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Digital Technologies in Heritage Conservation. Methods of teaching and learning this M.Sc. degree, unique in Germany

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Abstract A new master's degree commenced in 2017 at the University of Bamberg. The purpose of the M.Sc. Digital Technologies in Heritage Conservation is to impart theoretical and practical knowledge and develop competence in critical assessment and object-oriented solutions. The aims, curriculum and methods of teaching will be discussed in this paper.

Keywords: architecture, engineering, computer science, heritage conservation, digital technologies, curriculum, object-based learning (OBL)

1 Introduction

In his 'Ten books of architecture', Vitruvius Pollo requires that an engineer-architect must be multi-talented with a diverse education with knowledge based on *fabrica* (craftsmanship) and *ratiocinatio* (intellectual work), enabling him to judge all other crafts. He specifies ten fields of knowledge in which an architect should be well versed: writing, drawing, geometry, arithmetic, history, philosophy, music, medicine, law and astronomy (Vitruvius 2001).

The new master's joint programme M.Sc. in 'Digital Technologies in Heritage Conservation' aims to provide students with a similarly diverse set of skills, encompassing digital craftsmanship and intellectual skills along with many of Vitruvius' original set, adapted to today's high-tech world. Its contents and mission will be described in this paper.

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2 Brief introduction to object based teaching and learning (OBL) in heritage conservation

It has been observed that the use of object-based teaching and learning (OBL) as a form of 'student-centred' and 'activity-based learning' will be beneficial to students as a method of internalising and retaining theoretical and applied knowledge (Marie 2011). Object-based teaching and learning as a methodology, used in conjunction with university collections, can benefit teaching across many disciplines and departments (Hannan et al. 2013).

Furthermore, the combination of OBL with new technologies – such as those introduced in this Masters programme - contributes to active and experiential learning experiences and will help students to understand the issues involved in the digital and physical diagnosis and reproduction of an object. Kolb's research is strongly linked to pedagogies of active and experiential learning, which sees hands-on engagement with the object of study as key to personal meaning-making and the long-term retention of ideas (Kolb 1984).

Other research based at University College London uses a variety of methods to gauge relevant benefits for learners by using museum objects during OBL (Chatterjee et al. 2015). Object-based learning in connection with new digital technologies has also been discussed by (Loy 2014) which proposes using 3D printing in the classroom to create a new learning environment for students in design education, enhancing creative output.

Tiballi describes the use of OBL in higher education as a method for better cognitive and affective processing, and for learning through interaction with an authentic or even reproduced object. OBL increases observational skills, contextual knowledge, and empathetic imagination of the students, in particular, 'haptic engagement, which includes tactile, kinaesthetic, experiential and embodied knowledge, requires a student to become fully immersed in the learning environment' (Tiballi 2015).

The beneficial effect for learning can also be observed in the interaction with museum artefacts and on-site examination and digitisation of historic buildings, and are integrated into the new M.Sc. Programme which is outlined from section 3 onwards. OBL for teaching digital technologies in heritage has already been successfully applied in the UCL Bachelor of Arts and Sciences (BASc) and its interdisciplinary elective 'Technologies in Arts and Cultural Heritage'. In the BASc module, OBL has been very effective in promoting the successful acquisition of subject-specific knowledge and technical skills in the domain of digital workflows for heritage conservation (Hess et al. 2017).

3 Development of the new M.Sc. degree program

A new Master of Science degree 'Digital Technologies in Heritage Conservation commenced in October 2017 at the University of Bamberg, Germany. The aim is to expand the teaching expertise of the heritage science department alongside the well-established Master of Arts degree in Heritage Conservation. Over the last several decades, graduates of the M.A. Heritage Conservation program have gone on to fill many important positions in the heritage sector, and the same is hoped for the newly created M.Sc. The aim is to provide new students with an interdisciplinary skill set at the interface between heritage and technology.

The new degree course is taught and coordinated between the University of Bamberg and Coburg University of Applied Sciences and Arts, and is supported by The Free State of Bavaria and the Technology Alliance Upper Franconia (Technologie Allianz Oberfranken/ TAO, https://www.tao-oberfranken.de/). It is also part of the 'Digital Campus Bavaria' campaign for the overall integration of digital competencies into the curriculum (https://www.km.bayern.de/studenten/digitalisierung/hochschule-digitaler-campus.html). Both the University of Bamberg and Coburg University of Applied Sciences and Arts enjoy an excellent reputation in the monument, object and engineering sciences as well as in application-oriented digital technologies (University of Bamberg 2017).

4 Profile of the degree program

The new Master's programme 'Digital Technologies in Heritage Conservation', unique in Germany, offers an overview of the abilities and limits of current and developing digital technologies and provides the opportunity for students to gain in-depth knowledge in the application of digital technologies. The aim of this programme is to impart theoretical and practical knowledge in four main areas: **computer science** (cultural informatics and media informatics), **digital technologies** (2D and 3D optical surface imaging, measurement and analysis, monitoring, simulation), **engineering principles** (building physics and structural analysis) and **sensor technology** for a great variety of measurements in heritage conservation, as well as developing competence in **critical assessment and object-oriented solutions**. While the focus is on the assessment of heritage buildings and collections, students will also develop an awareness of the importance of cultural assets considered as knowledge stores, historical sources and components of regional identities. Details of the modules are outlined in section 5 below.

The programme was developed after observing the need for technology developments in the heritage and engineering sector. Therefore, the teaching objectives include attention to state-of-the art technology developments towards integration into heritage. Today, innovative digitisation and imaging technologies (often developed first in engineering and industrial quality-control) are being adopted in the fields of heritage conservation, monument preservation, museum studies and management as well as for the protection of cultural assets. The digital recording of buildings and objects is now as much a part of the preservation of historical monuments as the permanent monitoring of the condition of a building with intelligent sensor systems. Finite-element modelling (FEM) supports the assessment of structures and decision making for eventually needed repair, while numeric analysis in building physics can help avoid long-term degradation and increase the energy efficiency and usability of buildings.

The interdisciplinary team of teachers, the unique vocational profile and the modern technical equipment on this programme guarantee state-of-the-art training. The course is designed to accept a heterogeneous group of people with the aim to deliver a tailored-program for each student. Whilst in this degree course the topics and activities are naturally centred on historic materials, objects and buildings, the methodology of OBL also benefits joint projects involving students across multiple disciplines, departments and universities.

Admission to this program requires a German or equivalent University degree with a standard period of study of at least six semesters (three years) and 180 ECTS points in a related programme. These include architecture, civil engineering and courses in the fields of preservation of historical monuments and cultural property, restoration as well as building conservation and construction, computer science and applied computer science, digital humanities, archaeology, geography, surveying, archival studies, cultural management and communication design. Non-German native speakers require a B2 language qualification.

Completion of the two year M.Sc. (Master of Science) degree will give students a postgraduate qualification with high employability, equip them to take on highly technical tasks in heritage conservation and cultural management and allow them to fill professional roles where built heritage and museum issues interface with technological developments. The first graduates from this programme will be in the workforce in 2020.

5 Degree structure

This M.Sc. course consists of core, advanced and specialist module groups, as well as a practice-based final master's thesis (Fig. 1). The core modules introduce the topics relevant to the application of digital technologies in heritage conservation while the advanced and specialist modules allow students to focus on specific areas:

- **Digital modelling in heritage conservation** (subjects include: Building Information Modelling, Support Structure Simulation)
- **Digital analysis and monitoring in heritage conservation** (subjects include: Preservation Sciences, Buildings Physics, Monitoring, Structural Analysis)
- **Digital networking and knowledge distribution in the preservation of monuments** (subjects include: Web Technologies, Computing in the Humanities)

The specialist modules expand on the content of the advanced courses. The degree culminates with a practice-based master thesis centred on questions in heritage conservation, working in conjunction with institutions and authorities.

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5.1 Digital Technologies in Heritage Conservation, University of Bamberg

Introduction to Digital Technologies in Heritage Conservation: In this module, a general introduction to heritage conservation including the theoretical basis are taught as a prerequisite for working in the field. The digital technologies relevant for the preservation of historical monuments are presented, and placed in a scientific-historical context. Both the potentials and limits of their application are discussed (Fig. 1a).

Object recording: The students receive a theoretical and practical introduction to the potentials and methods of digital object recording. The objectives of fit-for-purpose data acquisition in heritage are explained, and different methods of recording compared. In addition to teaching the principles of optical imaging techniques (photography and 3D imaging) and the practical demonstration of standard imaging techniques available on the market, digital heritage case studies and the use and workflows of these technologies in real-world scenarios are presented. Students are given the opportunity to develop their skills in a practical residential course, where the process of learning by doing is encouraged (Figs. 2b and 3a).

Virtual modelling/ Processing of 3D data: The data collected at the residential course of the object recording module forms the basis for this module in which the principles of data processing are introduced. Here, the students are introduced to a variety of techniques including modelling point clouds to CAD files, the photogrammetry workflow, automatic geometry extraction, metric inspection, and the creation of virtual reconstructions. Pathways to 3D printing and to the development of Virtual Reality apps are taught (Fig. 3b).

Digital Modelling: The students deepen their knowledge of digital and mathematical 3D modelling. The module is divided into two parts: In the first, an introduction to Building Information Modelling (BIM) and its connection to infrastructure planning are taught at Coburg University. The second part of the module takes place at the University of Bamberg and includes virtual and parametric modelling with a focus on Heritage BIM (HBIM).

Digital Archiving: One of the aims of the new master's program is to bridge the gap to the digital humanities. In this course, students are introduced to the potential of digitisation and the fundamentals of collecting, archiving and disseminating data, as well as digital and metadata standards used in cultural heritage and 'memory institutions' such as museums, archives and heritage authorities. The course is supplemented by an excursion to the nearby State Archives as well as lectures from guests active in digital heritage activities.

Conservation Science: This module relates in-depth knowledge of conservation and restoration sciences from an art technology and materials science perspective. The focus is on the analysis of available analytical technologies, the anamnesis and diagnosis of material changes of historical substance and their therapeutic options, as well as inventory and condition recording by cartographic documentation and stratigraphic analysis (see Fig. 3c).

5.2 Digital analysis and monitoring in Heritage Conservation, Coburg

Signal analysis and measurement technology: The students are familiarized with the possibilities of sensor technology and common measurement data acquisition systems and receive an introduction to the further treatment of measurement signals.

Building Physics for Heritage Buildings: The module aims at preparing students - with and without previous knowledge of building physics - for the special questions posed by heritage buildings. The focus is therefore on understanding phenomena, identifying the influencing factors, selecting the right models and recognising the degree of precision of results –always based on practical examples. Active discussion within the course is encouraged, preparing students for the interdisciplinary discussion they will encounter in their professional lives.

Historic Materials and structural engineering: Students are given an introduction to the history and development of structural engineering techniques, and obtain an overview of the construction and chemical properties of historic materials. Students learn to model, identify and calculate static determined load-bearing structures such as beams and arches and they are to be able to describe the principle load bearing behaviour of walls, slabs and domes. An introduction to the computer modelling of bearing structures is given and geotechnical aspects and the influence of subsoil on damage and durability are taught.

Structural Simulation: Digital Modelling and Structures: This module deals with simulation of structures. Teaching includes the examination of historical structures by state-of-the-art calculation methods i.e. framework simulation programs and the Finite-Element-Method, in order to clarify the load-bearing behaviour and determine the causes of existing damage. Planning of necessary repair measures in accordance with the special requirements of historic monuments is also taught, with a focus on historical roof constructions, arches and vaults (Fig. 5).

Building Physics – Evaluation and Refurbishment: The theory imparted and the simulation tools introduced are applied directly to a practical refurbishment example in Bamberg. Among other things, static and dynamic thermal simulations at building and component level are compared, hygrothermal phenomena are simulated with different software packages and results evaluated. Damage models (salts, humidity) are applied to both monitored and simulated data (Fig. 4).

Monitoring and system analysis with digital data acquisition systems: Students acquire in-depth knowledge of the potentials of analysis and building monitoring using digital recording systems, non-destructive or low-destructive object and material analysis, the connection between damage mechanisms, damage progression and the preservation strategies at the monument, and the connection between building construction and object monitoring. These competences are applied to structures such as vaults, historical roof constructions and natural stone masonry buildings (Fig. 5).

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5.3 Computer science, University of Bamberg

The part of the curriculum devoted to computer science has been designed by two co-authors of this article who teach in the fields of cultural informatics and media informatics. In the planning phase, they addressed a number of critical questions. Which competencies in computing should the graduates possess? What skill level should they achieve? Which topics from computer science are most relevant to the digital workflows of heritage conservation? Finally, and related to the first three questions: How many of the program's total course hours should be assigned to computing?

While there are established curricular recommendations for undergraduate courses in computer science, most notably the Body of Knowledge compiled by the professional organizations ACM and IEEE-CS (Computing Science Curricula 2013), there is much less material available for the design of interdisciplinary programs. To the best of our knowledge, no recommendations exist for a computer science curriculum that is integrated into a heritage conservation program, neither at the undergraduate nor the graduate level.

It was clear, however, that the computer science curriculum should prepare graduates for a rapidly changing professional world. The curriculum designers wanted the graduates to become expert users of digital technologies, who do not just master tools but who also have a thorough understanding of fundamental concepts and methods from computer science. This understanding enables them to design digital workflows in heritage conservation, to bridge small gaps in such workflows by writing code, and to participate as a knowledgeable partner in the requirement analysis process for software solutions addressing larger gaps. In essence, this is how the planning team answered the questions of competencies and skill levels.

The selection of topics from computer science was guided by their importance for the field of heritage conservation. An obligatory general introduction to computing, which includes fundamental concepts such as relational data bases or operating systems serves as the base of the curriculum. All other courses are electives. With respect to the choice of teaching methods, it proved especially helpful that the curriculum designers could draw on extensive experience with an existing program, the M.Sc. Computing in the Humanities. Although the two programs have different objectives, they share the challenge of introducing students to computing who have not been trained in a natural science or an engineering discipline. For those students, the single most important form of teaching are the lab sessions, in which they work on practical problems such as data modelling or programming tasks.

For the **general introduction into computing** in the first semester, an existing introductory course for students from the humanities was revised specifically to serve the digital technologies in heritage conservation program. This concerns in particular the part dedicated to information systems (e.g. digital libraries, geoinformation systems). A new teaching concept was developed for the practical exercises in the lab sessions, which impart special competences, e.g. a Linux introduction in the context of treatment of operating system concepts.

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In the second semester, the students choose one of two electives. Option 1 is a **programming course** that teaches a first object-oriented programming language using examples relevant to the domain of heritage conservations. Version management systems and build management tools are also covered. Direct feedback showed that GUI programming is particularly time-consuming for the students. In the next teaching cycle this content will be replaced by a deepening of the basic programming part.

Option 2 is a course on **web technologies**. The exercises were planned to suit the special requirements of digital technologies in heritage conservation. One a unit was designed with concepts of Data-Driven-Documents (D3.js), which by default are only considered for simple 2D graphics, and are now combined with 3D visualizations based on the JavaScript library A-Frame. Furthermore, a stronger focus was placed on the use of Content Management Systems (CMS) for information portals.

The third semester provides a further set of electives: a course on **digital libraries and social computing**, a course on **computer graphics and animation**, and an **introduction to media informatics**. New teaching concepts have been developed for the lab sessions of all these courses. In summary, the students spend slightly more than 15% of their total work load in the program on computer science, that is, 19 ECTS from a total of 120 ECTS.

7 Conclusion

This paper has introduced a new degree program in 'Digital Technologies in Heritage Conservation' with direct connection to technological developments. The programme answers the needs of specialists at the interface of heritage conservation and technology.

It opens up opportunities to teach digital technology skills that are of use in the cultural sector and beyond. There is still, however, a challenge in selecting the appropriate methods for teaching and learning in the context of an ever-changing and fast moving technological environment, where existing technologies are constantly evolving whilst new techniques are being introduced from other fields such as engineering, computer science and medical imaging.

With an increasing demand in the cultural heritage sector for the use of innovative digital technologies to aid institutions in fulfilling their research, preservation and public engagement remits, it is vital that heritage professionals are educated in these new techniques. Similarly, it is also important that technology experts are made aware of the particular issues faced by the heritage sector. Graduates of 'Digital Technologies in Heritage conservation', the future stakeholders in the heritage field, will be aware of the potentials of new technologies and methodologies for cultural heritage and will be able to encourage and facilitate knowledge exchange in both directions.

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Figures

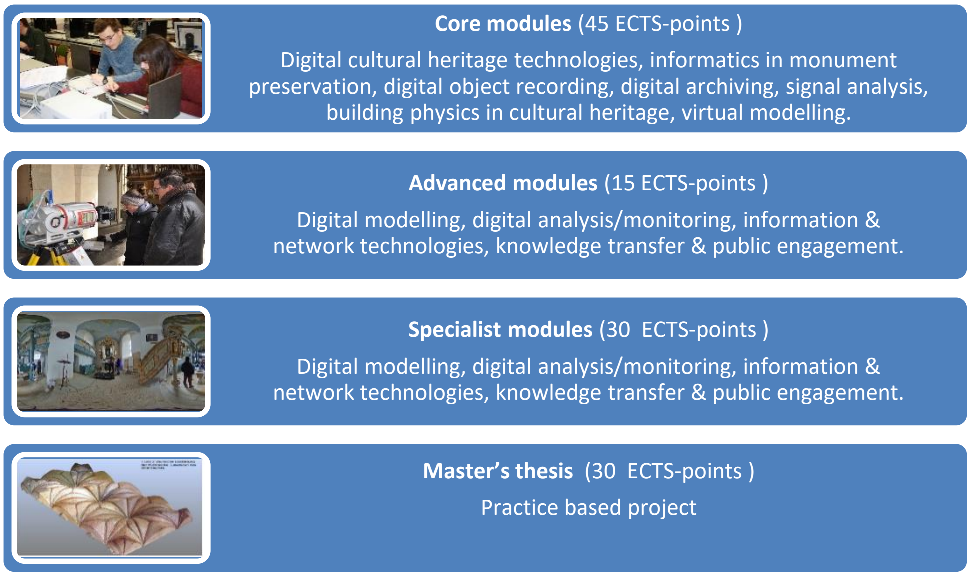

Fig.1 Degree structure of the M.Sc. Digital Technologies in Heritage Conservation – a Master’s degree with 120 ECTS.

Fig.2 Students receive theoretical classes in core modules, here digital reproduction and practical introductions to technical equipment in the classroom. **Fig. 2a**: Motivation for 3D printing and reproduction based on 3D imaging is explained in a lecture. **Fig. 2b**: A group of students are taught how to use a total station/ theodolite for 3D point-based imaging. **Fig. 2c**: A student is observing a thin-section of mortar in the microscope at an exercise in conservation science.

Fig.3 Students experience the full gamut of on-site work and lab-based processing. **Fig. 3a**: Students work hands-on in an 18th century church near Bayreuth, Bavaria, and are using 3D fringe-projection scanning on an epitaph. The target for 3D laser scanning of the complete church is also visible. The practical projects allow learning by doing, and students are faced with problems they have not encountered in the classroom. Errors are part of the learning process. **Fig. 3b**: Students working in the computer cluster on the creation of architectural plans and sections from 3D laser scans of the same church.

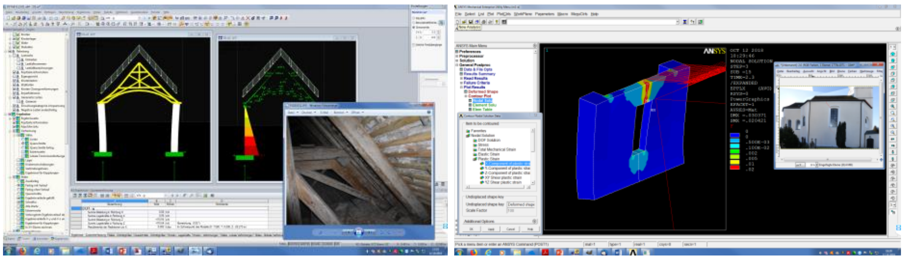

Fig. 4 Student exercises, Baroque church. **Fig4a**: Framework model of the collar beam roof without centering beam, horizontal thrust of the roof acts on the outside wall. **Fig4b:** Finite – Element – Model (FEM) of the wall; the horizontal thrust causes vertical cracks.

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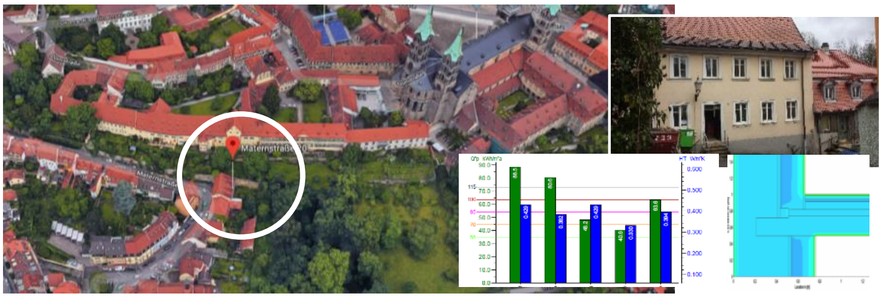

Fig. 5 The historic building in Bamberg the served as application case for the students. In the figure the building and its urban context, evaluation of different refurbishment options and an example for a hygrothermal evaluation of a building detail.

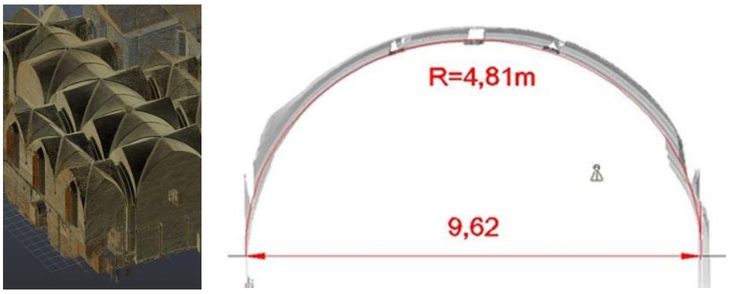

Fig. 6 The terrestrial 3D-scan of a gothic vault and the resultant derivation of their construction principles.

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