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Taking a step back from glass towers facades to make them compatible with the 2050 targets

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Abstract. Skyscrapers or glass towers are an extremely common model throughout the world. In the current context of climate change and resource depletion, we need to develop new postures towards these objects, especially for existing buildings that are becoming obsolete. This article begins by showing how the nature of the facades of these buildings influences the urban climate. It continues with the analysis of an emblematic building from the 1970s, the Tour Areva in Paris-La Défense (France). Through this typical example, we show how it is possible to improve the quality of use and the energy performance by exploring various scenarios. The main theme is the transformation of the façade and how it is possible, through different actions, to simultaneously improve daylighting performance, visual and thermal comfort and overall energy performance. New approaches to geometry and photometry are explored and show, through daylighting and thermal simulations, that it is possible to give these objects a new start. This work concludes with a life cycle analysis that quantifies the valorization of the intrinsic energy stock associated with the building and which elements can be conserved or reused. In this project, we demonstrate that with good design, it is possible to convert these office buildings into pleasant and generous flats and to achieve a high level of energy efficiency and comfort, without forgetting the environmental objectives for the 2050 horizon.

1. Introduction

The paper is divided into 5 sections, starting with an introduction that reviews the state of the art of the problem at the urban scale and shows a series of results obtained by our research team in previous studies. Sections 2 to 5 focus on a case study specific to the scale of the building. In section 2 we describe the case study. In section 3 we show several possibilities to improve the natural light level to show that it is possible to reuse this type of tower - with a lot of depth - and convert it to uses with higher daylighting requirements. Based on the different improvement scenarios presented and analyzed in section 3, we proceed to the energy evaluation (section 4) and the life cycle analysis (section 5) incorporating these improvements. In the last section, it is compared whether in terms of grey energy, a renovation, instead of a demolition and reconstruction, is pertinent.

Since the first glass tower in Manhattan, the Lever House, built about 70 years ago, entire neighborhoods of smooth façades have appeared in every major city in the world. The juxtaposition of tall glazed towers generates multiple reflections, mainly specular, which strongly influence the radiative exchanges. In thermal comfort, these exchanges are often expressed by the Mean Radiant Temperature (MRT) [1]. Here, the MRT is simulated in a complex urban scene using the DART (Discrete Anisotropic Radiation Transfer) code [2]. On a beautiful summer day, a wanderer stops on Park Avenue, right in front of the Lever House. The sun is reflecting on several of the high glass facades that surround him.

The heat he feels is unbearable. He wonders if it would not be better for him if these façades were painted white. At least half of the sun's rays would be reflected upwards. Maybe it would be even better if the towers were dark, like the very first skyscrapers in the city, with their brick façades pierced by small windows. In this case, however, the walls would absorb more radiation, which would be re-emitted in infrared, and it is not sure that the radiation balance would be better for the people passing by [3].

To answer this question, we studied - through several simulation including different buildings - the effect on a pedestrian's comfort of a radical change in the city's façades, going from black to white, and then from white to specular. The observation point is located at the height of a pedestrian (1.5m) who walks on Park Avenue and stops in front of the Lever house (Lat 40.71° Lon -74.00°).

We consider that the city is composed of two materials. The first one represents the ground: it is grey ($\rho = 0.5$, 100% diffuse) for all spectral bands, and invariant throughout the simulation. The second represents the buildings: it is variable throughout the simulation, but constant for all spectral bands (Figure 1). The mean radiant temperature varies with the city's surface (Figure 2). In the dark city, the only reflections occur on the diffuse surface of the street. As the reflectance of the surfaces increases, the shortwave contribution becomes more important. At night, a high reflectance means a higher radiative exchange with the sky, which, when clear, is very cold.

	Simulations				
	I	II	III	IV	V
Reflectance	0%	50%	100%	100%	100%
Specular	0%	0%	0%	50%	100%
Diffuse	100%	100%	100%	50%	0%

Figure 1. Optical properties of the simulation

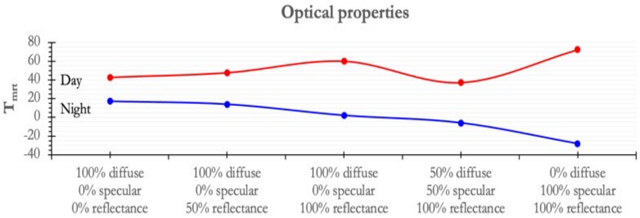

Figure 2. Evolution of Mean Radiant Temperature in summer, at noon (red) and at midnight (blue) according to the type of building covering

The first curve is the least intuitive, it corresponds to a sunny summer day at noon. Predictably, the mean radiant temperature increases at first, as the city gets brighter. In the second part of the graph, the surfaces remain perfectly reflective, but in a progressively more specular manner. The temperature decreases to a minimum, which corresponds to the semi-specular situation (50% diffuse, 50% specular), and then starts to increase again when the specular behavior takes over. A white and diffuse city increases the MRT due to multiple reflections. On the other hand, a perfectly specular city allows the sun to be reflected several times, while the scattering of solar radiation is practically non-existent. In a specular city, the concentration of several reflections of the sun on a point can lead to a much higher MRT. However, in a city with semi-specular surfaces, the partial scattering of radiation has the effect of reducing the multiple reflections and blurring the reflection of the sun. The semi-specular city appears quite dark, and the reflection of the sun is not very intense.

In all situations, the opaque, dark, diffuse colors of early industrial cities help maintain a more pleasant MRT. If a compromise is needed, then the semi-specular city seems to offer the best solution. In a previous work [4], we obtained the same conclusion by considering only the natural illumination of interior spaces: extreme solutions (city made up of mirrors or perfectly white facades) lead to glare and overheating. An intermediate solution (limited rates of glazing and gray surfaces) - that of Paris, Barcelona or Naples in the already dense neighborhoods of the 19th century - offer the best solutions for thermal and light comfort, both for passers-by and for residents.

2. Description of case-study used to test the potential for facade improvement

The Areva Tower, originally called the "Fiat Tower", was built in 1974 by the architects Skidmore, Owings & Merril and Roger Saubot & François Jullien, on the Paris-La Défense site. It has a surface area of 102,000 m^2 spread over 46 floors. Its height is 178 m above ground level. (*https://parisladefense.com/*). The external facing of the façade is made of polished black granite (glossy appearance). The windows are fitted with tinted glass whose estimated characteristics are: Tv= 0.22, g=

0.34, Ug= 2.8 W/m^{2}K. The observation of the plan (Figure 3 / left), shows the very important width and depth and suggests that the daylight contribution is rather limited. Indeed, a first simulation carried out with the DIAL+ [5] software shows that the zone benefiting from an autonomy of more than 50% for an illumination level of 300 lux is limited to 2m in relation to the perimeter of the façade.

We have concentrated on the first 10m of facade, which are the most influenced by the external environment (e.g., heat loss/gain, solar gain, natural lighting, natural ventilation). This "band" of 6-10m depth from the façade will also be used in the layout modification proposal to evaluate the change from administrative to residential use (see section 5). In order to be able to measure the impact of different measures on daylight gains, heating and cooling requirements and natural ventilation potential, we defined a 'typical' zone with a width of 6 m and a depth of 10 m. Figure 3 shows the daylighting analysis of this typical area with the existing facades parameters.

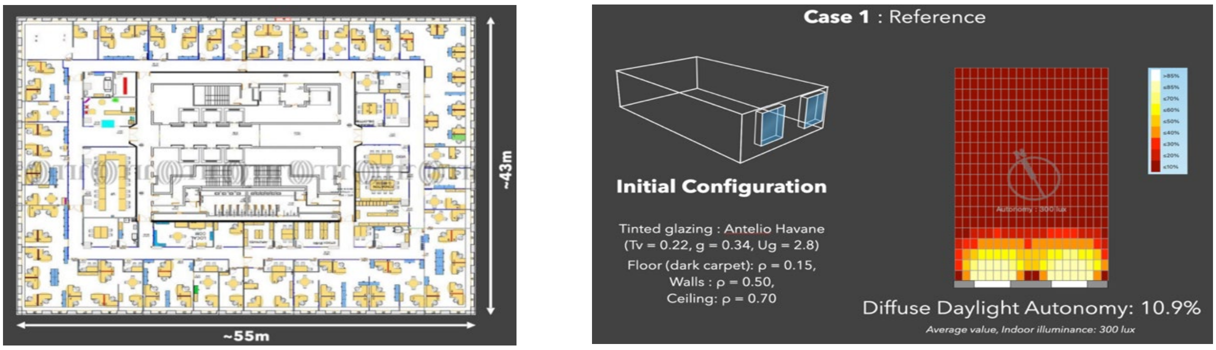

Figure 3. Left: Typical floor plan / Right: Daylighting performance of the reference case (existing situation)

3. Daylighting approach: List of potential actions for improvement

In the following, we will disregard the architectural aspects and the possible heritage value of the building and concentrate on the potential for improvement of the façade to explore the possibilities of transforming the building, including its use.

- **Glazing type**: When this building was constructed, the only way to limit solar gain for a façade without blinds was to use tinted or reflective glass to limit the solar factor (g) of the glazing. The implementation of a selective glass (Tv = 0.6, g = 0.28, Ug = 1.0) has a huge impact on both daylighting and thermal performance: It allows to multiply by 2.7 the amount of daylight and to divide by 2.8 the heat losses thanks to a drastical reduction of the Ug.
- **Windows height**: The possibility to interrupt the false ceiling before the façade allows to raise up the glazed area (+35 cm) which has a good impact on the lighting of the rear part of the room.
- **Recessed façade**: Due to the difficulty of servicing and maintaining external movable shading devices, most high-rise buildings are not equipped with them. To overcome this constraint, we proposed to move the building envelope inwards by 1.5m. This measure allows for the installation of protected and accessible movable protections and, consequently, the choice of standard glazing (Tv = 0.8, g = 0.62, Ug = 1.1), which results in an increase in visible transmission and therefore in daylighting potential.
- **Opaque surfaces**: Reducing opaque elements improves daylighting potential and view potential.
- **Interior walls**: Clarity of the interior finishes plays an important role in the perception of the spaces and increases the daylight autonomy of the spaces concerned.

The combination of all these actions makes it possible to significantly change the amount of daylight. Figure 4 shows that the diffuse daylight Autonomy has been multiplied by 4 compared with the reference case (existing situation), even though the reference space is set back 1.5 m from the plane of the façade. A comparison of Fig. 3 and 4Figure 6 shows the gap between the existing situation and the optimized solution. Moreover, the spatial perception is radically changed and makes it possible to imagine a change of use (residential vs office). Figure 5Figure 5 shows a comparison of the luminance values between the initial solution (existing) and the proposed optimization. The simulations were carried out using the Velux Daylight Visualizer software [6] and the exposure parameters are identical for both images.

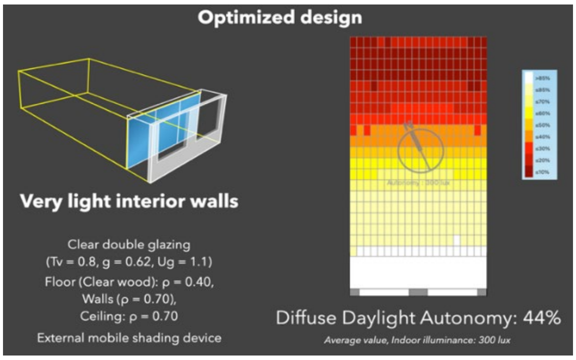

Figure 4. Performance of the "optimized" solution

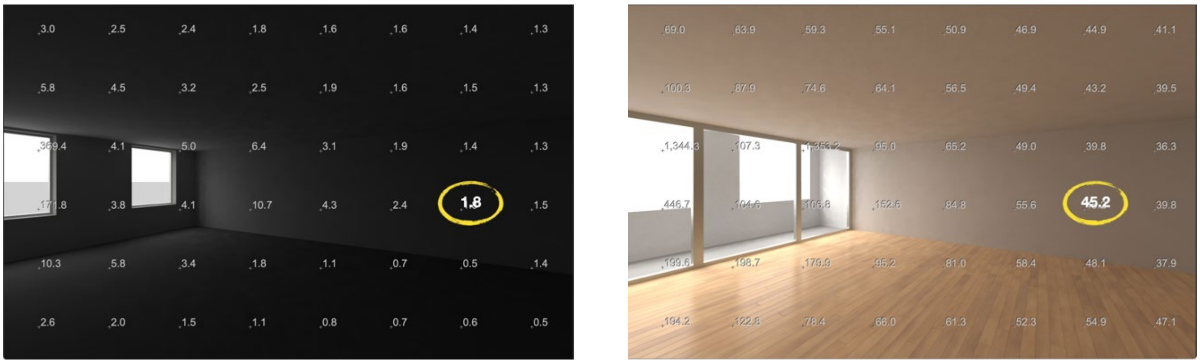

Figure 5. Comparison of the luminance distribution between the existing situation (Left) and the optimized design (Right) (Daylight Visualizer simulation, overcast sky conditions)

4. Energy issues

Some of the optimisation actions proposed above have a significant impact on the energy consumption of the building. As mentioned above, shifting the façade inwards allows the implementation of movable solar shading, which has a direct impact on solar gains. In addition, this solution also allows the use of natural ventilation and passive cooling strategies. To facilitate the comparison, we assumed that all requirements could be met with electrical energy and considered an identical assignment (office) between the two variants. What is striking here is how much energy is used for lighting in the initial case.

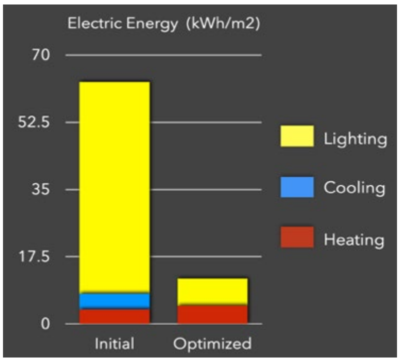

Figure 6. Comparison of energy requirements between initial and optimized version

This is due to the fact that, on the one hand, the natural light input is very low and, on the other hand, the replacement of the existing installation (fluorescent tubes) by LEDs allows a spectacular reduction in requirements. In addition, in the optimized version, the elimination of cooling needs (thanks to natural ventilation) allows a high level of performance to be achieved. In total, in this example, energy consumption has been reduced by a factor of 5, while at the same time the performance of the room (including spatial quality) has been significantly improved.

5. Life cycle assessment

With the increasing efficiency of energy use in buildings, the weight of grey energy used in construction has become more important [7-9]. In new buildings, environmental certification standards and labels are beginning to set limits on embodied energy (and associated equivalent CO_2 emissions) such as SNBS or Minergie ECO [10].

In this context, and with the growing trend of the circularity of materials, we asked ourselves how to consider the embodied energy contained in an existing building and how to take it into account to make the decision to **rebuild** - by demolishing the existing building - or **renovate** it by reusing and prolonging the useful life of a part of the existing components such as the structure and certain facade elements.

We applied the SIA 2032 Swiss standard [11], to assess the residual value (in terms of grey energy) of the building and thus evaluate what would be the best decision to make in environmental terms.

For this exercise we have evaluated three scenarios:

- **E0**: **Current status** - residual value,
- **S1**: **Transformation**: Residential vs Office,
- **S2**: **Demolition** & **Reconstruction**: Residential.

To carry out this study, we have compared the initial plan layout (cf. Fig. 3 Left) with a new design proposal adapted for residential use (cf. Fig. 7). For the calculation of the different scenarios, the construction details of the tower have been studied and the surfaces of the different components of the building (cf. Table 1) have been considered. The environmental impact of each material has been calculated using the KBOB database [12].

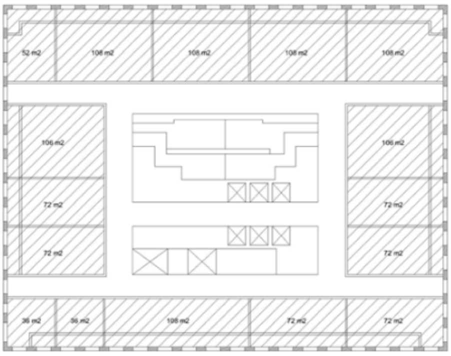

Figure 7. Design proposal adapted for residential use

Table 1. Surface areas of the building components

Facades [m²]	North	South	East	West	Total
Glazing	2'181	2'181	1'696	1'696	**7'755**
Frame	385	385	299	299	**1'369**
Opaque façade	6'146	6'146	4'815	4'815	**21'923**
Roof					**2'365**
Slabs					**97'328**
Ground slab					**2'365**

Figure 8 shows the residual value (E0) of the existing building. The impact and depreciation over the years for building components are calculated with a useful life of 20 (e.g. HVAC), 30 (e.g. envelope) and 60 years (e.g. structure).

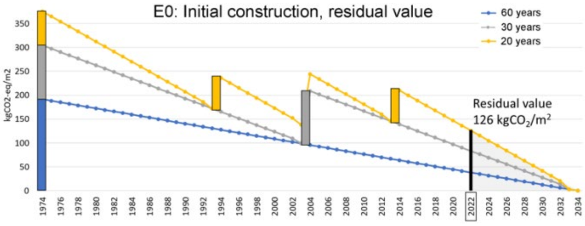

Figure 8. Residual value of the existing building

Figure 9 shows the comparison of two scenarios, namely S1: "Transformation" and S2: "Reconstruction". The residual value (E0) is 126 $kgCO_2/m^2$, the transformation (S1) is 197 $kgCO_2/m^2$ (residual value + transformation) and the reconstruction (S2) is 281 $kgCO_2/m^2$. The result of this study shows that, for this building, the impact of scenario S1 (Transformation) is significantly lower than that of scenario S2 (Reconstruction). Although we are aware that this result cannot be extrapolated to all existing buildings, it reinforces the idea that building renovation should be a priority. Furthermore, if re-use or recycling of materials had been taken into account and if we had considered the potential for renewable energy production in this example, the environmental impact could have been further optimized, always reinforcing the idea that it is better to transform by using the existing than to build new.

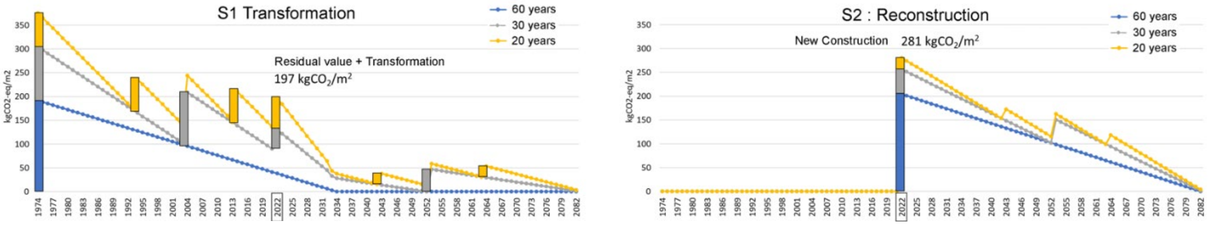

Figure 9. Respective life cycle impact for the scenarios S1 (Transformation) and S2 (Reconstruction)

Conclusions

At a time when the need for housing is becoming more and more pressing and the integration of teleworking is more and more present, it is pertinent to reconsider the nature of living spaces. This article shows that it is necessary to seriously consider the problem of the reconversion of high-rise administrative buildings before opting for direct demolition. Even considering that these large office buildings present difficulties of natural conditioning (e.g., daylighting, ventilation) due to their great depth with respect to the facade, we see that with a few simple strategies, such as modifying the height of the openings and the false ceiling, we can ensure in a 10m depth band an autonomy that goes from 10.9% to 44%. This translates into a reduction of 80% of the electrical energy demand (artificial lighting, cooling and heating). Also, since to achieve the 2050 environmental objectives we must integrate both operational and embedded energy in the building materials, including the residual value of buildings that have not yet reached their end of life (in our case study 126 kgCO$_2$/m^2), our analysis shows that conversion costs 197 kgCO$_2$/m^2 and demolition/reconstruction would bring us to 281 kgCO$_2$/m^2. Since we are based on a specific case study, extrapolation of results is limited. In the next phases of the studies, we will have to go deeper into the construction details to better evaluate the feasibility of the conversion proposal.

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