Development and Manufacturing a Selfshielding Model

KAAREL PÄÄSUKE[1], HENDRIK VOLL[2]
[1] Department of Machinery, [2] Department of Environmental Engineering
Tallinn University of Technology
Ehitajate Tee 5,Tallinn, 19086
ESTONIA
kaarel.paasuke@ttu.ee, hendrik.voll@ttu.ee

Abstract: Starting from July 1st in 2009 became into force the regulation number 258 („The Minimum Requirements for Energy Efficiency") of The Republic of Estonia. The regulation states, that every new and significantly renovated building has to correspond to the minimum energy requirements of energy efficiency. In case the building does not fulfill the requirements stated in the regulation, the building has to be redesigned. The main energy consumption of dwelling derives from heating the building, which is affected by insulation and ventilation-system. As in offices considerable amount of energy consumption is derived from cooling, the situation is more complex. To educate Estonian architects and engineers and explain one of the key-factors – the design of the facade –direct solar radiation table named Heliodon was established and an model of a building was manufactured. The model has different types of facade layouts in different quarters to visualize their influence of heating/cooling loads and energy demand. The present paper focuses onto the developing process of the exemplary model from concept idea to real physical model.

Keywords: Cooling demand, Energy efficiency, Rapid Prototyping, Selective Laser Sintering

1. Introduction

Starting from July 1st 2009 Estonia has a new minimum energy regulation. The regulation forces architects and engineers to intense cooperation. The fact that the local architects study mostly in Estonian Academy of Art and the engineers in Tallinn University of Technology or in other technical school causes often indistinctness on the local construction field. In spring 2010 Tallinn University of Technology started a program which attempts to join the architects and engineers. To carry through the practical tests and lessons, a new Energy and Indoor climate laboratory was established to Tallinn University of Technology. The laboratory consists of energy simulation software and scientific teaching tools like overcast simulator and direct sun heliodon table to test the building scale models and visualize the principles of simulation software.

2. Concept of the selfshielding model

In present chapter the concept of the selfshielding model will be described. The concept is illustrated by a sketch (fig. 1) and the requirements of the model are as follows. The model has to have four floors. The height of one floor is 100 mm hence the total height is approximately 400 mm. The first floor has to be square and have four rooms in series on each side. The rooms are also square (side of the room 150 mm), hence the overall dimensions of the first floor are 600 x 600 mm. Each following floor has to be longer by one row of rooms so that one of the facade will be stepped.

Consequently the dimensions of all four floors starting from the first floor: 600 x 600 mm, 600 x 750 mm, 600 x 900 mm and 600 x 1050 mm. As the use of diffuse light sensors is

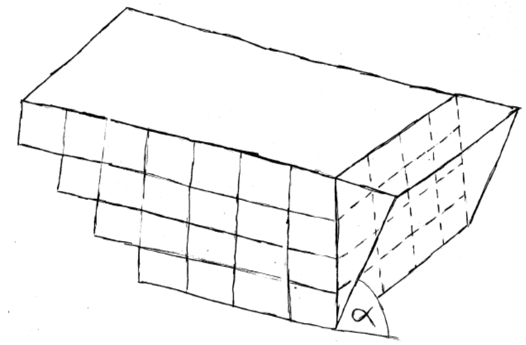

Figure 1. Concept of the model.

prescribed, the model has to be demountable for placing the sensors.

The solution of the facade has to permit to use windows with different sizes. The sizes of the windows are defined by their percentage of the total facade area: 0%, 20%, 40% and 70%. The concept of the windows has to enable the use of sunshades.

As mentioned before, one of the facades has to be stepped to illustrate the selfshieldment of this type of facade. It is also usual to have facades at a slant, but the effect of the self-shieldment depends then, in addition to the angle of the facade, on the latitude and the present season. The exemplary model has to have also a facade at a slant and as the direct sun heliodon table enables to test the models in different latitudes and seasons, the angle of the facade at a slant of the exemplary model has to be changeable. Although the present requirement increases the complexity of the task, the advantage of visualizing such solutions cannot be underestimated.

The specifications and the constraints are summarized in table 1.

Number of floors	4
Overall dimensions	600 x 1050 x 400 mm
Dimensions of the rooms	150 x 150 x 100 mm
Construction	demountable
Sizes of the windows:	0%, 20%, 40%, 70%
Facades North South	 Stepped At a slant (inclination angle changeable, removable)

Table 1. Specifications of the concept of the model.

3. Potential technologies

The concept can be realized by using different technologies, from which each will have bigger or smaller affect to the final solution (design for manufacturing). In present section several potential technologies are going to be described and analyzed.

3.1. Selective Laser Sintering

Rapid Prototyping (RP) is a technique for the direct conversion of 3D computer aided design (CAD) data into a physical prototype using a number of techniques, mostly based on slicing a computer model of a 3D object into multiple 2D layers and building them up, one layer at a time [1]. One of the main differences between conventional manufacturing technologies and RP technologies is that parts are produced by adding material not removing it, hence the RP is also often named additive manufacturing (AM). With traditional methods the manufacturing of a part requires several time-consuming preparative steps like selection of the technology (/-ies), selection of the tools, generation of the toolpaths, selection of clamping the part during operations etc.

Selective Laser Sintering (SLS) is a powder based RP technology that allows generating complex 3D parts layer by layer [2]. In the building-process (fig. 2) first a layer of powder is spread onto the building platform, next the

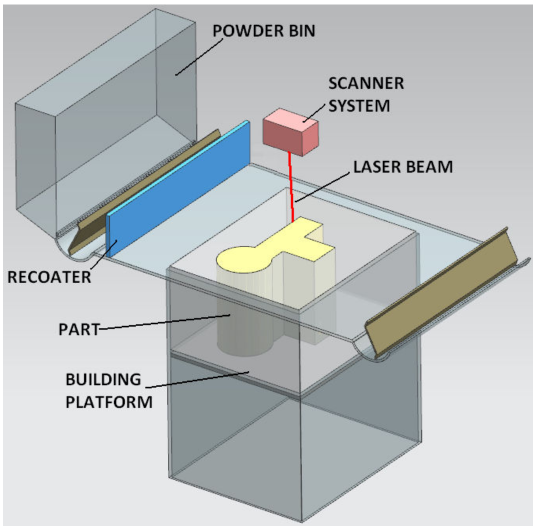

Figure 2. Process of Selective Laser Sintering [3].

present cross-section is hatched with a laser beam. As a result the temperature of the material rises over its melting point and as the material cools down solidified layer is formed. The unsintered material, which surrounds the part, has the supportive function. As the parts cannot be sintered directly to the building platform, a powderbed is needed. In addition several layers of material are spread onto the produced parts. Both, the powderbed and top-layers, carry the function to smoothen the cooling process after manufacturing.

SLS is considered suitable to produce complex functional plastic parts. The technology enables even to produce moving joints as one part, hence assembling operation is usually unnecessary. To manufacture the described model with SLS, first a three dimensional model is needed. As the model itself is an assembly, which has to be demountable afterwards, the fits of the model have to be defined very precisely to assure the tight fitting and simultaneously the disassembly of the parts. An assembly as complex as present requires an thoroughgoing analysis. In addition, the overall dimensions of the model are 600 x 1050 x 400 mm, but the dimension of building chamber of the SLS system on disposal are 200 x 250 x 330 mm, hence the manufacturing with present system necessitates the splitting of the model into at least 12 sections. As lots of parts of the described model are simple floor and wall panels, it is unreasonable to manufacture the present parts with such relatively expensive technology.

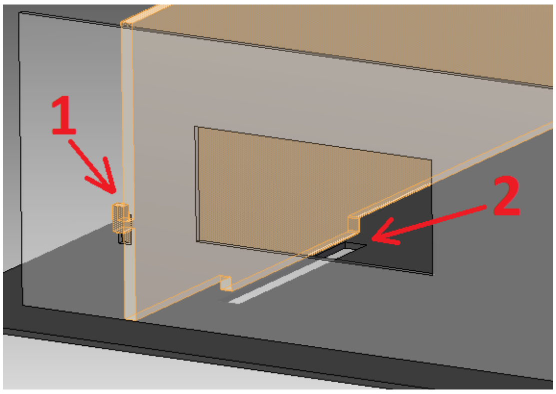

Figure 3. Tenons (1 and 2) which can be used by panels manufactured by laser cutting.

3.2. Laser cutting

One potential technology by which to manufacture the present model is also laser cutting. Laser-aided cutting has brought about a revolution in manufacturing industries, being used to cut through a variety of materials such as metal, wood, glass and plastic. The laser is directed at the required surface and moved around to cut the material in the desired shape [4]. As the model consists basically from walls and floors, these all can be considered as 2-dimensional panels, which can be cut out from sheetplastic. The panels can be joined by using different types of tenons (fig. 3). Laser cutting is comparatively precise (0,05 ... 0,2 mm) [5], which is enough to produce the fits for such tenons.

Although the solution is promising it has several uncertainties. First, as the panels are joined by tenons and no bonding agent can be used to assure the demountability, the rigidity of the model is questionable. Second, the design of the tenons has to enable compability, which is difficult to check and assure absolutely.

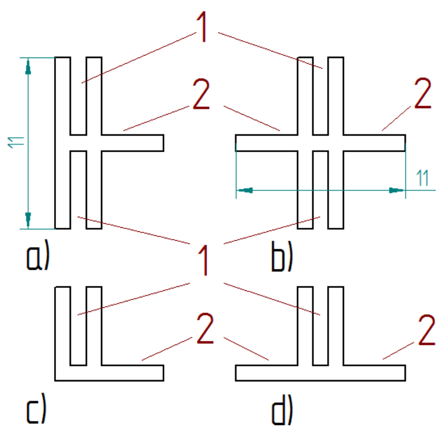

Figure 4. The cross-sections of the profiles of the construction.

4. Selective Laser Sintering combined with laser cutting

The previously described solutions have several strengths and weaknesses, hence the model was built by combining these two technologies. The walls and floors are simple panels which were reasonable to manufacture by laser cutting. SLS can be used to manufacture the complex parts like joining and construction elements etc. The design of the joining elements has to enable the easy and stable fastening of the panels, however the amount of material has to be minimized to reduce the own weight and material cost.

5. Design and manufacturing of the model

The chosen joining elements are in principle profiles with slots (fig. 4. nr 1) for walls and supporting edge for floors (fig. 4 nr 2). Profiles c and d on figure 4 are for the first floor; a and b for second, third and fourth floor. The model is held together by five frames of the profiles: four floors and the roof. To manufacture the mentioned frames, the frames were divided into sections of the size of building platform of the SLS system (200 x 250 mm). The four floors and the roof altogether consisted of 58 parts of the frame. The material, used for

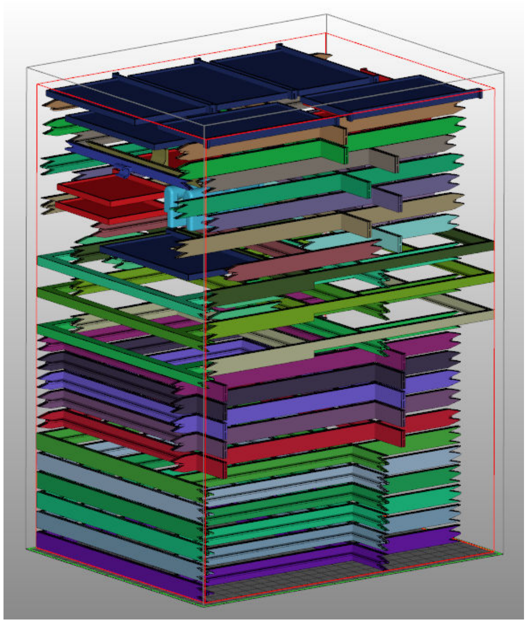

Figure 5. The positioned parts in jobfile of SLS machine.

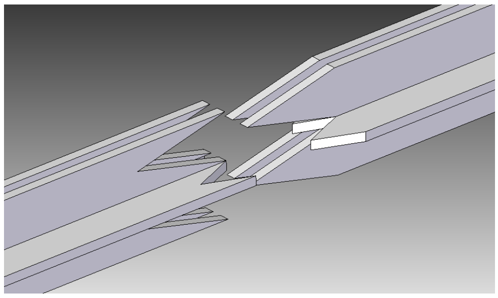

Figure 6. The tenons of the frames of constructions.

manufacturing the parts by SLS, was PA 2200 (σ = 48 Mpa [6]).
To prepare the job-file all the parts of the frame were oriented and positioned in special software (VisCam). By preparing the job-file the parts have to be positioned tightly to maximize the effectiveness of the run, still sufficient distances must be guaranteed to avoid the merging of the parts. The positioned parts in the model of job-file are shown on the figure 5. In the next step the positioned parts were divided into layers and the paths of laser for scanning were created. After manufacturing the parts were cleaned by sandblasting.
The parts of the frames were connected and fixed by tenons and bonding agent (fig. 6). As the wall-thickness of the profiles was only 1 mm, the effective design of the mentioned

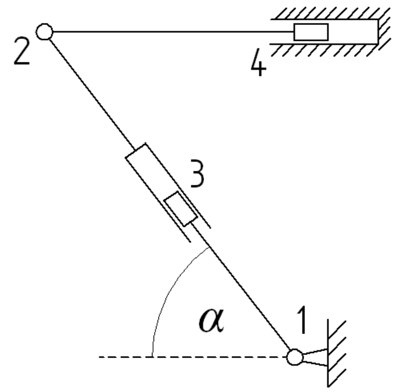

Figure 7. Kinematic chain of the facade with changeable inclination angle.

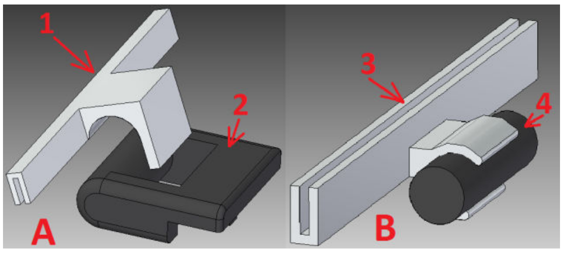

Figure 8. Joints of the movable façade.

tenons had a crucial role. The design of the present tenons was driven by the objective to reduce the degrees of freedom of the joining profiles. In addition, the chosen v-shape of the tenons centered the parts to one another in gluing-operation and increased the contact-surface.

As different sized windows were required, five sets of facade panels were manufactured (0%, 20%, 40% and 70% of the facade area). All the rooms are separated by partition walls, which are also inserted into the slots like the facade panels. The partition walls are tied with each other also by the tenons to increase the rigidity of the model.

5.1. Facade with changeable inclination angle

In addition to the stepped facade the model had to have a facade at a slant which's inclination angle is changeable. The angle α (fig. 7) of the moving facade has to be varied from 40° to 90°.

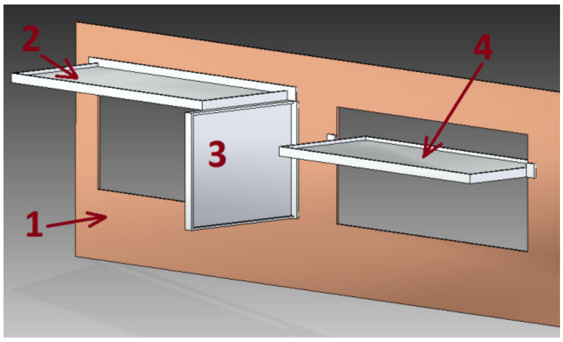

Figure 9. Sunshades which were used by the models.

The concept requires rotating joints in lower and upper side of the facade (fig 7. 1 and 2) and as the change of the inclination angle changes simultaneously the length of the facade itself and the roof, two translational joints are needed (fig. 7. 3 and 4). In addition, the moving facade has to be removable. Considering all the mentioned aspects, joints presented on figure 8 were used in the solution. The joints were designed into the construction and therefore manufactured also by SLS. The pivot of the lower joint (fig. 8 B. nr 4) is a part of the frame of first floor and the rotating cylinder (fig. 8 B. nr 3) is a part of the moving facade. The rotating cylinder is fastened to the pivot by a snap. The upper joint (fig. 8 A) consists also from a pivot which is attached to the moving facade and rotating hook which is attached to the sliding roof.

The change of length of the facade and the roof is solved with panels sliding in one anothers slots.

5.2. Finished model

The final CAD model is shown on the figure 10 and the finished physical model on figure 11. The CAD assembly-model was used to verify the dimensions and eliminate errors. The physical model shown on figure 11 has the sunshades on south and east side of building. There are three types of sunshades used in the present model: sunshades which are attached above the windows (fig. 9. nr 2), onto the side

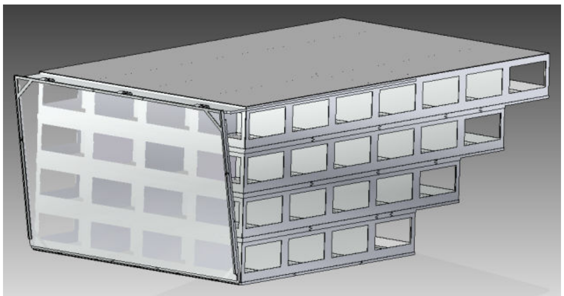

Figure 10. The final CAD model.

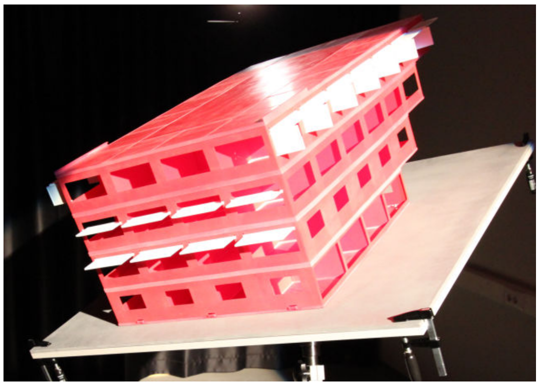

Figure 11. The final model

of windows (fig. 9. nr 3) and between the window itself are used light-shelves (fig. 9. nr 4). All the sun-shades were attached to the facade by tenons and therefore the shades were removable. All of the sun-shades were manufactured by SLS.

The light-shelves improve uniformity of illuminance by reducing light levels near the window [7]. As the light-shelves are rather rarely used in Baltic states, it is even more essential to visualize their practical aspects to local architects and engineers.

6. Conclusion

In conclusion, a model of selfshielding building was developed, designed and finally manufactured using Selective Laser Sintering (SLS) and laser cutting. The model has 4 floors and facades with different design to visualize their influence of heating/cooling loads and energy demand.

Acknowledgements

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