Laser scanning at Castle Hochosterwitz in Carinthia.

3d optical documentation techniques in the service of a time-efficient, highly precise and distortion-free architectural survey

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Abstract: The paper delineates a strategy capable of creating a number of efficient and practical outcomes that can be generated from 3d scanning data. In the field of architectural heritage conservation especially, and in all cases where substantial transformations have to be implemented, pure 3d outcomes do not really meet the needs of planners. While on the one hand a full surface 3d recording of the artefact is welcome to the national preservation authorities for documentation needs, planning architects are still forced to deal with 2d materials.

The strategy developed for the laser scanning campaign at Castle Hochosterwitz shows that both demands can be satisfied without the need of additional tachymetrical measurements. However density and geometrical precision of point clouds make sure, that 2d planning materials up to a certain scale can be deduced without loss of exactness and reliability. The innovative new workflow established has also shown to be more time and cost efficient, when compared with conventional documentation procedures. It is also more flexible: once a complete and homogeneous data set of the object containing 3d geometry and texture has been recorded, all kinds of outcomes – ground plans, sections, top views, prospects, ortho-photos - can be derived without the need to go back on site.

Keywords: Laser scanning – architectural survey – documentation strategy – optimized workflow

Introduction

Laser scanning is becoming a more and more refined and powerful working tool in cultural heritage documentation. In the field of archaeological and architectural documentation, and especially when combined with digital photogrammetry, it reveals a stunningly high potential which finally will question well-established documentation procedures based on a purely tachymetrical approach. Compared with conventional documentation techniques it strikes by its obvious capacity in documenting complete 3d surfaces thereby creating a consistent and textured 3d image of the historical artefact (ZIMMEMRMANN and ESSER 2008). All kinds of 3d modelling approaches have therefore been introduced into archaeological research projects in spite of often being time-consuming and difficult to handle. It might be because of the substantial problems inherent in the elaboration of 3d data that the scientific efforts concerning 3d matters seem to have covered relevant parts of our intellectual capacities. In consequence more easy and practical approaches which focus on reducing large quantities of information recorded in 3d scanning campaigns have rarely been adopted in order to acquire conventional but easy-to-handle planning materials. The problem seems to have a psychological dimension too: Do we consider research dealing with 3d problems more worthwhile than caring about the evident necessity of building a bridge between 3d research and recording

and 2d usage of geometric data which still represents the standard in the world of planning? Does it seem anachronistic to use a full 3d data set but focus on a final 2d output? The evident void between an innovation-oriented research field of 3d measurement technologies and a performance-oriented approach in the world of planning and building has soon to be bridged. It is time to think anew about 2d without falling back into a practice that seems to be outdated.

Fig. 1 – Castle Hochosterwitz, north-west view (Copyright: Jan Kanngießer)

There are quite a number of good arguments why a combination of the two approaches seems reasonable. Firstly, documentation in 3d space has the power to record the status of an historical object in an all-embracing way, by measuring its full surface geometry and by recording real colour textures for all the measured object surfaces (ESSER and MAYER 2008). The result is a 1:1 image of the artefact which can be preserved as a precious documentation of its specific status at a certain moment in time. Secondly, 3d scanning technologies have gained a stunningly high velocity and productivity in measuring complex 3d spaces; without doubt, they have the power to compete with conventional tachymetric measuring strategies. Not only has it become evident that the time necessary for positioning and orienting a laser scanner is even shorter when compared to a tachymetric system and that the precision of geometric data recorded by laser scanners can already be compared to that of total stations. But more importantly, the amount of information and richness in detail of any laser scanning data coverage easily exceeds the information recordable by the most experienced operator of tachymeters. When combined with digital photography the two data sets – geometry and texture – form a hybrid but still homogenous and uniform documentation output that cannot be gained by a conventional combination of tachymetry and photogrammetry (JANSA et al. 2004; ULLRICH

2004). The documentation results obtained by laser scanning devices thus have an unquestionable value that should not be disclaimed by hesitant or conservative approaches.
A reduction of the complete 3d and texture data into a practical and application-oriented 2d extract thus will have to be applied with respect to the right point in time in the course of a documentation procedure: once the 3d recording has been completed and a comprehensive 3d image has been created the possibilities regarding subsequent works are up in the air again. The elaboration of 2d documentation materials has a long and successful tradition in architecture. Starting with Renaissance artists like Raffael, Serlio and many more who were eager to document the standing remains of the Roman past, the 2d representation finally culminates in the powerful working tool of our times, which – in the best sense of a refined level-of-detail strategy – is able to build a bridge from the smallest detail representation up to an urban scale. At the same time however, architectural plans should not be understood as mere reductions of a seemingly more complex 3d environment. Quite to the contrary they are calculated abstractions that follow a well-established coding system, an international language able to express all the specific information necessary to describe the general disposition and all relevant details of a 3d architectural space. Thus architectural plans are in no way mere reductions but to the contrary they represent rich abstractions and meaningful concretions full of information which are worth being considered as valuable outcomes of an innovative 3d recording.

Fig. 2 – Earliest representation of Castle Hochosterwitz dating from 1575 (Copyright: Gerold Eßer)

Documentation history of Castle Hochosterwitz

Castle Hochosterwitz is situated in the district of St. Veit an der Glan, about 20 km north of Carinthia´s Federal Land`s capital Klagenfurt. As for its formidable position on top of a more than 175 meter high solitary crag and because of its extraordinary state of conservation it attracts about 100.000 visitors every year, a fact that has significantly contributed in transfiguring the organism into something like a cultural monument of a national dimension. Once a powerful medieval stronghold, it was transformed into a Renaissance castle on

a rock during the 16th century. Inhabited by a powerful family of regional – a little later supra-regional – importance and finally of European format, it has at all times been the impressive object of historical representations, executed in frescoes, oil paintings, etchings and drawings (DINKLAGE 1980), the earliest known dating from 1575. All of these images surely had the contractors´ wish for representation of earthly power being transformed into an image, which, technically speaking, had to deal with being forced to condense a complex 3d structure – the castle and its fourteen gates on top of a rock – onto the bi-dimensional surface of the canvas, a task which has seen great success as all these images bravely succeed in transporting a faithful view of the structure as a whole and yet in detail, that way putting today`s historians in a position to be able to reconstruct parts of the history of Castle Hochosterwitz, which otherwise would not have been documented.

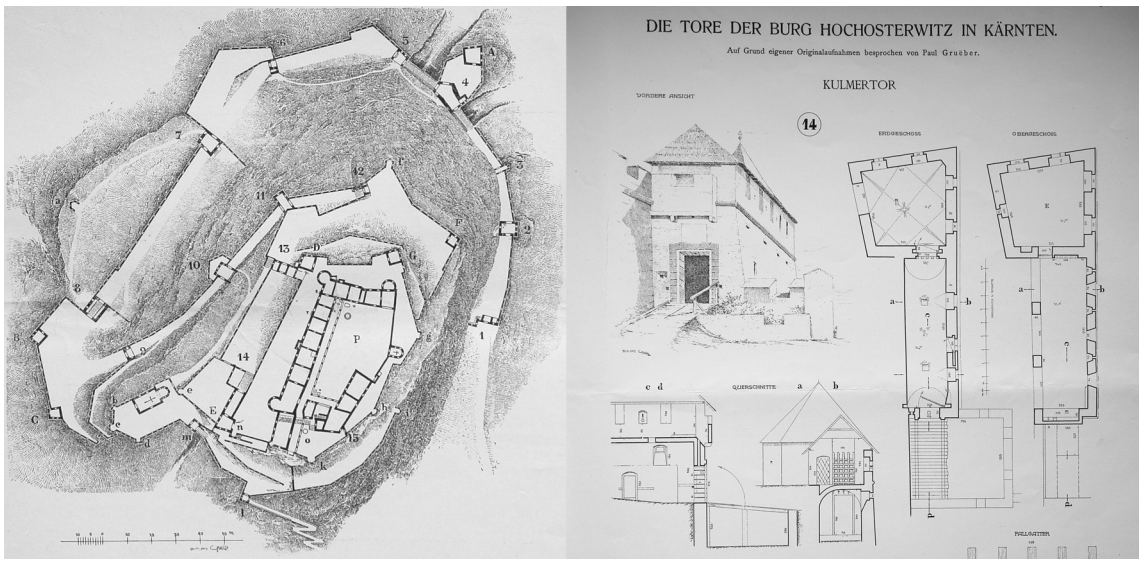

Fig. 3 – Scientific documentation of Castle Hochosterwitz by Paul Grueber in 1925 (Copyright: Verlag Kollitsch, Klagenfurt)

The scientific interest in the Castle`s history, that seemed to arise only at the end of the 19th and beginning of the 20th century, however substantially altered the view of an adequate way to represent the building´s structure. In 1889 and again in 1925 two different maps of the area were published which, with a good portion of intuition, succeeded in representing the basic conformation of the marvelous ensemble, yet failed to introduce known surveying standards of the time in order to get distortion-free and dimensionally accurate layout drawings (CENTRAL-COMMISSION 1889; GRUEBER 1925). The latter author, Paul Grueber in 1925, when treating constructions of limited dimensions, such as are the famous fourteen castle gates of Hochosterwitz, clearly showed a great capacity for transferring three-dimensional constructions into significant and accurate architectural plans, representing each of the gates in floor plans, vertical sections, prospects, details and perspective drawings with the obvious aim of conveying a comprehensive and complete idea not only of the geometric aspects but also of the constructional and functional contents of the displayed objects.

Hence, in looking back on the existing historical documentation material, it seems fair to judge that most of the representations conserved followed a definite and precise goal and achieved its objective fairly well. Efficient solutions for clearly understood problems have surely been found which, in most cases, had been

developed in accordance with the technological and psychological conditions of that era. But this judgment is in no way meant to glorify without criticism the representation techniques which are no longer up-to-date. To the contrary the displayed analysis has been executed with the clear goal of being able to act on a firm and conscious basis, which will assure that the still inherent, enormous potential for improvement is with confidence being exploited.

Project and documentation requirements

When in the spring of 2009 the Department of History of Architecture and Building Archaeology of Vienna University of Technology [75] was asked to undertake an architectural survey of the structures of the highest level of Castle Hochosterwitz – including all the buildings inside the historical outer ward – it soon became clear that the planned documentation would, with all probability, constitute a good opportunity to test state-of-the-art measurement techniques when confronted by a structure that, according to its largeness, complexity and topographical position, without any doubt belongs to the most challenging objects of its kind. Committed by Cultural Heritage Authorities and the Government of Carinthia, the documentation was aimed at fulfilling some quite different purposes. First of all a complete documentation as a faithful testimony to the castle`s state of conservation seemed necessary; secondly all kinds of yet undefined documentation material was needed in order to enable a profound and complete historical research of the castle`s history; thirdly a set of three floor plans and four transversal vertical sections in scale 1:100 was required in order to be able to conduct the intended restoration process. With respect to scale, quality and detail of information, the documentation was therefore required to cover the whole organism while still recording the architectural detail, thus bridging the gap between the scale of a layout drawing and the information inherent in 1:50 plans. Moreover the covered area of about 4.000 square meters, more than 60 rooms distributed over the three storeys of the castle and the hilly topography of the mountain top, represented conditions that would have aggravated every kind of conventional surveying strategy strongly. Summarizing all documentation requirements, it seemed quite unlikely that a tachymetrical survey would – with respect to limited financial and time resources – be able to satisfy the expectations.

Documentation strategy

It was therefore decided that in principle all utilizable measurements were to be recorded using a laser scanner and polygonal traverses where measured, in order to construct a rigid net of geo-referenced reflecting targets as tie-points in order to optimize the registration of the single scan positions. Strong arguments for that strategy were:

- Laser scanning would allow the recording a full surface geometry thus enabling the exploitation of the documentation in the course of further unknown purposes.
- Laser scanning would guarantee fast on-site progression of the documentation work thus decreasing personnel costs.

[75] For further information see Department homepage http://baugeschichte.tuwien.ac.at

- Additional close-range photogrammetry executed by way of a digital camera mounted on top of the scanner would allow the recording of real colours as an additive data set.

In comparison to a tachymetrical survey the challenges that had to be faced were to be faster and spend less time on site, to be as precise as when using tachymetry by working with the highest possible accuracy of measurement and to record more information thus creating a versatile and flexible data set.

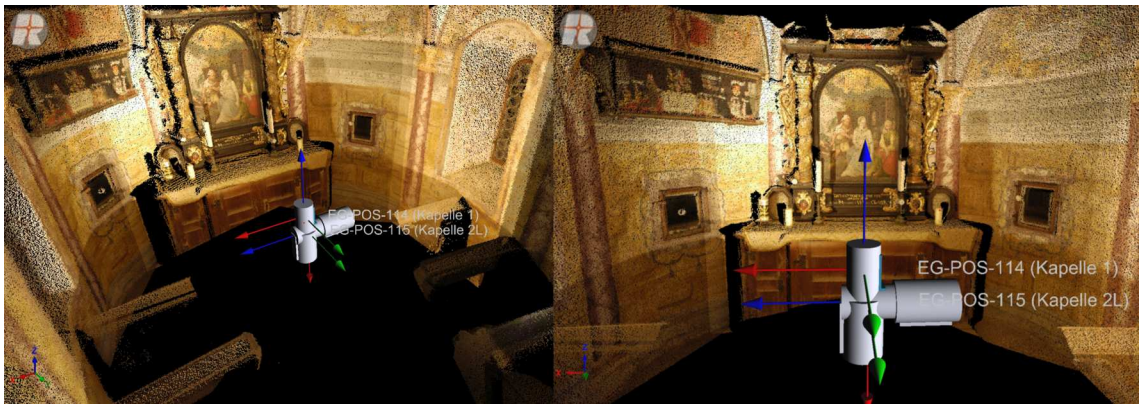

Fig. 4 – Coloured point cloud cluster of St. Nikolaus chapel at Hochosterwitz (Copyright: J. Kanngießer – M. Ganspöck)

For all laser measurements a long-range 3d scanner RIEGL LMS-Z420i was applied. [76] The scanner is worked on the time-of-flight measurement principle and is operated by RIEGL-own software RiSCAN PRO. [77] At Hochosterwitz a standard angle measurement resolution of 0,12°was implemented creating about 2.000.000 points in space per single scan. This means that in a distance of 5 meters the measured 3d points form a point grid of approximately 10 mm distance [≈ 5.tan(0,12)] on the object surface. While scanning, only in the very few cases of extraordinary narrow spaces which had to be documented, this resolution has been lowered, while in the case of the outer walls of the castle, where greater measurement ranges up to about 20 meters were unavoidable, the resolution was augmented by a horizontal and vertical step width of 0,03° [≈ atan(0,01/20)]. In order to calculate the effect of the standard measuring error on the documentation material the following considerations needed to be made: the scanner´s measurement error is defined as +/-10mm standard deviation of the scanning unit measured in the beam direction. With respect to the desired scale of the documentation plans, a measurement error of 10 mm transferred onto a 1:100 plan would cause a drawing error of only 0.1 mm; assigned to a 1:50 detailing, the error would be 0.2 mm maximum, still being of little importance for the accuracy of the drawings. In cases where continuous and quite plain surfaces are measured the effective accurateness of a plan is even higher as an average determination of a plain wall surface would with all probability represent the actual position of that wall; in the cases of geometrically more complex or quite uneven geometries the accurateness of the final plans would on the other hand be

[76] For technical specifications see data sheet of LMS-Z420i on RIEGL website http://www.riegl.com/products/terrestrial-scanning/produktdetail/product/scanner/4/.

[77] Technical specifications of RIEGL software RiSCAN PRO are found under: http://www.riegl.com/uploads/tx_pxpriegldownloads/11_DataSheet_RiSCAN-PRO_22-09-2010_04.pdf

considerably lower thus requiring additional measurements using measuring technologies of higher accuracy.

Special care was taken to maintain the measurement error of +/-10mm when considering the whole structure. A mere registration of the single scans by extracting local coordinates of all visible reflecting targets and orienting the scan positions in the manner of a chain registration, would have caused severe problems. Instead, by introducing a tachymetrical measurement of all the reflecting targets necessary for the registration of the single point clouds, the overall measurement error that way has been reduced to a minimum. In addition, all the 3d coordinates of the reflecting targets have been geo-referenced by measuring three triangulation points found in the vicinities of the castle belonging to the public monitoring network and by calculating a rotation-translation matrix for the reflecting targets. The 3d coordinates of the reflectors were then introduced into the RiSCAN PRO scanning project as a new global coordinate system and all the single scans were subsequently registered on that rigid and geo-referenced coordinate net. By doing so, a high accuracy of the global registration of all single point clouds was obtained.

During the short period of only five days at the beginning of April 2009, about 250 scan positions were measured by a team of three with the total result of some 500.000.000 points being recorded. In addition, for each scan position seven digital photos were automatically captured using a calibrated CANON EOS 1ds with a 14mm lens mounted on top of the scanning device. Each picture contained about 10 mega pixels of texture data. Via known internal and external camera calibrations these shades of colour have automatically been referenced to the geometry of their respective point clouds thus giving the opportunity to create coloured point clouds of all possible situations required in future evaluation projects. The total number of calibrated photos recorded is approximately 1750.

By this documentation strategy a coverage of about 95 % of the structure´s surface has been reached, merely omitting parts of the outer roof surfaces that, due to the fact that they are not visible from the ground, have not been measured.

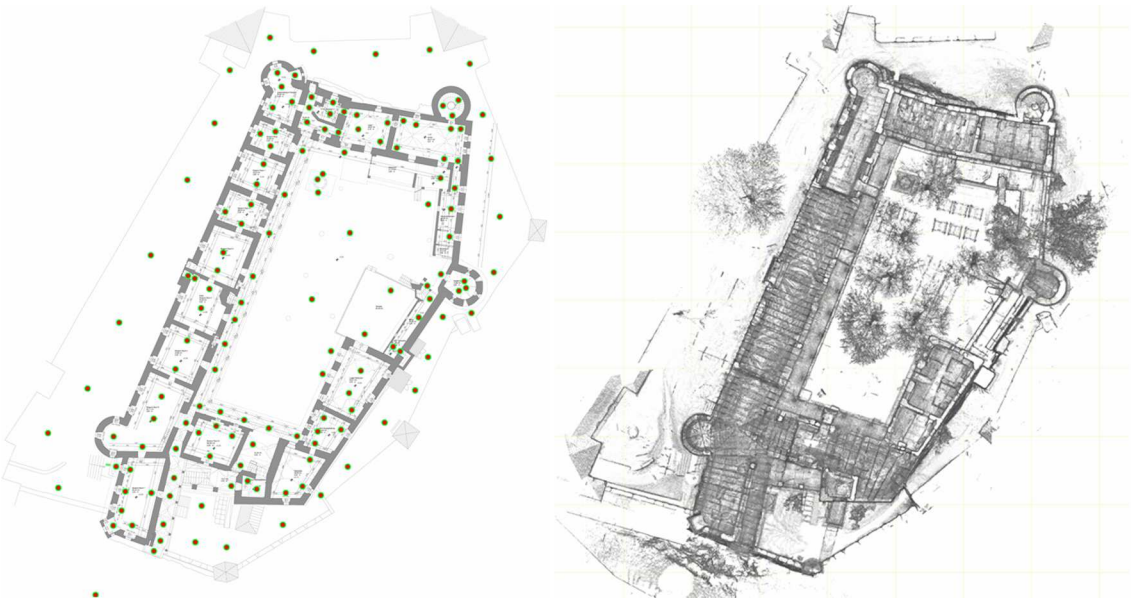

Fig. 5 – Scan positions necessary for recording ground plan information; overall point cloud (Copyright: J. Kanngießer – M. Ganspöck)

Data processing strategy

The post-processing strategy which will finally lead the way into drawing classical 2d architectural survey plans, requires some preparatory steps. After the final registration of all single point clouds is finished – a work that preferably should take place while still on site in order to be able to remedy possible documentation errors – the scanning raw data sets have to be cleaned of irrelevant information like vegetation, human beings, furniture et cetera. After that, an important decision has to be taken concerning the question of whether all single point clouds are going to be reduced to hold a homogenous resolution (e.g. by applying an octree algorithm or some other comparable filter for point reduction). Note that it is strongly recommended that the raw data be not reduced but all single point clouds be used with their full information, to retain the information being evaluated as close as possible to reality.

As a first step let us now imagine the method that will finally enable us to draw a ground plan of a specific area. All the following steps are still going to be made inside the RIEGL capturing and processing software RiSCAN PRO. The procedure follows an easy concept: to be able to draw a floor plan all relevant measuring data-sets have to be selected and exported into CAD (Computer Aided Design) software. A floor plan should basically contain information about three different, horizontally organized slices of the architectural space: a section slice which is preferably defined at approximately one meter above floor level; secondly, a floor slice which contains all the information which is visible below the height of the section slice, and thirdly, a ceiling – or vaulting – slice which shows all the constructional elements visible above the height of the section slice. [78]

As most of the single scans contain information covering more than one of the abovementioned slices, it is recommended that all relevant single point clouds concerning a given area of the building into one newly created view are imported. Once this compilation has been completed, the three horizontal slices which are part of the point cloud cluster are going to be selected, each in one operation, by defining the medium height of the slice – defined by its absolute z-coordinate – and its thickness. Each slice is saved as a polydata – a data unit which is a specifically assembled new point cloud – inside the RiSCAN PRO project, exported using an adequate file format (ascii xyz for the whole point cloud, dxf for the various sections) and finally opened in a CAD file. As all the recorded point data have initially been registered in one common coordinate system – in Austria the Gauss-Krüger Coordinate System – and because the XYZ Coordinates of the polydata are recorded keeping all the original coordinate values, the point coordinates once imported into the CAD drawing have not been altered.

As previously mentioned, horizontal intersections can be arranged at predefined heights and there is no limitation to doing so when evaluating a given point cloud. Wherever floor surfaces are heavily inclined or simply uneven a suitable procedure consists of evaluating the relevant parts by a number of intersections of equal distance (ESSER 2006a).

[78] For further information concerning national and international requirements for elaborating plan material for architectural documentations consult national norms and rules as e.g. ÖNORM A6250 “Bauaufnahmezeichnungen” for Austria and DIN 1356-6 Teil 6 “Bauaufnahmezeichnungen” for Germany.

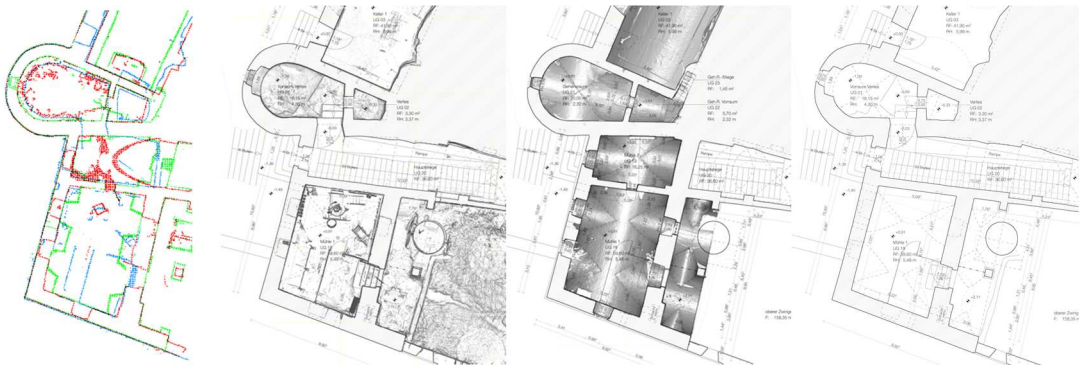

Fig. 6 – Elaboration of a ground plan: horizontal sections; triangulated mesh; final plan (Copyright: J. Kanngießer – M. Ganspöck)

An alternative procedure can be conducted in all cases when continuously bent or fairly uneven surfaces are to be interpreted, as for instance vaultings or unsteady floor surfaces showing fairly different height values. In order to be able to recognize orthogonal projections of section lines of intersecting vaulting surfaces or other break lines hard to be read from pure point cloud clusters clearly, it is recommended a relevant part of the point cloud be exported and opened in some kind of 3d modeling software (like GEOMAGIC or POLYWORKS) and this geometry be converted into a triangulated mesh. The mesh subsequently is to be shaded for a better reading, transformed into an ortho-photo – a 2d orthogonal projection normal to a horizontal plane – and exported in some pixel format. When opened in a CAD file the ortho-photo can be inserted into the existing floor plan and all relevant projection lines can be drawn precisely.
There are some cases which necessitate the acquisition of further data out of the point cloud as, for instance, the vertical sections of the vaults. As is common usage their profiles are to be retracted around a horizontal line connecting the two starting points of a vault so that all the vaulting profiles can be added to the floor plan. How can this information be recovered? Instead of evaluating the point cloud in the way described above by exploiting a horizontal section, the laser data are cut vertically along a base line which will define the requested direction – presumably perpendicular to the vault axis – of the intersection. Again the definition of the thickness of the slice to be selected is vital for the kind of information to be recovered. The selection of a vertical slice is once again transformed into a polydata and subsequently exported to CAD.

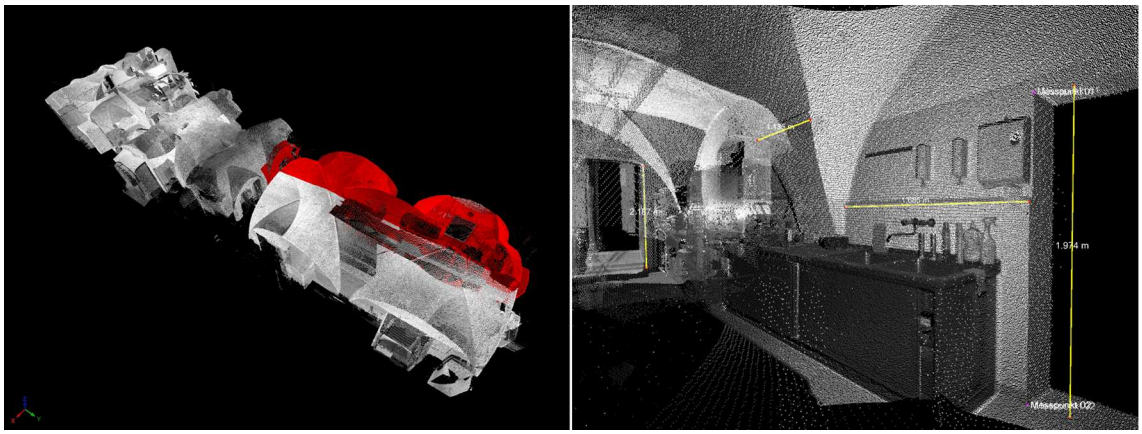

Fig. 7 – RiSCAN PRO software: single measurements directly taken in the point cloud (Copyright: J. Kanngießer – M. Ganspöck)

In other situations, for instance when indicated dimensions have to be inserted into CAD plans, it might be of great help to take measurements directly in the full point cloud. A function of RiSCAN PRO gives us the possibility to do this easily. In order to facilitate snapping on respective 3d points, parts of the point cloud can be selected and hidden. The measuring in 3d space this way constitutes an easy tool for taking every desired extra measurement. The rest is pure CAD drawing. All temporary results that are imported from RiSCAN PRO can be organized in layers and evaluated.

Developing the procedures outlined above, it has been possible to evaluate the recorded laser scanning data with the result of a total of three complete floor plans and four vertical sections of the Castle Hochosterwitz being produced. While recording of the data took about 250 man-hours, another 470 man-hours were needed in order to elaborate the final results, displaying a ratio of approximately 1:2 for the time required for the two main steps, impressively revealing the effectiveness of the proposed strategy. The first complete and highly precise geometrical documentation of one of the best known and frequently visited cultural heritage objects in Carinthia has thus been produced.

Summary

This paper has shown that complex architectural surveys can be executed primarily using laser scanning technologies instead of tachymetry and without any loss of the required exactness of the final result. The set of plans elaborated for Castle Hochosterwitz had been commissioned to be drawn in the scale of 1:100 but when it comes to the richness of their detailing the finally executed plans would without any doubt fulfill the requirements of a 1:50 documentation. Moreover it has been demonstrated that the total time of 730 man-hours needed for executing and elaborating a survey of the size of a fairly large castle such as Hochosterwitz was very low if not considerably lower than compared to a tachymetrical survey.

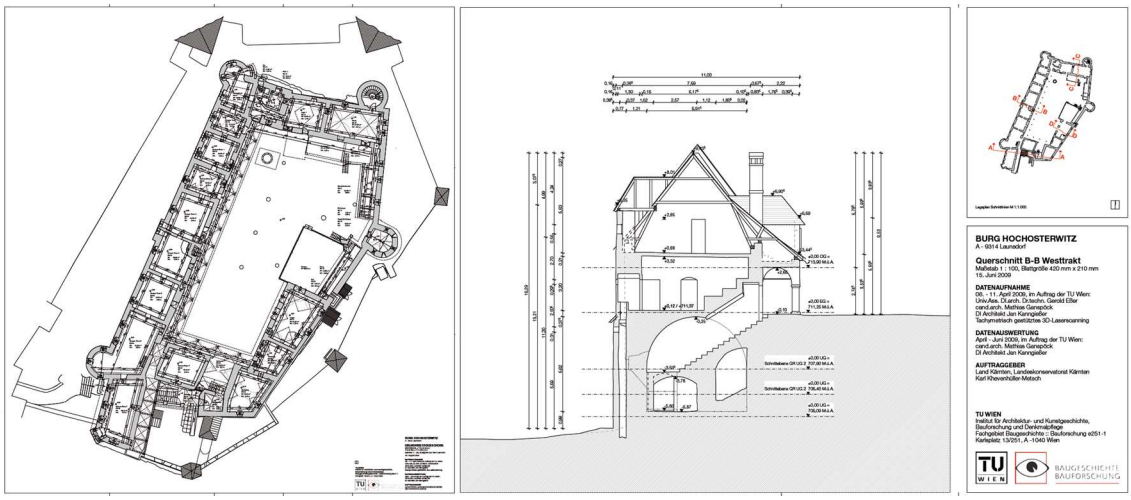

Fig. 8 – Examples from the final set of plans: ground floor and vertical section (Copyright: J. Kanngießer – M. Ganspöck)

As a further advantage which has been achieved without creating any additional cost, a full surface 3d documentation of the whole structure has been accomplished; a data set that is complemented by the recording of all material colours. An extraordinary 1:1 image which constitutes a valuable document of the status of the cultural heritage structure in the year 2009 has thus been produced. As yet another advantage

which, in the course of further elaboration works, will easily be rewarded, that 3d document represents an archive allowing further planning material – as e.g. a site plan or isoline representations, elevations, ortho-photos, and triangulated and coloured 3d models – to be achieved without the inconvenience of turning back on site.

The speed of the technological progress in scanning hardware and software and in computer technology, in the future will, without any doubt, strengthen the tendencies sketched in this paper towards a laser scanning dominated architectural survey. The latest innovations on the laser scanning market already show that today`s scanners are working much faster and even more precisely while executing much higher numbers of 3d measurements. [79] In addition to that, registration processes with higher grades of automation will once again shorten the effective time on site. Parallel to that development a significant change in the wishes of clients will surely occur. The adaption of the visual habits of contractors and end-users of architectural and archaeological documentations will finally lead to a more common double use of the recorded material: besides an unchanged use of 2d materials in research, planning and building processes, laser scanning data will more and more be exploited to achieve further steps in the application chain, as in 3d scenes and films that are going to be produced for exhibitions and presentations of all kinds.

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