Daylight Simulations based on a Digital-Twin Model towards Workplace and Facade-Individual Optimization

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CFS4LowCarb

Background project

- Funding scheme: TECXPORT – 3RD BILATERAL COOPERATION CALL AUSTRIA – CHINA
- TECXPORT MOST Call 2022

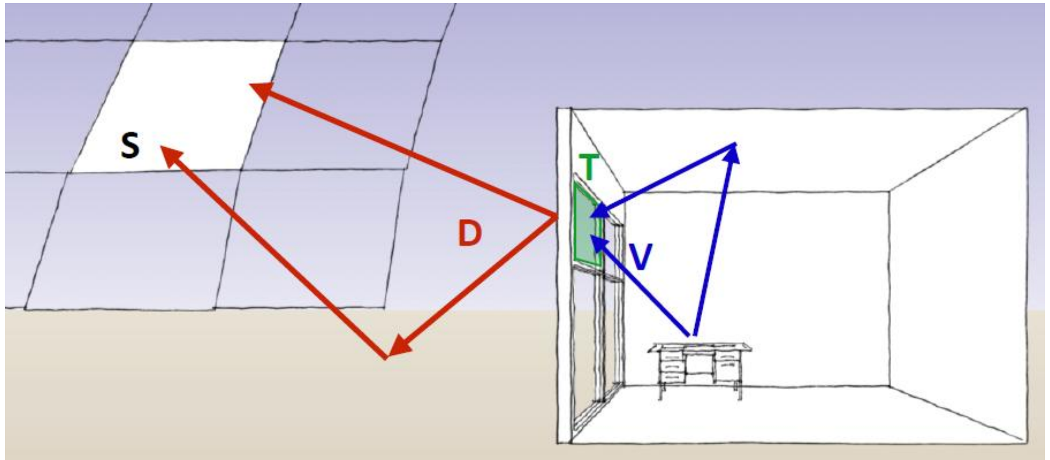
Consortium AT:

- Bartenbach GmbH (Lead AT)
- AEE - Institute for Sustainable Technologies
- Architekturbüro Reinberg ZT GmbH
- HELLA Sonnen- und Wetterschutztechnik GmbH
- Universität Innsbruck, Unit of Energy Efficient Buildings

The CFS4LowCarb – project...

- focuses on **complex fenestration systems:** simulation and compliance tools dedicated to predicting, evaluating and improving daylighting in buildings.
- focuses on novel **energy-efficient façade systems**: integrating solar-active components into transparent building envelopes.
- contributes in moving towards **a low-carbon built environment**: proposed methods for selected CFS solutions will be tested and evaluated in **virtual and real-world case studies** by integrating them into **digital twin testbeds** in Austria and China.

→ these developments aim to **enhance building energy efficiency** and support a transition toward a **low-carbon built environment**.



Current obstacles in integral day- and artificial light planning with BIM

(1) Interface

- Bidirectional compatibility of planning tools with the BIM software
- Support of open exchange formats (openBIM)

(2) Data exchange

- Standardized exchange of information (parameter definition)
- Direct use of BIM model data (geometry + metadata)
- Recirculation of calculation results (into the BIM software)

(3) Responsibilities

- Definition of specifications (material data, lighting targets,...)
- Undefined responsibilities in the different planning steps → unresolved liability issues

(4) Manufacturer neutrality

- No use of manufacturer-specific objects ("families")
- Use of internal "dummy" objects

Published literature review work

about Control Strategy Integration in Digital Twins

Main topics:

- BIM and Digital Twins
- Day- and artificial lighting controls
- Integrative methods of design and implementation

Contributed Insitutes:

- University of Innsbruck, Unit of Energy Efficient Building
- Bartenbach GmbH

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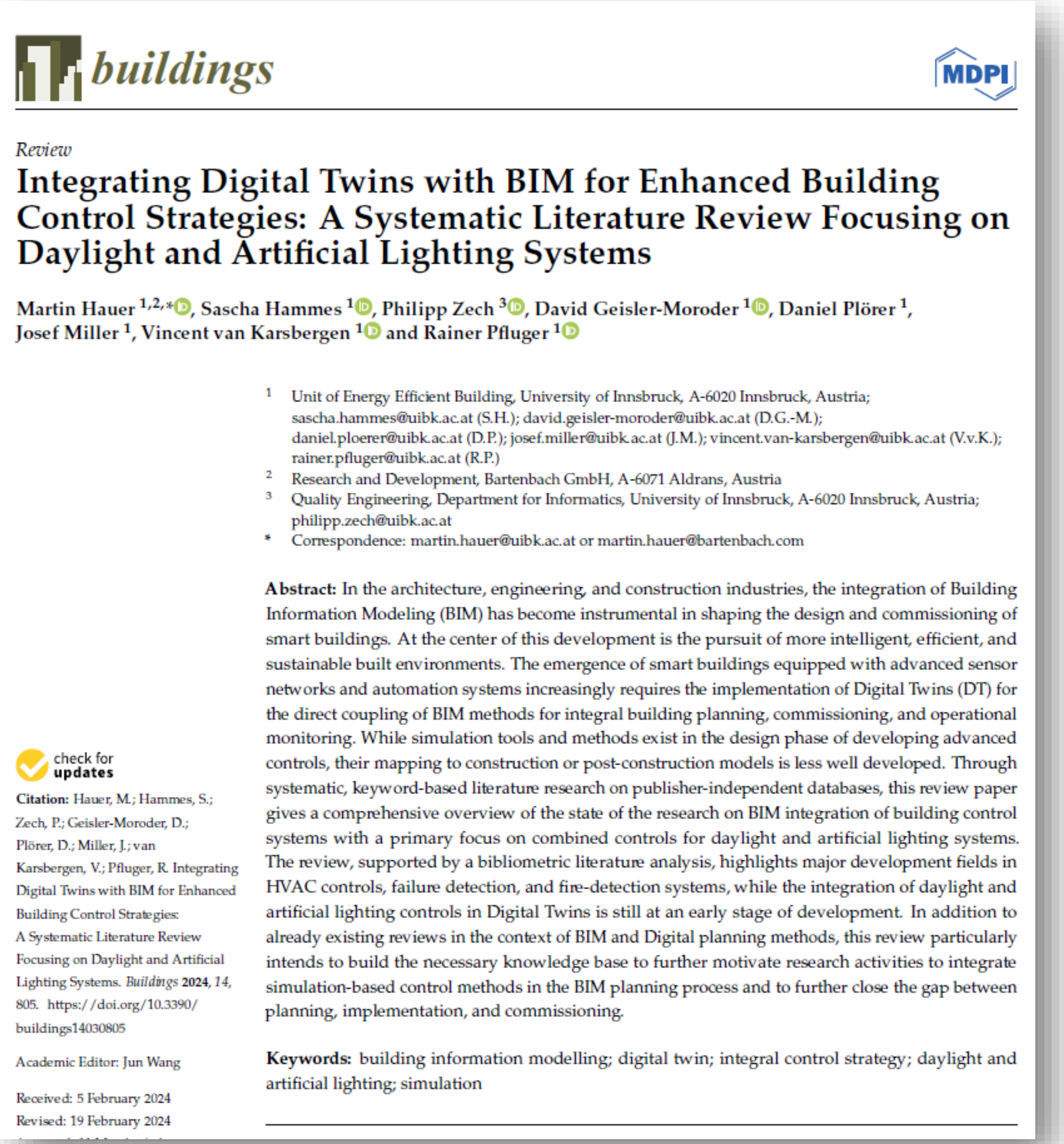

buildings

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Review

Integrating Digital Twins with BIM for Enhanced Building Control Strategies: A Systematic Literature Review Focusing on Daylight and Artificial Lighting Systems

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Abstract: In the architecture, engineering, and construction industries, the integration of Building Information Modeling (BIM) has become instrumental in shaping the design and commissioning of smart buildings. At the center of this development is the pursuit of more intelligent, efficient, and sustainable built environments. The emergence of smart buildings equipped with advanced sensor networks and automation systems increasingly requires the implementation of Digital Twins (DT) for the direct coupling of BIM methods for integral building planning, commissioning, and operational monitoring. While simulation tools and methods exist in the design phase of developing advanced controls, their mapping to construction or post-construction models is less well developed. Through systematic, keyword-based literature research on publisher-independent databases, this review paper gives a comprehensive overview of the state of the research on BIM integration of building control systems with a primary focus on combined controls for daylight and artificial lighting systems. The review, supported by a bibliometric literature analysis, highlights major development fields in HVAC controls, failure detection, and fire-detection systems, while the integration of daylight and artificial lighting controls in Digital Twins is still at an early stage of development. In addition to already existing reviews in the context of BIM and Digital planning methods, this review particularly intends to build the necessary knowledge base to further motivate research activities to integrate simulation-based control methods in the BIM planning process and to further close the gap between planning, implementation, and commissioning.

Keywords: building information modelling; digital twin; integral control strategy; daylight and artificial lighting; simulation

check for updates

Citation: Hauer, M.; Hammes, S.; Zech, P.; Geisler-Moroder, D.; Plörer, D.; Miller, J.; van Karsbergen, V.; Pfluger, R. Integrating Digital Twins with BIM for Enhanced Building Control Strategies: A Systematic Literature Review Focusing on Daylight and Artificial Lighting Systems. *Buildings* **2024**, *14*, 805. https://doi.org/10.3390/buildings14030805

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State of the art in the BIM-integration of day- and artificial light planning tools

openBIM

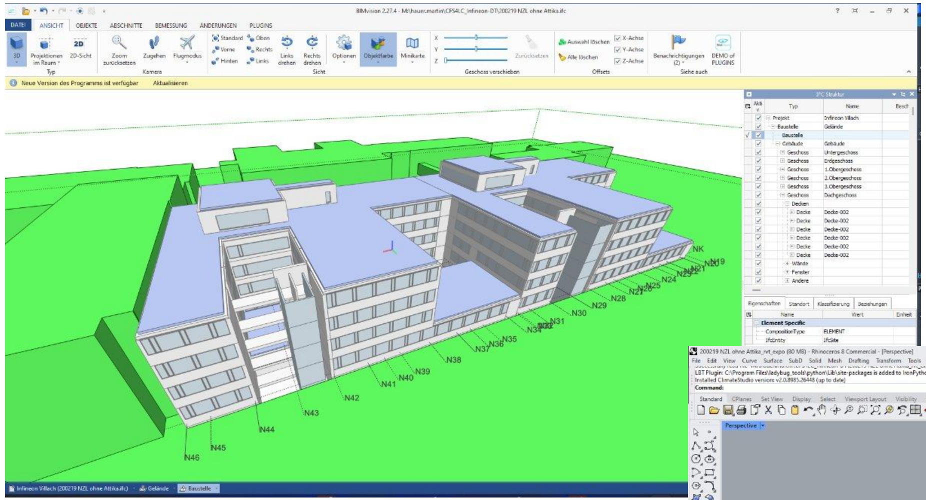
closedBIM

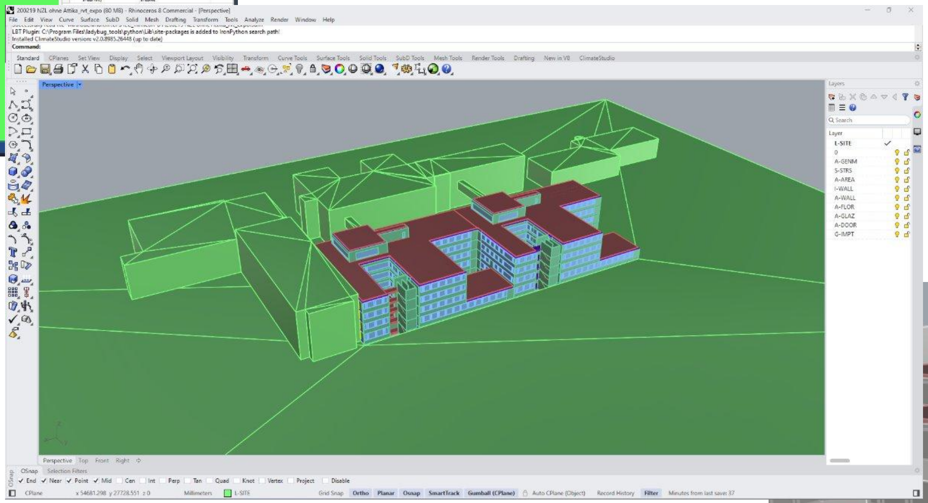
Tool	Bereich	Umsetzung	Anmerkungen
DIALux evo	AL (+DL)	IFC-import	Import of geometry data, no metadata, no back import of results → Update to latest release!
Relux	AL (+DL)	Revit-plugin	Model construction and calculation directly in Revit, display of results, export (one-way) to Relux Desktop
EulumTools	AL (+DL)	Revit-plugin	Model construction and calculation directly in Revit, presentation of results, own material mapping
Climate Studio	DL (+AL)	File export from Revit	Own Revit export file (*cse), import of geometry data in CS Rhino plugin, no metadata
AftabRad	DL (+AL)	Revit-plugin	Radiance daylight calculation based on Revit geometry, reference of material data from Revit model
Ladybug Tools	DL (+AL)	Revit-plugin (Pollination)	Use of Ladybug tools in Revit, automated geometry porting, no metadata.

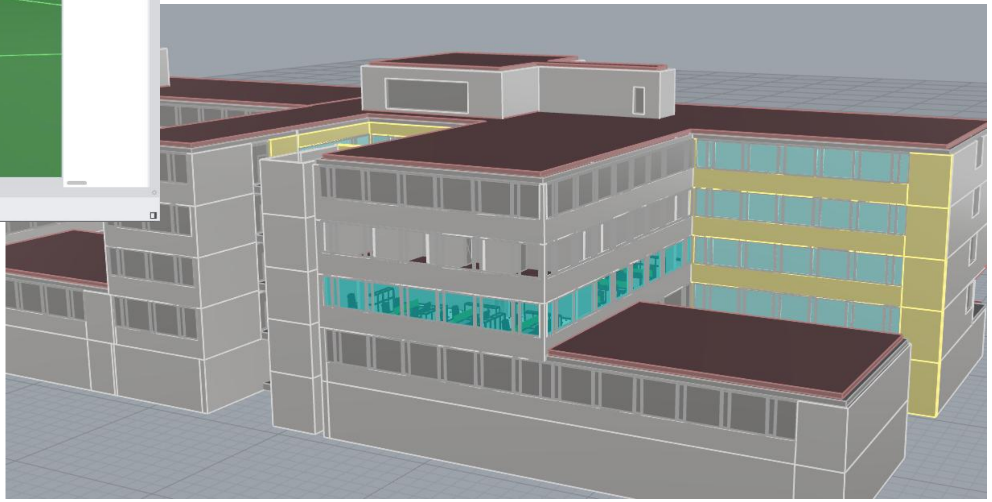
* Selection of common tools, no claim to completeness

Digital Twin IFC model – Geometry import & model setup

Analysed Digital-twin building: Infineon headquarter, Villach, AT







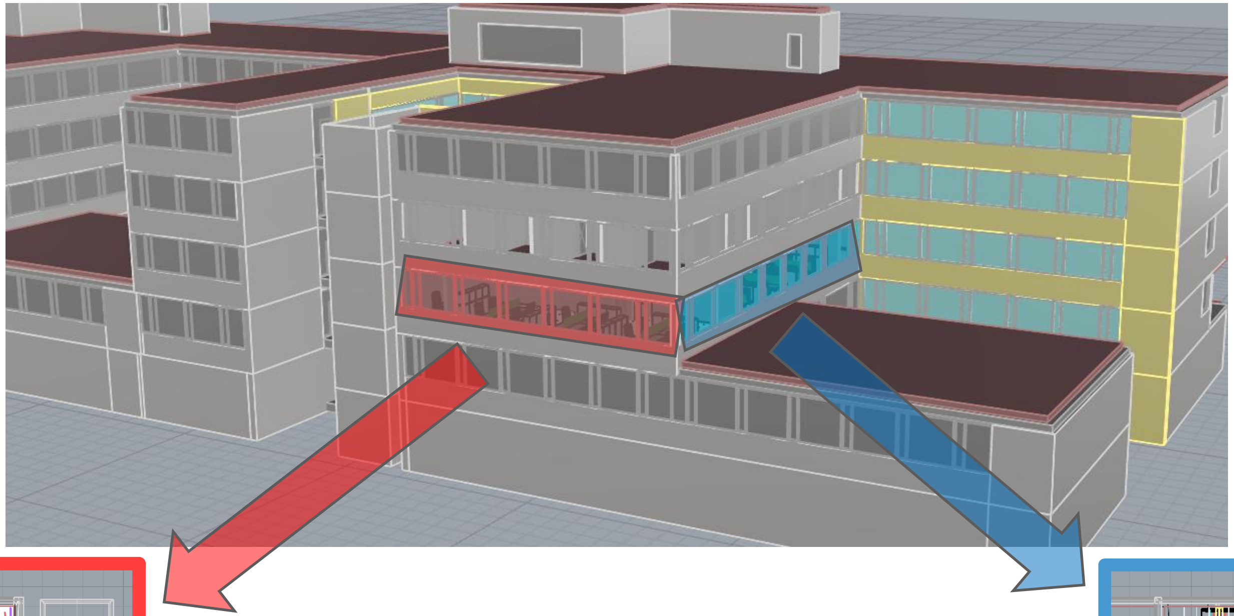
IFC-import in Rhino 8 using the ggIFC-plugin (3rd party)

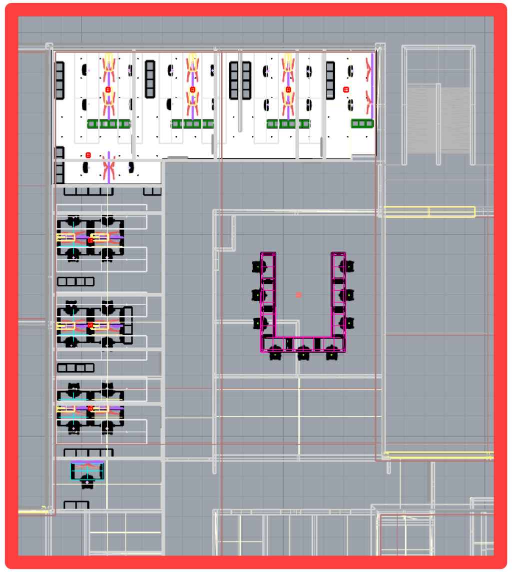
Setup CS-model in Rhino 8

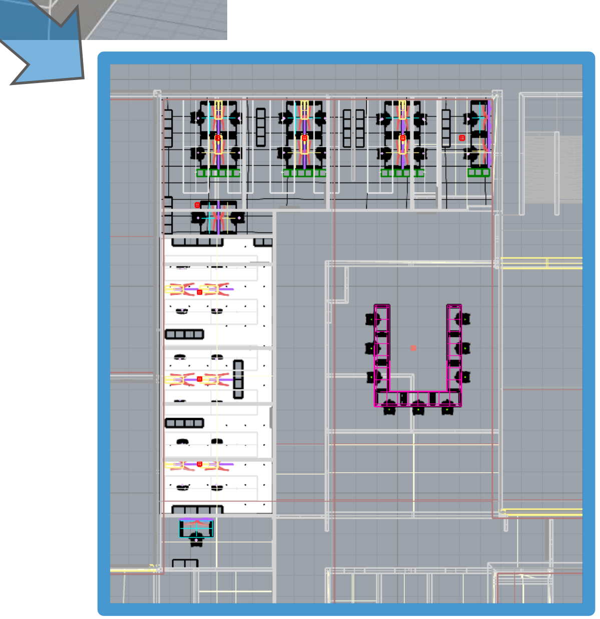
Open Space Office – Analysis areas

Analysed Digital-twin building: Infineon headquarter, Villach, AT

SE – Facade
SW-Facade



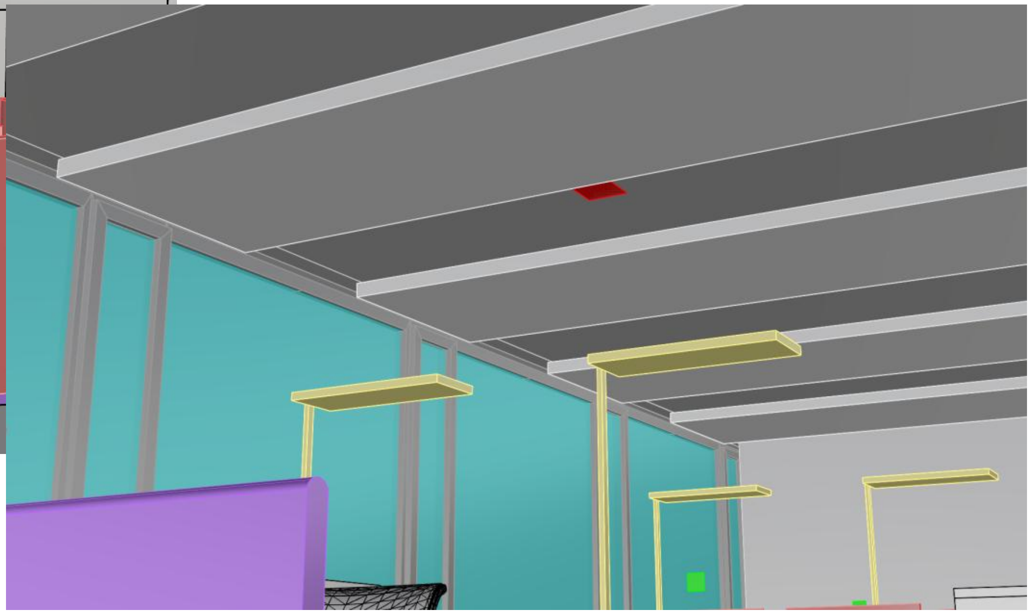




Open Space Office - Interior setup

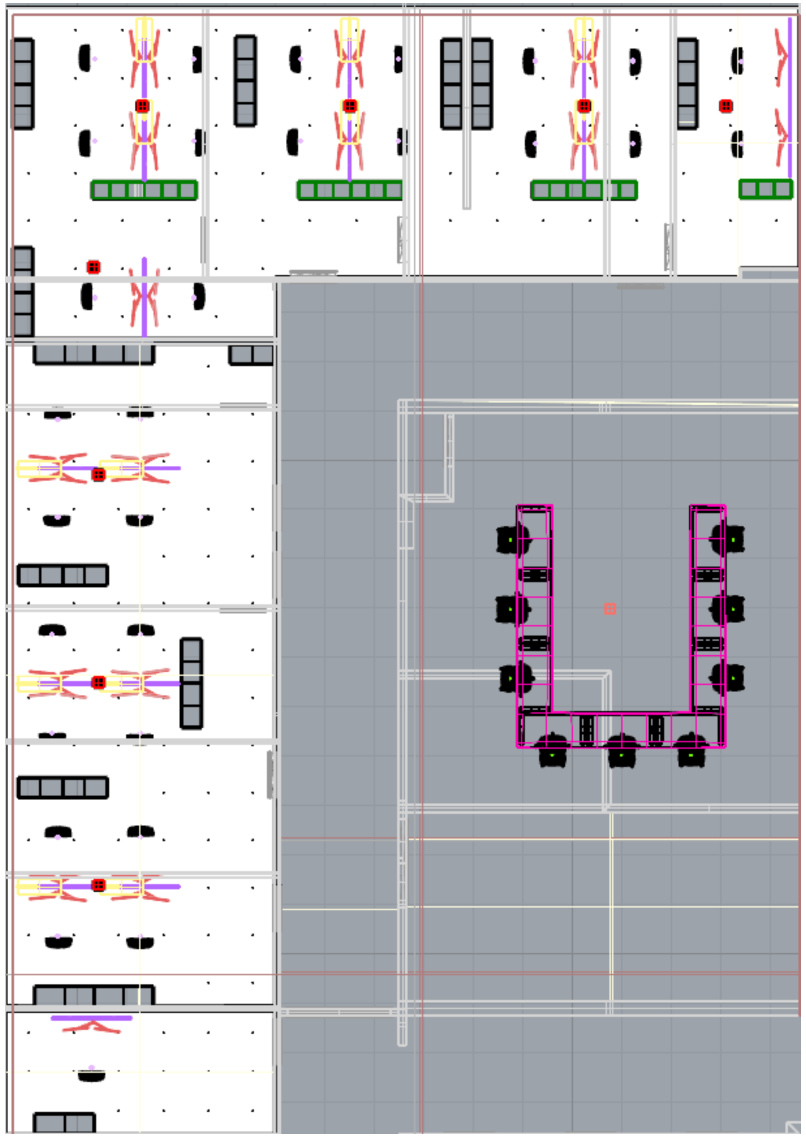
Sensor positions:

- 5 horizontal illuminance sensors on workplace height (0,75m)
- Sensor position on occupant eye-level (1,2m)
- Ceiling sensors (lockdown-sensor)

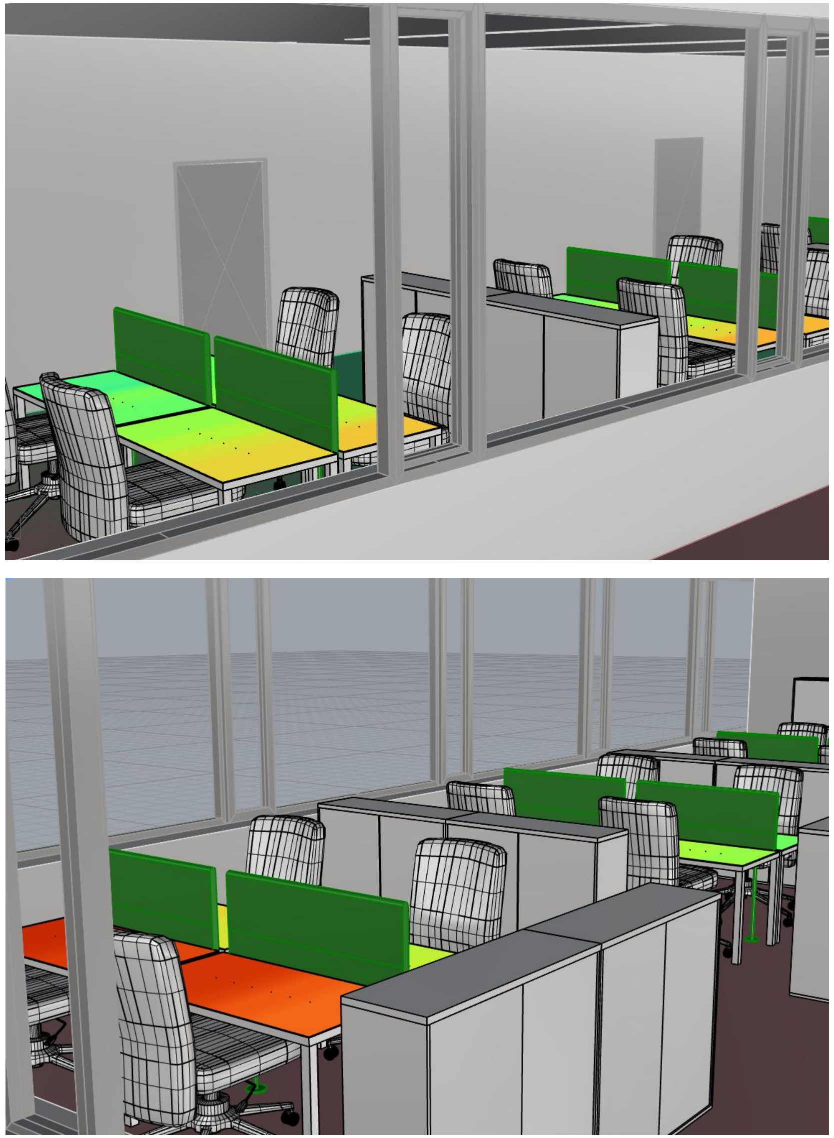


Open Space Office - Daylight sensor point placements (desks)

Room sensor grid – 1m distance



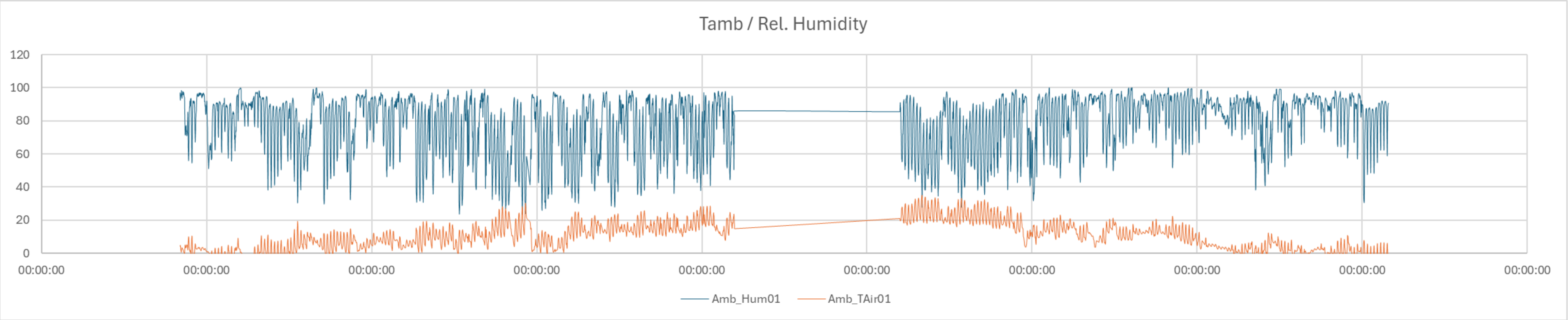
Workplace sensor grid – 6 sensors per worktable



Digital Twin – Monitoring data analysis

- Analysis of monitoring dataset from operational year 2024
  - Measurement data in hourly resolution (data break between 16.06.24 and 05.08.24)
  - Climate data from the rooftop weather station: rel. humidity, Dry bulb temperature
  - Global radiation horizontal + separation direct-/ diffuse radiation
  - Global radiation vertical - in all different façade orientation

Timestamp	[UTC]	Date+time	Anwesenheit (I	Amb_Hum01	Amb_TAir01	R_Diffus_V01	R_Direkt_V01	R_HOR_V01	RadHor01	R_Direkt (Ig_h-	RadVert01 (NO	RadVert02 (NW	RadVert03 (SV
01.01.2024	08:30:00	08:30:00	1	98.3589	1.33751667	67	87.0301667	84.9936667	88	20	45	38	54
01.01.2024	09:30:00	09:30:00	1	96.91665	2.22443333	107	79.1085	129.386	139	31	64	59	87
01.01.2024	10:30:00	10:30:00	1	95.0022667	2.59445	82	19.542	88.3915	97	15	46	43	56
01.01.2024	11:30:00	11:30:00	1	95.3769167	2.65891667	115	26.3725	123.666167	135	21	63	61	86
01.01.2024	12:30:00	12:30:00	1	93.8538833	3.30723333	121	61.4265	140.9665	152	30	67	66	124
01.01.2024	13:30:00	13:30:00	1	93.5891667	3.4547	98	26.4243333	104.463667	113	15	51	55	83
01.01.2024	14:30:00	14:30:00	1	95.2983333	2.96861667	41	4.34883333	41.12	45	4	21	22	28
01.01.2024	15:30:00	15:30:00	1	95.9211333	2.88226667	2	747.018167	2.25983333	2	0	1	1	2
01.01.2024	16:30:00	16:30:00	1	96.3650333	2.83108333	0	1199.88	0.06	0	0	0	0	0



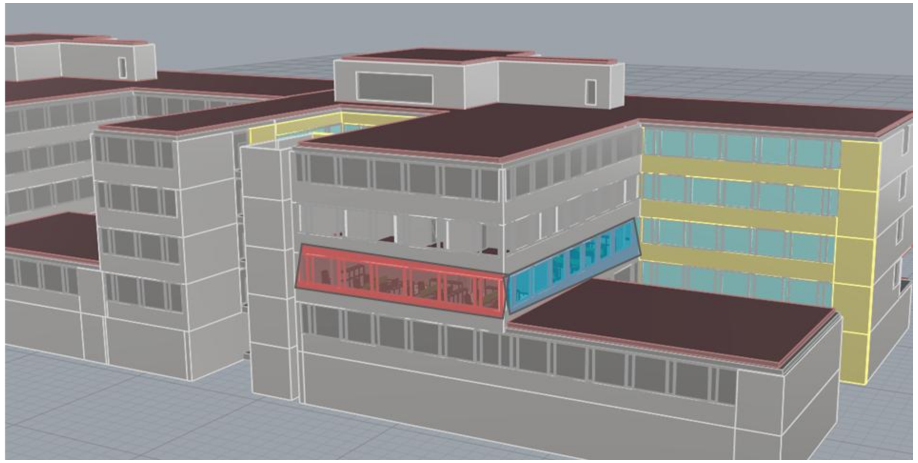
Digital Twin – Operational façade shading states

- Data series SE-facade: 11 separable façade segments (blind position and blind tilt angle)
- Data series SW-facade: 8 separable façade segments (blind position and blind tilt angle)
- Analysis of façade states: only for occupancy times: estimated from 07:30 – 17:30 (Mon-Fri)

South-west façade		South-east façade	
Louver tilt angle	hours in a year	Louver tilt angle	hours in a year
> 45°	4h	> 45°	55h
> 30°	165h	> 30°	74h
> 15°	201h	>15°	86h
= 0°	2478h	= 0°	3210 h

both façades	
Shading position	hours in a year
> 50% closed	~3300h (96% p.a.)
> 80% closed	~3200h (93% p.a.)
> 85% closed	~1450h (41% p.a.)

SE – Facade
SW-Facade



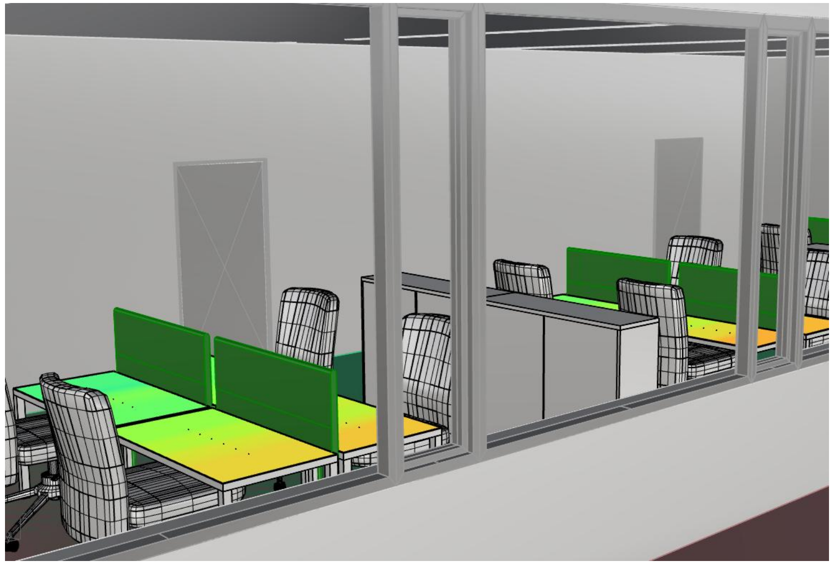
Initial step - Point-in-time evaluation (static conditions)

Daylight Factor (overcast sky) / Point in time (climate-based)

	Wheather file - Villach	Point in Time 3 June			Daylight Factor
correct NORTH exposure		9:30 AM	12:30 AM	15:30 PM	
	Baseline only Glazing	2062	3509	10649	5.6% mean DF
	Glazy + blinds 0°	1028	1604	2612	
	Glazy + blinds 15°	977	1508	2416	
	Glazy + blinds 30°	883	1391	2435	
	Glazy + blinds 45°	704	1181	2241	
	Glazy + blinds 60°	461	866	1658	
			mean lx		
			only desk		

→ Blind setting with 45-degree tilt angle was chosen for further annual analysis

→ Best compromise between (1) solar shading – (2) daylight utilization – (3) quality view to outside

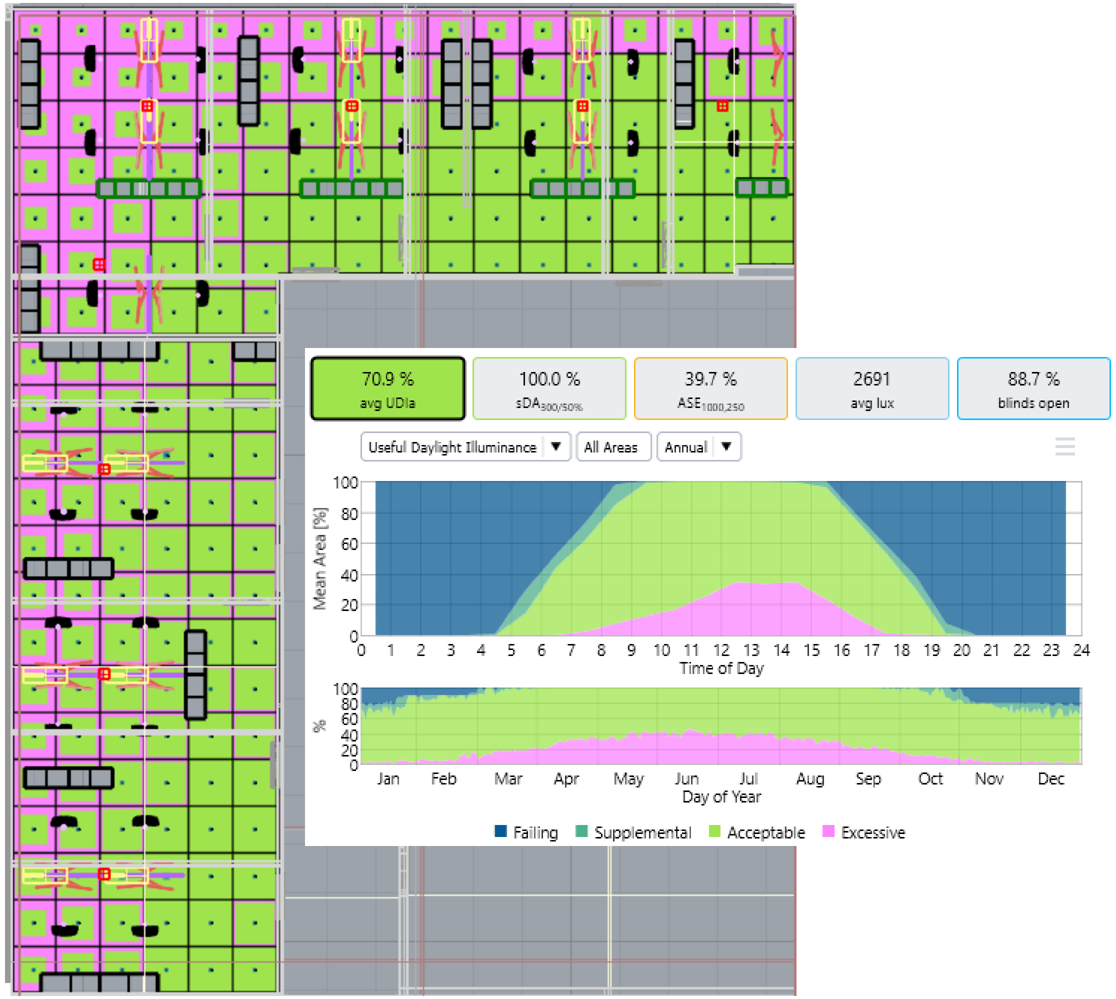


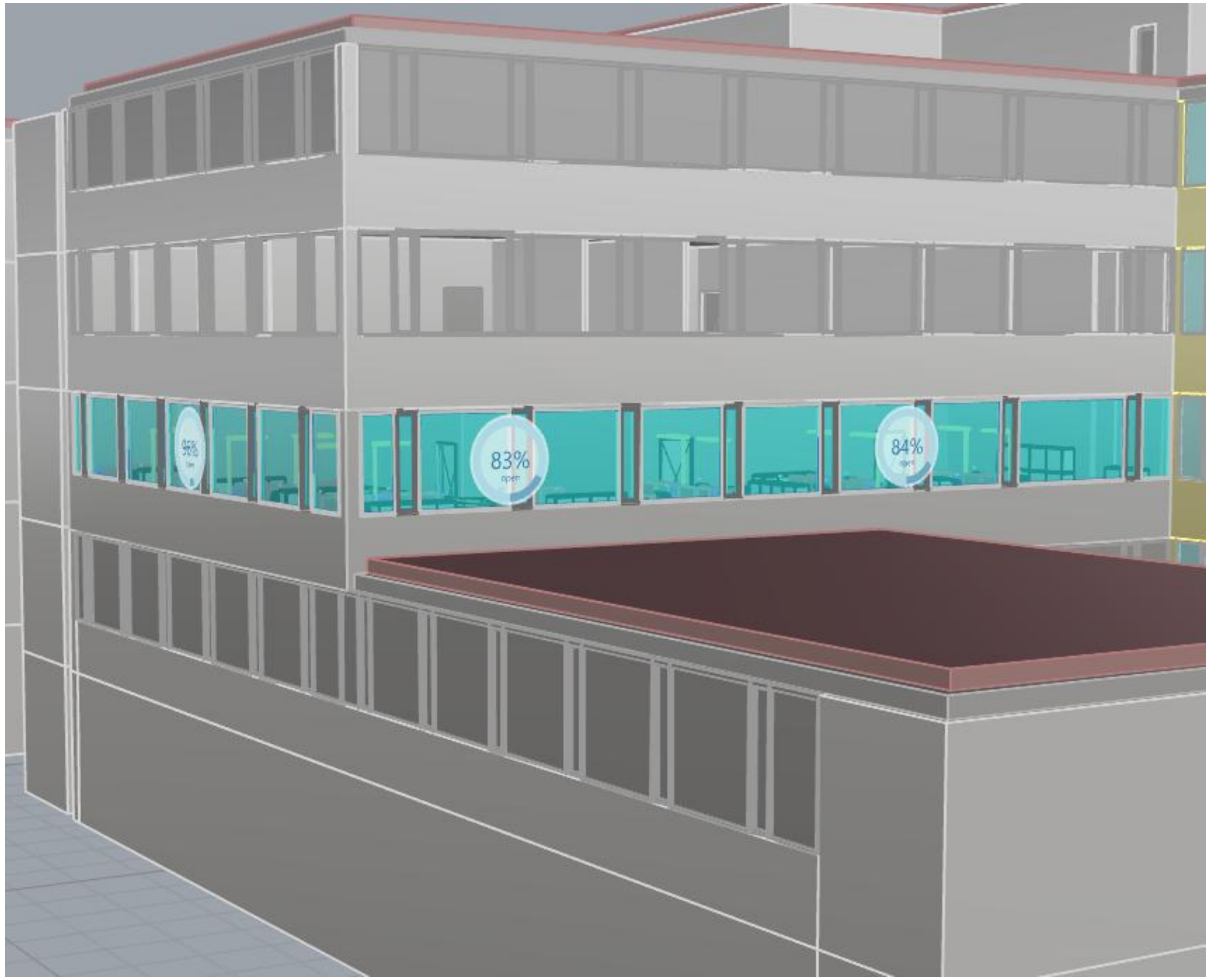
Outside view

Inside view

Step A – Façade-wide control

- Room-grid controlled
- shading closes, when direct sun enters > 1,5m in room depth





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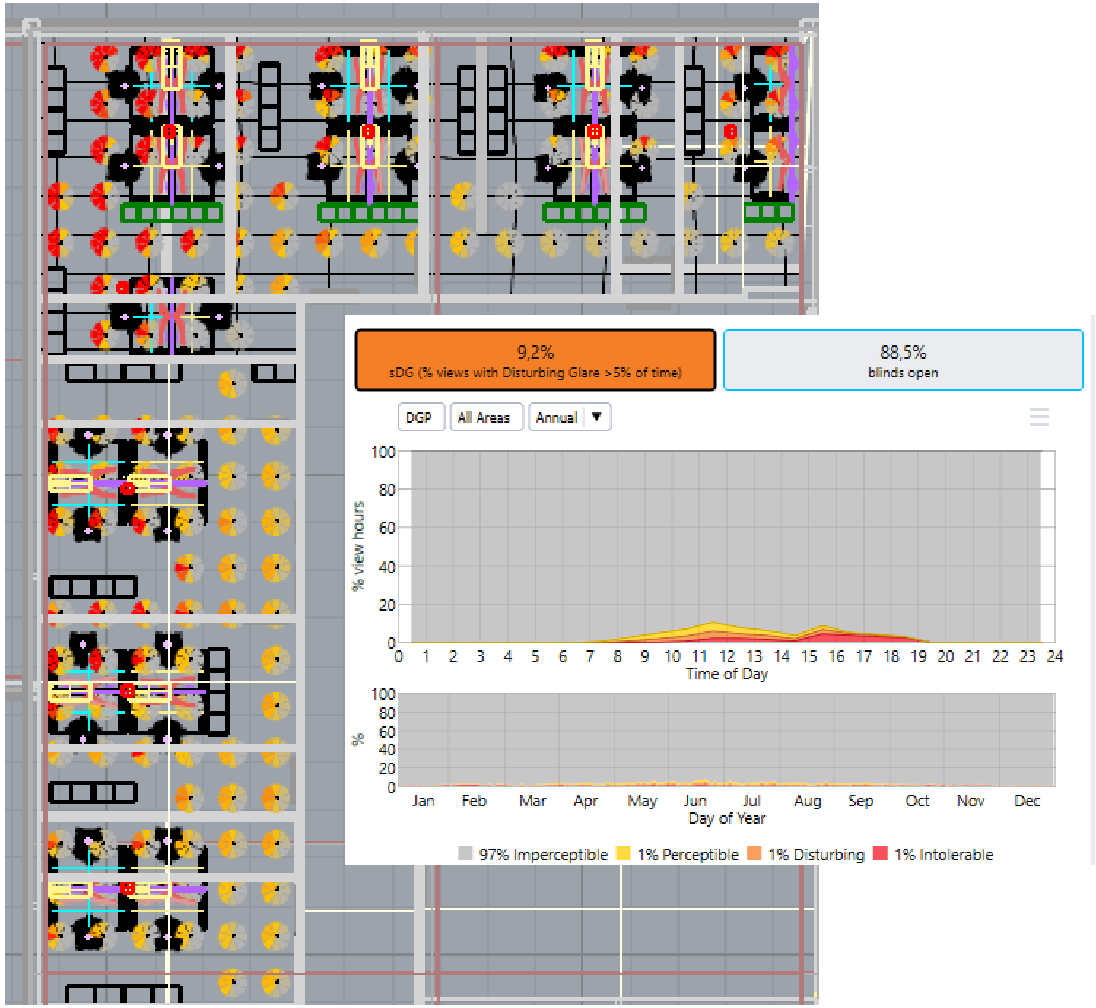
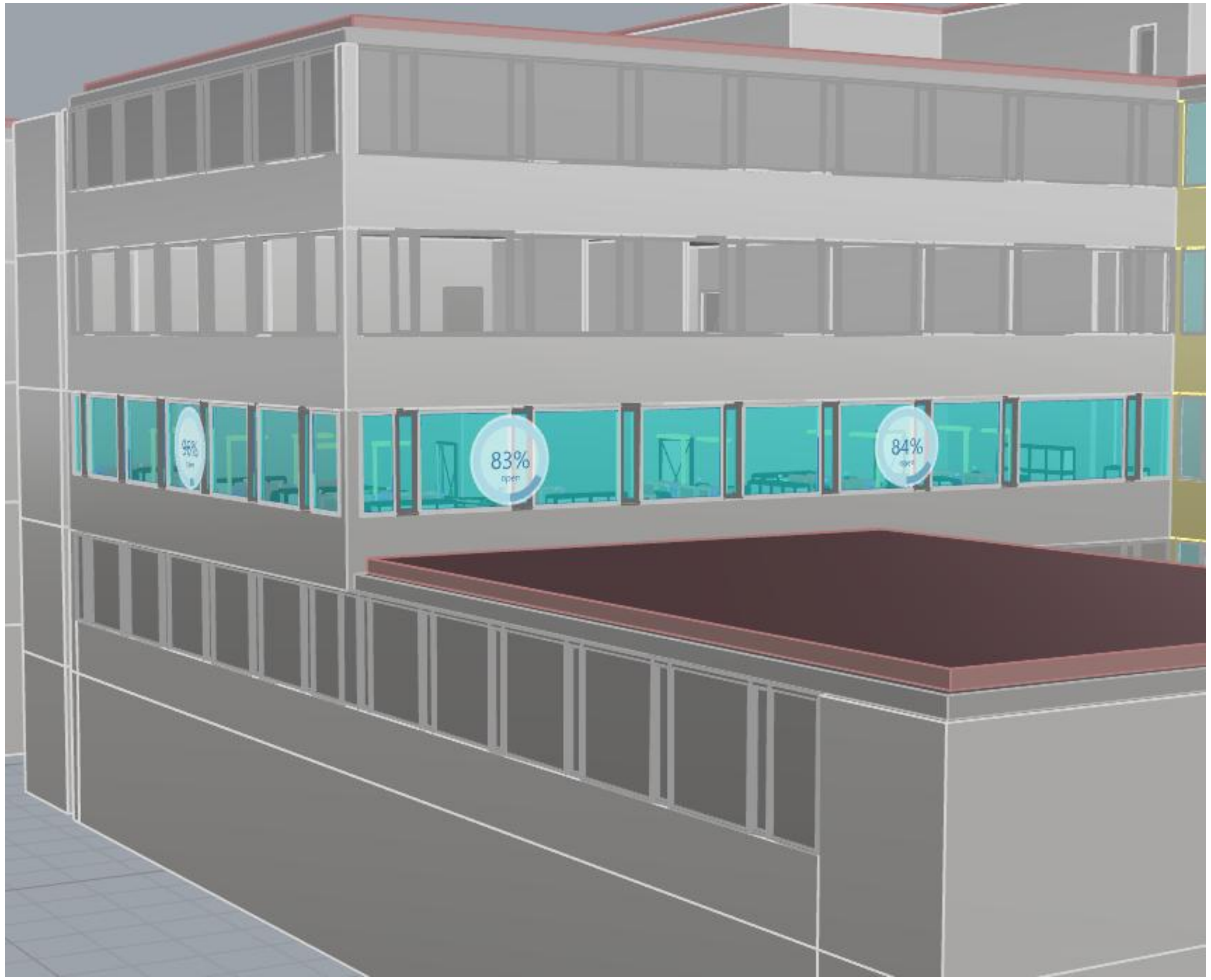
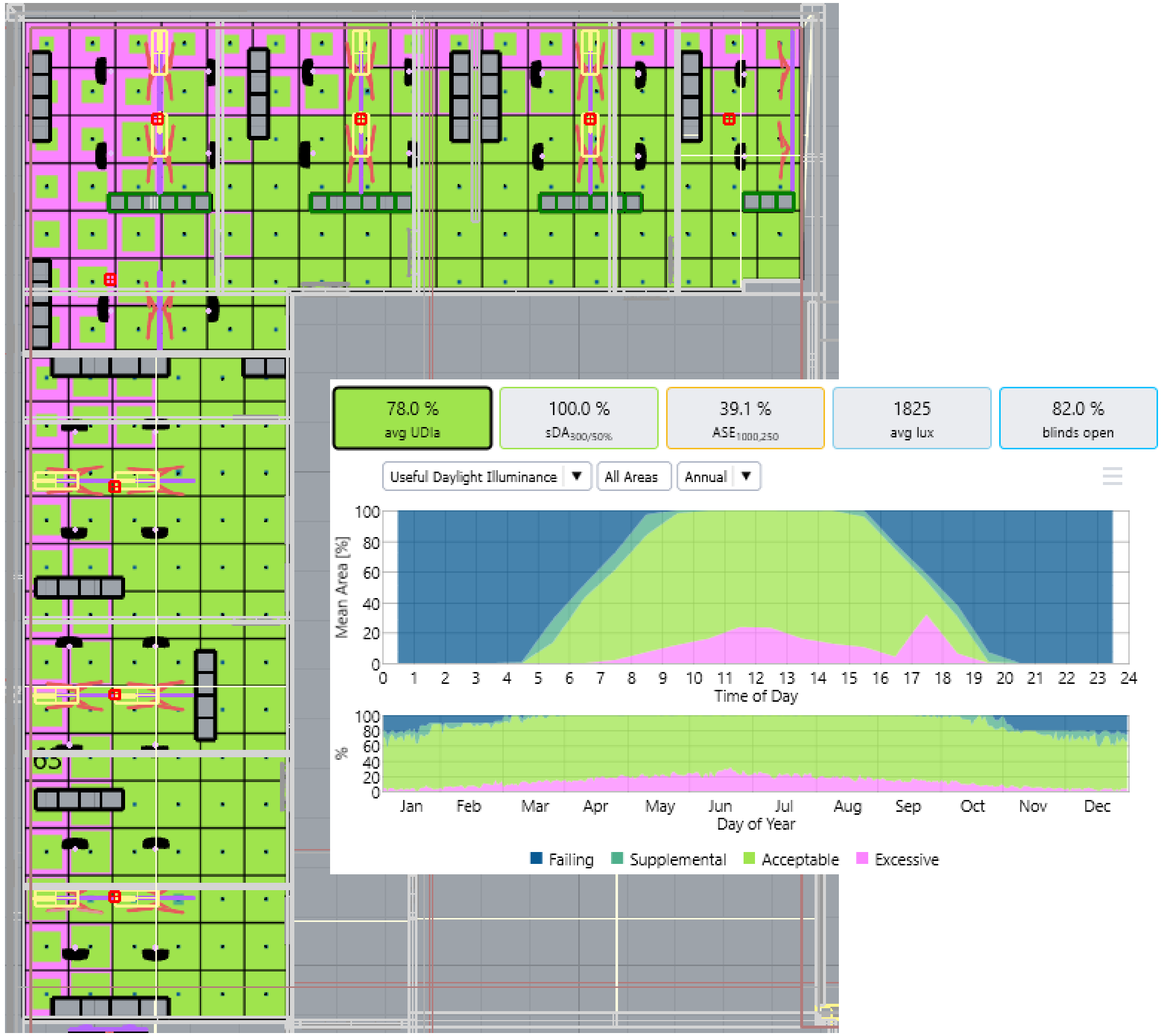
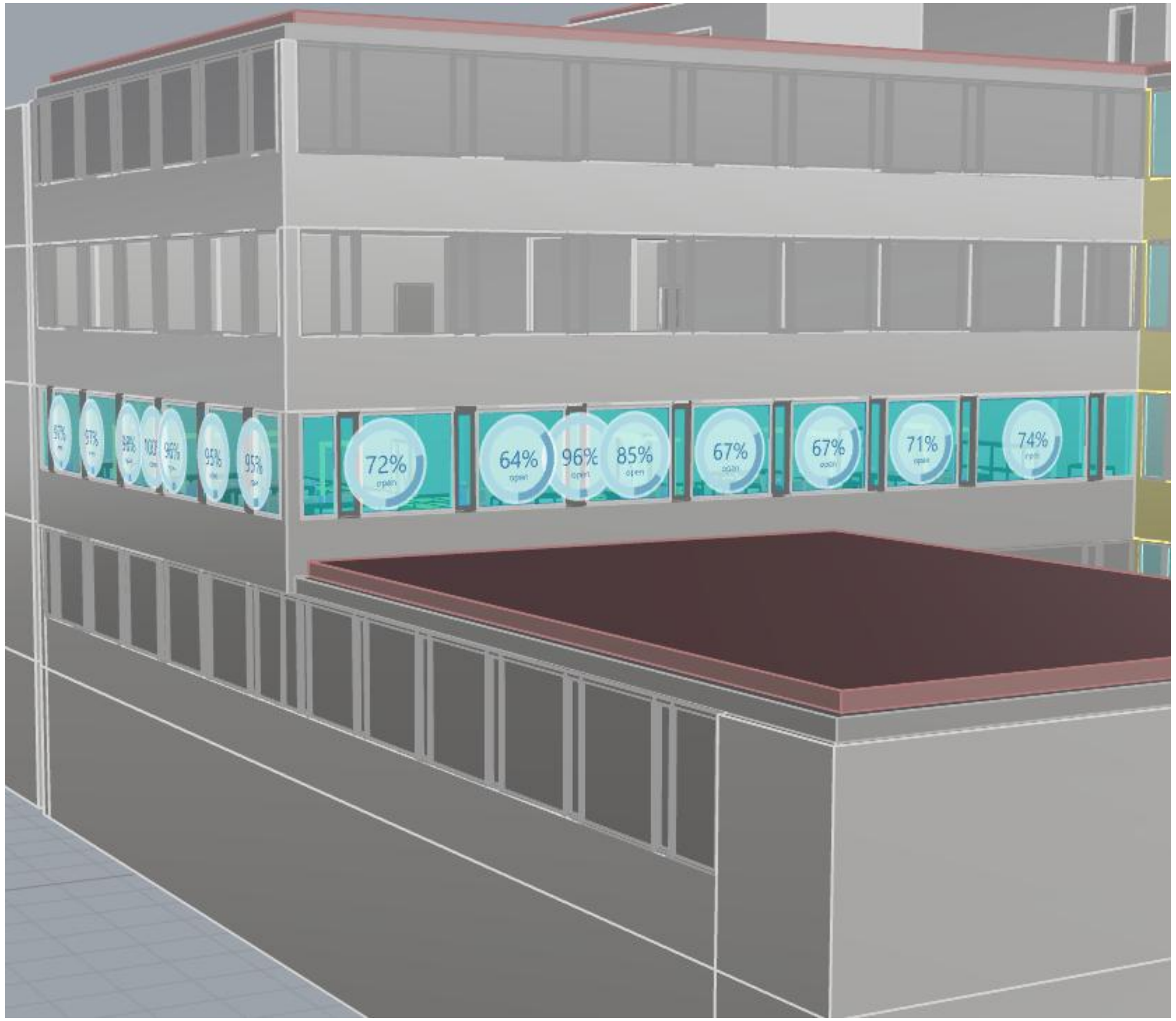




Step B – Façade-segmented control

- Room-grid controlled
- shading closes, when direct sun hits > 2% of the overall sensor points





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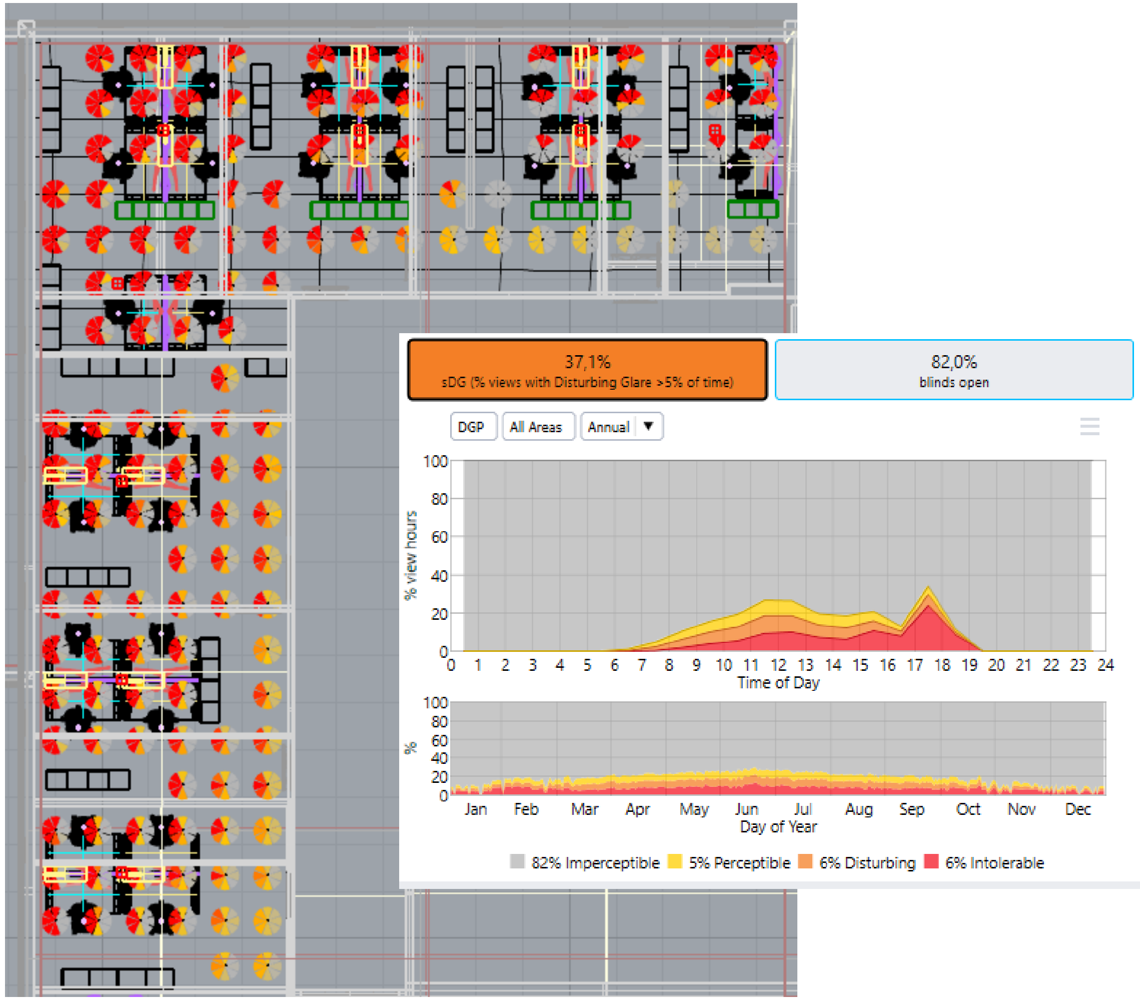
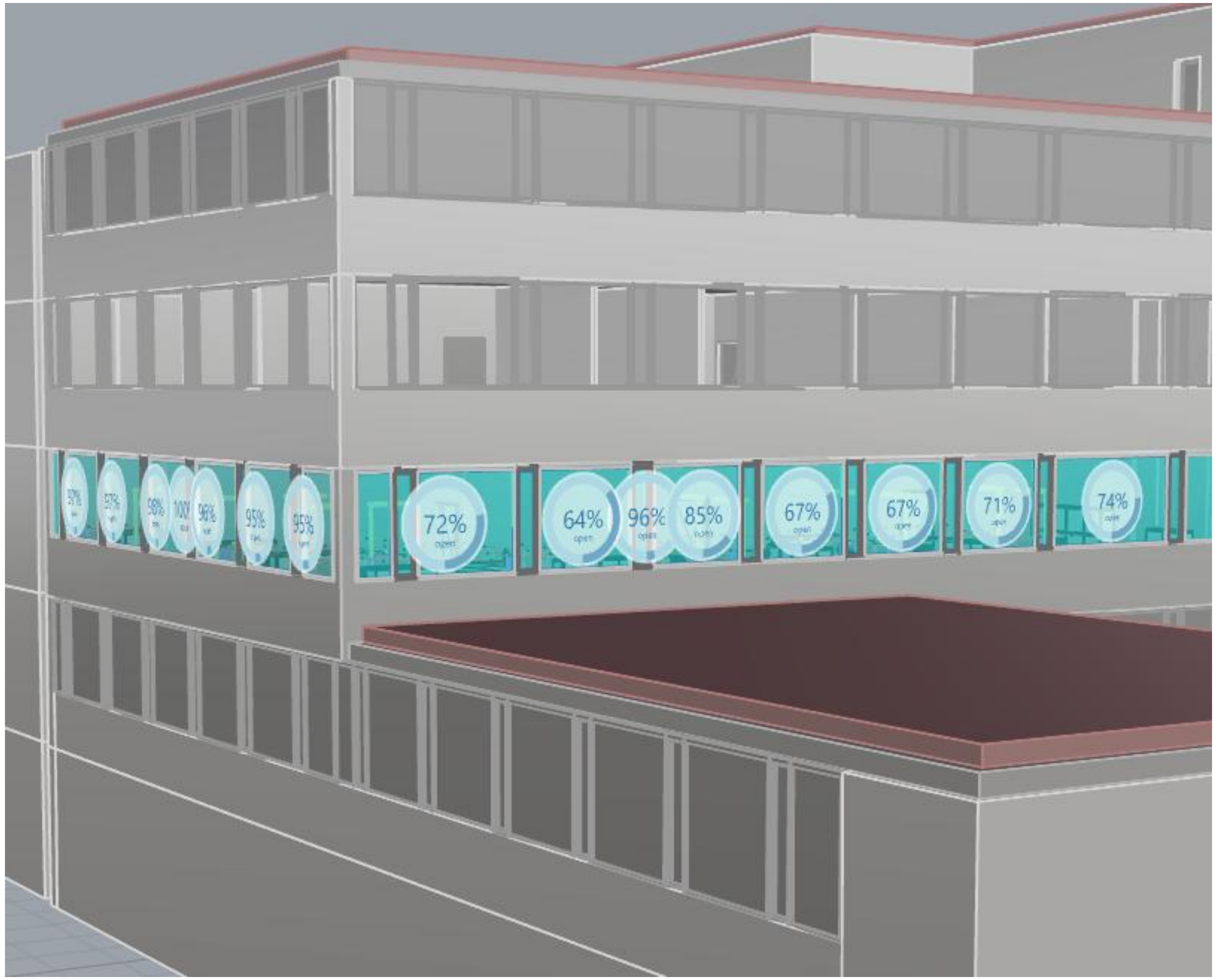
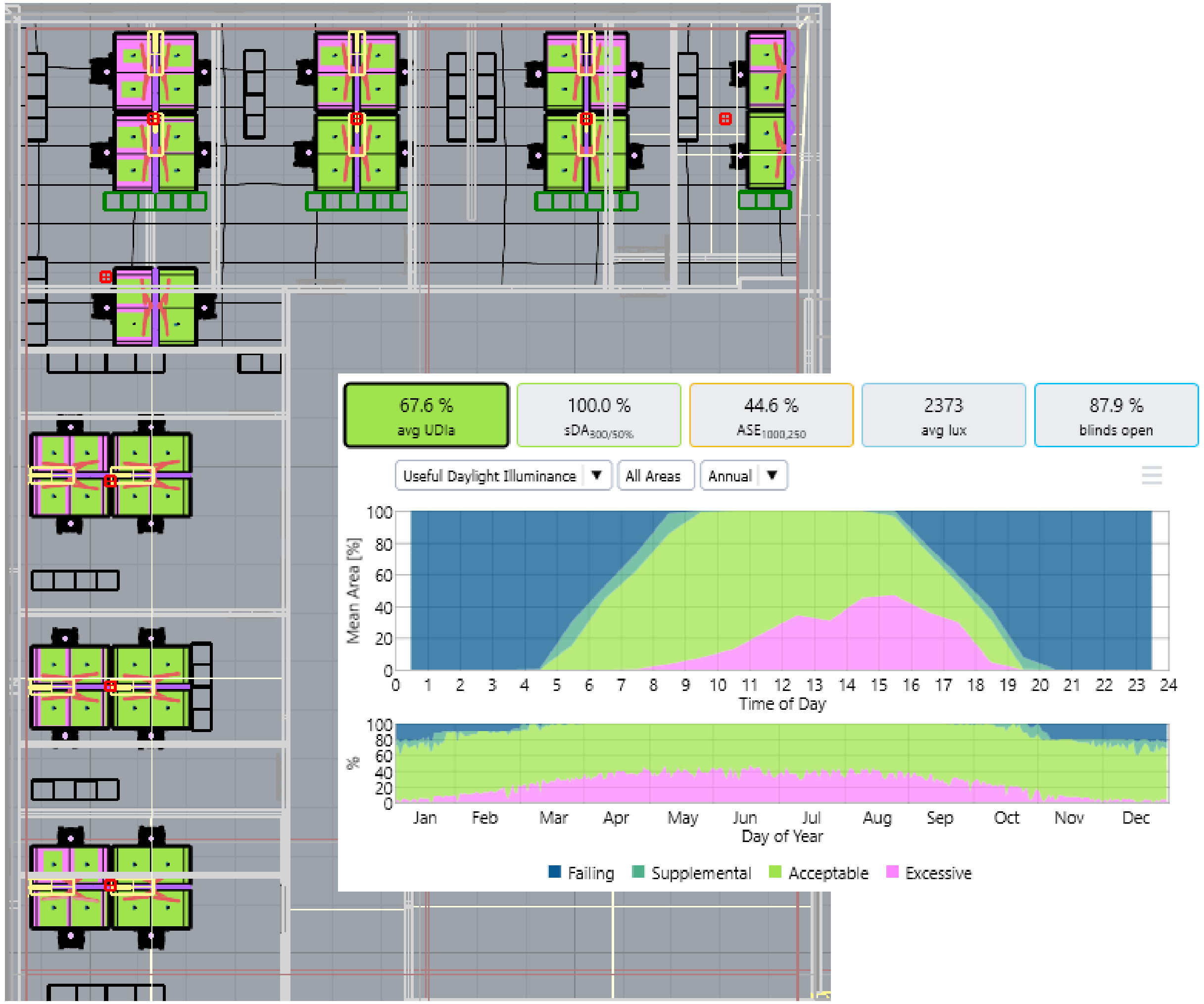
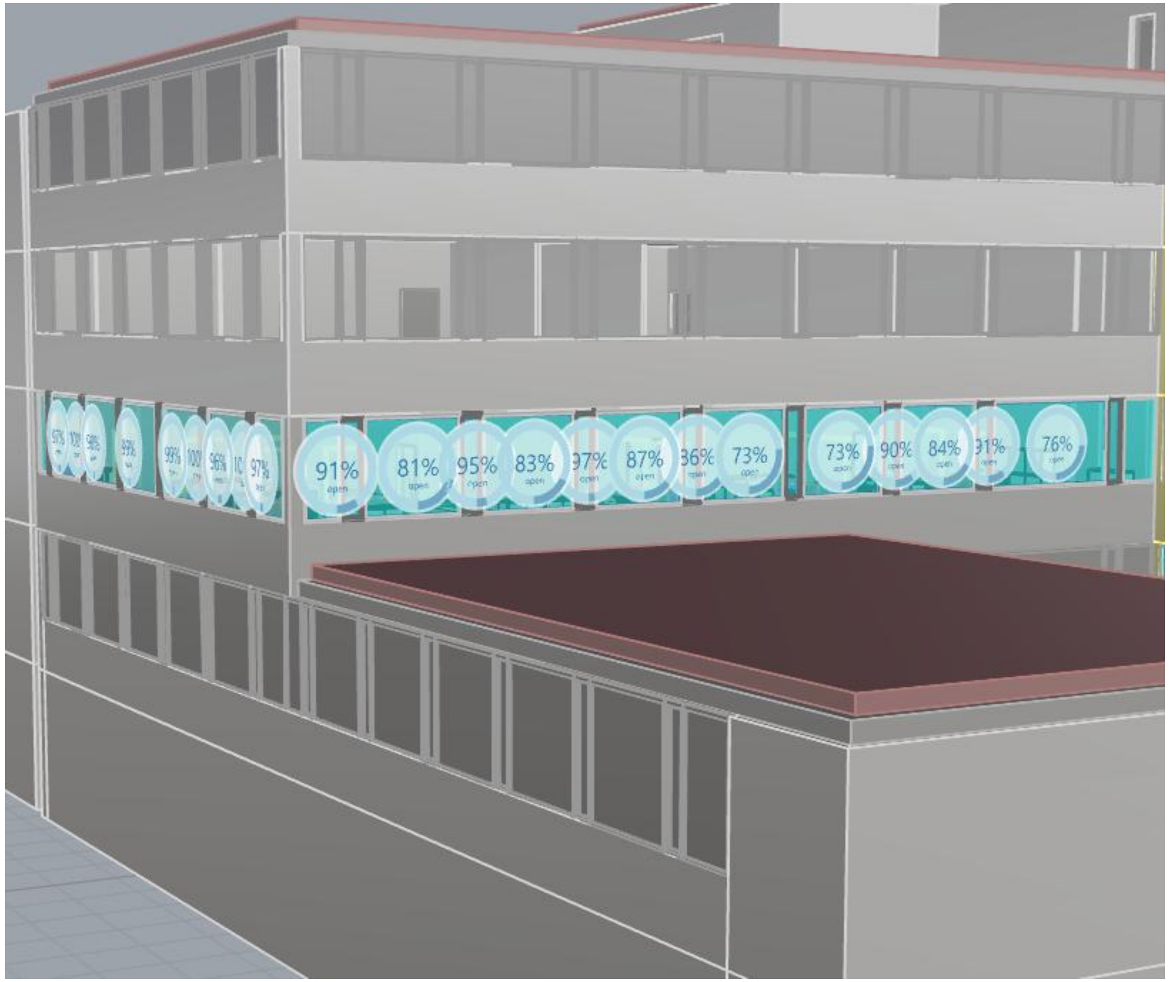




Step C – Workplace-individual control

- Workplace-grid controlled
- Shading closes, when direct sun hits > 2% of the overall sensor points





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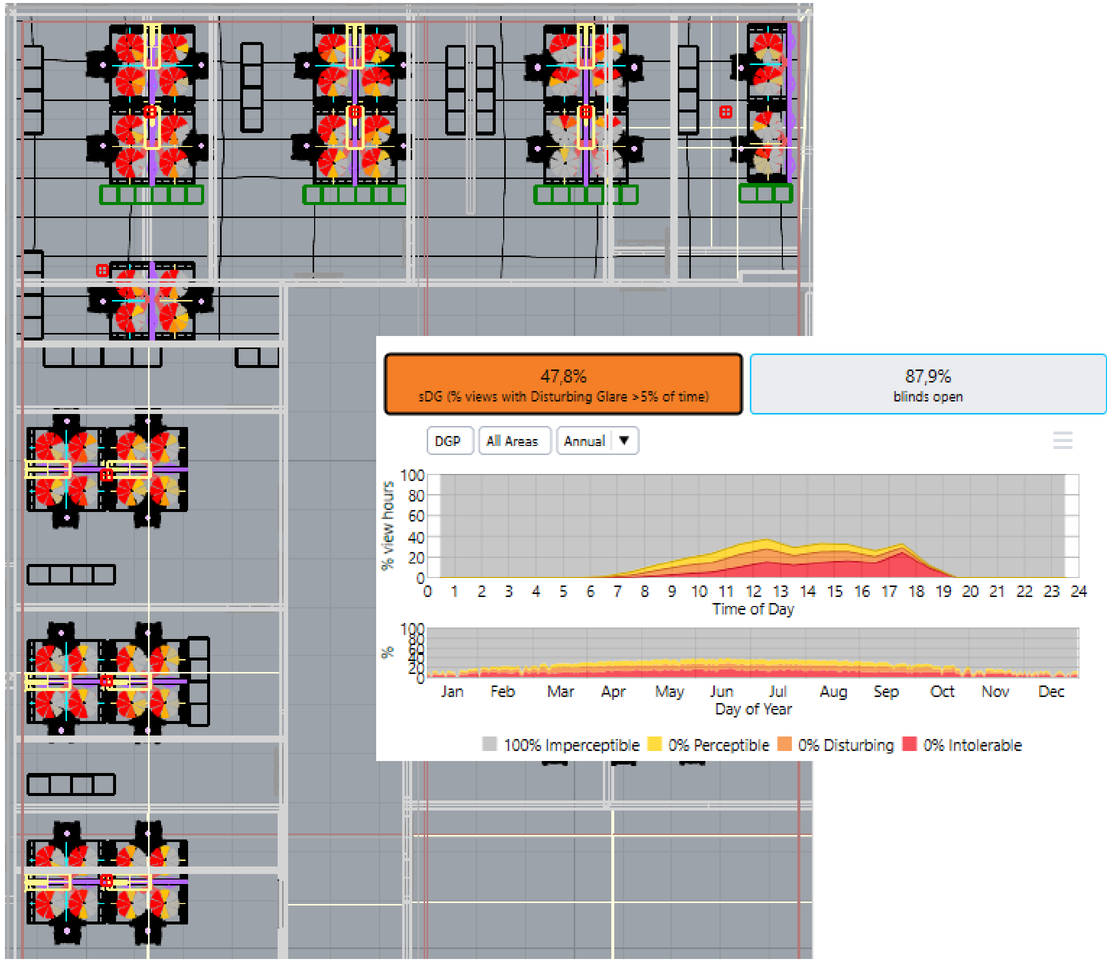

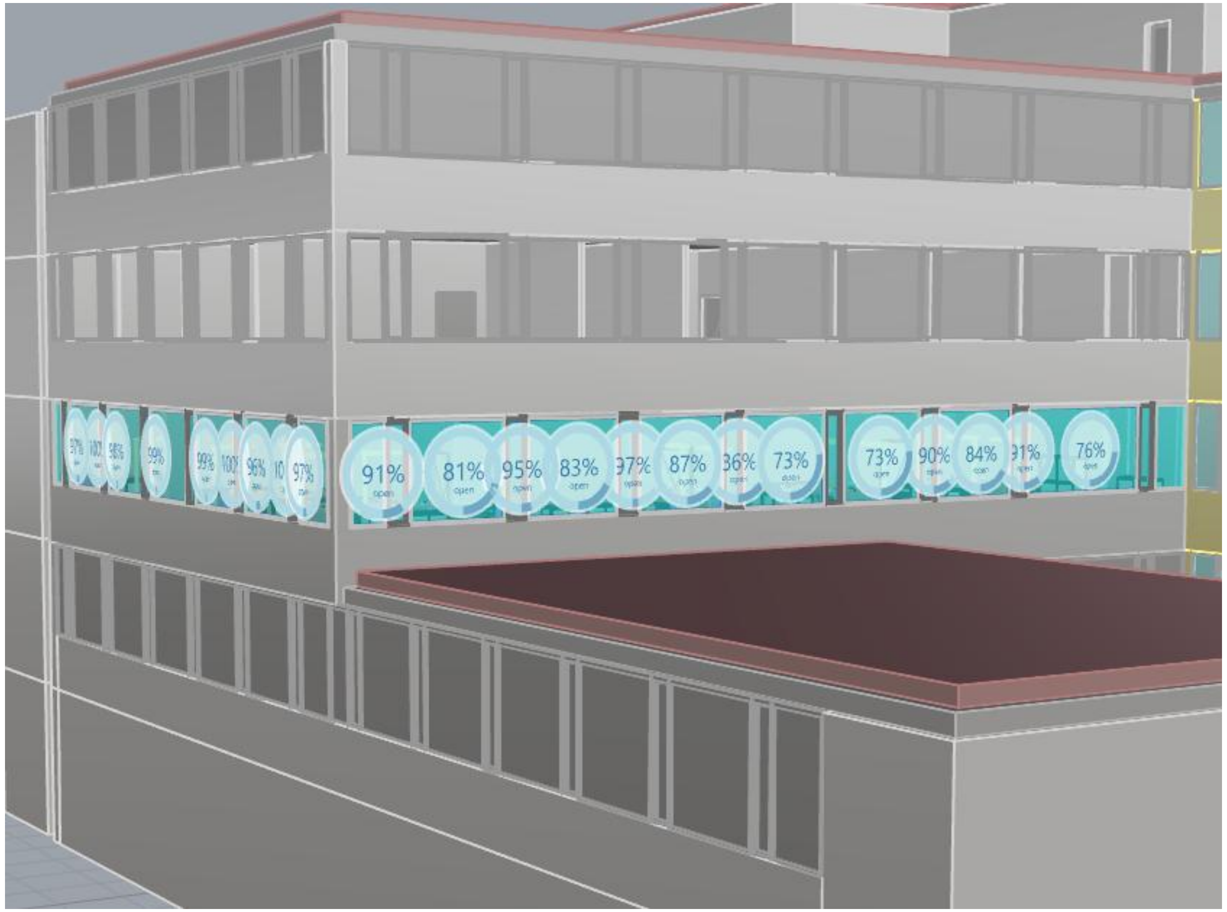

Results Summary & Conclusion

Steps	UDI_{accept}	$ASE_{1000lx,250h}$	$Illum_{ave}$	$Blind_{open}$	sDG
Step A	70,9 %	39,7 %	1663 lx	88,7 %	9,2 %
Step B	78 %	39,1 %	1825 lx	82 %	37,1 %
Step C*	67.6 %	44,6 %	2373 lx	87,9 %	47,8 %

* Only workdesk area

Simulation variants:

- Step A – façade-wide control with floor plan grid (max. 1,5 m depth with direct sun)
- Step B – façade-segmental control with floor plan grid (max. 2% of sensors)
- Step C – façade-segmental control with workplace-individual sensor grids (max. 2% of sensors)

- Simulation results do not reproduce the operating situation with 0° blind tilt angle throughout the year
- Significant glare issues occure due to inefficient control of individual facade segments
- Implemented control routine is faulty – less sensitive on excessive solar entries (high ASE, glare issues,...)

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