The making of the "Golden Rathaus"

Story and methods of a very specific 3D printed model

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Abstract: The twentieth edition of a conference happens only every twenty years, so, for this event, a group of habitual participants to the activities of the "Cultural Heritage and New Technologies" conference, decided to organize a special surprise, preparing and realizing a "golden" version of the Wiener Rathaus building to show and to homage Wolfgang Börner as the main chairman of this well organized and pleasant yearly event. It has been a nice experience, both because of the various troubleshooting needed to pass from an existing model to a 3D print and because the not easy golden material effect. So the situations were so articulated and various that we decided to write down a paper about all the realization phases, to enrich and to transmit the final result and complete this particular occasion with a full description about the "making of" of the "Golden Rathaus".

Keywords: 3D printing; Rathaus; Wien; 3D Modeling; Celebration.

Introduction

The making of a 3D digital model has always a specific story, when the process is not simply finalized to visualization, this story may became even more articulated. The making of this particular version of the Rathaus asked a special collaboration and many tests. The group participating to the making of this surprise was composed by Willem Beex, Peter Ferschin (Vienna University of Technology), Giorgio Verdiani, Francesco Algostino, Arkadiusz Szadkowski (Vienna University of Technology) and Peter Dorninger (4D-IT GmbH, Austria).

Different ways to use 3D models require specific optimization processes. In this case we studied the possibility to pass from a simplified, "low poly", model to a physical model, through a 3D printer[1].

The flexibility inherent in the nature of digital 3D models, sometimes threatens to lead to underestimate the processing necessary to make effective use a model already available in a different context.

A first problem lie in the storage formats: conversion paths using various software with the risk of losing some information about the geometry or the texturing. For example the OBJ[2] file format can be written in more way and different indexation.

Another problem concerns the topology of the mesh. It is possible to represent the same form with different geometry, but some are more suitable for 3D printing and less for visualization and vice versa.

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[1] With a 3D printer we mean a machine for additive manufacturing.

[2] http://people.cs.clemson.edu/~dhouse/courses/405/docs/brief-obj-file-format.html

A part of this paper focuses on the necessary processes in transforming a model previously developed with the unique purpose of viewing it online into a suitable one for 3D printing. In particular, we will describe the workflow needed to turn a mesh created in SketchUp[3] for real-time display in Google Earth[4] into a mesh printable on a fifth generation Makerbot 3D printer that uses FDM[5] technology[6].

FDM technology for 3D printing is a technology in which the pattern model is divided by horizontal stack of layers; each individual layer of the print head crosses the whole perimeter described by the geometry depositing a filament of material which melts at low temperatures, and it is made in ABS or PLA. The software that analyses the geometry and creates the print head pattern is called "slicers". If the geometry has inconsistencies, such as an edge shared by more than two faces, the software used for transforming the geometry path in the machine may not exactly compute the path.

Different needs for real-time visualization and for 3D printing

The Digital geometry from which we started represented the Vienna Rathaus (Friedrich von Schmidt, 1872-1883). The original model was developed by Arkadiusz Szadkowski student at the "Institute of Photogrammetry and Remote Sensing, Vienna University of Technology" and then processed at the Models for Architecture Laboratory (LMA) of the Department of Architecture, Florence University.

The main requirement of a model that must be transmitted and displayed in real time is to keep the overall size, while providing the desired level of detail, frequently (as in this case) by using the texture too. To this end, the model of the Rathaus was made by "components" which were repeated several times. In SketchUp, in fact, a "group" is a mesh that can be changed into a "component", which is a set of elements that will be available for been instantiated. Copying a component to new positions keeps the connection with the original object. A change to the primary object is reflected on each instance[7]. This makes it possible to streamline the process of modeling, mapping and texturing, limiting the time needed to complete the modeling while limiting the final size of the file. This hierarchy with strong reuse of geometry and texture optimizes the digital transmission and may be used to display the model using real-time visualizations[8].

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[3] Originally developed by @Last software, now Trimble - www.sketchup.com. About push/pull method: System and method for three-dimensional modeling US 6628279 B1, 22 nov 2000. Since 2004 is possible to export models for Google Earth in KMZ format.

[4] Google Earth, originally developed by Keyhole, 2001, is a navigable virtual globe, with different kinds of geographical information (vectorial maps, satellite photos, etc...) and user generated content in the same cartographic system.

[5] FDM fused deposition modelling, also called FFF fused filament fabrication by the RepRap project.

[6] For a framework on rapid prototyping technologies will: Additive Manufacturing Technologies, I. Gibson, D. Rosen, B. Stucker, Springer, 978-1-4939-2112-6.

[7] https://www.sketchup.com/it/products/sketchup-pro/features/model-organization/

[8] Marini, Bertolo, Rizzi, 2001.

Moreover, for the purpose of visualization, a model can have non-watertight geometries and non-manifold[9] errors are acceptable. In SketchUp normals[10] are forced to be present on both sides of the triangle, while for 3D printing they must be aligned to the outside of the model. Faces without thickness or with a thickness too thin to be managed by 3D printers, as well as geometries that interpenetrate or auto-intersect do not represent a problem for model visualization, but they must be corrected for rapid prototyping[11]

Modeling in SketchUp[12] is performed by using the "push/pull" technology, which accelerates the modeling procedure, in particular for objects with simple geometries. On the other hand, it sometimes entails the generation of two coincident faces. In this case too, model visualization is not affected, while the presence of redundant faces represents a problem during printing.

A characteristic of FDM printing is that you need to lay down the molten material on an already hardened layer. The presence of vaults, loggia or other embossed elements entails the creation of supports, which are removed at the end of the printing process.

The actual FDM 3D printer is not able to print colour information, it is just like erasing all the information stored in the textures, and see the model in a Blinn[13] monochrome shader. The lack of information leads us to model the window's recesses.

3D printing and optimization: The adopted workflow

During a first printing test, while performing a preliminary control, the model developed in SketchUp was analyzed in Magics[14], where many errors were detected, as stated above.

To avoid long manual correction procedures on the model, initially we tested two algorithms for automatic mesh repairing. The first, implemented in Magics, is a Shrinkwrap algorithm[15]. However, the result was not satisfying, because it requires a huge quantity of samples to produce a sufficiently accurate description of an object with sharp angles and complex concave areas, such as the Rathaus.

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[9] http://www.cs.mtu.edu/~shene/COURSES/cs3621/SLIDES/Mesh.pdf.

http://graphics.stanford.edu/courses/cs468-10-fall/LectureSlides/02_Basics.pdf

[10] Foley, 1996.

[11] For a generic reference about a right geometry for 3D printing: Printing Things - Product DesignVisions and Essentials for 3D Printing, C. Warnier, D. Verbruggen/ Unfold, S. Ehmann, R. Klanten, Gestalen, Berlino, 2014. http://www.shapeways.com/tutorials/?li=nav

https://ultimaker.com/en/support/11721-general-questions

[12] For a generic reference about topic: La Stampa 3D con SketchUp, F. Caraccia (a cura di), Janotek L'aquila, 2015.

[13] Blinn, 1977.

[14] Magics is a professional software for checking STL and preparing them for 3D printing.

[15] Shrinkwrap: An efficient adaptive algorithm for triangulating an iso-surface, K. van Overveld, B. Wyvill. The Visual Computer, Volume 20, Issue 6, pp 362-379, Springler, August 2004.

The second algorithm adopted is the Poisson[16], in the version implemented in MeshLab[17]. While the first was not truly fit for the purpose, the second algorithm is more efficient when used with high poly models rather than with low poly mesh. In both cases, the software used required a significant amount of ram, limiting the tests that we will try to repeat with more performing hardware.

Due to the substantial failure of the automatic procedures tested to optimize the model, we carried out the manual correction of geometry in Autodesk 3DS Max[18]. This step was then followed by the automatic correction of the remaining small errors in Magics and by the project of the model and the preparation of the file for printing with the same software.

The adopted strategy was to optimize and create portions of elements that were printable, in order to merge them in wider and wider meshes, up to obtaining a single correct mesh for 3D printing.

The following paragraphs describe the procedure adopted in detail.

Manual correction of geometry

The model developed in SU was exported in 3DS format and imported in 3DS Max.

The preliminary operations included:

- Determining the value of the unit of measurement of the original model (in this specific case 1u = 1 mm),
- Moving the model close to the origin of the axes, to eliminate the problems linked to the accuracy of modeling software in managing entities that are too far from the origin,
- Rotating the model until the main face is parallel to the X axis, in order to simplify its management.

In 3DS we then divided the model into parts, selected according to some criteria linked to the type of changes to be made, and we broke the model up into its main architectural elements (macroblocks); for each of them a layer was defined: base, building, roof dormers, façade, façade of the central tower, and balustrades. The non-printable parts, such as flagpoles, were filed in a special layer.

We first considered the macroblocks "base", "building", "roof dormers", and "roof". The groups of meshes present in each layer were merged and the coincident vertices were welded through the "weld" command. The faces marking the macroblocks were defined with partly manual and partly automatic procedures. The unnecessary elements were cancelled. Finally, we made sure that the different macroblocks suitably interpenetrate to guarantee a positive output during the following Boolean operations. For example, while re-modeling the base of the building (in light blue in the following image), the vertical walls were "sunk" into the

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[16] Poisson Surface Reconstruction. Michael Kazhdan, Matthew Bolitho and Hugues Hoppe, Eurographics Symposium on Geometry Processing Konrad Polthier, Alla Sheffer (2006).

[17] Meshlab: http://meshlab.sourceforge.net/ . It is an opensource system for the processing and editing of unstructured 3D triangular meshes.

[18] 3DS Max is a "digital content creation" software created by Yost Group in 1990, and published from Autodesk.

ground. The macroblock "balustrades" included geometries without thickness; besides the above mentioned operations we also applied a "shell" modifier, whose thickness was calculated according to the minimum thickness required by the FDM technology, that is approx. 1 mm in the final size of the model.

The remaining macroblocks required more demanding work. After having merged the meshes and their vertices, as described above, we closed open geometries and removed internal geometries to make every macroblock watertight.

In the loggia there were different non-manifold geometries. By carefully cutting, removing and remodelling portions of faces, we created suitable geometries for printing. We made corrections on a single module, which was then instanced.

The Rathaus is the perfect building to be modelled through a modular structure. As we said before, in SU we can manage instances in a convenient way, as a change made applies automatically to all of them. The export format adopted (.3DS) does not store this kind of information and therefore in some cases we needed to repeat the same correction for all modules. The .FBX format should instead allow maintaining the structure of the model, thus fixing this kind of problem.

This part of the work required almost half of the total amount of time necessary to prepare the model, that is approx. 18 man-hours.

Some examples of point corrections applied manually are:

- Inside the arches we removed coplanar faces, due to Sketchup push-pull modeling, and then we closed the remaining hole.
- In the towers we performed accurate manual operations;
- The cornices of the towers have been entirely remodelled due to the excessive presence of automatically interpenetrating meshes.

Automatic geometry refinement

After having made the manual corrections, further refinement of the model became necessary, by means of specific software such as Magics by Materialize, Nettfab or Meshmixer, both by Autodesk, just to mention a few. This software controls geometry, closes holes, merges coincident vertices and checks normals. Some errors are linked to the export format from 3DS, OBJ in this specific case. The control algorithms applied to this step are stricter and firmer than those present in 3DS.

Every single macroblock was imported into Magics, checked and individually corrected; then we merged them into a single mesh through a Boolean union that defined a final model made of 400,000 polygons.

Materials and testing: Project of the model and preparation of the file for printing

The final mesh was checked once again and some noise shells were detected and removed. The mesh was scaled to the size planned for printing and we analysed the thickness and overhang angles of the different elements to verify whether printing supports were necessary.

The first printing attempt was made with a FDM printer Makerbot Z18 by means of the PLA Makerbot. The result on façades was not satisfying due to the lack of details that in the original model had been given by the texture. Then in 3DS Max we modelled all the missing windows.

After that we tested the PLA colorFabb Pale Gold[19]. This material gave the best results on the 2nd generation Makerbot printer, which however allows printing only volumes smaller than the printer previously used. We therefore needed to partition the model.

Printing and post-production

The file for printing is saved in the STL format and opened in the program that stores the machine path in a file sent to the printer. Makerbot printers offer specific software with a proprietary algorithm to calculate the path of the print head.

Printing on Makerbot 2nd required approximately a total of 26 hours. The different pieces were then cleaned to remove residues, sanded and glued together. Finally they were painted with an acrylic colour in spray can and fixed on a wooden base.

Conclusions

The making of the Golden Rathaus has been an interesting experience that gave us the opportunity of optimizing a workflow partly already used in laboratory and testing new materials.

Excellent knowledge of the strong and weak points of 3D printing and modeling, as well as of the tools used to make corrections, which simplify and accelerate the workflow.

This workflow adapts to different types of models with different topological characteristics and problems and it can also adapt to different types of outputs by integrating texture management too.

Acknowledgements

References

BARNATT, C. (2014), 3D Printing: Second Edition, CreateSpace Independent Publishing Platform.

CANO, J.L. C. (2011), The Cambrian Explosion of Popular 3D Printing, International Journal of Artificial Intelligence and Interactive Multimedia, Vol. 1, Nº4, IMAI.

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[19] http://colorfabb.com/

CZEIKE, F. (1995), Rathaus, Neues. In: Historisches Lexikon Wien. Band 4, Kremayr & Scheriau, Wien.

DERAKHSHANI R. L. , DERAKHSHANI D. (2014), Autodesk 3ds Max 2015 Essentials: Autodesk Official Press 1st Edition, Sybex.

GIANNATSIS, J. DEDOUSSIS, V. KARALEKAS D. (2002), Architectural scale modelling using stereolithography, in Rapid Prototyping Journal, Vol. 8 Iss: 3, pp.200 - 207, MCB UP Ltd.

GIBSON, I. ROSEN, D.W. STUCKER, B. (2009), Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing, Springer.

LIPSON, H. KURMAN, M. (2013), Fabricated: The New world of 3D Printing, Wiley.

RITLAND, M. (2014), 3D Printing with SketchUp, Packt Publishing.

SMYTH, C. (2015) Functional Design for 3D Printing 2nd edition: Designing 3D printed things for everyday use, CreateSpace Independent Publishing Platform.

WARNIER, C. VERBRUGGEN D. EHMANN, S. KLANTEN, R. (2014), Printing Things - Product DesignVisions and Essentials for 3D Printing, Gestalen, Berlino.

WIESER, W. BECK L. (2011): Das Wiener Rathaus, Geschichte & Gesellschaft, Architektur & Anekdoten. Bohmann Verlag, Wien.

Figures
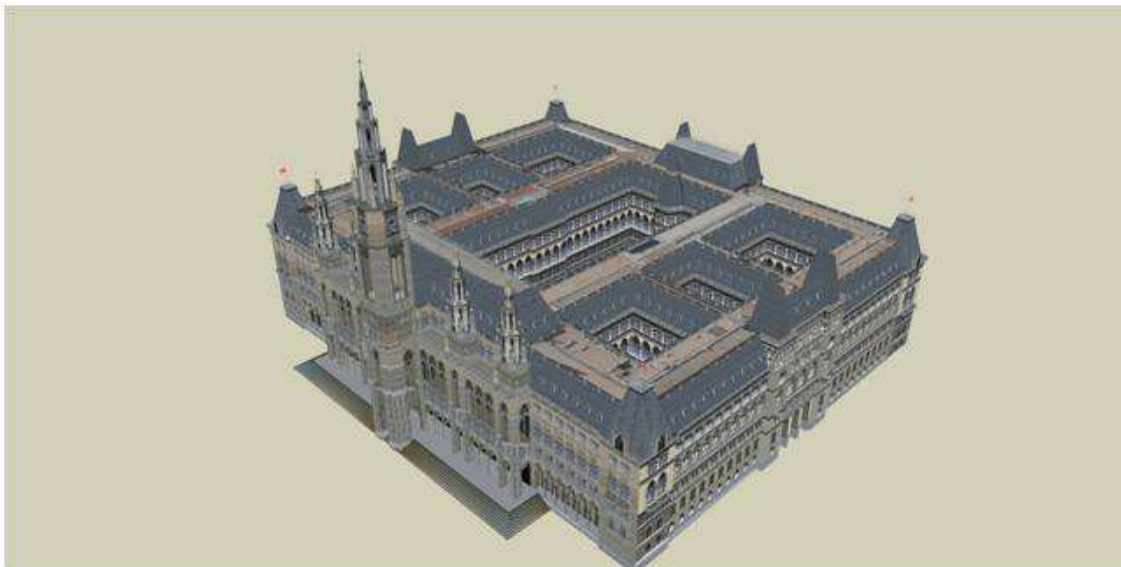
Fig. 1 – The model of the Rathaus in Sketchup.
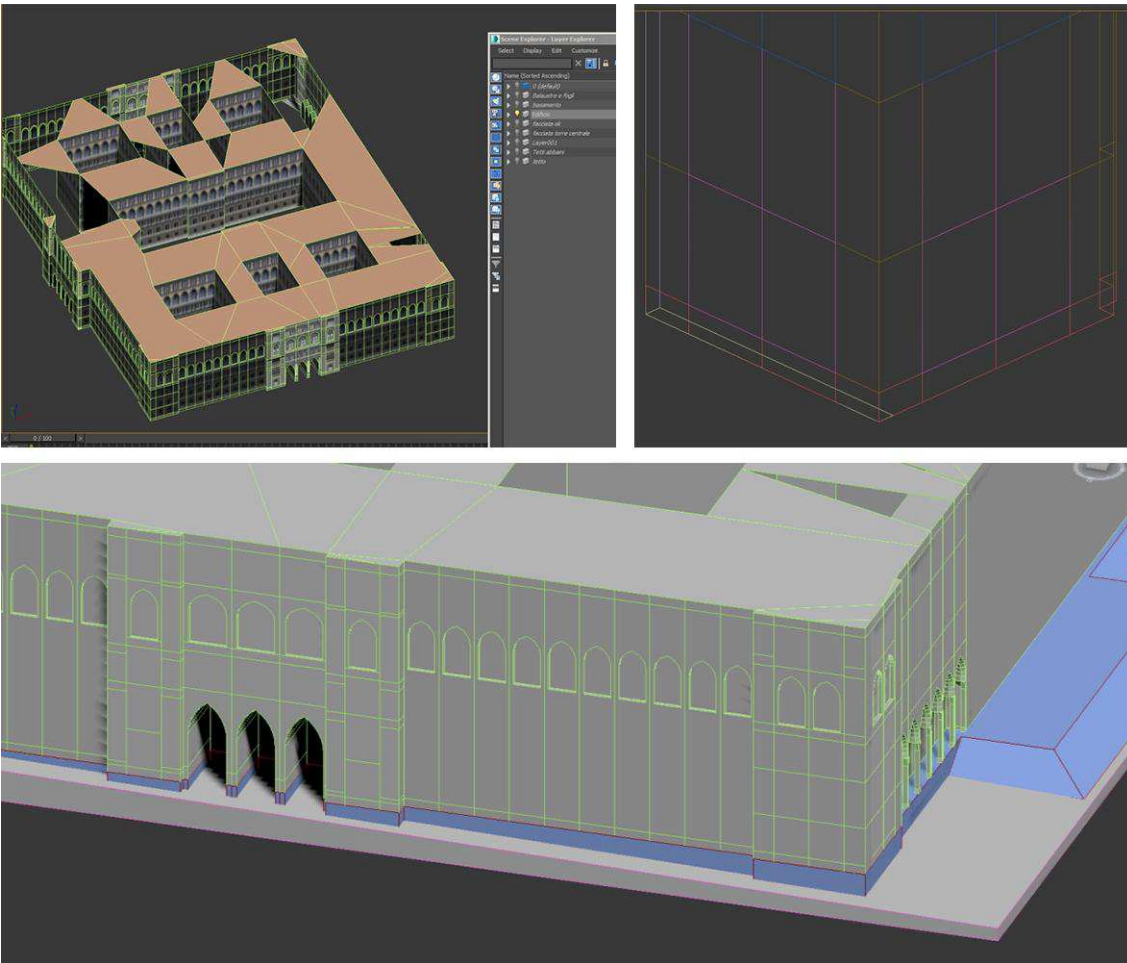
Fig. 2 – Above left: Handmade cap in brown, ready to be finished by software. Above right: The green mesh is not useful for 3D printing. Below: Remodelling of the base.
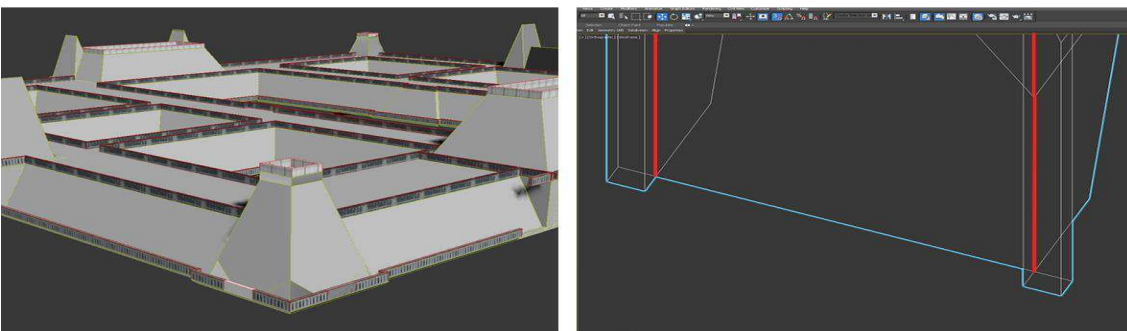

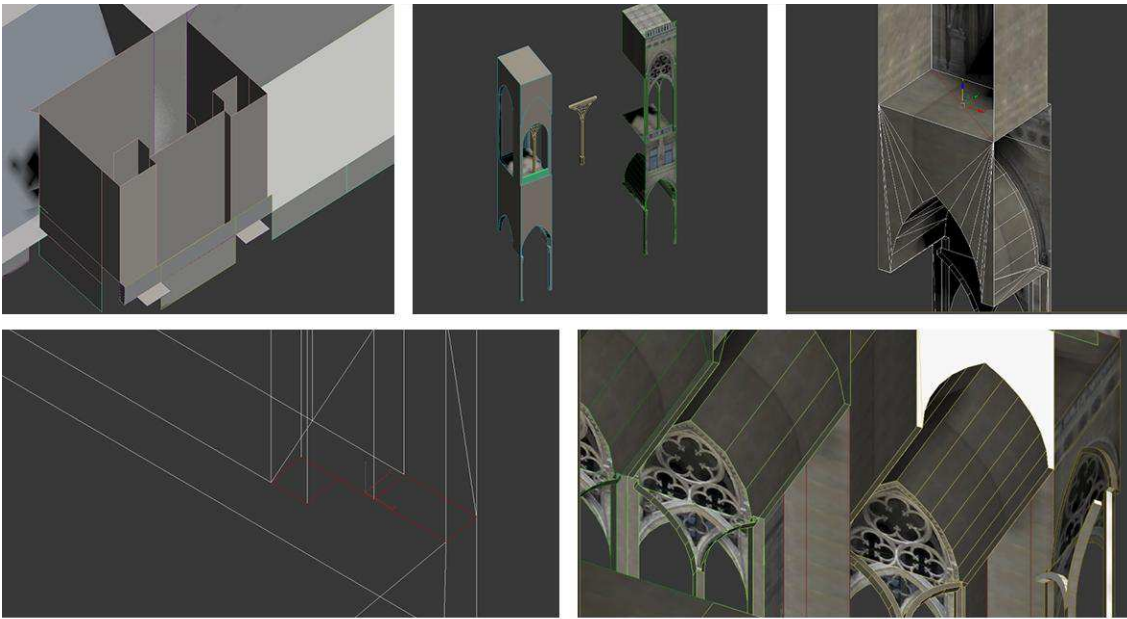Fig. 3 – Left: Some balustrade with thickness. Right: The red edge is a non-manifold error.

Fig. 4 – Above left: Mesh open mesh. Above center: Before and after the correction of the mesh. Above right: Non-manifold errors. Below left: Double surface. Below right: Missing elements.
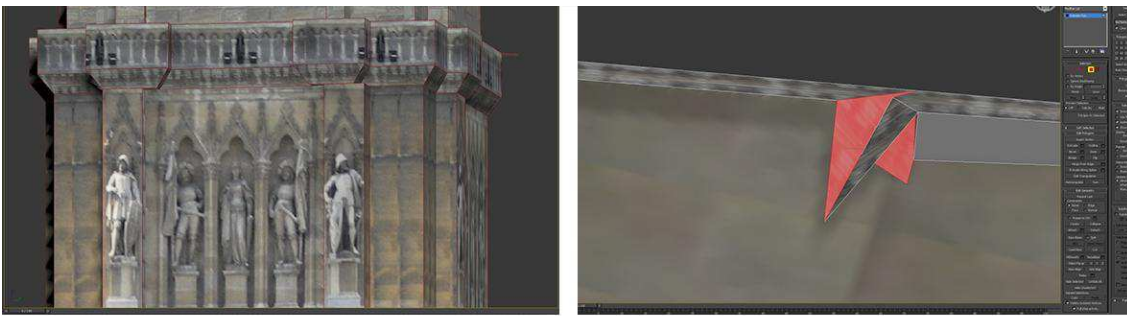

Fig. 5 – Above left: Compositing errors. Above right: self-crossing mesh.
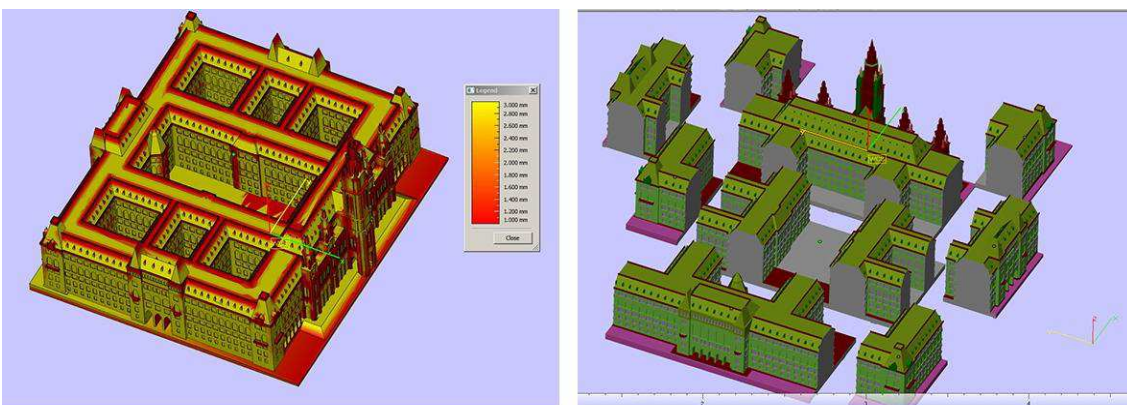
Fig. 6 – Left: Analysis of the thickness. Right: Subdivision in elements for the Makerbot 2nd generation.

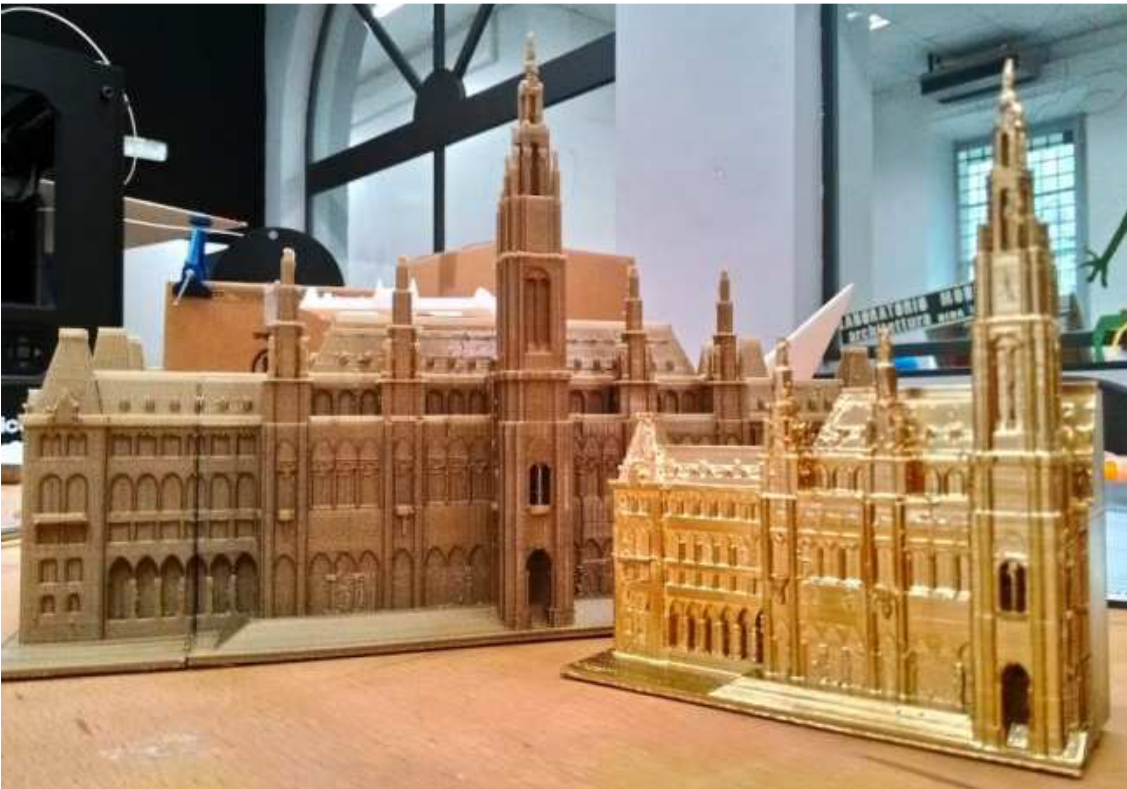Fig. 7 – Printed results, on the left: Makerbot 2nd, on the right: Makerbot z18.

Fig. 8 – Completed models and colour testing.

Fig. 9 – The finished model, coloured and mounted on a wooden base.

Fig. 10 – The homage of the "Golden Rathaus", during the 20th CHNT gala dinner (pictures by Anna Frascari)