
Determination of light entry areas of windows for automated code compliance checking

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Abstract

With the introduction of digital building permit processes, building authorities are on the verge of being integrated into the BIM workflow. This requires the automation of building code compliance checks. This paper presents an approach for automated compliance checking of natural light exposure of habitable rooms in the context of Austrian building regulations. In Austria, there are complex requirements for the determination of the light entry area, as only the area with unobstructed daylighting can be considered. The paper focuses on the determination of this unobstructed area. A software implementation demonstrates the ability to determine the precise geometry of each light entry area. The automation provides an accurate assessment of light exposure in all rooms, whereas current practice only assesses seemingly critical rooms, which is prone to error and lacks a complete assessment. Furthermore, the approach converts implicit information in building models into explicit elements, providing a complete, permanent dataset.

1. Introduction

Digitisation in the construction industry is advancing and covering an increasing number of areas. One of these is the involvement of building authorities in the BIM process by introducing digital building permit processes. Potentials of a building permit based on Building Information Modelling (BIM) have been recognised in the literature already, namely increased efficiency and reduction in time and cost (Beach et al., 2020; Eastman et al., 2009). However, implementing digital building permitting is still at the very beginning. Forerunners are Finland (Lavikka & Kallinen, 2024), Estonia (Ullah et al., 2022), South Korea (I. Kim et al., 2020), and Austria (Urban et al., 2024) where projects on implementing a BIM-based building permit have recently been conducted. In general, the focus in research is set on automatically checking BIM models against building code (Noardo et al., 2022). This includes translating building code written in natural language

into a computer-interpretable representation (H. Kim et al., 2019; Macit İlal & Günaydin, 2017) and general requirements and challenges in code compliance checking (Amor & Dimyadi, 2021; Eastman et al., 2009). While these topics set the basis for developing a code compliance checking system and automatically checking simple requirements, some complex regulations require special attention to be included in such a system. Such complex requirements have been tackled by Battisti et al. (2022) and Olsson et al. (2018). Olsson et al. (2018) analysed the Swedish building regulations on building height and building footprint area and developed automated checking rules for these specific use cases. Battisti et al. (2022) considered eight complex building regulations in Austria and implemented algorithms for them in a prototype system. The algorithms addressed, for example, the containment of a building on the building site, the roof gradient, the number of floors, and the light exposure ratio. While some covered the addressed building regulation sufficiently, e.g. containment check, others were simplifications, e.g. light exposure check.

With regard to light exposure, the Austrian building regulations define a ratio between the light entry area of a room and its floor area. Battisti et al. (2022) used the opening area as a simplification for the light entry area. However, the light entry area of a window or a glazed door is not necessarily the entire opening area in the wall. Instead, if the light entry or the clear view of the opening is obstructed, the obstructed parts are subtracted, and only the remaining parts are considered to be the light entry area. The process of checking for obstacles, reducing the light entry area, and calculating the remaining area is very time-consuming when performed manually. Therefore, in practice, a detailed check is only performed for rooms with a light entry area ratio near the critical value. Experienced building authority officers identify critical rooms through a visual pre-check. This reduces the manual effort but lacks a complete determination of all light entry areas and ratios. Consequently, automated determination of the light entry areas offers potential improvement in time consumption, completeness, accuracy, and comprehensibility for checking the building code regulations on light exposure.

As part of the development of a code compliance checking system for the Vienna Building Authority (Austria) in the BRISE-Vienna project, we attempted to include the light exposure check without simplifications. Besides being complex and time-consuming, it also concerns elements not explicitly modelled in the BIM model: the light entry areas. This is because, although windows and glazed doors are modelled, the area that can actually be used for light exposure is not modelled. The goals are to use the existing data from the planning phase, automate the checking processes, and provide valuable and accessible data for building authorities in the long term. By automation, the exact light entry areas can be determined for each window and relevant door within seconds, thus providing a complete set of light entry data, accelerating the process, and improving the accuracy of the calculated values. Moreover, it generates explicit data for light entry areas, which are defined in building models implicitly by the openings of windows and doors. This enables the light entry areas to be comprehensibly displayed and promises potential for permanent data archiving (Fischer et al., 2024).

This research describes the automated determination of light entry areas to check specific building regulations for light exposure as given in Austria. We describe the material, methods, and concepts used to develop a checking rule. Then, the results of a prototypical software implementation for the BRISE-Vienna project are shown and discussed. Finally, we describe the impact of the research and potential future developments.

2. Material and Methods

In general, a BIM-based code compliance check requires two data sources: a BIM model to be checked and the relevant building code integrated into a checking rule. In BRISE-Vienna, an openBIM building permit process for the Vienna Building Authority was developed (Krischmann et al., 2020; Urban et al., 2024). Therefore, the standardised open format IFC (Industry Foundation Classes) was mandatory for all building models. The light exposure check requires two different building models. First, the Building Application Model (BAM) represents the building project and is submitted by the applicant for permission. The BAM is the architecture domain model extended with additional information required for building permitting. Second, the Reference Model (REM) represents the geometric information of the building site. It includes the 3D envelope of the permitted building space and existing neighbouring buildings, which represent obstacles to light entry. The relevant data for the REM is provided by the survey plan, the information requirements for which were defined in the BRISE-Vienna project. In Vienna, the survey plan is drawn up by a surveying office in advance of a construction project. In the BRISE-Vienna project, in addition to the terrain data and property boundaries already contained in the survey plans, this survey plan also contains information on the surroundings, building alignment and zoning. This additional information is necessary in the survey plan because the legally valid dedication is not included in Vienna's GIS system.

The development of the checking rule for light exposure followed the general process for developing complex checking rules in BRISE-Vienna described in Fischer et al. (2023): Building code analysis, rule conception, software implementation, and validation.

2.1. Building code analysis

A detailed analysis of the concerned regulation is the basis of automating the validation of a BIM model against building code. Regarding light exposure, in Austria, the relevant statements are contained in the OIB 3 guideline (Austrian Institute of Construction Engineering, 2023b), a nationally applicable building regulation. Building code analysis always requires the inclusion of domain experts, as the statements in the building code can leave room for interpretation. Thus, in the BRISE-Vienna project, the analysis was conducted in close collaboration with building authority officers of the City of Vienna and representatives of the Austrian Chamber of Architects and Civil Engineers.

The requirements for light exposure in the OIB 3 guideline are fragmented into individual, interconnected statements. They can be categorised into statements concerning the inside of a building, defining the required light entry area, and the outside of a building, defining how surrounding objects can obstruct the light entry area. The required light entry area is defined as a minimum ratio of 12 % of the floor area for each habitable room in a building. This ratio increases by 1 % per meter the room depth exceeds a limit of 5 m. A room depth between 7 m and 8 m requires, for example, 15 %.

A prerequisite for calculating the ratio between the light entry area and floor area is the exact determination of the light entry area, which is the focus of this article. The light entry area of a window or glazed door is initially the finished opening in the facade plane or roof cladding. The window frame is not subtracted. However, surrounding objects, such as neighbouring buildings or trees, can obstruct the opening. Therefore, the OIB 3 guideline defines which requirements must be fulfilled by a light entry area to be unobstructed and thus applicable for light exposure. The light entry area must provide an unobstructed light entry at a vertical angle of 45° (see Fig. 1, left). However, if this unobstructed light entry is not provided, it can be swung up to 30° to the left or right (see Fig. 1, right).

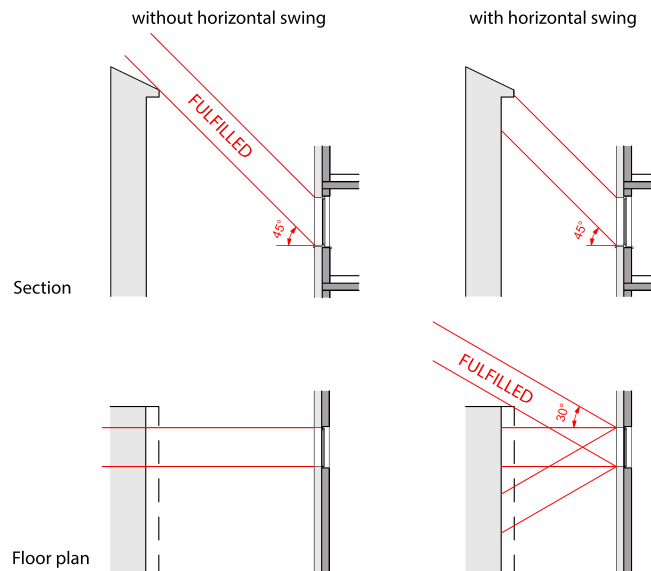


Figure 1: Free light entry requirements without a horizontal swing (left) and with a horizontal swing (right) (Adapted from (Austrian Institute of Construction Engineering, 2023a))

The OIB 3 guideline defines these requirements explicitly for the light entry area. Therefore, the light entry area is not necessarily the entire opening in the facade. Instead, obstructed areas of the facade opening are subtracted, and only the remaining area is considered a light entry area for light exposure. Otherwise, windows would be excluded from light exposure independent of how much they are obstructed. This is to prevent the downsizing of windows to avoid obstructions. Downsizing windows is not the intention of the light exposure regulation.

Another regulation concerns obstructing light entry by protruding objects in the same building. Such obstructions do not require excluding or subtracting the obstructed light entry area. Instead, the required ratio of light entry and floor area increases depending on the protruding distance from the facade plane.

The last two regulations concern the clear view of the light entry area. These regulations are only applicable to habitable rooms of flats. Each light entry area must provide a perpendicular clear view for 2 m for the entire area (see Fig. 2, left). If parts of the light

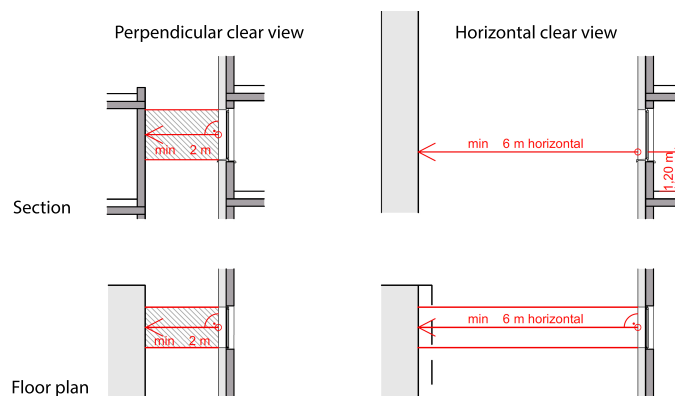


Figure 2: Clear view requirements perpendicular for the entire area (left) and horizontally at a specific height (right) (Adapted from (Austrian Institute of Construction Engineering, 2023a))

entry area are obstructed, they are subtracted, like for the light entry. In addition, at least one light entry area of the flat must provide a horizontal clear view of 6 m but only 1.2 m above the floor (see Fig. 2, right).

To summarise, whether an opening can be considered a light entry area depends on obstructions of the light entry from surrounding objects and protruding objects of the same building as well as obstructions to the clear view from surrounding objects. A crucial characteristic is the possibility of subtracting obstructed parts from the light entry areas instead of completely excluding an opening.

2.2. Rule conception

In the rule conception stage, concepts to determine the light entry area of an opening considering the requirements detected during building code analysis are formally defined. The main challenge is to detect obstructions in the light entry and the clear view and subtract these from the light entry area. The general process is shown in Fig. 3. The basis is to retrieve the opening area of a potential light entry object in the plane of the facade or roof cladding. Since the geometry of a window or door does not always represent the finished opening in the facade plane, instead, we use the corresponding opening (IfcOpeningElement) to retrieve this surface (see Fig. 4).

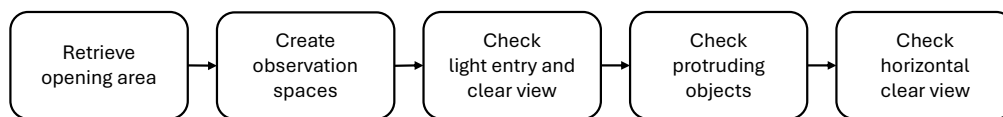


Figure 3: General process of determining the unobstructed light entry area.

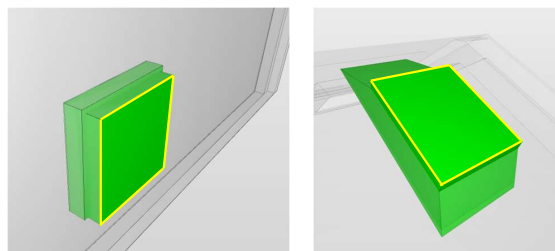


Figure 4: Surface opening (yellow) in the facade or roof cladding plane retrieved from the IfcOpeningElement (green)

Taking this surface as a basis, checking the free light entry and perpendicular clear view requires defining an observation space that is checked for obstructions. This can be realised by extruding the detected surface. The area is extruded perpendicular to the surface for the clear view by the required 2 m. For the free light entry, the extrusion axis has a vertical angle of 45° and a horizontal angle of -30° to 30° from the perpendicular direction. The range defined by this horizontal swing is represented by extrusion axes in 1° -steps, creating a pool of possible light entries. The building code does not define a distance for the free light entry. Therefore, a distance covering all relevant possibilities, like 100 m or 500 m, can be selected.

These observation spaces for the clear view and the free light entry are then checked for intersections with other buildings, trees, or other obstacles. If an intersection occurs, the intersected volume must be projected into the surface plane to be subtracted from the opening area (see Fig. 5). This requires a parallel projection into any possible plane in 3D space since the orientation of the surface plane differs for different openings. Moreover,

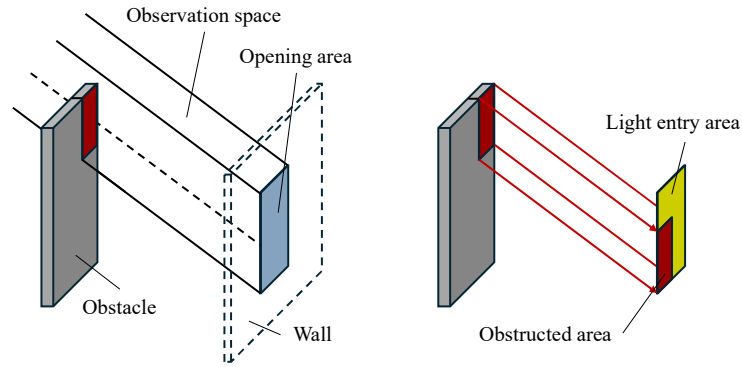


Figure 5: Detection of an intersection between the observation space and an obstacle (left) and projection of the intersection into the surface plane (right)

while an orthographic projection covers the clear view check, the free light entry check requires an oblique projection since the extrusion axis is not perpendicular to the surface plane. The formulae for this kind of parallel projection is

$$P(\vec{x}) = \vec{x} - \frac{(\vec{x} - \vec{r}_0) \cdot \vec{n}}{\vec{n} \cdot \vec{v}} \cdot \vec{v} \quad (1)$$

with \vec{x} being the point to be projected, \vec{r}_0 being any point on the surface plane and thus defining its location, \vec{n} as the normal vector of the surface plane to define its orientation, and \vec{v} defining the projection direction. After performing this projection for all points of the intersection, its area (red) can be reconstructed and subtracted from the initial opening surface (blue) to retrieve the remaining light entry area (yellow). The different possible horizontal angles for the free light entry create a pool of light entry areas with different dimensions (see Fig. 6). The more the light entry is swung in Fig. 6, the bigger the light entry area gets. These options are the input for the subsequent checking of obstructions from protruding objects from the same building. Since obstructions from protruding objects are only relevant for the calculated remaining light entry area, these areas are again extruded along the extrusion axes to create new volumetric observation bodies. Contrary to the checking of intersections with surrounding objects, intersections with protruding objects are not subtracted from the light entry area. Instead, depending on the protruding distance from the facade surface, the required ratio of light entry area

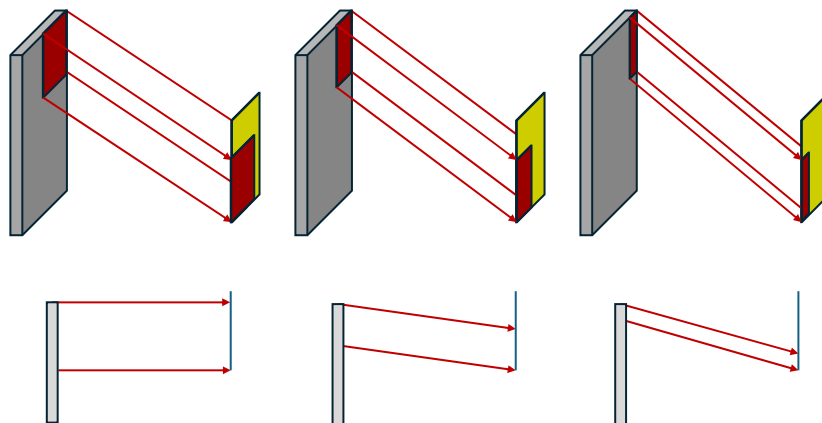


Figure 6: Obstructed areas (red) and remaining light entry areas (yellow) for different horizontal angles (first row) and top view of the projection (second row)

to floor area is increased. Thus, in this step, the geometry of the light entry area is not altered, but alphanumeric information is added to it. The protruding distance and the corresponding required light entry area ratio are stored as properties for each light entry area in the pool of options. The maximum light entry area per required ratio can be defined by comparing the remaining areas of all options of one particular required ratio. This is decisive information for the subsequent comparison of the light entry and floor areas because it specifies which areas of different openings can be considered together. At last, if the light entry area is part of a flat, the clear view in a horizontal plane 1.2 m above the floor has to be checked. For this check, the remaining width of the light entry area at the particular height must be determined first. Then, only for the remaining width is a horizontal observation area extruded from the surface and checked for intersections. After this last step, all requirements defined in the Austrian building regulations concerning the applicability of a light entry area for the light exposure check are covered.

2.3. Software implementation

After formally defining the concepts for automated checking, algorithms were implemented in the BIM checking software Solibri Office for a prototypical checking rule. Solibri Office was generally used in the BRISE-Vienna project, which had the advantage of using the available checking templates for simple code compliance checks. The provided API (application programming interface) based on the programming language Java enabled the software extension by new individual checking rules.

2.4. Validation

This research aims to provide a proof of concept for the developed algorithms for calculating light entry areas. Therefore, the validation should demonstrate whether the implemented checking rule can calculate and visualise the remaining light entry area. Thus, we created a fictional test model explicitly for light exposure checking containing test cases for all requirements.

3. Results

This research resulted in a checking rule that calculates light entry areas as preliminary work for the light exposure checking according to the Austrian building regulations. The checking rule implements the concepts described in Section 2.2. Fig. 7 shows the results of the main challenge of determining the light entry areas: subtracting obstructed areas. The three left examples show the determination of the remaining area for the free light entry check. The first row shows a top view that visualises the different horizontal angles of the observation spaces. The second row displays a 3D view of the partition of the opening area into a remaining light entry area (yellow) and an obstructed area (grey) according to the detected intersections. This example comprehensibly shows the effect of the allowed alteration of the horizontal angle to find the optimum orientation for the free light entry. The example on the right shows the combination of the free light entry and clear view check. We subtract the clear view check's obstructions from the free light check's optimum remaining area to get the maximum remaining light entry area. Each light entry area carries alphanumeric information about the exact remaining and obstructed area and the required light entry area ratio. If protruding objects in the same building obstruct free light entry, the required light entry ratio is increased according to the regulations, and the corresponding protruding distance is stored.

Fig. 8 shows the final check for a horizontal clear view. The basis is the combined remaining area of the free light and perpendicular clear view check. From this remaining

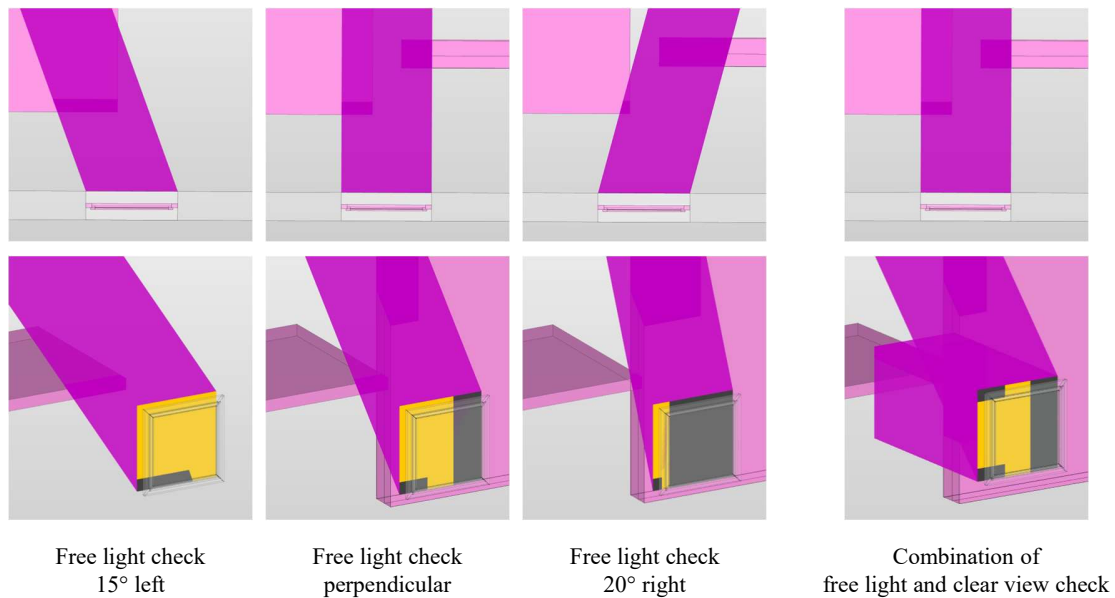


Figure 7: Three examples of the free light check (left) and one combination of the free light and clear view check (right). The first row shows a top view and the second row shows a 3D view.

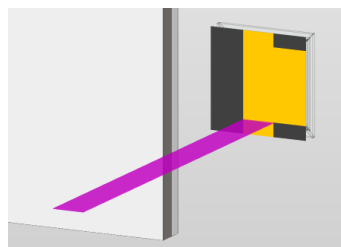


Figure 8: Extrusion of the observation area from the remaining light entry area (yellow) for the horizontal clear view check

area, only the width of the unobstructed area at 1.2 m above floor level is extruded and checked for obstructions. Since the OIB 3 guideline explicitly demands a clear horizontal view of the light entry area and not the entire opening, the building code requirements are precisely represented. However, this strict following of the exact formulation of the building code can cause problems if the width of the remaining light entry area approaches zero. The check is passed if a thin light entry area provides a horizontal clear view. Even though technically correct, an area only about 5 cm wide that provides a clear view is not in the intent of the building authority.

4. Discussion and Conclusions

This study presents an approach for covering the Austrian building regulations' complex light exposure requirements. The focus is set on the preliminary determination of the light entry area of windows or doors, as these can be partially obstructed by surrounding objects outside the building. We propose concepts to detect obstacles for the free light entry and clear view and to subtract them from the original light entry area. The critical functionality to realise that was the implementation of a parallel projection into an arbitrary plane in 3D space.

The results shown demonstrate the functionality and applicability of the proposed concepts. The algorithms developed can automatically determine usable light entry areas.

The automated approach enables the calculation of accurate values for all relevant windows and glazed doors. Performing the described operations manually would be complicated and very time-consuming. Therefore, in current practice, only seemingly critical rooms are analysed in detail. Our automated approach provides a reliable input for calculating the light entry area ratio for each relevant opening.

However, the ambiguous nature of building code written in natural language brings challenges for automation. The horizontal clear view check results show that full automation could result in unwanted decisions. As the requirements for a horizontal clear view are explicitly formulated for the light entry area, the width of the light entry area is irrelevant. However, a human building authority officer would not grant permission if a clear horizontal view was provided for a width of 5 cm. To cover this in a code compliance checking system, the definition of critical values for human oversight (e.g. minimum width of the horizontal clear view) or regulation changes are required.

Another interesting aspect of this work is creating explicit information for the exact light entry areas. So far, this information has only been implicitly contained in the building models based on the orientation of openings and the position of surrounding obstacles. The now explicitly determined geometry can be used to create new individual objects for the light entry areas. Individual objects enable comprehensible visualisation and data archiving (Fischer et al., 2024), e.g. in an individual IFC domain model for light exposure. During operation, this data could be used to analyse the impact of changes in the built environment on the light exposure of the existing building. Therefore, future work should consider the potential of the explicit information on light entry objects for building authorities. In conclusion, the automated approach extends the manual checking of current practice by providing a complete and accurate dataset that can be permanently stored as explicit light entry elements. In doing so, it has the potential to speed up the checking process, make it more reliable and help building authorities to assess the impact of new buildings on existing buildings. Other building authorities with different building regulations can adopt the general approach of creating observation spaces for light entry and clear view and subtracting obstructed areas by choosing the steps relevant to their conditions, e.g. defining only the facade opening or extruding the observation space perpendicularly or at a different angle. Regardless of how the exact light entry areas are calculated, the approach results in new explicit information for the light entry areas. Next, the approach will be implemented in the extended pilot phase system of the Vienna building authority to be validated with real-world BIM models.

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