An Empirical Study on 3D Artefacts in the Scientific Life Cycle

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Abstract

3D models, objects and data are being used in an increasing number of scientific disciplines throughout different points in the research life cycle.

In addition to architecture, civil engineering and mechanical engineering – disciplines that traditionally plan and construct in three-dimensional space – they are also used in the fields of electrical engineering and information technology, physics and astronomy as well as in the conservation of cultural heritage. The types of models used differ considerably in the different disciplines. In addition to CAD models, there are for example formats such as point clouds resulting from laser scans, which are used to capture buildings or landscapes. In addition, there are simulations in which the temporal dimension also plays a role. Furthermore printable 3D models that allow the direct generation of a physical object are increasingly being created. The study presented here takes a closer look at the diversity of 3D artefacts, the point of their creation in the research lifecycle as well as the purpose these artefacts serve.

Contents

1 Introduction

The usage of 3D research artefacts is increasing in a number of scientific disciplines. A study conducted between the end of 2016 and the beginning of 2017 shows, that already one in ten researches states that 3D artefacts are generated during the research process Einbock 2017. Besides disciplines with a long tradition in planning and construction in the three-dimensional space like architecture or civil and mechanical engineering, 3D artefacts are also used in fields of electrical engineering, information technology or the preservation of cultural heritage. The kind of 3D artefacts differs considerably along the different disciplines according to the purpose they serve. There are for example point clouds, which result from 3D laser scanning or photogrammetry and document the scanned artefacts or buildings in their current state, or CAD models that are used for planning and constructing real world objects. In other disciplines (e.g. process engineering) we have simulation data visualized in the three-dimensional or even four-dimensional space or objects generated for a usage in a virtual environment (e.g. computer sciences).

As an information infrastructure institution, we want to support scientists throughout the complete research process and therefore need to understand the requirements and needs of scientists in the various disciplines. Building on the results of the above cited TIB study on information procurement and publishing behavior in science and technology Einbock 2017, the present study aims to gain deeper insights into user requirements and usage scenarios as well as the associated information needs with a special focus on 3D data, but also considering the interaction with other material, especially non-textual materials like images, videos or software.

2 Method

Understanding the needs and requirements of the scientists when it comes to their work with 3D data and artefacts calls for a method, that allows to gain deep insights in the working processes of the different disciplines. The method of choice in this case were semi-structured interviews, as to their open structure and the possibility to gain insights and details on the topic that might not have been thought of beforehand. During the interview phase it showed, that most of the interview partners requested the questions before hand and then answered the questions in writing. In those cases the answers were examined carefully and follow up interviews were conducted to answer open questions or add more context to the given answers.

The selection of the scientific disciplines considered in this study was based on the preceding survey Einbock 2017, choosing those with a higher usage of 3D data during the research process: Above the average of 11% and thus selected were architects and civil engineers (approx. 25%), mechanical and process engineers (approx. 22%), information and electrical engineers (approx. 15%) as well as physicists and astronomes (approx. 12%.

As the aim of the study is to identify use cases and possible actions for the TIB as an infrastructure facility a special focus was on participants working with three-dimensional artefacts in the above mentioned scientific disciplines.

The questions for the semi-structured interviews were grouped in five categories. First the interviewees were asked to give some details on their discipline and work environment, e. g. scientific research area and main research interests and involvement in teaching. The second block considered the use of and work with 3D data and other non-textual materials like software, videos or images. Questions about the publication of the corresponding material formed the next category. The two last blocks considered problems and challenges when working with 3D data in the respective field and wishes or requests for future work.

3 Data

Between July 2017 and December 2017 the engage AG conducted the study on behalf of the German National Library of Science and Technology. In total 53 scientists in eight disciplines participated in this study with a minimum of 5 participants per discipline. Table 1 gives an overview of the different disciplines and the number of participants in each field. The last column indicates the number of interviews that could not be considered for the final analysis. In one case the participant was working at an infrastructure institution and was not working with 3D data personally, in another case two persons of the same institute have been interviewed and their answers were near duplicates in many cases.

field	#participants	#excluded
architecture	5	
civil engineering	5	
mechanical engineering	5	
process engineering	5	
electrical engineering	6	1
information technology/engineering	16	
physics	5	
astrophysics	6	1

Table 1: Overview on the number of participants per field

4 Relevant results from previous studies

As mentioned in the introduction, this study has been conducted as a follow up of the survey on information procurement and publishing behavior in science and technology Einbock 2017. Therefore the most relevant results of this study considering 3D objects, models and data are summarized in this section.

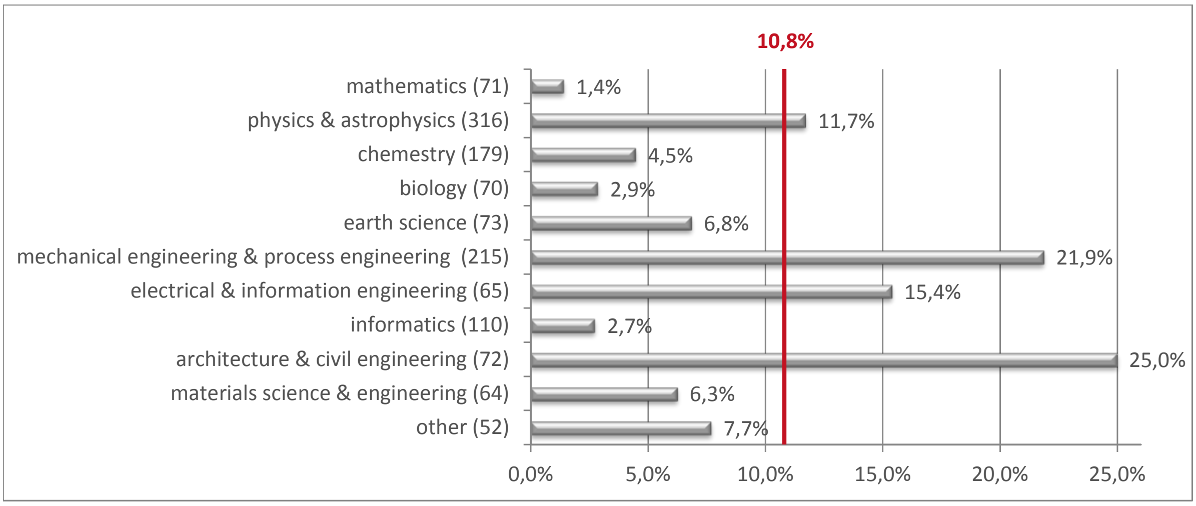

Figure 1: Details on the creation of 3D models in the context of research activities (The red line indicates the mean over all participants. The number of participants in each discipline is given in brackets on the ordinate.)

The study with 1,400 participants showed, that already one in ten scientists creates 3D models during the research process (see Figure 1). This of course varies between different disciplines as can be seen in Figure 1. Naturally the number of scientists creating 3D models is higher in disciplines that traditionally plan and construct in three-dimensional space like architecture, civil and mechanical engineering. But one can also see a higher number in electrical and information engineering as well as physics and astrophysics. All of these disciplines are in the focus of this follow up study.

Even though quite a number of scientists develop 3D models during research activities, only 37% say that they also publish these at least occasionally. On the other hand nearly 40% of the respondents also state, that they need support with the search for non-textual materials. Another 25% state a need for assistance with licensing and also publication of these materials (multiple answers allowed) (Einbock 2017, p. 17). Therefore one objective of the following study was to get deeper insights into the kind and characteristics of support that is needed in these contexts and also to determine additional reasons for not publishing the 3D materials.

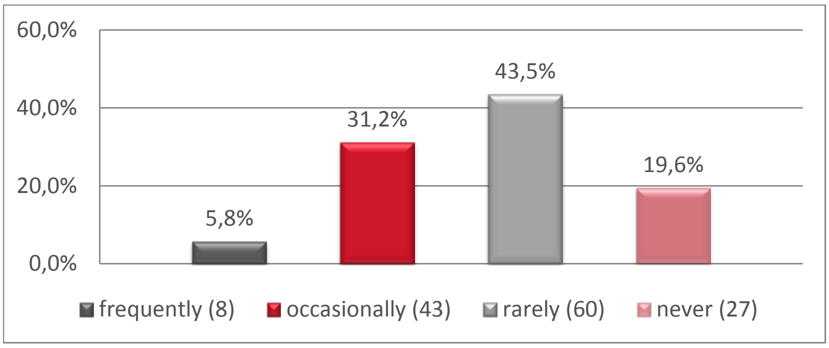

Figure 2: Details on the publication of created 3D models (n=138)

5 Results

The following sections present the results of the qualitative follow-up study about the use of and work with 3D artefacts and other non-textual materials as well as their publication and desires for future work.

5.1 Use of and work with 3D data and other non-textual materials

Research produces quite a range of different materials nowadays. Besides classical text based outcomes such as papers or books, the number of non-textual materials like images, videos and software is increasing.

When asked what kind of non-textual materials originate from their research processes, besides 3D objects more than two third of the 51 researches in the sample specify images and graphics, followed by research data and software, which is mentioned by almost half of the interviewed scientists. One third of the interviewees also mention videos and in a few cases also hardware and virtual realities are named.

Three-dimensional objects are used or created by almost all interview partners, which was requested for this study. Nine of ten scientists in the sample work with 3D objects and the ones not working with these kinds of objects use research data visualized in the three-dimensional space.

More than one third of the scientists also state, that the different 3D artefacts do have an interrelation to other non-textual materials. How these interrelations are implemented varies widely. Some use shared IDs and databases or links to keep the relation between materials. Others save these materials to the same folder on their local machine or shared cloud. Sometimes other formats like images or two-dimensional representations are loaded into the 3D model as starting point for modelling.

Most of the researchers reuse non-textual materials at least partly (9 out of 10). Particularly software is mentioned by the participants, but also 3D-objects are reused or at least intended to be reused in future work.

Besides new research projects which form the largest group of reuse purposes for 3D objects and data these materials are in a few cases also used for different kind of presentations to the public, e. g. in exhibitions or documentary films, but also for teaching or student thesis. Currently most of the 3D material is only re-used within one research group or even by a single researcher. Only one interview partner (architecture) stated that they try to produce machine-readable data following corresponding standards and implement controlled vocabulary.

The practices in data storage also reflect the closed up usage of the non-textual materials: The vast majority use folder structures on internal servers or institution-wide clouds. Nearly a quarter of the researchers also states, that they use their local machine for saving their materials. Only one in seven to eight participants states that they also use repositories to store their non-textual materials. Some kind of versioning is at least used by around a quarter of the participating researchers, with none of these stemming from architecture or physics. Searchable databases are only used by two researchers from astrophysics.

When asked for the metadata that is stored with their material the complete range from no metadata at all to the usage of object specific metadata standards is mentioned. Four in ten participants state each that metadata is added manually respectively automatically generated by the software or device. Such (technical) metadata is often only accessible within the corresponding program or device.

A closer look at the 3D material used by the participants also reveals a wide range in terms of types and modelled objects. The majority of 3D materials form modelled objects e. g. CAD models. More than two third of the participating scientists state, that they use these kinds of 3D artefacts. The second big group of 3D artefacts which is used by almost one third of the participants is formed by models originating from 3D scans, e. g. with laser scanners or unmanned aerial vehicles. Two in ten researchers also state, that they use 3D data, which is for instance visualized in the three-dimensional space and often used for simulations. While most interviewees only name one type of 3D artefacts around a quarter works with more than one type in their research. In the field of architecture and mechanical engineering in particular, there is a tendency to use more than one type of 3D artefacts, while in physics and astrophysics the scientists' state that they only work with one kind. Nevertheless these may still vary within one discipline. In Astrophysics for instance there are – besides "traditional" 3D-models having three dimensions in space – also models, that only consist of two spatial planes and a third dimension is formed by the wavelength. Table 2 gives an overview on the types of models used in each discipline.

As already suggested by the different types, 3D artefacts serve a range of different purposes

architecture	**point clouds**, **3D models with three spacial dimensions**
civil engineering	**3D models with three spacial dimensions**, printed 3D models, 3D models from simulations
mechanical engineering	point clouds, **3D models with three spacial dimensions**, 3D models from simulations
process engineering	**3D models with three spacial dimensions**, 3D models from simulations, models generated from medical imaging techniques (e. g. tomography)
electrical engineering	point clouds, **3D models with three spacial dimensions**, 3D models from simulations
information technology/ engineering	point clouds, **3D models with three spacial dimensions**, 3D models from simulations
physics	**3D models with three spacial dimensions**, 3D models from simulations
astrophysics	**3D models with three spacial dimensions**, 3D models with two spacial planes + wavelength

Table 2: Overview on the type of 3D artefacts used in the disciplines considered (The most frequent type is marked in bold.)

in the research lifecycle. Amongst the most frequently mentioned ones are the visualization of simulations, planning or design of objects like houses, machines or experimental setups. In addition to that 3D data and objects quite often serve as test data. Beside the evaluation of newly developed algorithms and software prototypes they are also used for user tests e. g. in virtual environments. An overview on the different purposes within the different disciplines is given in Table 3. The table is further extended by information on the type of modelled objects in the respective disciplines. Some of these are specific to the respective subject area like atmospheres of stars or planets in astrophysics. Others occur in quite a number of different disciplines. Besides 3D models of buildings or parts of buildings which are mentioned by five respectively four of the eight subject areas, there are also models of materials like (micro) porous ones, which are used by interviewees from electrical and process engineering as well as physics.

The animation of this 3D artefacts or the usage in a virtual reality is also quite common. More than six out of ten respondents state that this is relevant for their work or research. More than half of them use animations, e. g. for presentation purposes or to allow a deeper understanding of the build constructions. One third of these scientists explicitly state that they use virtual reality, e. g. in a cave to allow navigating through a building. Disciplines that mostly do not use animations of 3D artefacts or implement virtual reality scenarios are electrical engineering and partly physics. Disciplines with a strong usage of animations are information technology and engineering, astrophysics and mechanical as wells as process engineering. The discipline with the strongest usage of virtual reality in this sample is civil engineering, followed by architecture and information technology and engineering.

In civil engineering virtual reality environments are for example used to discuss and coordinate plannings with building owners or others involved in the planning, but also with the general public.

discipline	purposes	modelled objects
architecture	planning/design, visualization/demonstration	**(parts of) buildings**, site/terrain, cultural heritage
civil engineering		**(parts of) buildings**, structures
mechanical engineering	research on 3D objects/technologies, visualization/demonstration	buildings, **(components of) machines**, surfaces, production facilities and equipment, site/terrain, logistic processes
process engineering	research on 3D objects/technologies, visualization/demonstration, simulations	**(components of) machines**, **materials**, production facilities and equipment, furnishings, assemblies, flow channels
electrical engineering	research on 3D objects/technologies, visualization/demonstration	**(parts of) batteries and fuel cells**, materials, surfaces, experimental setups
information technology/ engineering	test data/objects (development of algorithms, szenarios in virtual realities), visualization/demonstration	(parts of) **buildings**, materials, furnishings, experimental setups, objects from the automotive industry, cultural heritage, (sensor) prototypes, human organs, simple geometric shapes, road networks, head poses, persons, topological structures , not specified
physics	simulations	(parts of) buildings, (parts of) Batteries and fuel cells, materials, production facilities and equipment, structural components, (sensor) prototypes, **fluids**, aerospace objects
astrophysics		experimental setups, **galaxies**, structural components, stars, prototypes, atmospheres of stars, planets etc., planets, gas mist and clouds

Table 3: Overview on the purposes for the 3D artefacts and the modelled objects

In information technology and engineering virtual reality is often a research focus of the respondents. Software applications for virtual realities mentioned include surgical training or the design of automotive user interface in a 3D cave.

5.2 Publication of 3D data and other non-textual materials

The description of the usage and work with 3D data showed a wide range of scenarios. This section centers on the question of publishing the 3D materials used throughout the research, which is vital for transparency and replication studies. As in the preceding study most (six out of ten) of the scientists in this study say that they do not publish their 3D materials. In the two disciplines electrical and process engineering none of the respondents publishes his or her 3D materials.

If 3D material is published, which is the case for almost four in ten respondents in this study and thus matching the results of the prior one; it is not always the complete object or the complete data. Some only publish images of their 3D models or video sequences showing selected angles or details of 3D objects. This is also reflected in the way 3D materials are published. Besides journals the respondents also name databases and their homepages, but also video portals like YouTube. Also only one person states, that all 3D objects are published, the other scientists share only some selected objects with the public.

If 3D materials are shared. most of them are published under a Creative Commons license. Only one person indicates that they use a private license or the Open Database license.

The reasons for not publishing 3D materials are manifold. Most often problems with licenses or missing rights or unclear legal situation for publishing the data are mentioned (four out of ten respondents), followed by a presumed limited usage for other researchers and a low priority of 3D materials when it comes to publication. One in seven researchers also name time constraints for publishing their data. Individual persons also say that they do not publish their data, in order to keep their knowledge edge.

Since legal problems or missing knowledge about the legal situation are quite common, the respondents were asked, if the publication in a protected environment, e. g. with password protection, would be an alternative for them. Half of the respondents expressed their interest in this possibility.

Besides questions around the publication of 3D materials the respondents were also asked about long-term preservation and long-term traceability and citation. An interest in long-term preservation is expressed by half of the interviewed scientists, with a very strong interest in physics and astrophysics and a moderate interest in architecture and civil engineering.

When asked for the current situation with terms to long-term traceability and citation (e. g. with DOIs) only seven of the respondents answered, that this was taken care of. They were coming from architecture, physics and astrophysics. An interest in the usage of DOIs for 3D materials was expressed by one third of the respondents. Another third explicitly state that they are not interested. Also the granularity (single objects vs. collections) for the usage of DOIs was mentioned critically.

5.3 Requests and desires for future work

In this section the focus is on the voiced problems and challenges in the context of working with 3D materials and corresponding requests and wishes for future work.

One major point that is raised by a number of scientists in this study concerns software. More than a quarter of the respondents asks for better software in connection with their work on 3D materials, especially in process engineering. The specialized software is often quite complex and still limited in its possibilities and adaptions are needed quite often. Also a visualization of data or models prior to downloading and open them is requested.

The different purposes and objects modelled along with their technique of origin suggest as shown in Tables 2 and 3 that a wide range of formats are used as can be seen in table 4. So converting 3D models from one format into another is fairly common and often very time consuming. Therefore it is not surprising, that quite a number of respondents voice this topic as a point for optimization in future and express the desire for more standards or even a standard format that makes all the conversion obsolete.

architecture	c4d, fbx, ftl, **obj**, pds, ply,
civil engineering	amf, ifc, rvt, **stl**, occationally other proprietary formats
mechanical engineering	dwg , **stl**, open cv formats
process engineering	hdf, proj, prt, sldprt, **stl**, stp, unv, VRML, OpenFOAM format
electrical engineering	cst, mphx, **stl**, stp, vtk, Comsol/Matlab formats, other not specified open source formats
information technology/ engineering	blend, f3d, fbx, ftl, itk, mhd, mtl, **obj**, ply, skp, stl, vtk, wrl, xyz, custom formats, topsolid formats
physics	3ds, dwg, hd5, stp, **vtk**, Matlab formats
astrophysics	**hdf5**, fits, iam, ipt, obj, stl, VOTable, **vtk**, custom formats

Table 4: Overview on the 3D data formats used in the different disciplines. (The format in bold mark the ones, that were mentioned most in the sample.)

A third point addresses the generation of metadata and the loss of these data when converting files. Possible solutions voiced by individual researches include semantic enrichment of 3D objects or systems for manual entry that do not overwhelm the user with their input forms.

When explicitly asked for work tasks they would like support for, beside the above mentioned topics, a reduction of the preparation efforts when trying to use 3D materials is voiced as well as long term preservation of materials. Some also ask for support in finding free 3D objects or data visualization. With more than a quarter of respondents a central 3D database was one of the most voiced requests for future work.

6 Conclusions

The details in the prior sections show a complex picture of the usage of 3D materials in the research lifecycle. Currently most of the 3D objects are not published, often because of legal implications or a doubted relevance for other researchers. Nonetheless the request for a central database with open 3D models is voiced by more than a quarter of the participants, ideally with the possibility to convert the contained objects into different formats with minimum or no loss in metadata at all.

This discrepancy between the desire to find and use open 3D materials and the reluctance in publishing the own data can only be overcome when a change in scientific practice regarding the publication of such materials will take place. Additionally the development of methods for automatic extraction of metadata from the objects themselves as well as automatic semantic enrichment could help to reduce the effort and thus the inhibition threshold for publishing 3D objects.

Furthermore the TIB could engage itself in initiatives for more standardization to address the problem of the multitude of formats and the loss of details and metadata when converting from one into another format.

7 Acknowledgment

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8 References

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