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New computational methods with Sunlight, Daylight, and Quality Views for Regenerative Design

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Abstract

This paper investigates novel computational methods for Regenerative Design by developing further on the European Daylight Standard EN 17037, to make it useful at both urban and architectural scales. Case studies are evaluated for sunlight, daylight and quality views. A computational method, compliant with EN 17037, is introduced for the evaluation of sunlight. An assessment of daylight metrics, for an office building in Helsinki, with a 300 lux target, demonstrates a 12% difference between spatial Daylight Autonomy (sDA; occupied hours) and Illuminance levels (EN 17037 method 2; daylight hours), 37% between sDA and Daylight Factor (EN 17037 method 1), and 25% between methods 1 and 2. A new computational method for evaluating 'views' on the floorplan is proposed that considers 'view content' (EN 17037 View Out layers), 'view access', the potential viewpoint-based 'outside distance', and can be extended to add the 'quality of environmental information'. Further research directions and use of spatial metrics are discussed for sunlight, daylight, and view quality.

Introduction

Even though Regenerative Design has been introduced as a separate discipline in 1994 by John Tillman Lyle (Mang & Reed, 2013), it is still an emerging field with a growing number of proponents in research and practice. Sustainability practice as it is applied today has focused primarily on reducing environmental impacts on natural systems, and increasing efficiency in the use of resources and processes. The Regenerative Sustainability paradigm aims to shift from the slow degeneration of the planetary boundaries, toward restoring earth's systems to a healthy state and supporting the co-evolution of human and natural systems (Cole, 2012). A Regenerative Design and Development approach aims to provide for human health and well-being, improve the environmental performance of buildings and restore natural systems to a healthy state. New ways of thinking and a holistic approach are needed in architectural design, and that can be supported by digital technologies for integrated design.

Background

In industrialized nations, individuals spend on average 65-90% of their time indoors (Klepeis et al., 2001). Daylight is an important aspect of design for building performance and occupant well-being. The role of daylight in research and practice is growing. New evidence and knowledge are implemented in some codes and voluntary standards such as LEED v4.1 (USGBC, 2021), WELL v2 (IWBI, 2022) and EN 17037 (European Committee for Standardization [CEN], 2022). The contribution of Daylight for Regenerative Design, in research and digital practice for the built environment, is being explored nowadays with a fresh perspective in contributions that investigate the possibilities when bridging research, design process, and simulations with computational tools (Naboni & Havinga, 2019).

Daylight metrics in standards

The daylight factor (DF) has been introduced in 1895 as a means to quantify the interior levels of daylight independently from the instantaneous sky luminance (Love, 1992). DF is still widely used in some building regulations in European countries such as Norway, Sweden and Italy. Each regulation describes a method to follow i.e., DF point, mean DF, and median DF. In Finnish, and alternatively, in Italian, Danish, and Swedish regulations, the window-to-floor ratio can be used. An average daylight factor (ADF) value of 2% is to be met in the case of Norway and Italy. However, ADF results can be misleading when comparing single and multi-aspect window spaces (Mardaljevic & Christoffersen, 2017), and was shown that the median DF is more informative for the daylight of a space. Additionally, the 300 lux Daylight Autonomy (DA) for 50% of occupied hours was found to have a better correlation, when pairing occupant surveys with digital analysis, for the boundaries of what is considered a 'daylit area' compared to 'window-to-head-height' rules of thumb, or the 2% DF contour lines (C. F. Reinhart & Weissman, 2012).

The methodology for transitioning from ADF to a target DF on basis of interior daylight provision levels, derived from daylight availability in climate files, as well motivations to refine the methods and reduce misinterpretation, are explained in detail in a paper before the publication of EN 17037 (Mardaljevic & Christoffersen, 2017). The European standard EN 17037:2018 "Daylight in buildings" provides comprehensive methods for the evaluation of daylight properties in buildings. The standard includes Sunlight based on exposure in sun hours, for Glare the Daylight

Glare Probability (DGP), and a framework for evaluating views to the outside. Each area of assessment has three levels of recommendation. The Daylight Factor in the EN 17037 is introduced as a provisional method towards the adoption of the second method of the standard using annual Illuminance values found in weather files. Currently, LEED and WELL standards require Climate Based Daylight Modelling (CBDM) metrics for daylight assessment. BREEAM evaluations are based on an ADF value determined by latitude (BRE, 2021).

Novelty of the study

The evaluation methods of Sunlight and View Out in EN 17037 can be carried out on paper. It can be time-consuming and requires a lot of skill to evaluate. Computation-based approaches and 3D models in design tools can be combined to explore how to perform geometrical analysis and carry out evaluations. A computational approach can provide new insight and clarity on methods and new use cases. Additionally, the new methodologies for daylight provision in EN 17037 raise the question of how to carry them out, as well as what are the differences between these two methods, and other existing daylight methodologies. Past research provides some answers in assessing EN 17037 methods for compliance in dwellings, where DF resulted in being harder to meet compared to CBDM (Bournas, 2020). Another paper investigates the use of EN 17037 as a restriction for density in residential developments (Šprah & Košir, 2020). Additionally, case studies can be used to learn and gain an in-depth understanding of daylight methods, quantify differences and make qualitative comparisons of metrics.

Methods

In this study, novel computational methods are investigated through Grasshopper for Rhino (Robert McNeel & Associates, 2020), on basis of EN 17037 areas of assessment for sunlight, daylight and views. The goal is to explore the standard as a tool in the architectural design process, that is useful from the early stages to developed design, rather than in post-design assessments. Previous research has demonstrated the links of views and daylight to health and wellness in buildings (Aries et al., 2010; Commission Internationale de l´Eclairage [CIE], 2009), but does not put forward ways to use and communicate results for designers e.g., workflows, colour-coded visuals of performance to support data-driven architectural design. The study demonstrates that computational methods can enable faster analysis and thereby facilitate the adoption of EN 17037 to influence positively the design of buildings. These methods can support integrated design, increase the clarity of results, be used in further research studies, and help practitioners to design with actionable insights.

Exposure to Sunlight

Sunlight provision in EN 17037 has three performance levels that are 1.5, 3 and 4 hours of direct sun. Direct sunlight cannot be counted below minimum solar altitudes on 1 February and 21 March, and maximum solar azimuth on 1 February for given locations in EN 17037 tables D.1 and D.2. The evaluation is performed for each daylight opening of a space from a reference point. It does not consider computational methods, that could be used with 3D models, on a spatially distributed grid of points. The workflow herein proposed uses 'Sun Path' and 'Direct Sun Hours' components in Ladybug Tools (Sadeghipour Roudsari & Pak, 2013) to perform an EN 17037 compliant sunlight assessment. The colour-coded results can be categorized according to any of the three performance levels or as one colour-coded map. The geometry was translated into a mesh grid for the simulation of one metre as an appropriate level of accuracy. A timestep of 10 minutes for the sun vectors was used to allow for accurate sub-hourly results, balance computation time, and use the simulation feedback in an interactive process. Sun altitudes and solar azimuth values in annexe tables in EN 17037 are used to filter in only those sun vectors that contribute to direct sunlight for standard compliance. New methods of assessment of solar access and solar envelopes have been proposed recently (de Luca et al., 2021), and are implemented in the plugin the 'Solar Envelope Tools' from Tallinn University of Technology. However, such workflows can only be applied in a defined urban condition for controlling the new building shape. The objective of the proposed method is to study the performance of designs as 3D models, matching sunlight levels to façade areas, in the unit of square metres (or as percentages), to inform decisions e.g., building distances, massing, program, window location and size, the layout of units (exposure or disposition on two levels) to reach a minimum or higher levels of sunlight provision for the buildings to be designed, as well as considering the impact on the existing buildings.

Daylight provision

Daylight simulations are performed with Ladybug Tools' Honeybee plugin, which connects to Radiance for point-in-time daylight factor, and annual daylight simulations. Visual scripting in Grasshopper is used to produce the results according to daylight metrics of EN 17037 and selected climate-based metrics.

In EN 17037, Daylight is considered adequate if a target illuminance (E_t) is reached across 50% of the reference plane and a minimum target illuminance ($E_{t,min}$) achieved across 95% of the plane, categorized in three levels of recommendation that are given in Table 1.

Method 1 of EN 17037 uses corresponding Daylight Factors for a 'target internal illuminance' determined by the 'median external diffuse illuminance' ($E_{v,d,med}$) of the local climate. Method 2 uses dynamic daylight provision of Illuminance levels for at least 2190 hours (i.e., half of the daylight hours of the year). Currently, and to our best knowledge, there is no software implementation for Method 2.

Table 1 Summary of EN 17037 reference values, and specific DF and E_t values for Finland.

Area of assessment	Means of assessment	Level of recommendation		
		Minimum	Medium	High
Sunlight Provision	Daily Sunlight Exposure	$\geq 1.5\,h$	$\geq 3\,h$	$\geq 4\,h$
Daylight Provision (corresponding DF values are only for Finland	Illuminance target	300 lux	500 lux	750 lux
	Daylight Factor target	2,2 %	3,7 %	5,6 %
	Illuminance minimum target	100 lux	300 lux	500 lux
	Daylight Factor minimum target	0,7 %	2,2 %	3,7 %
View Out	Horizontal Sight Angle	$\geq 14\,°$	$\geq 28\,°$	$\geq 54\,°$
	Outside distance of view	$\geq 6\,m$	$\geq 20\,m$	$\geq 50\,m$
	No. Layers seen (Ground, Sky, Landscape)	1	2	3
Glare Protection	$DGP_{e<5\%}$	< 0.45	< 0.40	< 0.35

Climate-based metrics such as spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) present in LEED are based on 'occupied hours' as described in IES-LM83 (2013). In addition, the Useful Daylight Illuminance (UDI), using the same 'occupied hours' schedule (8 am – 6 pm) will be presented in the results. Since daylight provision in EN 17037, is based on (i) local climate files, and (ii) the same principle of concurring climate-based metrics where illuminance levels are considered valid for at least half of the hours of the period considered, the results of each can be compared. Only the minimum level of recommendation, E_t of 300 lux, and $E_{t,min}$ of 100 lux is considered, as it provides (1) the best correlation with daylit area studies, and (2) for comparison with CBDM metrics. Corresponding Daylight Factors to Illuminance values for Finland are provided in Table 3. Both methods 1 and 2 in EN 17037 will be compared with existing Climate Based Daylight metrics.

Case study for daylight metrics

An open-space office building in Helsinki (Finland) was used for comparing selected daylight metrics. The case study has core zones in the centre and collaborative spaces with glazed partitions around the core for daylight. Work desks in the open space are distributed around the perimeter. The building has cantilevered slabs and façade frame elements every one metre, at the outer part of the glazing and along all orientations. The first level of the buildings was subject to daylight simulations with Ladybug Tools' Honeybee plug-in in Grasshopper with a high-level setup, provided by Honeybee components. The space dimensions are 90.0 m in length, 25.0 m wide, and 3.4 m in height. Section B.3.1 of Calculation methods in Annex B of EN 17037, recommends reflectance values (Tvis) for main surfaces. Table 2 reports the values utilized in the Honeybee daylight model. The Tvis properties in the model are within the ranges recommended in EN 17037.

Table 2 Daylight surface properties.

Element	Light Reflectance / Tvis	
	Honeybee – Radiance model value	EN 17037 Annex B recommended range of values
Ceiling	0,8	0,7 to 0,9
Interior Walls	0,5	0,5 to 0,8
Floor	0,2	0,2 to 0,4
Exterior Walls	0,35	0,2 to 0,4
Exterior Ground	0,2	0,2
Context	0,2	-
Exterior glazing	0,64	-

View methodology

Numerous studies have been dedicated to the evaluation of the quality of views from windows and the correlation between daylight and visual comfort (C. Reinhart, 2018). Comprehensive frameworks for views and related metrics have been developed recently in research (Ko et al., 2021; Turan et al., 2020, 2021). Further research and limitations were identified in each study. The development of view metrics in EN 17037, green building standards and recent research need to be validated and integrated into tools for architectural practice. The implementation in CAD and BIM tools or through visual programming remains underdeveloped. Currently, the Ladybug Tools plug-in (Version 1.4.0, 2022) for Grasshopper in Rhino offers a few components for simulating View types, that are too generic for EN 17037 and the metrics of recent research. 'View Out' methods in EN 17037 refer to point-in-space assessments as presented in Annex C. The View method presented develops further on the framework of 'View Out'. Three algorithms are implemented in Grasshopper for computing the components of the View Out in EN 17037 that are (1) Horizontal Sight Angle, (2) Outside Distance of View and (3) Number of Layers Seen.

Table 3 From EN 17037 Table A.3: Daylight Factor values for Finland to exceed illuminance levels of 100, 300, 500 or 750 for a fraction of daylight hours $F_{time,\,\%} = 50\%$.

Nation	Capital	Median external diffuse illuminance $E_{v,d,med}$	Geographical latitude φ [°]	DF ≥ 100 lux	DF ≥ 300 lux	DF ≥ 500 lux	DF ≥ 750 lux
Finland	Helsinki	13500 lux	60,32	0,7 %	2,2 %	3,7 %	5,6 %

Ko defined three variables of views that are view content, view access, and view clarity (Ko et al., 2021). View content is determined as the 'layers seen' in EN 17037 i.e., ground, sky, and landscape (built or natural). 'View access' is considered in the computation of each 'layer seen'. View access is defined as 'how much of the view can be seen through the window from the occupant's position' (Ko et al., 2021), and is captured in the implemented algorithm in the geometry-based computation of each 'layer seen'. 'View clarity' from the window is not considered in EN 17037 and neither in the computational method presented in the paper. The simulation is performed for a spatially distributed grid in the interior floorplan at seated eye-level 1.2 m above the floor. The definition of Outside Distance of the view in EN 17037 is given as "*distance from the inner surface of view opening to opposite major obstructions located in front of the opening*". Thus, the same level of performance would result for each point in space within the floorplan. The method proposed evaluates the view distance on basis of the 'position in space' and 'potential view directions'. The algorithm uses vector ray-tracing and measures the distances for each grid point to the ground and nature, or to all layers within a distance limit e.g., 100 m. An average result of the distances (remaining vectors that were not obstructed by the interior geometry) for each grid point is used.

Results

The computational methods are tested on real-world case studies in Helsinki. Simulations were performed during early and developed design iterations by the first author of the paper.

EN 17037 sunlight analysis for early design

The results are presented for a new development project with existing surrounding buildings in Figure 1. The colour-coded maps are a default sunlight analysis in Ladybug, a 1.5 hours minimum level, and an EN 17037 complete sunlight assessment. February 1st was chosen as the analysis period as it is more restricting than the 21st of March, and all performance levels in EN 1037 resulted in the facades of the case study. The simple model can be contoured with lines to guide the designer in relating the performance of the façade to the building level.

The areas corresponding to each level of performance are extracted from the simulation, in the unit of square metres, and as percentages, and represented in charts in Figure 1. Additionally, charts can be generated within Rhino for tracking the progress of design iterations with Grasshopper plugins such as "Conduit" and "Human UI".

CBDM results for the open space office building

This part of the study presents a comprehensive review of climate-based daylight metrics and EN 17037 daylight methods for an open space office building with openings on all facades and orientations in Helsinki, Finland. sDA in conjunction with ASE and UDI is shown in Figure 2. The contour lines represent 50% of the time for DA, for the threshold of 300 lux. For UDI, the 100-3000 lux range boundaries are indicated. Spatial DA and UDI results are given. The colour map is categorized in 10% steps for ease of comparing spatially the results of metrics.

Annual Sunlight Exposure (ASE) of at least 250 hours for more than 1000 lux of direct sun is presented and categorized every 250 hours up to 1000 hours, to show a higher level of granularity and visualize the differences between orientation exposures and the impact of the position in proximity to glazing.
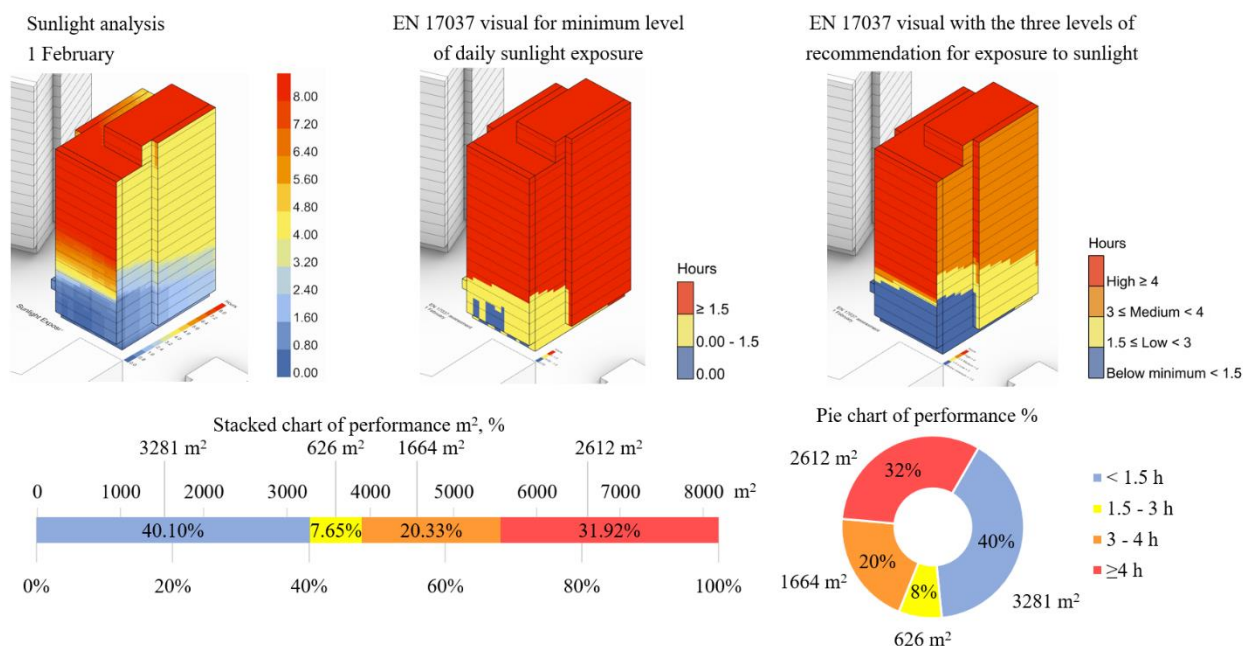

Figure 1. Left to right. Southeast views of colour-coded sunlight analysis, categorized based on 1.5 hours minimum level, categorized based on the three performance levels in EN 17037. Charts with results.
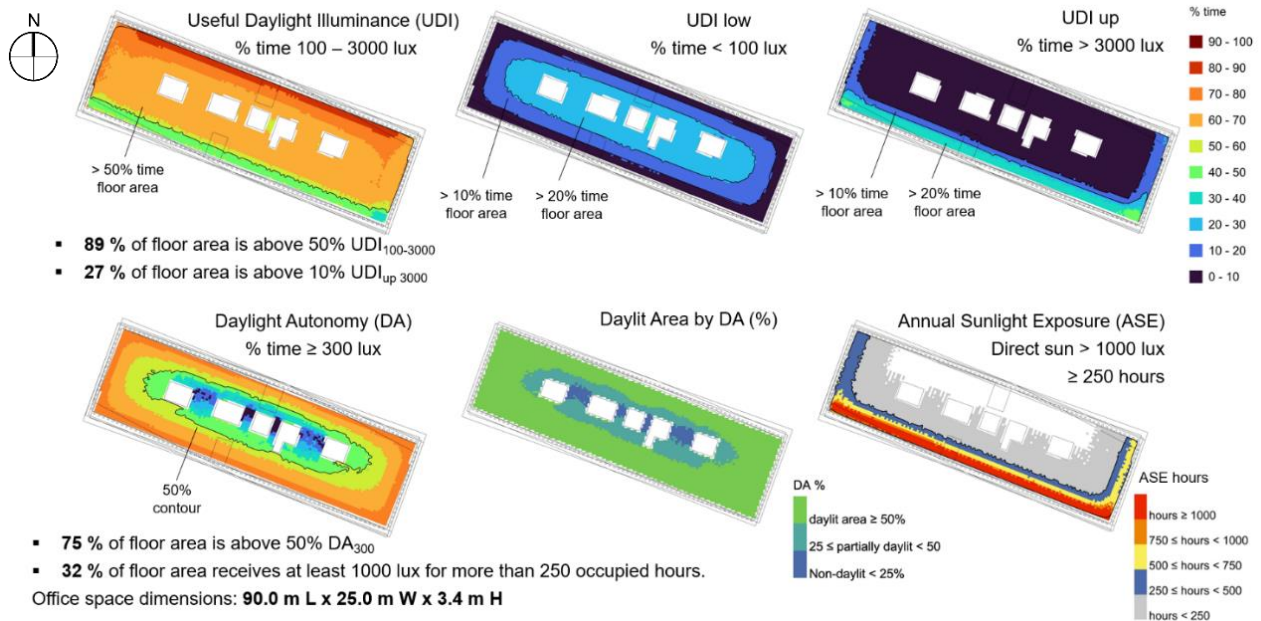
Figure 2. Climate Based Daylight metrics for an open space office building in Helsinki.

Daylight Illuminances below 100 lux are considered insufficient (UDI$_{low}$), and when exceeding the useful range (UDI$_{up}$) are likely to produce visual or thermal discomfort, or both (Nabil & Mardaljevic, 2006). Contour lines of 10% and 20% of the time for UDI$_{low}$ and UDI$_{up}$ are shown in Figure 2 for comparison of metrics. There is a 5% point difference between UDI$_{up}$ of 27% and ASE of 32% across the space. While there are some differences between UDI$_{up}$ and ASE, there is a similarity in the spatial distribution of results between ASE$_{>1000lux,1000h}$ to UDI$_{>3000lux,>20\%}$, and ASE$_{>1000lux,250h}$ to UDI$_{>3000lux,>10\%}$.

Comparison with EN 17037 daylight methods

Daylight Factor and Illuminance levels based on EN 17037 methods are simulated and presented. The design proposal fails to meet the requirements of EN 17037 based on the DF. An "Option 2" of the DF is calculated when a larger core area is not considered in the results, as indicated by a dashed rectangle in the right-side colour map in Figure 3.

The following differences are found:

- Spatial Daylight Autonomy (sDA$_{300lux,50\%}$) of 75% versus a target DF that is met for 38% of the reference plane. There is a 37% point difference for a target illuminance of 300 lux between sDA and DF (method 1, EN 17037).
- 63% of floor area is above Illuminance levels (method 2) of 300 lux. Compared to the Daylight Factor, there is a 25% point difference in spatial results.
- sDA$_{300lux,50\%}$ (based on occupied hours) results are higher by 12% points compared to the fraction of plane meeting Illuminance levels for half of the daylight hours as in EN 17037 method 2.

Additionally, a comparison of results between EN 17037, LEED, and BREEAM daylight metrics is given in Table 4. The WELL standard is not presented, as it is based on the IES LM-83-12 as LEED, and European projects can follow EN 17037 methods, but with average sDA targets of 55% and 75% for regularly occupied spaces.
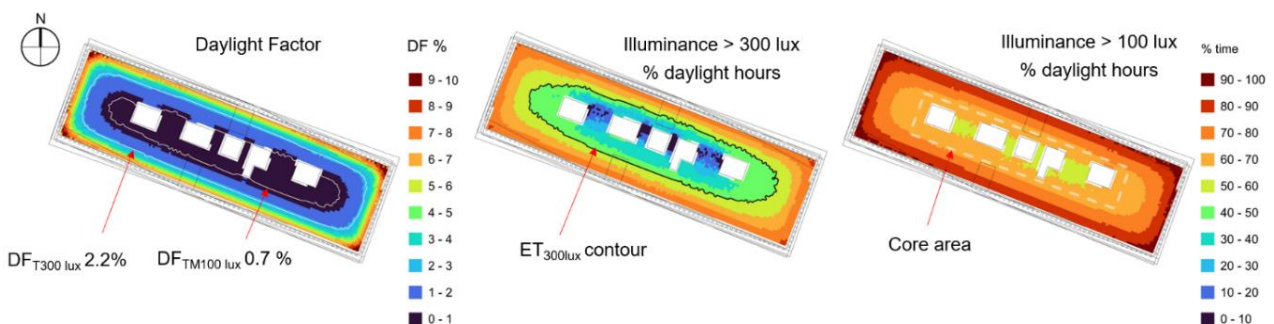

Figure 3. Left to right. Daylight Factor (target and minimum target), Illuminance levels of 300 lux, F$_{plane,50\%}$ and 100 lux F$_{plane,95\%}$ based on actual daylight hours as in method 2 for Daylight Provision in EN 17037.

Table 4 Comparison of simulation results of EN 17037 daylight methods, LEED v4.1 and BREEAM.

	Daylight metric	Target value	DF, F_{plane} (option 1)	DF, F_{plane} (option 2)	Illuminance levels, F_{plane} (option 1)
EN 17037	E_t 300 lux, F_{plane}50%	≥ 2.2%	38%	50%	63%
	$E_{t\,min}$100 lux, F_{plane}95%	≥ 0.7%	81%	97%	100%
	LEED v4.1 sDA300/50%	40%, 55%, 75%	-	-	75%
	UDI$_{100-3000/50\%}$	-	-	-	89%
	BREEAM INT NC v6 ADF, F_{plane} 80%	2.2%	2.4% (F_{plane} 100%)	2.9% (F_{plane} 100%)	-

Quality Views

The method is tested on a master plan and shown for a unit of residential development with context buildings in Helsinki in Figure 4. The potential of incorporating view analysis early in the design process is presented. The location of the unit in the design and its context are shown in wireframe display mode in Rhino in Figure 4. The dimensionality from 1 to 3 levels can be extended by adding geometrical objects that account for the "quality of environmental information" in the computation of the view metric. Based on real-world conditions, simple geometrical elements can be modelled to increase or reduce the score.

The computation on a spatially distributed grid for the *Outside Distance* shows differences in the reference plane regarding the level of performance based on the position in space and view direction in the interior, in an urban setting with varying morphological features and building heights. The façade-based distance evaluated with a plane projection suggests there is only a medium level of performance per every floor as shown in Figure 4. It would influence to a greater extent the cumulative Quality Views assessment. When the performance of the 'outside distance' metric is lower than the other two metrics, it would override the colouring and performance level of the total view evaluation. The viewpoint-based 'outside distance' is combined with the 'Layers Seen' and 'Horizontal Sight Angle' in one visualisation for communication purposes. However, the granularity of information from each metric is partially lost in the combined "Quality Views" evaluation in the case study.

The results can be further analysed by extracting the area (m^2) for each level of performance and deriving a "spatial metric". In addition, as in the Sunlight method, a stacked or pie chart with area in the unit of m^2 or % for each performance level can be used to predict the performance of a building when design variables change e.g., façade patterns, building layout, window size & locations, internal obstructions.

The developed method achieves the following:

- Translating EN 17037 View methods into *near real-time spatial assessment* in a design modelling environment.

- *View access* based on space geometry is embedded in the computation for each layer seen.
- Understand the implications of decisions early, how window size and location, shadings, and facade elements can influence access to views and its performance.
- The difference between *point-of-view Outside Distance* versus *Façade-based Outside distance* is demonstrated.
- Additional levels of performance are needed and can be added to the score for the **quality of the environmental information** (e.g., art, landmark, natural, water) with computational design.
- Layers Seen metric limitation is suggested e.g., Low-rise can have higher levels of three layers seen across the reference plane. Depending on urban morphology, lower floors could see the Ground layer and not Sky, while, higher floors could see Sky but not the Ground layer.
- Spatial metrics (% space) can be extracted from the results.

Discussion

This paper explores the potential of using the European Daylight Standard as a design tool rather than just an assessment method through its introduction to computational design workflows. The graphical methods and reference values of the standard are transformed into algorithms to automate parts of the process for evaluating projects, towards near real-time spatial assessments, that are communicated with colour-coded visuals in 3D models. Novel computational methods for sunlight, daylight and quality views can help architects to achieve higher goals of Regenerative Design. Solar access requirements are present in many local regulations at European and International levels. CAD and BIM tools can visualize a 3D Sun Path, and shade the model, but lack the development of analysis features to evaluate the design or its surrounding context. Visual scripting in Grasshopper and Ladybug Tools plug-ins are used to develop design-based workflows for evaluating the performance to improve designs.
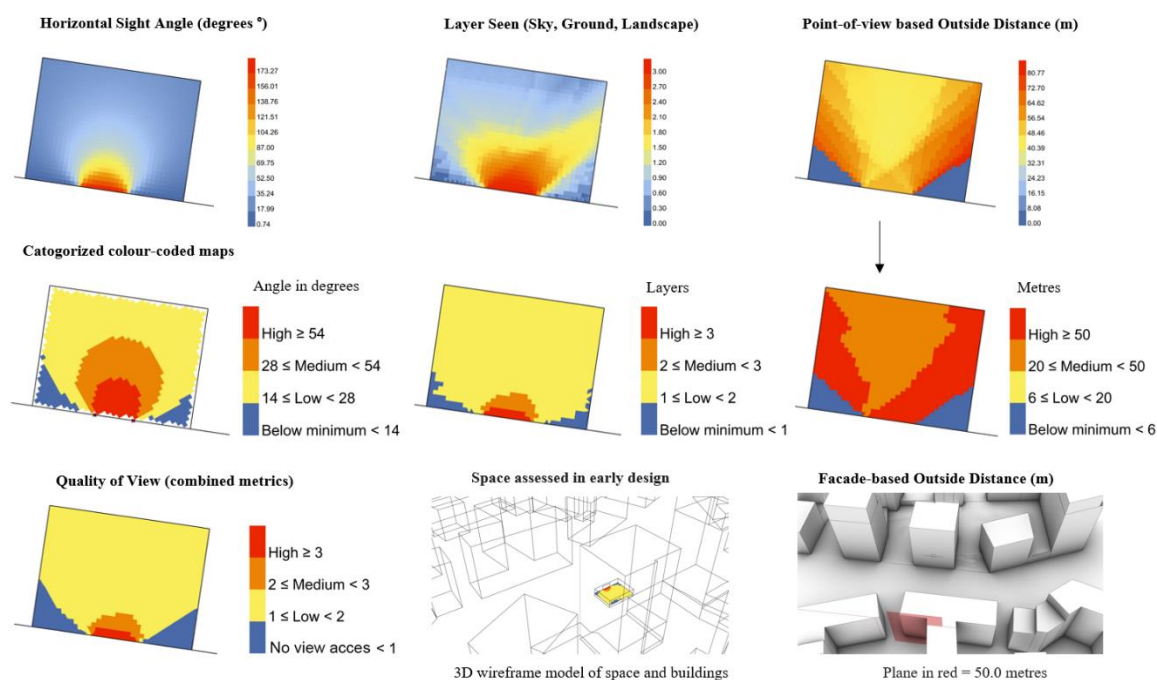
Figure 4. Spatially computed metrics for View Out in colour maps, categorized colour maps, and cumulative visualization of Quality Views developed from EN 17037.

The results of the Sunlight analysis can be used for the design as follows:

- Improve masterplan e.g., distances between buildings, or adjust the shape of the designed building.
- Adjust program of building levels and internal layout of units/offices, and other functions.
- Allow for sunny/shaded open spaces and courtyards based on climate and season.
- Provide units with double exposure, or on two levels to reach the minimum or higher levels of sunlight recommendation on basis of the standard.
- Add rooms in the building layout that receive sunlight to units that could benefit from it.
- Add new/larger windows to units where low levels of sunlight result from the simulation.

Further research can explore the influence of climate, day of analysis, and simulation parameters in the evaluations of Sunlight performance.

Different CBDM metrics inform the design in different ways. DA suggest the design is performing well along the perimeter for all exposures. UDI would suggest that the north façade has the highest daylight potential and that the south façade performs below the threshold 50% of the time, between 40-50%. $UDI_{<100lux,>20\%}$ can be an indicator of the need for integrative artificial lighting in the design.

ASE appears to be more detailed in representing differences due to orientation. However, UDI is the result of a single and easier simulation workflow. Since UDI_{up} results are comparable to ASE, further research could indicate its potential as a superseding metric of DA and ASE for standards and regulations.

The Daylight Factor method in EN 17037 would suggest the design does not meet the minimum level of performance in the standard. However, annual daylight metrics using 'occupied hours' schedules or 'daylight hours' indicate that the design is compliant. Relying solely on the Daylight Factor would suggest providing higher a Window-to-Wall ratio and light transmittance of glazing. Even in a Nordic climate with fewer sunshine hours, the DF has a considerable difference in results from climate-based metrics. Future studies can explore the influence of climate, shadings and their dynamic modelling in simulations.

New frameworks for views take a holistic approach to a complex subject. However, fast and easy-to-use methods are needed to increase adoption in by practitioners, going beyond traditional daylight performance and visual comfort studies. An overview of the three components of the "Quality Views" and a combined visualisation are recommended, to avoid bias from just one combined representation. Having a myriad of real-world possibilities for views, further studies are needed to explore how this approach could be useful and if it can provide recommendation levels for different urban scenarios such as dense urban environments, low-density, low-rise, high-rise, and suburban areas.

A critical review is needed to turn the results into actionable insights, avoid the bias of relying on a single metric, and highlight the limitations of metrics. For example, is the condition of low-rises better in reality when it comes to views? The view quality depends on a wide range of real-world factors such as location, landmark or natural values, human preferences e.g., noise, privacy, thermal comfort, and something to gaze at.

Flexibility, adaptability and reuse of buildings is a topic of growing interest to transition towards a low carbon and

regenerative built environment. During the pandemic, the nature of work changed, where more tasks could be done in-home settings. The following question arises. Is 'daylight hours' better than the 'occupied hours' method for annual daylight metrics if we are to think of new hybrid and flexible working hours, and adaptable buildings for the future?

Conclusions

New computational methods developed in line with the EN 17037 standard are proposed at both the urban and architectural scales to support the design process for sunlight provision, daylighting and quality views. Significant differences between current CBDM and both EN 17037 methods are presented, reinforcing the need for a transition towards annual daylight simulations. The Quality Views on basis of the View Out method in EN 17037 demonstrates an improvement and refinement of the method with the support of computational design. The developed workflows were carried out in Rhino and Grasshopper. Visualizing colour-coded results in the 3D models is recommended to support an interactive and integrated design process. Simulations need not be performed in the end for building permit applications but for every design stage to make informed decisions. Computational and data-driven approaches have the potential to aid practitioners to explore the design with the performance and well-being evolving requirements in today's practice.

Acknowledgement

Nomenclature

Abbreviation	Term
ADF	Average Daylight Factor
ASE	Annual Sunlight Exposure
BIM	Building Information Modelling
BRE	Building Research Establishment
CAD	Computer-aided design
CEN	European Committee for Standardization (CEN, French: Comité Européen de Normalisation)
CIE	Commission Internationale de l´Eclairage
CBDM	Climate Based Daylight Modelling
DA	Daylight Autonomy
DF	Daylight Factor
DGP	Daylight Glare Probability
E_t	Illuminance, target
$E_{t\ min.}$	Illuminance minimum target
EN 17037	Daylight in buildings (European standard)
$E_{v,d,med}$	Median external diffuse illuminance
Fplane	Fraction of the reference plane
Ftime	Fraction of time (hours) considered based on the EN 17037 daylight method
IES	Illuminating Engineering Society
IWBI	International WELL Building Institute
LEED	Leadership in Energy and Environmental Design
LM	Lighting Method
sDA	spatial Daylight Autonomy
Tvis	Visible Light Transmittance
UDI	Useful Daylight Illuminance
UDI low	% time UDI < 100 lux
UDI up	% time UDI > 3000 lux
USGBC	U.S. Green Building Council
WELL	WELL Building Standard

References

Aries, M. B. C., Veitch, J. A., & Newsham, G. R. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology*, *30*(4), 533–541. https://doi.org/10.1016/J.JENVP.2009.12.004

Bournas, I. (2020). Daylight compliance of residential spaces: Comparison of different performance criteria and association with room geometry and urban density. *Building and Environment*, *185*, 107276. https://doi.org/10.1016/J.BUILDENV.2020.107276

Building Research Establishment. (2021). *BREEAM International New Construction Version 6.0*. https://www.breeam.com/discover/technical-standards/newconstruction/

Cole, R. J. (2012). Regenerative design and development: current theory and practice. *Building Research & Information*, *40*(1), 1–6. https://doi.org/10.1080/09613218.2012.617516

Commission Internationale de l´Eclairage (CIE). (2009). Ocular lighting effects on human physiology and behaviour. *CIE, 2004/2009, ISBNCIE 158:2009*. https://cie.co.at/publications/ocular-lighting-effects-human-physiology-and-behaviour-0

de Luca, F., Dogan, T., & Sepúlveda, A. (2021). Reverse solar envelope method. A new building form-finding method that can take regulatory frameworks into account. *Automation in Construction*, *123*, 103518. https://doi.org/10.1016/j.autcon.2020.103518

European Committee for Standardization. (2022). Daylight in buildings. (EN 17037). *Http://Store.Uni.Com/Catalogo/Uni-En-17037-2022*.

IESNA-Daylight Metrics Committee. (2013). Lighting measurement #83: Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). *Illuminating Engineering Society*. https://store.ies.org/product/ies-spatial-daylight-autonomy-sda-and-annual-sunlight-exposure-ase/

IWBI. (2022). *WELL Building Standard v2*. https://v2.wellcertified.com/en

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., Behar, J. v, Hern, S. C.,

& Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, *11*(3), 231–252. https://doi.org/10.1038/sj.jea.7500165

Ko, W. H., Kent, M. G., Schiavon, S., Levitt, B., & Betti, G. (2021). A Window View Quality Assessment Framework. *LEUKOS*, *0*(0), 1–26. https://doi.org/10.1080/15502724.2021.1965889

Ladybug Tools (1.4.0). (2022). https://www.ladybug.tools

Love, J. A. (1992). The evolution of performance indicators for the evaluation of daylighting systems. *Conference Record of the 1992 IEEE Industry Applications Society Annual Meeting*, *1992-January*, 1830–1836. https://doi.org/10.1109/IAS.1992.244539

Mang, P., & Reed, B. (2013). Regenerative Development regenerative development and Design. In *Sustainable Built Environments* (pp. 478–501). Springer New York. https://doi.org/10.1007/978-1-4614-5828-9_303

Mardaljevic, J., & Christoffersen, J. (2017). 'Climate connectivity' in the daylight factor basis of building standards. *Building and Environment*, *113*, 200–209. https://doi.org/10.1016/j.buildenv.2016.08.009

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings*, *38*(7), 905–913. https://doi.org/10.1016/j.enbuild.2006.03.013

Naboni, E., & Havinga, L. (2019). *Regenerative Design In Digital Practice. A Handbook for the Built Environment.* https://www.eurestore.eu/publications-and-articles/

Reinhart, C. (2018). *Daylighting Handbook II*.

Reinhart, C. F., & Weissman, D. A. (2012). The daylit area – Correlating architectural student assessments with current and emerging daylight availability metrics. *Building and Environment*, *50*, 155–164. https://doi.org/10.1016/J.BUILDENV.2011.10.024

Robert McNeel & Associates. (2020). *Rhinoceros 3D* (Version 7.15). https://www.rhino3d.com

Sadeghipour Roudsari, M., & Pak, M. (2013). Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. *Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association*, 3128–3135. http://www.ibpsa.org/proceedings/BS2013/p_2499.pdf

Šprah, N., & Košir, M. (2020). Daylight provision requirements according to EN 17037 as a restriction for sustainable urban planning of residential developments. *Sustainability (Switzerland)*, *12*(1). https://doi.org/10.3390/su12010315

Turan, I., Chegut, A., Fink, D., & Reinhart, C. (2021). Development of view potential metrics and the financial impact of views on office rents. *Landscape and Urban Planning*, *215*. https://doi.org/10.1016/j.landurbplan.2021.104193

Turan, I., Reinhart, C., & Kocher, M. (2020). A New Framework for Evaluating Views throughout Open Plan Work Spaces. *Proceedings of Building Simulation 2019: 16th Conference of IBPSA*, *16*, 1098–1105. https://doi.org/10.26868/25222708.2019.210755

U.S. Green Building Council. (2021). *LEED v4.1 for building design and construction*. https://www.usgbc.org/leed/v41