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Application of Atrium Tensile Structure in Historic Building. Case study:Daylight Modeling of Atrium within Historic Building.

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Abstract

The specific area of application of tensile roof structure is their use in the historical environment. They do not have the character of historical constructions considered as elements of long life spans such as masonry, wood, steel (especially in the 20th century). In general, the tensile structures represent desirable structural elements in contemporary architecture. They are suitable in the historical environment due to low bulk density (lightweight skins), and reversibility to monument structures. On the other hand, their optical properties of translucency and transparency is the reason for studying the effects in daylight exposure as well as the effects of night image. In this paper, the daylighting simulation for the selected atrium tensile roof structure is added and its effect on daylighting distribution of the historic building's rooms is evaluated. These are daylighting outputs that can help or to lead to choose a preferred type of tensile roof structure already during preliminary design phase.

Keywords: daylight modeling, atrium, tensile roof structure, refurbishment of historic buildings

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1. Introduction

Many historical buildings have a new function in adapting their atriums. They transform the exterior space into the interior. New social functions for a short stay are integrated here. In this context, it is necessary to consider in advance the real impact of the new atmosphere of the future interior and the demands on technical solutions (roof drainage system, air flow, acoustics, lighting, etc.). In our contribution, we focus on the material selection effect in terms of optical properties on daylighting in the renewed atrium of a historic building, since the daylight is the still considered as the healthiest form of lighting. [6] The impulse for our experimental exploration was the previous design project of atrium roof using a glazed structure (Fig. 1a-b - current state of 3D model, 1c - conventional design of glass roof in atrium). However, in variants of calculation on illuminance a glazed structure was replaced by tensile roof construction. It is a framework findings demonstrated by calculation that would be important in the initial design phase of the atrium. The following question arises: What are the impacts of tensile roof structures on the daylighting in atrium space of building, as a second variant, compared to the glazed roofing? For this reason, a model simplification was chosen for daylight modeling.

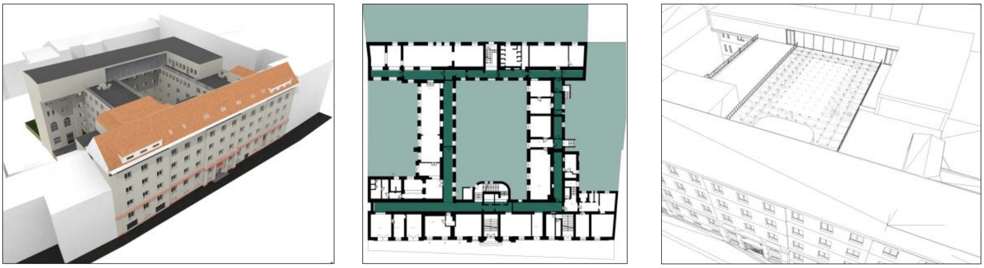

Fig.1a-b (current state of 3D model), 1c (conventional design of glass roof in atrium)

Method for the theoretical experiment: To calculate the daylight distribution of the ground floor area and in adjacent rooms and the amount of light and its uniformity on the façade, we neglect the load bearing and supporting construction, so theoretically we consider a flat element in which two parameters are changed: the specific transparency and the particular surface area in the given shape when making a combination of two materials. By combinations of these parameters, we obtained 10 variants. Subsequently we could choose the most optimal design for different purposes.

2. Selected example of atrium at Faculty of Education Comenius University in Bratislava, Office building in Šoltesova street.

The studied building was built in 1923 as a Young Women's Christian Association (YWCA). It had been rebuilt several times, and finally adapted to school. It still preserves its architectural cultural and historical values, especially in the street tract. It is a larger 4-storey building, has 4 wings. There are three atria located between 4 wings of building's floor plan. The new renovation of faculty will convert attic into new spaces of building and utilization of space in faculty environments (offices) will become more efficient throughout the building. We are interested in the central atrium, where a new small campus, connected to the social spaces and the school buffet will be. It is a simple shaped atrium with volume of 6960 m^3 (25.8 x 16.85 x 16.0m of height). Only the space of staircase enters the area of the atrium. The classrooms are situated behind the fourth facade, which presents the southern facade. There are the large classroom windows in the southern façade in accordance with daylight requirements for school classes. Above this atrium space a new tensile roof structure is considered. Here, it is important to take into account daylighting (falling light on(to) the ground, into the interior – classroom and the third on the façade of the atrium). In relation to the requirements for daylight, the height of the atrium and the function of the surrounding interiors were not considered. The need of shading devices will be solved locally, depending on the requirements of individual rooms.

3. Transparency and tensile structure materials

Light transmission in membranes as an important aspect ranges from zero to 95% transparency. The control and use of daylight in the inside environment is improving, and that not only reduces the cost of artificial lighting but also improves the interior quality of the space. [2]. In the case of films or foils, the translucency as a property is the result of the very essence of this material. Consequently, these materials represent higher transparent values reaching up to 95%. [3]

Transparency of roofing material: Within fabric solutions, PVC polyester and PTFE glass fibres present blackout capabilities, the first material starts with a value around 0 and reaches up to 25% translucency, and the next material with values ranging from 4 to 22%. Silicone glass fibres presents transparency values of 10 to 20% (Pudenz, 2004). Consequently, the entrance of diffused daylight, and the regulation of the amount of daylight entering the building is allowed. [4]

For the calculation, we applied the available real transparency coefficients for the textile and foil products used for such constructions. There were two groups of variants. First one consists of homogenous material with transparency ranging from 95% to 30 %. The second group consist of a combination of two materials that have different transparency 30%, 50% and 95% where the whole roofing is divided into central part with one type of material and perimeter part of a different type. The area ratio between those two parts was set to 50:50. The material composition of tensile roof structure is irrelevant for our preliminary model study. Although in real life we can count with a more diffuse behaviour of this material.

4. Results of calculation

The WDLS sofware (Building design package by Astra 92) was used for daylighting calculations. We used standardized uniform CIE overcast sky (the changes of luminance from horizon to zenith in ratio 1:3) that resulted into daylight factor (DF[%]) distribution outputs: minimal, maximal and average values in combination with its uniformity across the evaluated areas of the atrium´s inner surfaces. This is helpful since most climates across Europe have substantial periods of overcast skies and DF is therefore a useful metric to inform design decisions. However, for the climates with a greater portion of sunny days, a more sophisticated dynamic, year-round simulation would give us more precise outputs. We are planning to do so in a next step as an advance in our initial research.

4.1 Calculation focusing on illuminance of atrium ground floor area.

In this case, it is the amount of daylight that would fall on the working plane sufficient and allow various functions including visual tasks (reading – writing). Such conditions in accordance with STN requirements can be found across the whole area, even using the worst material combination variant in this case (central (c) 95% /perimeter (p) 30%).

From the point of view of the combination of materials, the most appropriate solution is one that prefers a higher transparency on the perimeter of the tensile fabric structure thanks to the effect of interreflections of adjacent walls of the atrium. This solution (50/95 and 30/95) is also satisfactory if shading devices are placed in the centre of the tensile fabric structure to reduce thermal gains and increase the luminous comfort resulting from glare suppression.

Calculation 4.1	min.DF	max.DF	average DF	uniformity
	[%]	[%]	[%]	[-]
variant 1 - no foil				
variant 2 - homogenous foil 95%	8.5	42.5	**34**	0.2
variant 3 - homogenous foil -80%	7.2	35.8	28.7	0.2
variant 4 - homogenous foil -70%	6.4	32.1	25.7	0.2
variant 5 - homogenous foil -50%	4.6	22.9	18.3	0.2
variant 6 - homogenous foil -30%	2.7	13.7	11	0.2
variant 7 - combination center 95%, perimeter 50%	4.7	30.3	23.1	0.15
variant 8 - combination center 95%, perimeter 30%	3	24.9	18.2	0.12
variant 9 - combination center 50%, perimeter 95%	8.3	34.5	**28.8**	0.24
variant 10 - combination center 30%, perimeter 95%	8.2	31	26.5	0.26

Tab.1: Calculation of illumination on the atrium ground floor area, comparative plane height of 0.85 m

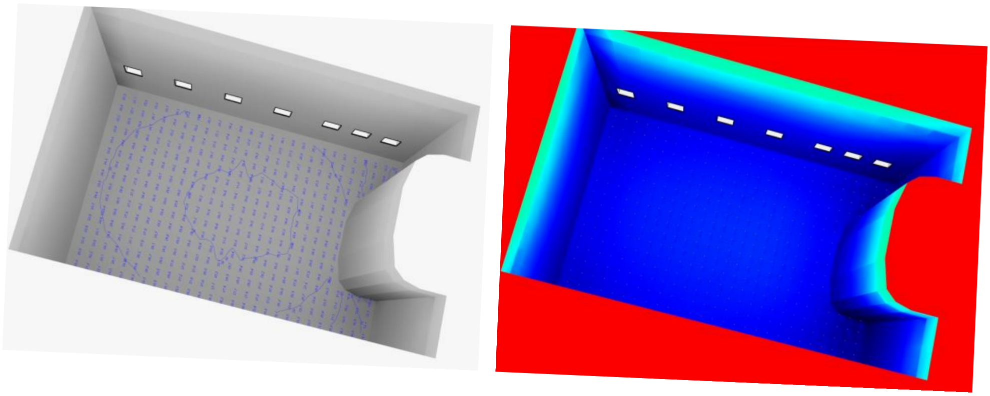

Figure 2: Typical light distribution on the atrium ground floor area at 50/95 combination, illumination (left) - false color (right).

4.2 Calculation focusing on illuminance of classroom interior.

The subject of the calculation was light distribution on the working plane in the room as a result of material selection of the tensile atrium structure. In terms of classroom design in the building space, we are limited by dimensions of the room and size of the window. This room, even without any roofing structure, does not provide enough daylighting to meet the standard for newly built classrooms, which is typical scenario by historic buildings. Therefore, we used the evaluation based on requirements for a combined lighting – daylighting and artificial lighting, with lower requirements for daylight levels. The results of the calculations show that using the composite materials combination, the best values of daylighting can be obtained with the variant 50/95 (floor ratio with sufficient daylighting is 45.85%). Therefore, designs which prefer higher transparency on the perimeter of the tensile fabric structure, are preferred for interior daylighting in this type of building geometry.

floor	Calculation 4.2	min.DF	max.DF	average DF	uniformity	area DL	floor ratio	area IL	floor ratio
		[%]	[%]	[%]	[-]	[m2]	[%]	[m2]	[%]
5th.	variant 1 - no foil	0.2	8.1	1.1	0.025	3.63	16.43278	12.81	57.99004
	variant 2 - homogenous foil 95%	0.2	7.7	1	0.025	3.47	15.71	12.35	55.90765
	variant 3 - homogenous foil -80%	0.2	6.5	0.9	0.025	2.95	13.35	9.46	42.82481
	variant 4 - homogenous foil -70%	0.1	5.7	0.8	0.025	2.55	11.54	8.48	38.38841
	variant 5 - homogenous foil -50%	0.1	4.1	0.5	0.025	1.7	7.70	5.37	24.30964
	variant 6 - homogenous foil -30%	0.1	2.4	0.3	0.025	0.8	3.62	3.31	14.98416
	variant 7 - combination center 95%, perimeter 50%	0.1	4.7	0.7	0.025	2.12	9.60	6.73	30.46627
	variant 8 - combination center 95%, perimeter 30%	0.1	3.4	0.5	0.025	1.44	6.52	5.12	23.17791
	variant 9 - combination center 50%, perimeter 95%	0.2	7.1	0.9	0.024	3.11	14.08	10.13	45.85785
	variant 10 - combination center 30%, perimeter 95	0.2	6.8	0.9	0.024	2.95	13.35	9.06	41.01403

Tab. 2: Calculation of illuminance in the classroom on working plane at height of 0.85 m

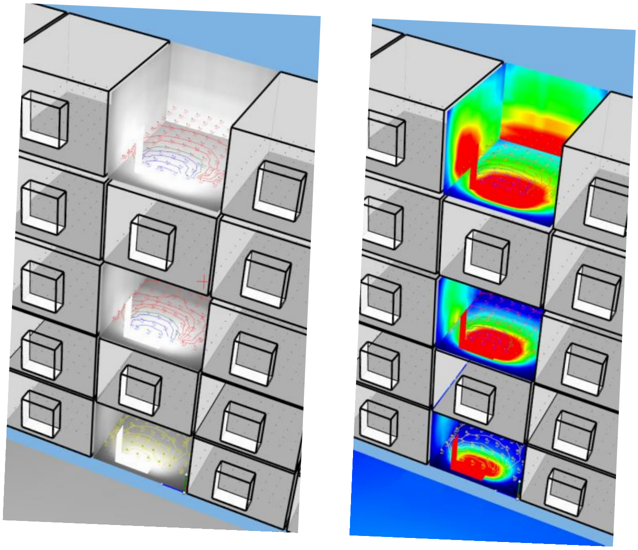

Fig.3: Daylight distribution in the room – illumination (left) , false color (right)

4.3 Calculation focusing on translucency of the facade of atrium.

Concerning uniformity of the facade illuminance by natural daylight and its aesthetic appearance, it is preferable when the uniformity, a dispersion of values of the illumination on the facade surface, reaches the highest values. In the visual image of the facade area, it means a quality of the uniformity and an exclusion of contrasting places. In our case of the atrium, different variants of the transparency of film/ foil materials V1 to V10 have been applied.

The results show that the greatest influence on uniformity (although the differences between variants seems to be small) of the facade illuminance has a combination of different film or foil materials (see Table 3). The most preferred variant (0.25) for wall luminance is a combination of materials (c95/p50), it means, the middle part offers a higher light flux towards remote parts of the facade.

Výpočet 4.3	min.DF	max.DF	avg.DF	uniformity
	[%]	[%]	[%]	[-]
variant 1 - no foil	9.9	45.3	27.9	0.22
variant 2 - homogenous foil 95%	9.4	43.1	26.6	0.22
variant 3 - homogenous foil -80%	7.9	22.4	36.3	0.22
variant 4 - homogenous foil -70%	6.9	31.8	19.6	0.22
variant 5 - homogenous foil -50%	4.9	22.7	14	0.22
variant 6 - homogenous foil -30%	3	13.6	8.4	0.22
variant 7 - combination center 95%, perimeter 50%	6.2	25.1	16.9	**0.25**
variant 8 - combination center 95%, perimeter 30%	4.8	19.9	12.6	0.24
variant 9 - combination center 50%, perimeter 95%	8.2	42.6	23.8	0.19
variant 10 - combination center 30%, perimeter 95%	7.6	42.4	22.5	0.18

Table 3: Calculation of illuminance and uniformity of the facade in atrium.

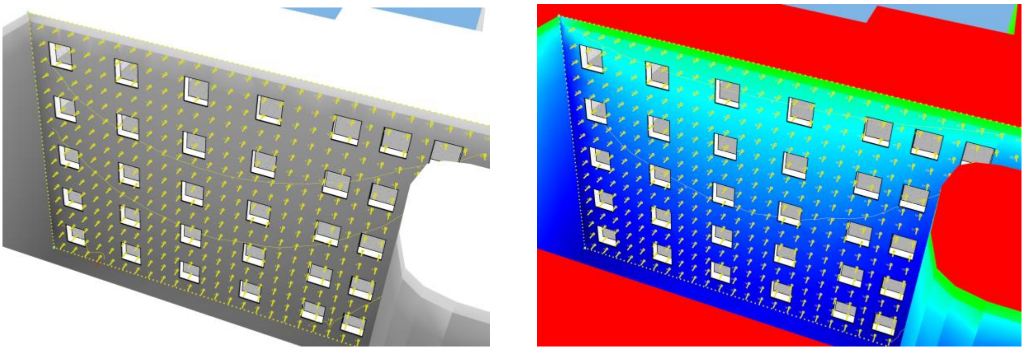

Figure 4: Light distribution on the façade in the atrium - distribution of control points. Display of illumination (left) a false color display (right)

5. Conclusion

In terms of lighting function over work surfaces, taking into account the performance of the visual tasks, the best possible options concerning material combinations are as follows: In the centre of atrium area, the material with a lower transparency is used and the most transparent on perimeter of the area.

The primary objective is to illuminate the atrium area, the secondary objective is the impact on the illuminance of the interiors (corridors, space to work or study space). In this case study, the influence of the percentage of transparency on atrium façade is only tertiary. Aesthetic inequality is not essential here.

This reduced verification procedure serves as an example that assists the author in deciding on the preference of the amount of incident light. There is a need to achieve a greater amount of incident light either on the floor area of atrium and in the space to work, eventually in the study space, behind the atrium facade (on a horizontal plane) or on the atrium facade in front of common areas (on a vertical plane with windows of different cardinal points).

We showed, that not only the parameter of transparency of a single material, but also a combination of two different materials in the roofing area of atrium can bring us different results. Therefore, a preliminary design verification is necessary. This is an example of the interdisciplinary cooperation which is needed to design the architectural project in renovation of the building. In the presented verification method, the tensile roof structure was converted into a plane and two parameters (area size and transparency in %) were considered. The simplification is both, sufficient and relevant to the expected results in architectural designing.

4. Acknowledgements

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