APPLYING NURBS MODELING TO RECONSTRUCTION OF A GOTHIC-FLEMISH FACADE

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ABSTRACT

The city hall of the municipal town Wesel, located on the river Rhine, was built in the middle of the 15th century and was destroyed during the Second World War. Future generations will owe extraordinary gratitude to the citizens of Wesel, their activism and hard work of many years, for the fact that this late Gothic building will be reconstructed as the first of its kind in Germany.
Only a few pictures and maps of the city hall could be retrieved during the past years. Under this circumstances, comparable buildings had to be examined to obtain geometric dimensions for the reconstruction process. Therefore, site visits to cathedral huts and stonemasons were helpful and instructive. After this, the different normal stones, cuboids, profile stones, and consoles could be reconstructed. These stones were compiled in a stone catalogue. For the production of this hierarchically structured stone catalogue, suitable CAD modeling procedures were developed. Characteristics were then applied to facade construction. Well-known standard methods of solid modeling, like extrusion and tessellation, were employed and extended by NURBS modeling methods.
The NURBS (Non-Uniform Rational B-Splines) geometry is a mathematical representation of each shape of geometrical elements. Simple lines, circles, and surfaces can be represented, as well as complex 3D free form surfaces or solids. NURBS-generated models are very precise since the surfaces are not approximated by polygonal meshes. This enables the exact reproduction of facade stones for the building process.
The photo-realistic visualization presents the city hall facade in its environment, as it will appear after reconstruction. A virtual reality model enables the citizens of Wesel to view the building in advance. The model will also be used to secure funding for the project, as the virtual facade will symbolically be sold stone by stone.

1. INTRODUCTION

The citizens initiative "Historic City Hall Wesel" was founded in 1986 with the aim to reconstruct the city hall in its old gleam. The initiative plans to finance the reconstruction by fundraising. To this end, single facade stones are symbolically sold to benefactors.
The digital reconstruction of the project is meant to represent the object between the existing buildings, so that urban development can be visualized better. This digital model is supposed to increase the citizens willingness to donate for the project. For the reconstruction of the city hall, the digital model is to serve as a spatial representation in order to facilitate and accelerate both preparatory planning and actual reconstruction.
Changes to the model should be easily made. Different variants of details can be represented spatially without them having to exist as solids.

2. HISTORY OF ARCHITECTURE

2.1. Gothic style

The Gothic style was an architectural preference in the Middle Ages. It followed the previously predominating Romantic style after the year 1140. The emergence of this new style originated in the Paris area. From there, it quickly spread to all of Europe. The epoch lasted approximately until the year 1500 and was then succeeded by the renaissance. The most famous building in the Gothic style in Germany is the cathedral of Cologne.
Typical features of Gothic buildings were pointed arches, slim pillars in close proximity, high walls interrupted only by tall and narrow windows, and high and simultaneously powerful towers with filigree helmets. Many of the Gothic construction elements stem from the plant world, for example milkworts and crabs (creeping flowers). The professions of master builders, sculptors, and stonemasons were established because of these difficult-to-produce stylistic elements. These occupational groups frequently joined so-called church masons guilds, of which some still exist to this day.

2.2. The historic city hall

The city hall facade to be reconstructed was located in the main market place in Wesel upon the Rhine. The city hall stood at the southern side of the square, where the building "Grosser Markt Nr. 9" is to be found today.
Construction of the city hall began in 1455. In the middle of the 15th century, sandstone was used for the erection of such buildings, and in this case, Baumberger sandstone was employed.
The city hall was built in the late Gothic and Flemish style. It was extensively decorated in a very finely filigreed manner. The city hall was subdivided into five facade axes at that time.
During the years of 1698 through 1700, a sixth facade axis was added to the city hall. This sixth axis was executed as a stairs tower, which towered above the part of the city hall already completed. This stairs tower carried a baroque hood, which was probably planned as a Gothic Pomeranian hood. The entrance to this sixth axis consisted of open stairs. A spiral staircase was located in the interior of this tower. In the afternoon of February 16th, 1945, the city hall was destroyed in a bomb raid by the Allied forces of World War II.
The reconstruction of the city hall was subdivided into two stages of construction. The first stage consists of the reconstruction of the facade proper, which will be built in front of the facade of the building "Grosser Markt Nr. 9". In the second stage, the individual rooms behind the facade will be rebuild in accordance with the original.
After completion, the historic city hall can be used by the public. Furthermore, the main market place shall gain new attractiveness and increased value by this reconstruction and shall shine in new gleam.

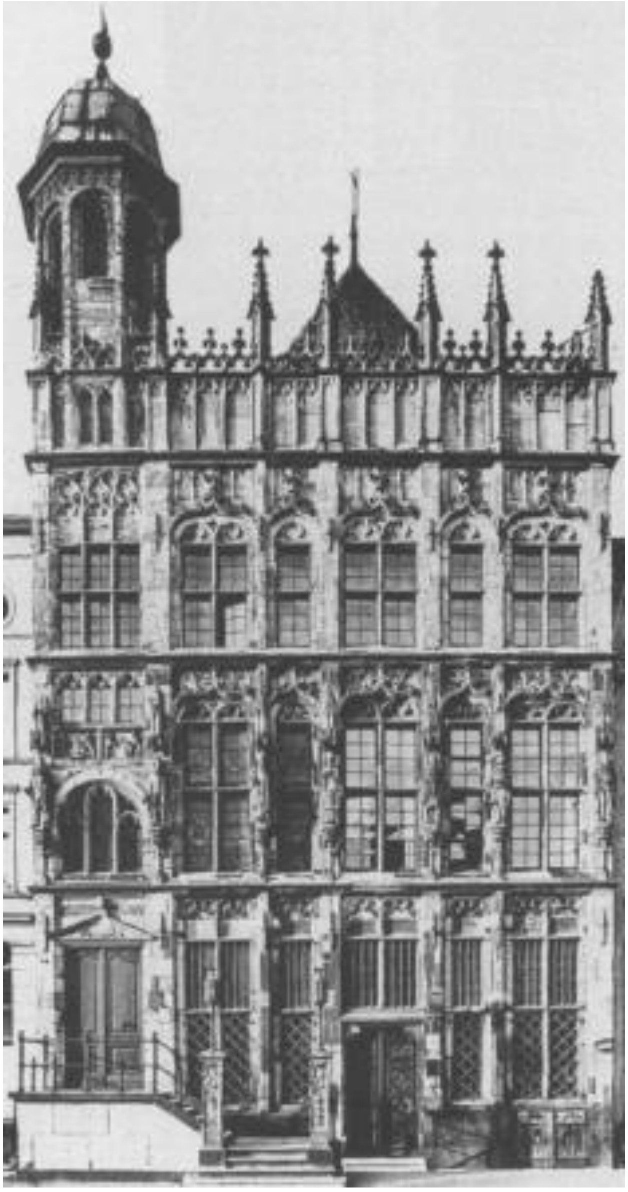

Figure 1. City Hall Of Wesel before World War II

3. CAD MODELING

3.1. Standard modeling method

2D, 2½D and 3D models can be employed for the construction of objects. 2D models confine themselves to the representation of two of the three space coordinates (top view, flat lines). In a 2½D mode, the 2D data are supplemented with the altitude information for the object.
The 3D model contains detail data, such as the depth of the object, in addition. These data can then be represented by means of wire, surface, and solid models.
Wire frame models are the simplest form of representation. They consist of dots which are connected by lines. In this model, doubling algorithms and sectional views are not possible, and crossings and penetrations can also not be represented.
A surface model consists of wires with areas between them. In this kind of model, the individual areas are used to represent different objects. There is no connection between areas, so it cannot be determined on which side the deposited material is located.
A solid model consists of areas which enclose a volume and define it exactly. The basic elements of these models are bodies such as cuboids, top-hats, and pyramids. Furthermore, regions become a body by extrusion or rotation.
More complex objects arise through combination by Boolean operations, like union, difference, and average. Independently of the internal mathematical representation of the bodies, curved surfaces are always approximated by flat meshes.

3.2. NURBS modeling

3.2.1. Characteristics of NURBS: NURBS is the abbreviation of Non-Uniform Rational B-Splines. Every mathematical object can be represented with NURBS geometries, for example circles, lines, areas, and complex 3D solids.
NURBS-modeled bodies are very precise, flexible, and exact. Thanks to this advantage, NURBS models are used for processes like illustration, animation, and the production of objects. NURBS surfaces are not approximated by polygonal meshes. It is another advantage of NURBS geometries that the required input information can be much less than it is the case with the usual representations.
A further advantage of NURBS modeling is the efficient and exact delineation of objects and the circumstance that simplest free-form geometries can be represented just as well as complex objects.
A NURBS curve or a NURBS area is defined by four qualities: the degree, the checkpoints, the knots, and the assessment rules.
The degree is described by a positive integer. These integers are 1, 2, 3 or 5. However, arbitrary positive integers are also accepted. For example, curves have the degree 1 (linear), circles have the degree 2 (square), and free-form surfaces have the degree 3 (cubic) or 5 (quintic). The order of a NURBS curve equals the degree plus 1. In turn, the degree is the order minus 1.
Checkpoints have at least a degree of plus 1. A list of checkpoints makes it possible to change a NURBS curve by simply moving these checkpoints. The checkpoints themselves have an attached number which is called weighting. These numbers are usually positive numbers. If the checkpoints of a curve have the same weighting, the curve is non-rational. Otherwise, the curve is called rational.
Knots are numerical values calculated as follows: degree plus number of checkpoints (in short, N) minus 1. This list is oftentimes called knot vector. Numerical values and knots which appear once are called simple knots, while those which appear several times are called full multiple knots.
Knots are called uniform if the list of knots begins with a full multiple knot, followed by a simple knot, and ends with a full multiple knot. Beyond this, knots must have an even distance pattern, such as 0,0,0,1,2,3,4,4,4. Non-uniform knots, such as 0,0,0,1,2,5,6,6,6, indicate that a NURBS curve is not uniform.
Working with NURBS creates very soft objects which look organic. NURBS models are mainly used because they are so exact and are widely applied in graphics and industry design. Moreover, they can be used for construction, production, and animation.
During the export of NURBS objects, they are converted into a polygonal net and therefore can be processed in other programs.

3.2.2. Tesselation: Tesselation is the name for the first of three steps of calculation of 3D objects. Tesselation consists of calculation of polygons, which completely cover objects by means of point coordinates (2D representations) and space coordinates (3D representations).

There are two types of the tessellation: regular and irregular tesselation. The former consists of uniform elements which are equal in size, e.g. a grid. The latter (different form and different size) is the opposite of the former.
After tessellation, transformation into a geometric object is done, and then, rendering is carried out. The number of calculated polygons is decisive for the quality of the 3D object. Before rendering tesselation is followed by extrusion, see 4.2.

3.3. Rendering

Rendering is the English expression for translation or assignment. In means of CAD drawing it denotes the visual betterment of a three-dimensional CAD model. An arbitrary number of light sources can be placed, and colors and textures can also be assigned to individual objects. Flat shading and smooth shading are the standard procedures. Higher demands of photo-realistic representations need raytracing and radiosity.

3.3.1. Raytracing: The raytracing procedure determines a color value for each pixel. For this, the orientation of the object to the light source and to the observers perspective must be calculated first. The computing times are always dependent on the materials used (e.g. glass and other reflecting materials) and on the picture size. Radiosity is better than raytracing in that it lets every area emit light.

3.3.2. Radiosity: Radiosity is the process used for lighting the CAD model. This method is the reason why the model can depict sharp shades, reflections, and materials. After this calculation the object is represented photo-realistically. Diffuse illumination and diffuse shadows are included. Radiosity rendering is very time consuming and can lead to ultra photo-realistic images.

3.3.3. Real time representation: The interactive view of models with a navigation freely accessible to the user is the most flexible method of data presentation, but also the most demanding due to real time requirements. A compromise has therefore to be made between detailing the geometric model and rendering algorithm. For this, models are converted into polygon surfaces and reduced to a certain degree of detailing. These models are then converted into the scengraph data structure or, for Internet applications, into the format X3D. X3D is the XML wording of the previous VRML format.

4. EXAMPLE OF A TRACERY WINDOW

4.1. 2D representation

The Gothic construction elements of the former Wesel city hall are very filigree. For the reconstruction of the facade, consultations of comparable objects were undertaken, for example of the Cologne cathedral. Furthermore, details were compared to data from the literature and further refined. The textbook “Lehrbuch der Gothischen Construktion, Atlas“, second edition published by Georg Gottlob Ungewitter in 1875, is a major source in this field.

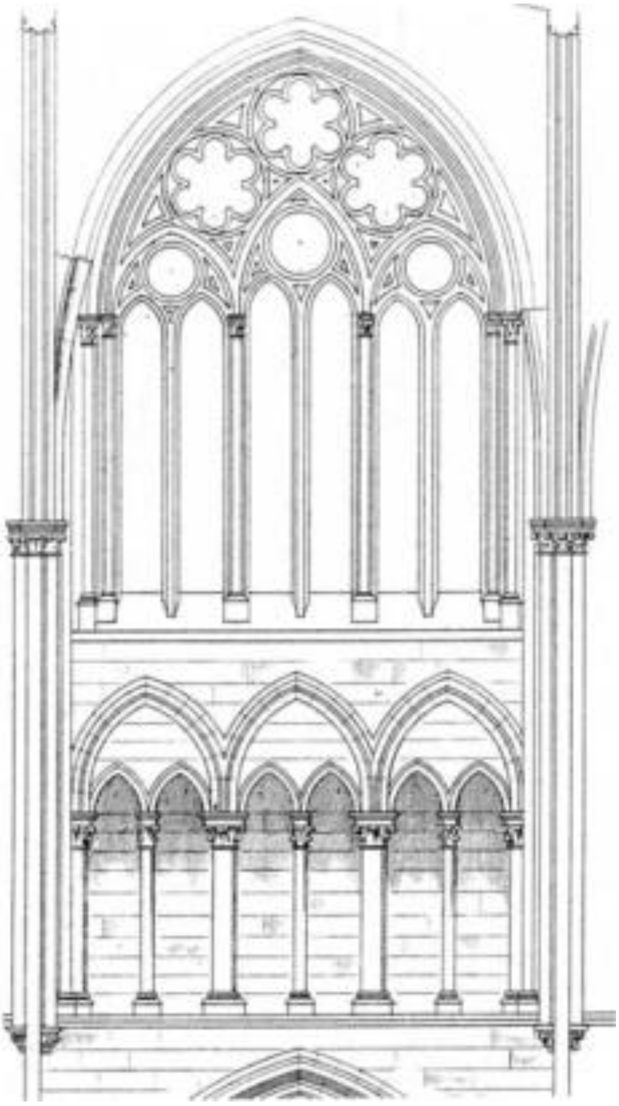

Figure 2. Filigree component from the book by Georg Gottlieb Ungewitter

4.2. Transformation into 3D representation

Obviously, the depiction of such detail-oriented Gothic architectural components is a challenge for CAD. The 2D drawing proposals are supposed to be transformed into 3D CAD objects without losing the filigree patterns of the parts. Space curves have to be modeled first, which represent the contours of the object. Then, 2D areas are generated, which are assembled into 3D area bodies.
To carry out this transformation from 2D into 3D, the operator must use different aids, such as functions like lofts, rotation bodies, curve networks, path objects, and also Boolean operations. Some helpful procedures are not available as functions and must be invented by the operator.
The generation of path objects is an important function for the production of components. Two different curves are needed for this function. The first must represent the cut through the building component, and the second indicates the length or height of the object, in general the path. The curves are then extruded along that path. This method is very suitable for simple objects, such as single stones. However, it has limited value for complex components.
Boolean functions, named after the English mathematician

Georg Boole (1815 - 1864), are still used today for representations of logical relationships. With the help of these orders, areas or bodies can be changed. These operations provide the possibility to combien different parts of an object. Separate parts can be assembled in retrospect, without occurrence of double surfaces, for example.

Figure 3. Modeled detail from CAD

Figure 4. 3D detail from CAD

Single stones were modeled and put together to the complete object. Stones appearing several times in the model were referenced as blocks. They were then reinserted into the drawing as blocks in order to save storage space and construction effort.

5. CONCLUSIONS

Modeling Gothic components requires the transformation of filigree components into an adequate CAD model under consideration of later processing of the data, e.g. detail construction in large format or visualization of the whole object in small format.

Most details of the Gothic style correspond to growth patterns in nature, mostly taken from the plant world. For this reason, it is frequently possible to obtain help from nature for modeling. This can be done with the help of plant leaves, for example with the milkworts of the Gothic style. Thereby it is possible to obtain an impression of an object, in which it is visualized as a 3D object and not only as a 2D drawing. If the CAD editor loses himself in details, his software file quickly gains considerable size.

Overall, review of the topic leads to the conclusion that 2½D standard modeling methods, which are normally used in the building and construction industry, will not be successful in the long run. However, NURBS is a way to success.

Remark: At the time of writing this paper, the project was short after its starting point. Final results will be published on www.imagefact.de.

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