Acta Polytechnica CTU Proceedings **38**:375–381, 2022
https://doi.org/10.14311/APP.2022.38.0375

SOLAR SHELTER: EXPLORING ARCHITECTURAL DESIGN INPUT FOR INDUSTRIALLY-CRAFTED SHADING DEVICES

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Abstract. European Cities are strongly affected by the Urban Heat Island effect and Climate change impacts in recent and future summer periods. As such, the integration of passive cooling strategies is of increasing importance for the overall AEC (Architecture-Engineering-Construction) domain. Amongst other strategies, one of the most prominent strategies is the timely deployment of shading devices. While the shading device constructions connected to the inside, interstitial position or exterior of transparent building envelope components is thus an important part of the building, little change can be observed in the principal design and technology of such shading elements. Moreover, target conflicts between shading device deployment and architectural appearance can be observed in European Cities. For instance, the ensemble protection of the Vienna City morphology was – for a long time – considered to be more important than potent shading devices.

The present contribution presents the approach of an effort toward highly-esthetical, functional shading devices that provide – despite their architectural-design approach – a high degree of shading performance. Together with the window-building industry, four different shading device designs have been designed, developed and virtually tested. The design process was guided by critical reviews by domain experts and performance simulation efforts. We present the genesis of the four designs and their performance implications as a proof of concept that effective shading systems can be understood as part of the esthetics of a building and practical passive cooling device at the same time.

Keywords: Shading devices, summer overheating, passive cooling strategies, industry-university collaboration, urban heat islands, climate change, cooling demand reduction.

1. Introduction

Summer overheating has become a prominent topic in recent years, which can be seen by the rising number of scientific research, publications, and the action plans of different cities and regions to react to summer overheating. Once specific topics reached the attention of governments, regularly it can be assumed that the issue is not any longer just an academic one. While the analysis of the impact of CO_2 emissions on global temperatures can be traced back to the 19th century [1], the information of the general public of rising temperatures is a matter of the second half of the 20th century [2–5]. Moreover, most people – by feeling – would say they did not identify the environmental issue of rising temperatures as a severe one before the millennium change to the 21st century. Other environmental issues, however, were a matter of public interest and also international action was taken against these issues: This is true for the hole in the ozone layer [6, 7], and on the forest dieback phenomena [8]. Both matters were identified to be majorly caused by emission of certain harmful substances that reacted with atmospheric components to acid or diluting substances. In contrast to the mentioned environmental threats, climate change and urban heat island effects has rather seldomly popped up in the public perception. One of the first occurrences might have been the summer heat wave of Central Europe in 2003, which showed the high vulnerability of urban citizens against overheating, in detail for people who themselves are part of vulnerable groups due to their age, health situation, or social status [9]. Studies and reports reckoned that the heat wave caused up to 70 000 people's death [10]. It might be clear that fighting global warming by de-carbonization is somehow a half-lost battle, even if politicians proudly announce successes such as the Paris treaty [11], and its different follow up international treaties. While the concepts and ideas for reducing emissions, decarbonisation of industry, economy, and society are discussed and memoranda of understanding are signed and declared as path guide by decision makers, the reality is different and still shows rising CO_2 emissions [12] and thus a clear and present risk of reaching tipping points which would inevitably move mankind and nature into a hot-house earth scenario [13]. Urban citizens are stricken not only by the climate change itself, but also by the so called Urban Heat Island effect. This term describes the observation, that urban agglomerations tend to show higher temperatures and also accelerated heating up in heat waves, which is widely due to reduced vegetation, use of materials of low albedo and high energy storing potential, and – a major aspect – anthropogenic heat emissions by buildings, traffic, and systems. Between 2011 and 2014, a central European research project was conducted by a large consortium, which intended to identify sources and extent of the urban heat islands in European Metropolitan Regions [14], and – moreover – to develop strategies in mitigation [15]. Mitigation refers to minimizing the UHI effect as such by specific urban interventions, such as a balanced ratio of buildings and greenery, implementing greenery in building facades and roofs, minimizing unnecessary heat emissions, and utilizing the benefits of deployed green-blue infrastructure. If mitigation also refers to minimizing the harmful effects of heat waves, urban heat islands, and climate change onto citizens, the scale of interventions can be described as from "general city master planning" to "small scale impacts at the individual residential unit". The recently published guidebook on cooling of cities edited by the UN [16] clearly defines passive cooling strategies such as adapted design of the buildings regarding orientation, morphology and ratio of transparent components, careful operation of the buildings, and education of the occupants as key elements in fighting overheating. Needless to say, architects play a key role in implementation of such passive cooling strategies. Previous studies, however, identified that while the selection of appropriate building materials for summer overheating protection is of importance, it is by far outnumbered by the impact of the occupants' behaviour regarding shading deployment and ventilation [17, 18]. While ventilation via windows can be considered as easy-to-implement passive strategy, effective night-time cooling might require semi-automated windows that employ a ventilation-only position and automated opening and closing, as for instance suggested in [19]. Shading devices can be fixed or moveable/deployable. As of today, many architects consider shading device implementation as a severe aesthetical issue for new building designs, but also for adaptation of the existing building stock. This has – in part – to do with the rather "functional" design of deployable shading devices. While architects often dream of performance-oriented architecture far away from today's built practice (compare [20, 21]), a close-by industry designing of shading devices rarely can be found in academia or in the architectural practices of today. The authors and the window- and shading-device building industry therefore decided to ask graduate students of architecture to rethink today's available shading devices. The present contribution presents the methodology and the results of these efforts and shall thereby act as a proof that solar shading can be aesthetically pleasing and highly performative at the same time on the one hand, and on the other hand as a showcase of the reached design solutions.

2. Methodology

The overall efforts were conducted within a 5 ects Design Studio for graduate students of architecture. The task was to develop non-of-the shelf shading devices for both existing, richly-decorated Gründerzeit-Buildings as can be found in many European Cities, and new (generic buildings). Thereby, both design, functionality and performance impact was set for in-depth explorations during the design studio. Naturally, architects are not full-fledged engineers, but generalists and designers. As such, the students were supported by three instructors of architectural and building construction engineering background. Moreover, during the semester, three review sessions with experts from the window- and shading-construction industries were held, which allowed the students to receive a SWOT (strengths-weakness-opportunities-threats) analysis of their concepts and inspiration and guidance for the further development. Beyond the design and construction integration, the participating students were asked to consider the aspects of kinematics and performance impact. While the kinematics required animation or at least "thumb cinema" illutstrations that show the state of the system in any state during the operation, the performance impact on the summer overheating of buildings was emulated via the generation of virtual buildings that employed the corresponding design and a thermal building performance simulation via the simulation process described in the Austrian Standard for summer overheating [22]. These simulation efforts were conducted with the software Archiphysik in version 17 [23]. Students were asked to generate presentations for the Austrian community of window constructing companies (Plattform Fenster), which evaluated the projects and acknowledged the principle necessity of rethinking shading devices.

3. Results and Discussion

In this section the four different designs are presented briefly, including their potential application domain (new windows / new buildings or building stock / existing windows), and performance impact. Thereby advantages and potential challenges are highlighted as well.

3.1. Project 1: Rutatus-Blende ("Rutatus – shutters")

The defined aims of this design were as follows:

(i) integration in window-retroffiting efforts,

(ii) development of a Casement window upgrading kit,

(iii) compatible in aesthetics to traditional Gründerzeit facades,

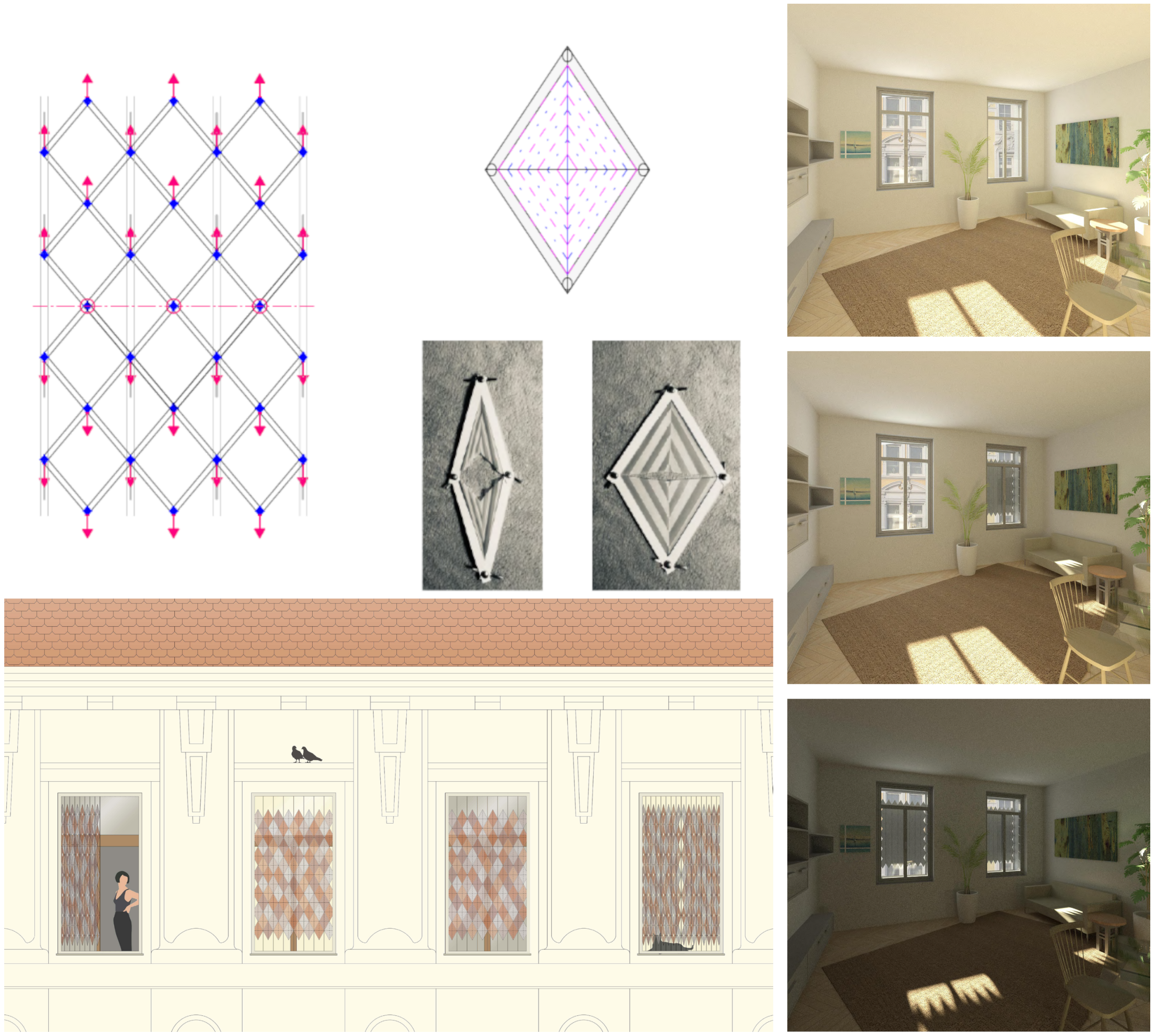

Figure 1. Project 1: Rutatus-Blende: Upper left: functional principle, Lower left: Façade view be integration in a Gründerzeit façade, sequence on the right: Shading effect / sun penetration reduction (rendering).

(iv) inexpensiveness in investment and operation (maintainance).

Given these goals, some design decisions could be made, such as the positioning of the shading device at the outside of the window plane, the manual operation (no motorization), and a specific identity in the design. The final design was inspired by claws grid systems, which for a very long time have been used as anti-burglary devices in front of doors and windows. While this systematic in its traditional form never was intended as a "shading device", the key further development of the project was to find possibilities of attaching fabric that does not hamper the kinematic of the system but unfolds for cutting short of sun penetration and glare. Figure 1 illustrates the Rutatus-Blende principles.

The strong part of this project is for sure in its easy to implement concept as a frame that can simply be set into the window niche. The aesthetical impact on Gründerzeit facades might be an acceptable one, in comparison to traditional jalousies. Moreover, the shading device can be deployed independently from the state of the window as opened or closed (given that we have turn windows opening to the inside). This means that sun shading and ventilation would in principle be possible at the same time. An integration in the interstitial space of casement windows can be considered. However, some shortcomings of the design need to be mentioned as well: The shading device is – due to its frame limitation – not useable to fully darken a room, some "open" spots remain. Depending on the used canvas simulations showed reductions of 21 to 79 % of transmitted short wave radiation. As a result the amplitude of indoor temperature curves over 24 hours can be significantly lowered, if the shading device is deployed during daytime in summer heat waves.

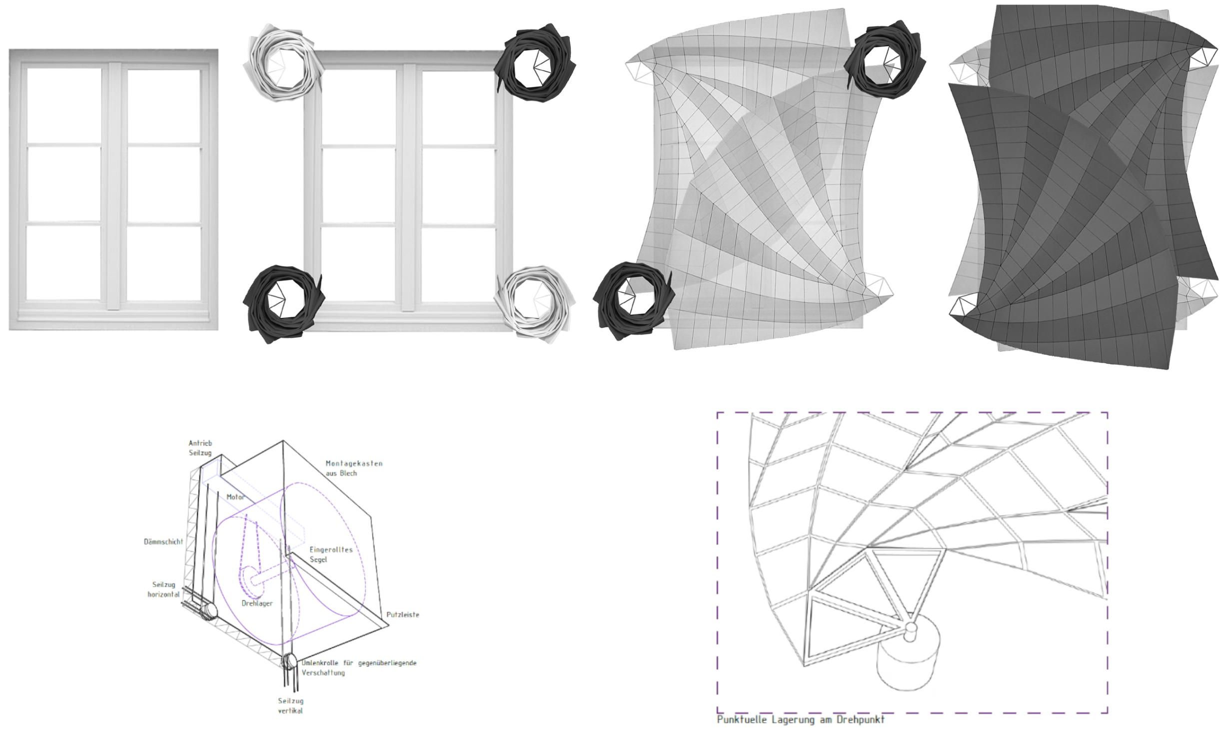

FIGURE 2. Project 2: Whirlshade: Upper Row: Installation and opening sequence; Lower Row left: Box with mechanics (pulleys, motorization); Lower Row right: principle construction of the foldable sail.

3.2. PROJECT 2: WHIRLSHADE

This concept – illustrated in Figure 2 – was inspired by the folding principles used for solar panels of satellites and space-faring vehicles. Utilizing a box structure that can be mounted in line with additional insulation material on the outer perimeter of existing and new buildings' walls close to the window, the wings of the shading system can be transformed from hidden to visible, to partly deployed and fully deployed. This step-wise deployment allows gradients of light penetration to the inside but also full shading.

Needless to say, the system of Whirlshade offers a high degree of innovation and can – if applied accordingly – also provide a "sense-of-wonder" aesthetics, as for instance the Façade of Jean Nouvels' Centre Du Monde Arabe [24]. However, it shares also the shortcomings, which are a potential high degree of maintenance and thus connected cost and effort. One might argue that different deployable membrane-based shading devices also have a certain degree of complexity, as such the design would require a further technical fine-detailing to allow for a concluding evaluation of its usability. Regarding the summer heating mitigation the system – if deployed at the right time with the right extent – provides full relief of summer overheating for typical residential rooms. Similar to project one, the deployment of the system is independent of the opening state of the window behind.

3.3. PROJECT 3: SONNENSTERNE ("SUN AND STARS")

This concept has been developed based on innovation pertaining to "translucent" timber [25, 26]. This material can be generated by removing major parts of the lignine structure from the wood. The material provides slow bio-degradability (such as any other timber element), and as such will change over time. The design of the shading devices utilizing this material is based on vertical construction axis, which can be moved from a hidden position of the left and right perimeter of the window niche to central positions via a railing system. Along these axis a set of rotation points in provided, which – in the basic version have one "part" of the star visible. Similar to the concept of the solar flower [27], different parts of the system can be deployed via rotation around the central rotation points. As such gradients of shading are possible. Different levels of overlap also form different light and radiative penetration barriers, allowing users to adopt their degree of shading accordingly. Figure 3 illustrates the principles of the Sonnensterne-System. Advantages of the system include – similar to the other projects – the independence from the window open/closed state, the flexibility of the system regarding degree of shading on the one hand and the application possibilities on the other side: The system can also be used as an alternative to photochrome or electrochrome glass panes used for generating privacy at still transmitting light in a translucent fashion. Such application could be used in fully glazed conference

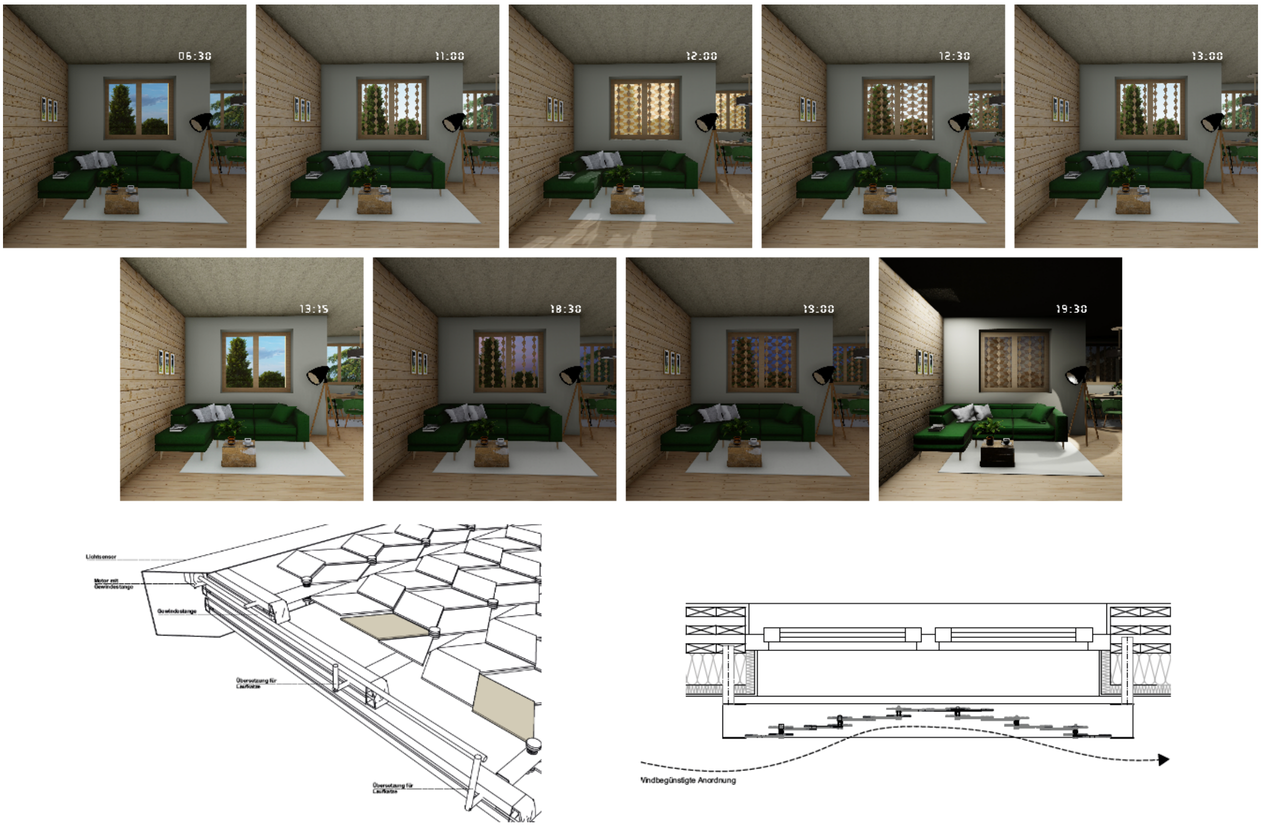

Figure 3. Project 3: Sonnensterne: Upper rows: Sequenze of different states of deployment; Lower Row: Isometry and horizontal section of the technical principle of Sonnensterne.

rooms.

Similar to the other projects, simulations conducted in the framework of the development proofed that summer overheating could be significantly reduced by deployment of the Sonnensterne system. Disadvantages of the system encompass the complex kinematics, even if this was reduced to "sliding" and "rotating", and potentially the sensitivity against wind pressure events, as the system is foreseen to be outside of the buildings and window niche perimeter.

3.4. Project 4: Fenster-Krausen ("window neck brace")

This project is inspired by the historic neck braces worn by noble(wo)men of earlier centuries. This idea has been translated into a folding system that can be used as alternative to traditional deployable jalousies. Similar to them, the degree of lowering and the position of the individual elements can be changed. However, the relative position of the single blinds is not just rotated but can be folded / unfolded to the neighbouring blinds. As a result the shading structure of this project provides a lively, irregularly pattern, comparable with the leaves of a tree and their diffusing effect on light and radiative transmission. Performance-wise, the system is as capable as regular deployable blinds. Challenges connected with this system include the rather complex fabric-pull-rope relation in the different parts of the shades. Figure 4 illustrates the system schematically, as well as the gradients of shading possible.

4. Conclusion

The present contribution showcased four different innovative and non-of-the-shelf shading device ideas. Two of them – Fenster-Krausen and Rutatus-Blende – seem to be widely adaptable in the sensible building stock of Gründerzeit-Buildings without shock-changing the overall appearance of such facades. Given the necessity to provide sun shading also for these buildings, such ideas should be followed up more in detail. The two other projects – Sonnensterne and Whirlshade – are rather ambitious and innovative in their kinematic patterns but seem to be better suited for new buildings. All of the designs were examined towards their lighting and shading impact. Whereas performative aspects in both domains could be satisfactorily fullfiled, open questions, such as potentially disturbing light/shadow patterns in the inside remain a matter to be worked upon. While this contribution on the one hand highlighted the early design phases of such shading devices, it highlighted that architectural designers can contribute to the mitigation of overheating also in a creative fashion, not only by purchasing and implementing the industrial products by now. On the other hand, the industry acknowledged the necessity to supplement the current offer of shading devices by high-performantive, aesthetically satisfying

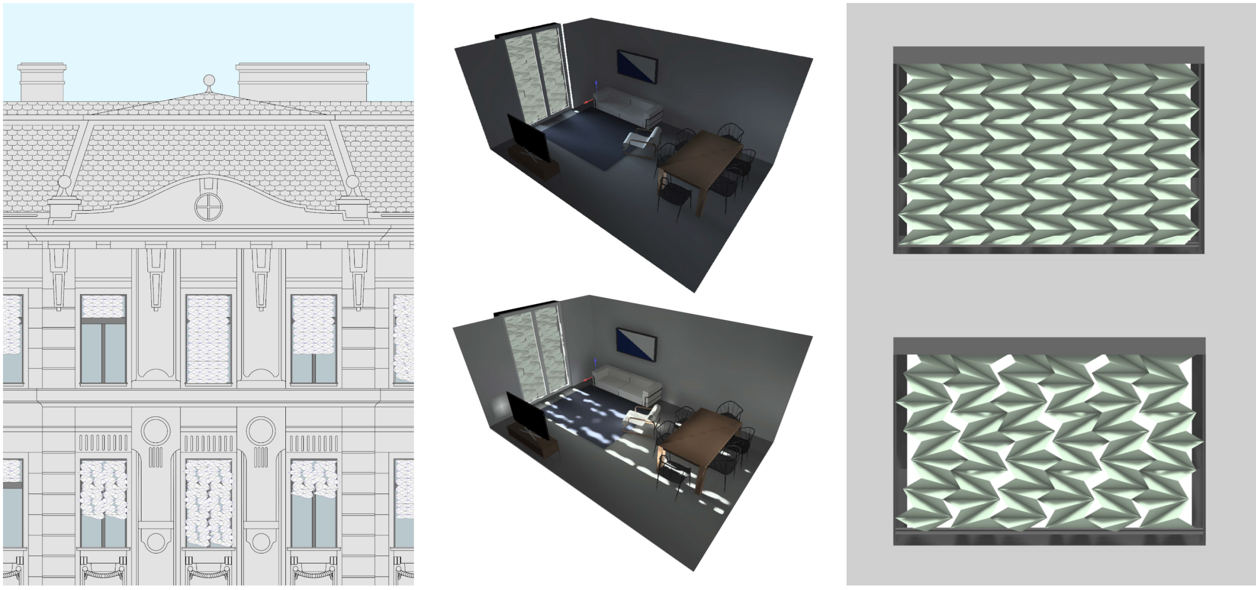

Figure 4. Project 4: Fenster-Krausen: Left: Façade view, middle and right, upper row: Fully closed system, middle and right, lower row: Nature-inspired light / radiation transmission.

and contemporary technology using shading possibilities. Future research shall emphasize the collaboration between the industry and academia to intensify the knowledge exchange and thus allow to realize shading devices close to the presented ones of this contribution.

Acknowledgements

The authors thank the participating students, who participated in the design studio Solar Shelter in Winterterm 2020/2021, namely P.N. Dettmer, A. Iankov, C. Ließ, and G. Yilmaz. Moreover, the authors want to thank the officals and contributors of the Plattform Fenster, who generously funded a student competition that was the basis for this design studio work.

References

[1] Wikipedia. History of climate change science. [2021-06-01]. https://en.wikipedia.org/wiki/History_of_climate_change_science

[2] D. H. Meadows, D. L. Meadows, J. Randers, et al. *The Limits to growth: A report for the Club of Rome's project on the predicament of mankind*. Universe Books, New York, 1972.

[3] World Commission on Environment and Development. *Our common future*. Oxford University Press, Oxford, 1987.

[4] UNFCCC. Kyoto Protocol to the United Nations Framework Convention on Climate Change adopted at COP3 in Kyoto, Japan, on 11 December 1997, 1997.

[5] S. Oberthür, H. Ott. *The Kyoto Protocol: international climate policy for the 21st century*. Springer, Berlin, 1999.

[6] P. M. Morrisette. The evolution of policy responses to stratospheric ozone depletion. *Natural Resources Journal* **29**(3):793–820, 1989.

[7] United States, Environmental Protection Agency. Achievements in stratospheric ozone protection. [2021-06-01]. https://www.epa.gov/sites/default/files/2015-07/documents/achievements_in_stratospheric_ozone_protection.pdf

[8] A. Requardt, J. Poker, M. Köhl, et al. Feasibility study on means of combating forest dieback in the European Union. Tech. rep., 2007. [2021-06-01]. https://ec.europa.eu/environment/forests/pdf/forestdieback_technical_report.pdf

[9] J. Ogg. Heatwave: Implicatons of the 2003 French heat wave for the social care of older people, 2005. Young Founation Working Paper No 2., ISSN 1749-4311 [2021-06-01]. https://youngfoundation.org/wp-content/uploads/2013/04/Heatwave-October-2005.pdf

[10] J.-M. Robine, S. L. K. Cheung, S. Le Roy, et al. Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus Biologies* **331**(2):171–178, 2008. https://doi.org/10.1016/j.crvi.2007.12.001

[11] United Nations. Paris agreement, 2015. [2021-06-01]. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[12] Intergovernmantal Panel on Climate Change. Climate change 2021 – The physical science basis – Summary for policy makers, 2021. [2021-06-01]. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

[13] W. Steffen, J. Rockström, K. Richardson, et al. Trajectories of the earth system in the anthropocene. *Proceedings of the National Academy of Sciences* **115**(33):8252–8259, 2018. https://doi.org/10.1073/pnas.1810141115

[14] K. Kiesel, M. Vuckovic, A. Mahdavi. The extent and implications of the urban heat island phenomenon in Central European region. In A. Mahdavi, B. Martens (eds.), *Proceedings of the 2nd Central European Symposium on Building Physics 9-11 September 2013, Vienna, Austria*, pp. 415–419. 2013. ISBN 978-3-85437-321-6.

[15] C. Cazachs, F. Reinwald, D. Damyanovic, et al. Urban heat islands – strategy plan Vienna. In *Proceedings REAL CORP 2013, 20-23 May 2013, Rome, Italy*. 2013. ISBN 978-3-9503110-5-1. https://www.corp.at/archive/CORP2013_78.pdf

[16] United Nations. Beating the heat: A sustainable cooling handbook for cities, 2021. [2021-10-01]. https://www.unep.org/resources/report/beating-heat-sustainable-cooling-handbook-cities

[17] A. Wurm. *Sommerliche Überwärmung: Ein Vergleich zwischen unterschiedlichen Bauweisen und Nutzerverhalten*. Master's thesis, TU Wien, 2016.

[18] A. Wurm, U. Pont, F. Tahmasebi, A. Mahdavi. Overheating risk in buildings: A case study of the impact of alternative construction solutions and operational regimes. In P. Hájek, J. Tywoniak, A. Lupisek (eds.), *Proceedings of CESB 2016: Central Europe towards sustainable building 2016 – innovations for sustrainable future*, pp. 1325–1332. 2016. ISBN 978-80-271-0248-8.

[19] P. Schober, U. Pont, M. Wölzl, et al. Einfach auf die Seite geschoben – Fensteröffnungen neu gedacht (Top-Thema Bauelemente in Bewegung). *Glaswelt (invited)* **2020**(11):20–23, 2020. [2021-07-01]. https://www.glaswelt.de/top-thema/fensteroeffnungsarten-neu-gedacht-einfach-auf-die-seite-geschoben

[20] B. Sommer, G. Moncayo, U. Pont. Ecological ballet – a design research towards environmental-reactive, adaptive architectural design. In A. Mahdavi, B. Martens, R. Scherer (eds.), *Proceedings of the 10th European Conference on Product and Process Modelling (ECPPM2014), Vienna, Austria, 17-19 September 2014*, pp. 215–220. 2014. ISBN 978-1-138-02710-7.

[21] B. Sommer, U. Pont, G. Moncayo, et al. Recent progress in the EVA Project: Evaluation of Visionary Architectural concepts – State of the art. In *12th Envibuild – Buildings and Environment – From Research to Application*, vol. 887 of *Applied Mechanics and Materials*, pp. 227–236. 2019. https://doi.org/10.4028/www.scientific.net/AMM.887.227

[22] Austrian Standards Institute. ÖNORM B 8110-3 Wärmeschutz im Hochbau – Teil 3: Ermittlung der operativen Temperatur im Sommerfall (Parameter zur Vermeidung sommerlicher Überwärmung), 2012/2020.

[23] Archiphysik. [2021-10-01]. https://www.archiphysik.at/

[24] Wikipedia. Institut du Monde Arabe. [2021-06-01]. https://en.wikipedia.org/wiki/Institut_du_Monde_Arabe

[25] Deutsche Bauzeitung. Transparent timber by WooDoo. [2021-06-01]. https://www.db-bauzeitung.de/produkte/holzbau/transparentes-holz-woodoo/

[26] Wikipedia. Transparent wood composite. [2021-06-01]. https://en.wikipedia.org/wiki/Transparent_wood_composite

[27] Solar Flower-concept. [2021-06-01]. https://www.wiwo.de/technologie/green/faecher-modul-mobile-solarblume-ersetzt-den-stromanschluss-/13876018.html