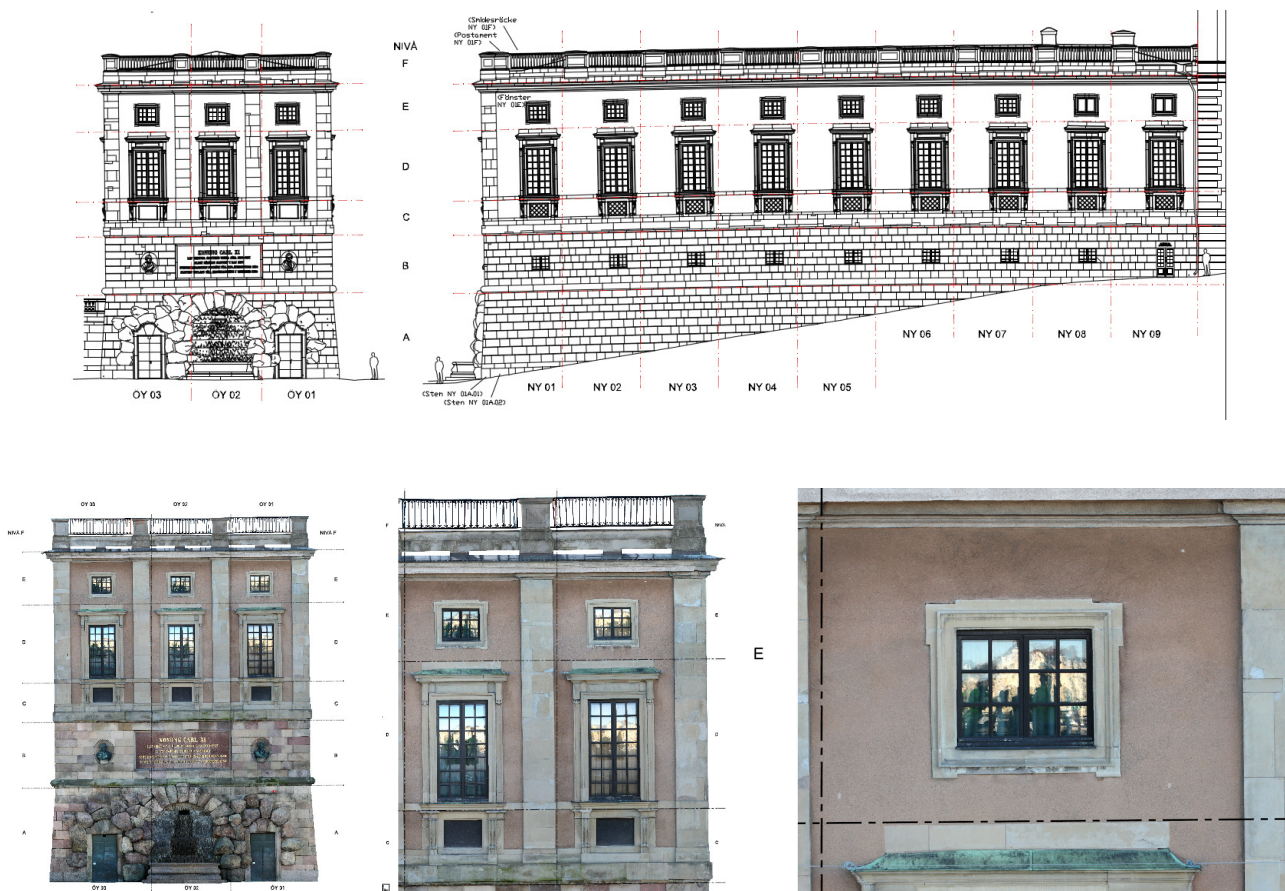


Figure 6: Examples of the delivered line-drawings and orthophotos

Presently, the methods described in the above have proven adequate and the deliverables have found use in many applications. For instance, the line drawings have already been used for producing layouts for the required conservation actions. Also, after discovering the true extent of damage in the sandstone cladding, the value of having created the orthophotos cannot be overstated and the existence of the orthophotos is the very reason that made possible the option of removing every single piece of the Roslag sandstone for the conservation process. Currently, point clouds and image data are acquired for phases 2-5, for the production of line-drawings and orthophotos. It is also considered that the same should be done for phases 6-9 sometime in the immediate future.

As already mentioned, another aspect of the documentation process is the detailed 3D recording of the sandstone sculptures, column capitals and artistic decorations in general. These assets of the facades are in particularly bad condition and as already mentioned several parts or even entire pieces must be replaced. It is already known that a lapidarium is required on site for this kind of work. However, given the bad condition of many pieces, traditional methods of replication that employ plaster molds are out of question and it is investigated how modern methods of 3D recording and 3D printing may be employed. White-light scanning has already been tested for part of the facade, but since it has proved impossible to completely stabilize any kind of platform for that purpose, this method is no longer an option. Presently, the alternative of handheld scanning is investigated and is found to be promising, since this type of equipment is impervious to platform motion and vibration. However, the requirement for targets on the surface and the rather time consuming nature of the process calls for a carefully planned strategy. In this respect, it is considered that only severely damaged and fragmented pieces of decoration are to be immediately scanned with such a scanner from a lift while the rest will be scanned at a later stage, when a scaffolding is set on site. In any case, it is rather clear that this type of scanning is the most appropriate for this case and that 3D modeling is also a possibility for completing missing parts on statues and on decoration. 3D printing is also expected to be very useful since in this way, materials can be roughly shaped very quickly and a small part of the work can be performed manually in order to also have the precious sense of handicraft.

4. CONCLUSIONS AND FUTURE WORK

This paper provides insight into the processes of research, documentation and decision making for a large architectural heritage conservation project, the “Long-term maintenance program of the facades of the Royal Palace of Stockholm”. Several aspects, regarding research, investigation are discussed in conjunction to the ICOMOS “Recommendations for the analysis, conservation and structural restoration of architectural heritage” in order to demonstrate how the suggested principles and guidelines may be employed for such a large project. Methods employed for the geometric documentation of the facades are also presented and discussed. However, several issues such as monitoring or information management remain open. Every architectural heritage conservation application calls for extensive documentation and monitoring during all stages and the amount of information that is produced overtime can only be handled by appropriately designed information systems. Issues related with software, the database design, metadata schema, data hosting and AAA protocols will be under investigation shortly. The properties and the functions of the information system will probably be defined as proposed in [3] but it is also considered that it could be good practice if the team could build on the experience of systems employed for other architectural conservation projects such as that of the Acropolis.

5. REFERENCES

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