

A guide for the building of daylight scale models

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ABSTRACT: Scale models are frequently used to evaluate daylighting performances of buildings. In order to get accurate results, there are several rules to respect for building these scale models. Some of these rules are universal and others depend on the measurement and observation devices, the type of sky under which the study is carried out and the objectives of the study. This paper, based on the authors experience and on a literature review, presents rules to respect when building a mock-up for daylighting studies. These rules are illustrated by project examples that were tested under the Belgian artificial skies (Single-patch sky and sun simulator, Mirror box and Mechanical sun).

Keywords: daylighting, scale models, artificial sky

1. INTRODUCTION

Daylight is one of the key elements of all architecture projects. Architects have used scale models for centuries in order to evaluate their projects under a real sky. Moreover, the development of artificial skies has made the studies less dependent on factors like the weather, the time or the date for many years [1].

Today, even if computer simulations can give very accurate results in a reasonable time, our experience indicates that it is essential for architects to personally appreciate the luminous environment of a space and to compare several solutions qualitatively. This intuitive appreciation obtained by scale models cannot currently be obtained by use of computer simulations.

When properly constructed, scale models portray the distribution of daylight within the model as exactly as in a full-size room. Comparison works on simple models have shown that daylighting studies carried out under sky and sun simulators can give very accurate results [2]. However, the complexity of the models will generate errors if the models are not built accurately and with respect to several rules. This paper describes in detail these rules and gives some advices for the building of architectural scale models in order to achieve precise daylighting measurements and analyses. Section 2 lists information that is essential for the laboratory technicians and Section 3 encourages the model designer to use modular models that are less expensive than using different models. Section 4 shows that the scale of the model should be chosen as a function of the study's objectives but also as a function of the type of sky and the appliances used for the study. Section 5 shows that the inaccuracy in the model geometry can lead to large errors. Section 6 discusses the illuminance sensor and the camera position while some advices on the edges joining are given in

section 7. Section 8 discusses the scale model material colour and reflection mode; a link is made to a web tool especially focussed on this aspect. The window geometry and material is discussed in Section 9 and finally, Section 10 and 11 introduce the external surfaces modelling.

2. GENERAL INFORMATION

General information like precise building or site orientation, site latitude, scale of the physical model and name of the building has to be referenced on the model. All those information should also be resumed and reported on an identification card.

3. MODEL MODULARITY

It is easy to test façade or skylight options with one generic model. For testing of different façade configurations, it is most of the time possible to use the same model by modifying only small elements or the tested façade.

Interchangeable elements should be clearly labelled and an outline of permutation should be prepared before the tests.

Figure 1 and 2 show, for example, how to test several positions of a solar shading system by using hook and loop tape; the hoop side is pasted on the ground and the hook side is pasted on the base of the vertical structure of the shading system. The structure can thus be tested in a vertical or a sloped position.

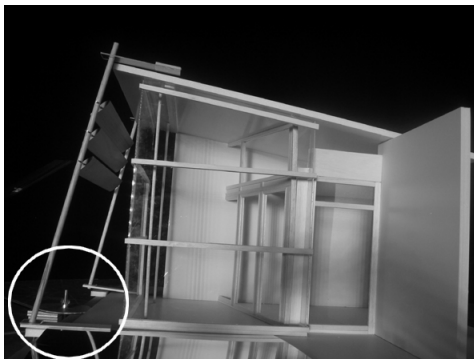


Figure 1 : Example of modularity of a solar shading system – sloped position.

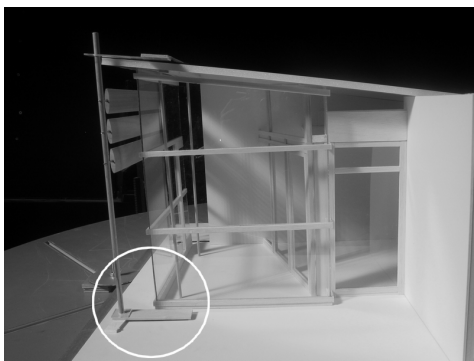


Figure 2 : Example of modularity of a solar shading system – vertical position.

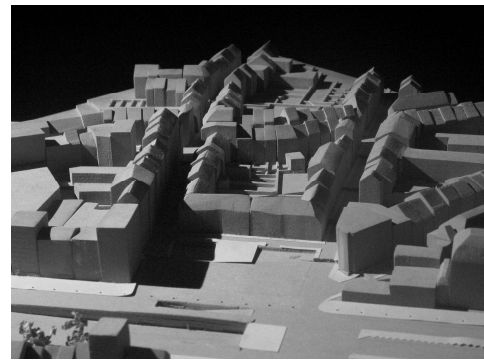


Figure 3 : Example of a mass model (scale 1/200).

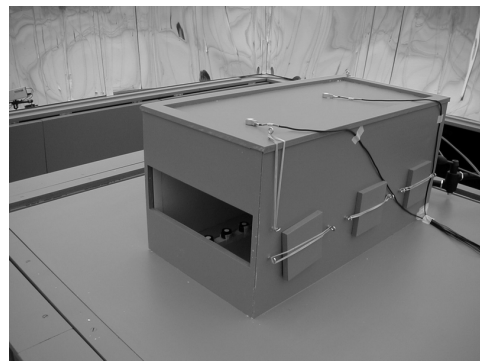


Figure 4 : Example of a model for a detailed study of daylighting penetration (scale 1/10).

4. SCALE AND SIZE OF SCALE MODELS

4.1 As a function of the objectives

The construction of a model must be preceded by the determination of the appropriate scale, which is directly related to the model's particular purpose. Scale ranging from 1:500 to 1:1 are to be considered. Three types of scale models may be distinguished in function of the performance and the design [3-5] :

- Mass models for the study of solar access for purpose of site planning, building location and orientation (see figure 3 as example).
- Models for studying the building's performances, including daylighting penetration and internal distribution, measurement of illuminance and luminance levels, of glare and contrasts (see figure 4 as example).
- Models for investigating individual apertures, glazings, shading devices or advanced daylighting systems.

Table 1 gives information on the choice of the scale as a function of the study's objectives.

Table 1 : Scale choice as a function of daylight design purpose

Scale	Objectives
1/200 to 1/500	For preliminary design and concept development. To provide a gross sense of the massing of the project. To study the shadows generated by the future building or from a neighbouring building.
1/200 to 1/50	To study direct sunlight penetration into a building. To study diffuse daylight in a very big space.
1/100 to 1/10	To consider detailed refinement of spatial components. To have highly detailed inside views. To study accurately diffuse and direct daylight penetration.
1/10 to 1/1	To integrate critical industrial components. To consider daylighting devices that cannot be reduced in scale. To proceed to final evaluation of advanced daylighting systems through monitoring and user assessment.

The detail accuracy has to be adequate in function of the information required. This has an influence on the choice of the model size.

Massing models can be built crudely (i.e., the openings do not necessary have to be modelled) as the objective is to get a general view of the impact of the buildings size and location on existing buildings (shadows of one building on another, views,...).

Full scale mock-ups may be used to examine the effectiveness and workability of control elements or new materials and therefore have to be built with a high degree of accuracy.

4.2 For accuracy reasons

The scale model size can also be fixed by the visualisation type or by the measurement devices used in the model. For models that would be tested under an artificial sky or sun, restriction on the size can also come from the artificial sky or sun themselves, in order to limit errors.

It has long been appreciated that scale modelling in artificial skies under non-uniform luminance distributions is prone to parallax errors, due to finite dimensions of the sky vault ; two observers placed side by side and looking in the same directions do not exactly see the same sky luminance distribution.

Under an artificial sky simulator of fixed diameter, the parallax error increases as the scale model size increases. Maximal size dimensions have to be fixed for each artificial sky, according to its dimensions. Generally, the maximal dimensions of scale models are set to 10 % of the apparent diameter of the sky vault.

For shading analyse under sun simulator, the size of the model must be reasonable with regard to the distance to the light source and the width of the sun spot.

4.3 As a function of the measurement appliances characteristics

For internal pictures, it is essential to focus on, at least, one room surface. In our case, a macro lens with a focal distance lower than 28 mm is used. It allows a sharp image at low distance and has a large opening angle. This leads to a floor to ceiling minimal height of 0.15 meter and a minimal room depth of about 0.30 meters. For most of the buildings, this corresponds to a minimal scale of about 1/20 to 1/25. The figure 5 shows an example of the placement of the camera in a model.

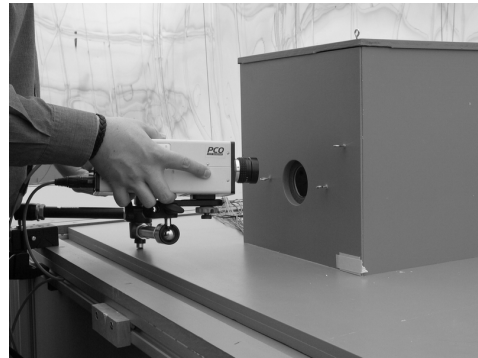


Figure 5 : Opening for the camera.

In order to obtain a view comparable to the view that would be obtained in the real room, It is necessary to place the lens centre at the eyes height, in the scale model. This height varies between 1.5 to 1.7 meter. For a scale of 1/20, it corresponds to 75 or 85 mm height in the scale model. According to the lens diameter, a scale higher than 1/20 can be required.

The illuminance sensor size can also influence the scale ; the illuminance should be measured at work plane height. With sensors of 15 mm height, the minimum scale for modelling a working plane of 0.8 m height is the 1/20 scale.

4.4 For practical reasons

The dimensions have to be limited for local and practical reasons as for example, the laboratory doors width (see figure 6), the turntable dimension and the fixation system (figure 7) or simply, the model transportation mode.



Figure 6 : The mirror box doors width fixes the maximal scale model dimensions.

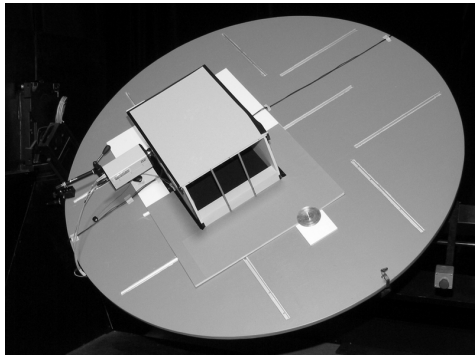


Figure 7 : The size of the turntable and the fixation mode determine the maximal model dimension.

5. MODEL GEOMETRY AND MODELLISATION OF WALLS

The respect of the exact building dimensions and geometry is very important and errors in on-site measurements (if the real-building already exists) can lead to substantial errors [4]. Thanachareonkit et al found that the accuracy of the geometrical dimensions is one of the key factors, together with the internal surface reflectance, regarding the discrepancies between the scale model and the real building. [6]

Each surface has to be modelled. Mirrors are useful for the modelisation of large symmetrical spaces but only under overcast sky conditions analyses (figure 8). Under clear sky conditions, the direct sun would reflect on the mirror into the space, creating light distribution errors. Mirror must be fixed very accurately and taped with black tape. Horizontal and vertical surfaces must thus be perfectly aligned to avoid any light penetration that would be reflected by the mirror and create large sources of errors.

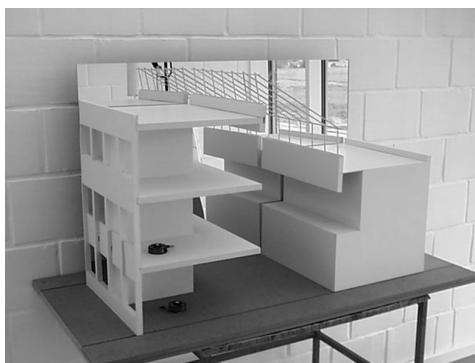


Figure 8 : Example of mirror use for the modelisation of symmetrical spaces.

Internal walls have a large influence on the light penetration and distribution. It is thus essential to model them. Furniture can also influence the light distribution; its influence depends from its colour, its size and its localisation. The furniture modelisation can be time-consuming and can increase the model budget. It is not compulsory for preliminary studies

but, in the final phase of the project, it is interesting to model the furniture, in order to visualise the final solution (figure 9).

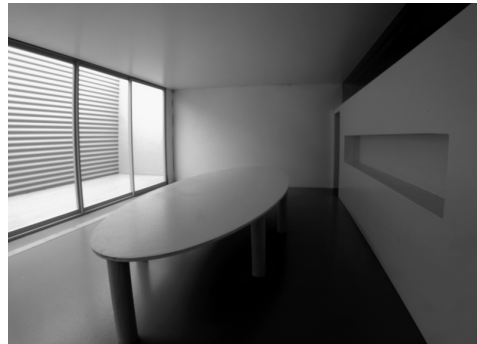


Figure 9: The modelisation of the furnitures gives very realistic views.

6. SENSOR AND CAMERA LOCATION

Access to interior of the model is necessary for placing the illuminance sensors. If there is no opening (window) allowing the sensor passage near the measurement points, one of the external walls must be easily and quickly removable. It is also useful to plan a small hole, for the passage of the wires through an external wall.

It is essential that the sensor wires do not pass through a wall that has to be moved during the measurements, in order to avoid displacing the sensors during the study. It is time consuming and leads to problem of accuracy in the position of the sensors.

It is essential to mark and to number the measurement points before the measurement phase (see figure 10). An interesting solution is to cover the floor with a printed grid, that can be, for example, marked at the edges with numbers in one direction and letters in the other [7].

For vertical illuminance measurement, holes have to be done in the walls in order to align the top of the sensor with the wall plane. These holes should be sealed, for example with art, in the case of museum, for qualitative analysis.

Effective view ports for the camera must be provided. They could be easily accessible and large enough to allow the best camera orientation, in order to have the most interesting views. Each view port should be labelled and covers must be planned to seal these holes, when they are not used.



Figure 10: Illuminance sensors in a scale model.

7. MATERIAL AND EDGE JOINING

All the light leaks must be discarded. For scale models made in foam core, the joining can be made following the technique described at figure 11.

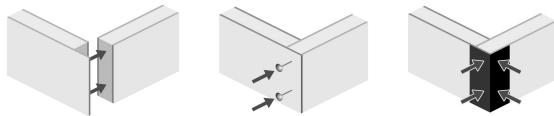


Figure 11: Fixation of moveable foam core walls [8].

For scale model building, almost each material that is usually used for architectural models can be used. The white foam core, which is often used for the building of daylight scale models, is translucent. It is thus necessary to cover the foam core with non translucent dark paper like showed on figure 12; the easiest is to stick black paper to a large sheet of white foam core before beginning the model construction.

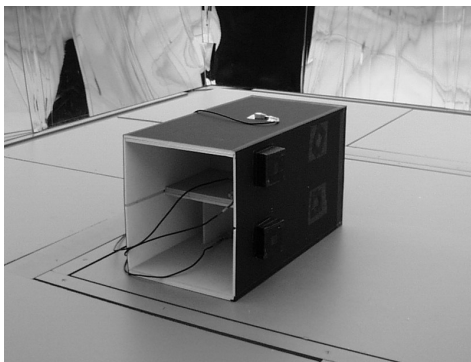


Figure 12: The foam core should be covered with opaque dark paper.

Wood can also be used for the mock-up building; these mock-ups are then very robust but a disadvantage is that their weight grows rapidly. It is also important to avoid light leaks that induce inaccuracy, especially in poorly daylit rooms.

8. COLOUR AND WALL REFLECTION COEFFICIENTS

The material choice will depend on the study's purpose. For an accurate quantitative luminance and illuminance study, it is essential to choose a scale model material having a reflection coefficient and a lightness very close to the full scale material's values.

An overvaluation of the reflection factor can lead to large errors. For example, if the vertical wall has a reflection coefficient of 50 % and if the scale model has white walls ($\rho=85\%$), the measurements made in the scale model can overvalue the results of about 150 to 200 %, for a point localised at the far end of the room.

For a black and white visualisation in a scale model, it is important to favour the wall lightness while for a quantitative daylighting study, it will be preferable to support a material having a reflection coefficient very close to the full-scale material's reflection coefficient.

If the objective of the study is to evaluate the visual impression felt in the room, it is the colour of the scale model material that will be as close as possible to the colour of the full-scale material.

White foam core is more shiny than most of the internal wall materials: it should then be covered by diffusing paper, unless if the real material is shiny.

As the choice of the best scale model material is difficult, the authors propose to use a web tool they developed in order to help the scale model designer [9]. This web tool proposes a large choice of scale model material, as function as the colour, the lightness, the reflection coefficient and the reflection mode of the real material.

9. MODELLISATION OF THE OPENINGS

Windows have to be modelled accurately as they affect the internal daylight penetration and distribution; the window width and the window sill have to be modelled.

If possible, the designer has to use a thin glass (of 3 or 6 mm width) with the same visual properties than the real glazing. This may be found using glazing with coatings directly delivered by the manufacturers. If there is no glazing available; measurements can be done without any glazing. A reduction factor is then introduced in order to correct the experimental results.

If the main daylight source enters the building through the openings at angles of incidence greater than 60°, the glazing material has imperatively to be included in the model to establish the proportion of daylight reflected of the glazing.

The opening size must correspond to the glazed part of the window unless the frame is precisely modelled.

10. MODELISATION OF THE EXTERNAL FLOOR

In some cases, the proportion of external reflected light that enters the room is high. It is thus then essential to model accurately the external floor reflection coefficient and its colour unless if the windows are all roof windows. Figure 13 show the modelisation of grass in the case of a daylit basement room.

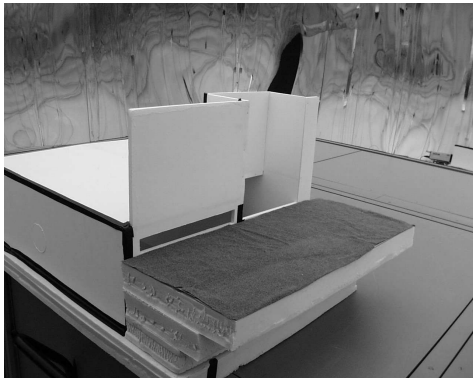


Figure 13: Modelisation of grass.

11. MODELISATION OF EXTERNAL OBSTRUCTIONS

The size and the colour of near external obstructions (neighbour buildings, vegetation) must be modelled accurately, like shown in figure 14. Reflection coefficients of the external surfaces of the building itself have low influence on the internal light level. They can thus be covered with black paper without influencing the internal results.

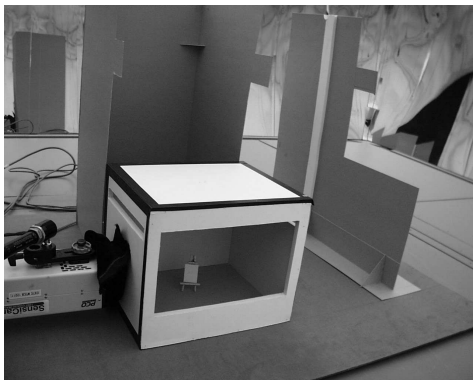


Figure 14: Modelisation of external obstructions.

12. CONCLUSION

Building a daylight scale model is not more difficult than building a traditional architectural model like usually used to visualise the building geometry and volumes. However, there are some rules that have to be integrated when building the model in order to get

as accurate as possible results. It is essential to integrate all the rules before starting the scale model building. Some of the rules are general and other are local; they vary as a function of the sky simulator that will be use to test the model. General rules concern, for example, the respect of geometry, the elimination of each light leak, the choice of materials, of furniture, etc. Local rules concern, for example, maximal model dimensions, illuminance meter dimension and camera port dimension. This paper gives the general rules that have to be respected in every scale model and introduces local rules in order to help scale model designers to ask the good question to the lighting technician, before building his model. The respect of each of these rules is essential and will lead to accurate daylight scale models.

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