New approaches towards reductive thermal insulation of Gründerzeit facades via autonomous robots

A review onto the SPIDER project

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Introduction

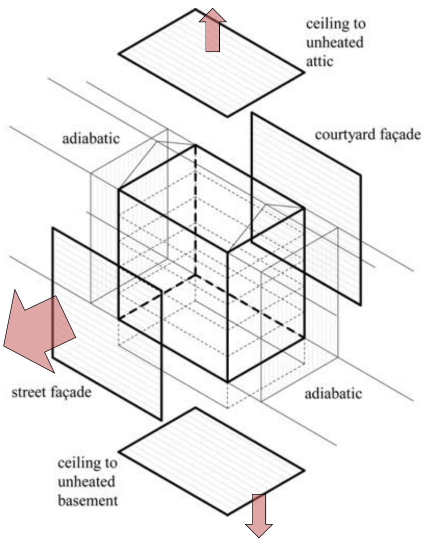
It is common knowledge that the reduction of building-related emissions and energy use require a considerable performance improvement of the existing building stock. However, given the cultural meaningfulness of traditional buildings and their facades in most of the major European Cities, thermal retrofit has to be conducted not only based on energy-related interests, but rather also under consideration of upkeep of aesthetics and history of these buildings. New and innovative technologies for retrofit are required. This is due to the fact that common thermal retrofit is done by adding thermal insulation either on the outer or inner perimeter of the building envelope, which regularly is connected with a set of issues. The former variant is often in conflict with articulated and ornamented historic facades unless specific, in cost-intensive technologies as Aerogel-Plasters are used (compare Schuss et al. 2017). The latter comes with increased condensation risk, which is problematic in both short-term and long-term perspective. Condensation and connected mould growth can be considered as negative for the hygienic conditions in buildings during cold season already in a short-term perspective. On the long-run deterioration of load-bearing trusses can occur, leading eventually to critical devastation of the historic building envelope. Furthermore, the application of insulation panels on the inside can lead to a considerable loss of useable gross area. This contribution reports on a disruptive different approach toward increased thermal insulation of existing building envelopes, which has been explored in an exploratory study conducted from 2019 to 2021. The basic idea of this thermal improvement is based on subtraction of material from existing walls in *Gründerzeit* buildings, which is possible from the perspective of structural engineering without endangering the stability of these walls. Moreover, autonomous robots that use digital technologies and knowledge about the corresponding façades shall conduct the insulation efforts. We shortly explain our approach, the behind-lying concepts from structural engineering and building physics, and illustrate the approach in its principle. It has to be considered by the reader that this is early-stage research, and thus shall not considered as technology to be applied ad hoc from tomorrow onwards. Rather, the contribution wants to present the concept to the audience of the CHNT26.

Background

The city of Vienna, Austria, as a representative city of rich built heritage, is estimated to feature about 351.000 apartments in Gründerzeit buildings, which are in average inhabited by two people. Key performance indicators from these apartments, respectively the buildings the apartments are situated in, include an average heating demand of 150 $kWh.m^{-2}.a^{-1}$ and CO_2-emissions of around 247 g per kWh heating demand. If upscaled, the energy demand of these apartments would be around 5.27 TWh and causal for 1.3 Mt of annual CO_2 emissions. If one takes these numbers for granted and compares these numbers with the annual consumption of Gas in Austria, a significant portion of the gas consumption is related to these residential units (if oil-fired apartments and apartments supplied by alternative energy sources are neglected, this portion is up to 38% of Austria s space-heating-related Gas consumption (Sommer et al. 2021)).

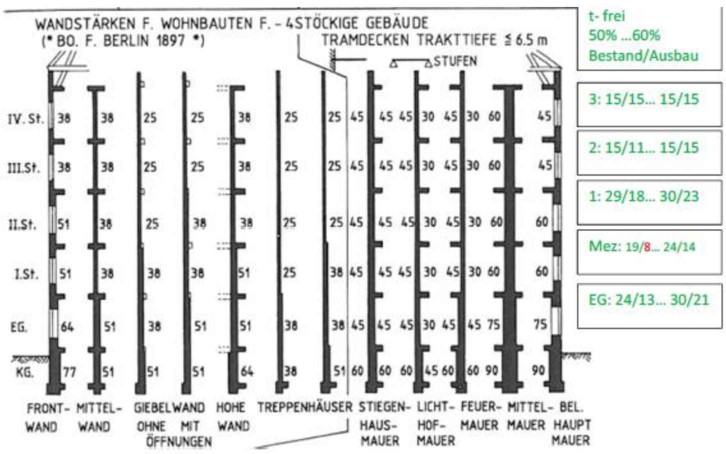
Approach & Aspects of Structural Engineering and Building Physics

In principle, the approach followed up in the research project SPIDER was as follows: Based on the knowledge that the façades to outside air are responsible for the majority of heat losses in *Gründerzeit* buildings (see Figure 1 for a virtual demonstration Gründerzeit building), and thus cause the majority of heating energy demand and emissions, the structural reserve of Gründerzeit walls was considered as to be activated for insulation purposes. Autonomous, façade-climbing robots are foreseen to drill holes in the walls from outside (where this is possible from a building construction point of view). These holes are either filled with insulation material or just sealed from the outside to form air encapsulations. Why is that possible? In the Gründerzeit, the structural stability of walls was predetermined by the building codes, which rather generously over-dimensioned the walls of many buildings, which is in part due to the fact that the same codes had to be used for buildings of different sizes and dimensions. Needless to say, walls in the ground and lower floors were made up of a larger number of brick rows and cross-binding bricks than those of upper floors, given the larger structural load they had to carry. Figure 2 illustrates the demanded wall thickness by historic building codes of Vienna and Berlin. Based on the expertise and knowledge of many previous project around 15% of the wall thickness could be identified as structurally surplus in the case of many Gründerzeit residential buildings. The effect of sealed drillings in the wall results in a better thermal insulation of the wall. However, based on the way the whole is filled and sealed, the effect is ranging from neglectible to enormous. The best setting, based on drill depth, hole diameter and sealing strategy allowed – in simulation and by normative calculation – to lower the U-value of the wall from 1.55 W.m^{-2}.K^{-1} to 0,35 W.m^{-2}.K^{-1}. Figure 3 illustrates a drill roboter as prototyped on the University of Applied Arts in Vienna.



Element	Area x temperature correction factor	percentage
street façade	297,5 x 1,0 297,5	32,3
courtyard façade	297,5 x 1,0 297,5	32,3
topmost ceiling	204,0 x 0,9 183,6	20,0
basement ceiling	204,0 x 0,7 142,8	15,4
total corrected heat loss area	921,4	100,0

Fig 1: a (left): Schematics of the heat loss via ceiling to unheated basement, facades to the exterior and ceiling to unheated basement (Sommer et al. 2021, modified); Figure 1: b (right): area multipled by temperature correction factors for the demonstration building of Fig 1a.: It can clearly be seen that the majority of energy (64.6 %) is lost via the vertical facades to street and courtyard (Sommer 2021).



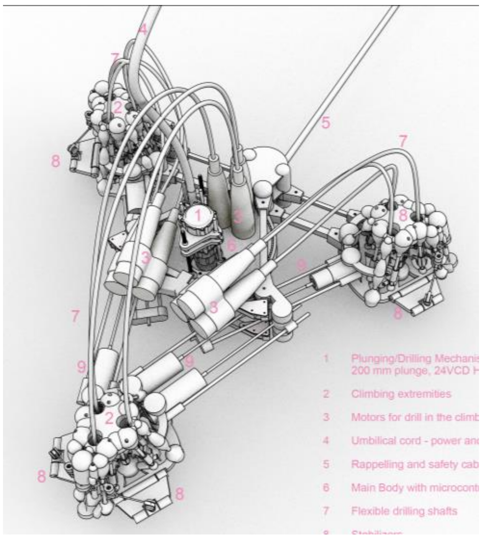


Fig 2 (left): Dimension requirements of buildings in historic building code (Kolbitsch 1989)

Fig 3. Illustration of an autonomous, façade-crawling robot (courtesy of the authors).

Where are we now: Potential, Limitations, and flaws of this approach?

The authors are fully aware that a set of question might be asked instantly by peers from heritage protection and conservation. Such questions might be: *Is there an effect of the drills on to the aesthetical appearance of a richly-decorated façade? How can you think about drilling protected facades?* These are questions that are justified and need to be answered in follow-up efforts. It seems clear that the approach will not work everywhere on a façade, given that we have different sensible parts both from building construction and structural stability, such as the areas below and above windows. Moreover, the material characteristics of specific decorative elements are important to understand if and how drills and seals can be set, without harming the building structure and appearance. As such, methods of building information modelling are required to determine the basis for our robots to work. A digital twin of a façade might allow to algorithmically and manually determine areas, where the proposed subjective insulation methodology can be applied, as well as regions, where it is a no-go. The idea to utilize robots, who are fed with this data and might perform slow- but coninous retrofit work without scaffolding, seems temptind, but of course requires to answer a set of robotic- and mechanical engineeting related aspects such as the identification of fitting drilling instruments, the supply with and material of sealing material (plaster materials? Aerogel?), and the way the robot moves and fixates itself on the façade. However, we believe that certain advantages can be found in the approach, such as precision, reduction of retrofit cost, and performance-driven retrofitting accompanied with building stock sensitive methodologies.

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Conflict of Interests Disclosure

The authors declare no conflict of interest.

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Conceptualization: Sommer, Pont, Bauer
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Funding acquisition: Pont, Sommer
Methodology: all involved
Project Administration: Pont, Sommer, Bauer
Validation: All authors
Visualization: Minovski, Moncaya, Braun, Bauer, Sommer
Writing – original draft: Sommer, Pont,
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