Did we Build Enough? Pleadings based on Statistics and Technologies for the Building Stock

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1 ABSTRACT

This contribution wants to argue for a fundamental transformative change for future development of the built environment in Austria (and generally Central Europe). Thereby, innovative technologies to update and adapt the existing building stock play a fundamental role, to improve comfort and energy performance of existing buildings and built structures. This contribution is based on a talk the author held two years ago about innovative technologies for building stock improvement in view of we built enough as a statement.

When we address the existing building stock, we find buildings and structures that can be considered of high value for European cities appearance. However, an even larger fraction of existing buildings might not be considered as "beautiful" or "identification landmark" for European cities. While the replacement of the sooner would mean an immense loss of identity, the latter might in part be considered as "the ugly child", but still provides a sink of past Greenhouse Gas (GHG) emissions. If we would demolish and replace these buildings by new ones, huge energy consumption and GHG emissions would be the consequence, connected with the demolition, depositing of old materials, and material movements and utilisation of the new buildings, as circularity concepts in the AEC (Architecture – Engineering – Construction) – Domain are not yet well established. Cities are expanding, which can be explained by rising numbers of population, but on the other side also with a increased space consumption of inhabitants. These expanision tendencies on the one hand require extensive overwork of public infrastructure and accelerate sealing of surfaces and loss of natural resources and green-blue infrastrucutres, and on the other hand seem strange, given that we face empty built infrastructures e.g. on groundfloor level in many residential districts.

Toward this end, the present contribution advocates for holistic view of the update possibilities of the building stock, while at the same time critically warns against romantification of the building stock in view of outdated perspectives of the past. Rather, research, technologies and approaches are presented and discussed that have been worked upon in the past 10–15 years and directly address the existing building stock. These efforts all tried to balance out the difficult relation between heritage protection on the one hand, and comfort and energy performance improvements on the other hand.

As such, this contribution tries to utilise the concept of imperial lifestyle as critically brought up by scientistst from environmental political science and maps it on the AEC-domain.

Keywords: Building Stock, Space consumption, technologies for retrofit, pladoyer, vacuum glazing

2 INTRODUCTION

In recent years the role and responsibility of the built environment regarding climate change shifted from being an issue discussed majorly amongst scientists and domain experts to a convolute of topics perceived and discussed in media and the broad public. This might be due to the fact that the effects of climate change cannot any longer be neglected, especially during Summers in the cities. One example for these topics is urban sprawl, which euphemistically often is named Verhüttelung in German (denoting the sprawl of a large number of detaches houses instead of more condensated forms of dwelling), and the associated issue of surface sealing (WWF 2021). Planning sciences for decades have scientifically worked on the topics and reasons for urban sprawling effects. In Austria, the situation is complex, given the relation between the country administration and its federal states that involves different responsibilities, economic interests and policies, leading to a strange culture that not only not hinders urban sprawl, but provides fruitful grounds for this development (Umweltbundesamt 2001, p147, Bröthaler 2020). Parallely, Austrian Cities, especially Vienna, experience population rises after times of stagnation leading to increased demand for urban dwellings, and at the same time – paradoxically – face large real estate vacancies (Kadi et al. 2020, Plank et al. 2022): Up to one fifth of all residential units in Vienna are considered to be vacant/unused. At the same e time, the AEC (Architecture-Engineering-Construction) sector is subjected to tightening regulations stipulated by national and supranational administration bodies. This is due to the key role the built environment plays in approaches to fulfill ambitious, but increasingly unlikely to be achieved emission cuts, as defined by the Paris climate targets (UN 2015) and initiatives such as the as the ‘European Green Deal’ (European Commission 2019). The focus on the built environment seems logical, given the large percentage of climate-damaging emissions that are directly or indirectly related to buildings. This percentage varies in studies due to different geographical or temporal scope. A frequently mentioned statement is that the built environment is responsible for up to 40% of the end energy demand (Weber and Zucker 2022, p18). As a result of the European Building Directives of 2002 and 2010, Austria already has very “harsh” requirements for the thermal-energetic quality of buildings (OIB 2023a, OIB 2023b). While it seems easy to design new buildings to be energy efficient, i.e. with low or almost zero operational energy consumption and climate-damaging (gas) emissions, the existing building stock is often “forgotten” on the one hand, and on the other hand is seen in the literature as the key to energy-saving measures (Weber and Zucker 2022, p3). Buildings should clearly be designed or refurbished in such a way that it is practically possible to minimise the energy required for operation (e.g. to create a high level of thermal comfort for users). comfort for the users) as low as possible in order to minimise as low as possible so that as few or no negative emissions are caused. If the occupants of such buildings behave in a correspondingly “sensible” way, then the low energy consumption might be realizable. However, the everyday experiences illustrate that this is not necessarily the case (see Housez et al. 2014, discussed later in this paper). Moreover, many so-called retrofits conducted in recent years have pursued the goal of preserving (or at least beautifying) existing buildings, but not necessarily improving them thermally/energetically. In 2013, the German Federal Environment Agency assumed that 40 percent of building retrofit did not or barely include any thermal improvements (DENA 2013).

This article aims to highlight innovative technologies and approaches to improving the existing building stock that go into borderline areas where, for various reasons, such as the protection of the ensemble or the preservation of the architectural and aesthetic quality, “conventional” thermal improvements (such as the application of thermal insulation panels) are not possible or not possible without further ado. At the same time, the article aims to show that “all that glitters is not gold”. To this end, the article is structured as follows: Firstly, Section 2, under the heading “Everything used to be better”, looks at building traditions and their role in today’s discourse, as well as the danger of (rather useless) glorification. Section 3 discusses the concept of the existing building stock and the challenges associated with it using a number of examples. Section 4 is dedicated to the concepts of “rebound” and “prebound” as well as the problem of energy performance certificates as a supposedly reliable indicator of building quality. Section 5 looks at which construction measures still appear necessary and sensible despite the ‘build enough’ paradigm. Section 6 focuses on innovative technologies for the refurbishment/optimisation of existing buildings and illustrates this using current research projects as examples. Section 7 discusses the available and necessary instruments and tools that are required to identify sensible measures for existing buildings and to provide evidence. Section 8 takes stock of the previous chapters and attempts to answer the question: ‘Haven't we already built enough?

3 ‘EVERYTHING USED TO BE BETTER’ OR THE DANGER OF ROMANTICISING PAST BUILING STOCK

For centuries, people used to employ locally available materials and constructed residential and other buildings by low energy, majorly manual work. As an example: The arrangement of Mbaru Niang roundhouses from the village of Wae Rebo, Flores, in West Manggarai, Indonesia, shown in Figure 1, demonstrates such a low-energy, high-performance architecture from a long ‘trial and error’ tradition. In the case of this village, which even today can almost only be reached on foot due to its location in a remote high valley/volcano caldera, these houses were built with the material that could be obtained from the surrounding countryside within walking distance with reasonable, machine-free effort. It was used to withstand the local rigours of nature in the form of strong sunshine, storms, or heavy rainfall. These are renewable raw materials (e.g. the draining, quick-drying roof covering made of lontar palm thatch) or materials that were used as found (stone material underneath the uprights) and combined in such a way that they offered the users (comparatively) pleasant living conditions or a comfortable living centre (e.g. storage tanks in the pitched roof, elevated construction to prevent water ingress in the event of heavy rain). Needless to say, these buildings offer pleasant living conditions all year round without heating or cooling, as many other local building traditions offer passivly. The author of this article is always tempted to show this image when someone from the architecture scene comes along with a design for a ‘sustainable’ detached house in Vienna's suburbs and praises it with excessive fervour as ‘sustainable architecture’.

Fig. 1: Traditional Mbaru-Niang-Buildings, Wae Rebo, Flores, West-Manggarai, Indonesia (Image by the Author)

But does this mean that we “only” need to look at and copy architectural traditions in order to create “sustainable buildings” for the present day? Not at all. First of all, the traditional houses in this village have been disappearing over time because the inhabitants of the village built houses next to them in the 20th century using materials such as concrete and corrugated iron, where they “preferred” to live (Some of the depicted buildings have been reconstructed for touristic purposes). This also has something to do with the fact that eight families, usually of three to four people, lived together in each of the buildings, which no longer fits in well with today’s requirements in terms of privacy and cohabitation of the residents. The comfort requirements, both in terms of living habits (e.g. eating at a table instead of on a mat on the floor, sleeping in a bed instead of on a mat) and in terms of building physics parameters (temperature, room acoustics, daylight), have also changed over time and can only be met to a limited extent by the buildings shown in the illustration. Instead, the comfort requirements are – energy-intensively, powered on site primarily by diesel generators – fulfilled in newer homes not shown in the illustration. The traditional buildings have been reconstructed from a cultural-historical point of view, some of them rebuilt from scratch and now serve as a main source of income for the village, tourism – as a tourist, you can stay overnight “traditionally” in the village. The fact that the village’s main source of income used to be a different one, mainly from agriculture through coffee cultivation, is only mentioned here in passing, as is the fact that a 1:1 transfer of this building tradition would not even work within Indonesia, as the habitus of the users, other microclimatic conditions, other available materials and other requirements for the buildings would be different. These traditional buildings, just like traditional buildings from Austria, would not fulfil requirements such as “watertightness” (i.e. “sealed” instead of “draining” roofs) or ‘airtightness’ (no convective heat loss through structures). So what can we take away from this example? Taking inspiration from traditional building forms and principles is certainly advisable. This is important for the reactivation of the existing buildings and with regard to the discourse on Haven’t we already built enough?; romanticising the forms and presenting them as the ideal ideal solution is certainly not expedient. At the same time, however, it should also be questioned whether certain requirements that we place on today’s buildings due to “building preservation” and and “comfort requirements” really make sense. For instance, Central European building regulations demand a high degree of air tightness, but such envelopes are usually perforated by pipes of technical systems for ventilation. Another example is the assumption that all rooms of residential units are heated at all times during Winter. We should thus ask ourselves if such requirements make sense or should rather be seen as results of self-made construction problems and false ideas of comfort?

3 CHALLENGES RELATED TO THE BUILDING STOCK

According to Statistics Austria (2023a) (reference year 2021), the building stock in Austria consists of around 2.4 million buildings, of which around 93 per cent are predominantly used for residential purposes. Figure 2 shows the development of the Austrian building stock over time in terms of the total number of buildings (buildings and buildings with predominantly residential use).

It is striking that the total number of buildings has increased by over 85 per cent within fifty years (1971-2021, Figure 2). In contrast, the population has only increased from 7.5 million to 8.9 million people between 1971 and 2021, which is an increase of 18.7 per cent. In purely mathematical terms, there were 5.85 people per building in 1971; in 2021, there were only 3.75 people per building. This consideration makes comparatively little sense without taking into account the flats or number of residential units per building, but nevertheless shows the trend towards "fewer residential units per residential building". Boom phases of growth were apparently between 1971 and 1981 (+ 23.9 per cent) and between 1981 and 1990 and 1991 and 2001 (14 per cent and 13.1 per cent respectively). So at least the 'growth rate' has fallen somewhat, even though the total number of buildings has risen.

Figure 3 shows the composition of the building stock from different building ages in absolute figures. With regard to the age composition of the buildings, it is striking that between 1971 and 2021 the number of Gründerzeit buildings (built up to 1918) fell by 40 percent, the number of buildings erected between 1919 and 1945 fell by 17 per cent and the number of buildings erected between 1945 and 1960 fell by 15 percent. This contrasts with a large number of buildings erected between 1961 and 1980, which have "only" declined by 5 per cent since 1981. The loss of building fabric, most of which has been replaced by new buildings, has therefore particularly affected the oldest building stock. In a lecture in 2022, civil engineer Andreas Kolbitsch pointed out that, compared to the 13 per cent of buildings from the Gründerzeit period in Austria as a whole, a quarter of Vienna's buildings date from the period up to 1919 (Kolbitsch 2022).

Fig. 2: Absolute number of buildings in Austria 1971 – 2021 (Source: Statistik Austria 2023, illustrated by the author)

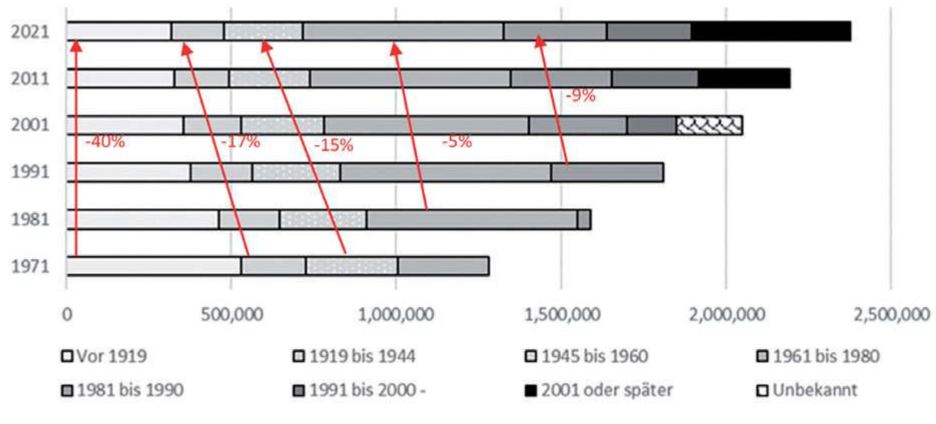

Fig. 3: Age distribution and development of number of buildings in Austria 1971 – 2021 (Statistik Austria 2023, illustrated by the author)

Basically, it should be noted that the "image" of a Central European city is largely constituted by its existing buildings. This applies to cities such as Vienna, Prague, Bratislava, Brno and many others and can be confirmed by looking at cities in Germany that were destroyed and rebuilt during the Second World War: Those cities where efforts were made to "rebuild" the old stock are today perceived as "more attractive" compared to those where reconstruction was carried out purely through new construction. Today, however, the old stock includes not only the Gründerzeit and the interwar period (as evidenced, for example, by the imposing and architecturally valuable buildings of "red Vienna" to this day), but also the post-war period and the "off-the-peg" buildings of the period between 1945 and 1980. The fact that the question of the value of even relatively "new" architectural icons often depends on the urban planning and utilisation-specific context can be seen when studying the work of some former professors of the TU Wien, Vienna, who held chairs in high-tech architecture, construction and installation (Seidel and Steixner 2020).

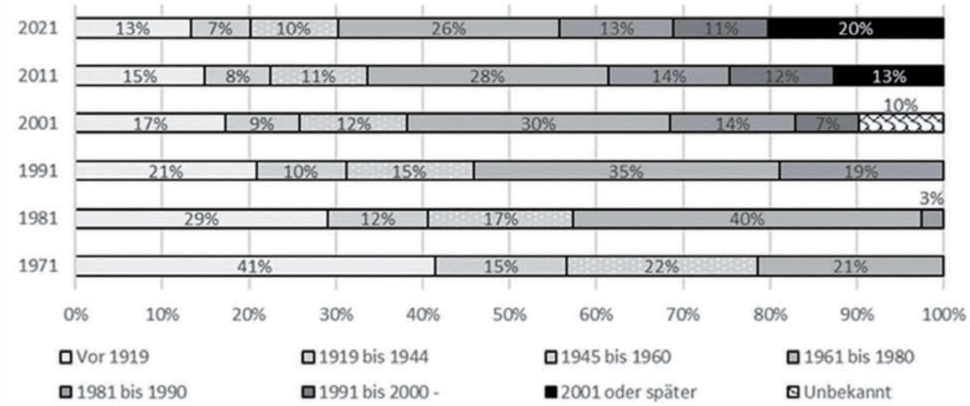

Fig. 4: Relative distribution of different building ages in Austria between 1971 and 2021 (Statistik Austria 2023, illustrated by the author)

The construction of the so-called Juridicum by Ernst Hiesmayr is still considered a milestone among the university buildings that belong to the University of Vienna, even though a Gründerzeit inner-city block was demolished on its site. Hiesmayr's successor at the TU Wien, Helmut Richter, is internationally recognised for the school on Kinkplatz (14th district of Vienna) and for the residential complex on Brunner Straße (23rd district of Vienna). While Brunner Straße is a popular residential building for residents despite a number of adaptations and its difficult location (the building is situated in industrial surroundings along a busy road), the glass and steel icon of the Kinkplatz Computer Science Secondary School, built in the 1990s, is today affected by disuse and slow decay despite its significance for recent Austrian architectural history and was long threatened with potential demolition (the school has since been listed as a historical monument). As far as existing buildings are concerned, one has to accept the idea that a black-and-white approach is not expedient. Looking at social housing from the post-war period up to the 1960s, one will find supposedly low-quality off-the-shelf buildings that are hardly considered adequate in terms of current thermal or acoustic requirements. Nevertheless, a huge proportion of residential units in Vienna is made up of/situated in these buildings. Buildings from the Gründerzeit of 1850–1918 (and even older buildings), which have been set under special protection recently due to certain incidents (deliberate decay to enable demolition), certainly have qualities that should not be underestimated; however, if they are not cared for and fall into disrepair, every building will eventually "come to an end". If this is accepted wilfully by the building owners in order to achieve technical readiness for demolition, the idea that can be found behind is very often that a new building could possibly generate more profit through lower storey heights (which just meet the minimum requirements of the building regulations). From a building ecology perspective, it should be noted that a building that stands for 100 or 150 years represents a certain degree of sustainability, despite possibly poorer thermal-energetic parameters. Bricks that form the construction material of such buildings have a lifecycle that outnumbers the predicted lifespan of today's new buildings by a factor 4 to 5. Replacing the (historic) building stock with new buildings is neither advisable nor expedient; numerous studies and theses have shown that the ecological footprint of existing buildings is significantly lower than that of new buildings over a long service life (Padayhag et al. 2016, Schmidt 2020). Furthermore, the loss of the architectural value cannot be quantified. The endeavour to replace the existing building stock with new buildings would take up to a century at today's new construction rates and would leave an enormous ecological footprint as well as a cultural black hole.

Challenges that the (historical) building stock must cope with today include, in addition to the usual maintenance work that every structure requires, aspects of adaptation to climate change. Urban heat islands in inner-city areas, which often lack sufficient green-blue infrastructure, pose a challenge to users. The fact that there are often no simple solutions available in densely built-up urban areas will be addressed later in this article.

4 (P)REBOUND, ENERGY CERTIFICATES OR "DO YOU GET WHAT YOU DEMAND?"

This section describes two research efforts that deal with the Key Performance Indicators (KPIs) often used to evaluate buildings. However, before that, two terms will be introduced that occur in the context of such energy metrics in the building sector, as well as generally in the "measurement" of any kind of "performance"'

4.1 Rebound Effect

The term rebound or rebound effect refers to the phenomenon where a specific target (e.g., the potential savings from efficiency improvements in construction) is not or not fully achieved – despite careful attempts. An example of this would be that a building is thermally and energetically upgraded through construction measures, but the energy savings are negated by changed user behavior – such as prolonged showering, the use of additional energy-consuming appliances, or excessive ventilation in winter, etc. It is important to consider the systemic perspective here: a rebound effect could also occur if the saved heating costs are then invested in a vacation trip by airplane, which may cause even higher greenhouse gas emissions.

4.2 Prebound Effect

In contrast to the rebound effect, there is the prebound effect: a 'worse' performance is expected than what actually occurs. An example of this would be heating demand calculations (HWB calculations) for historic buildings that determine much higher heating demands than what is actually evidenced by energy bills. Reasons for this could include differing user behavior, such as heating only one or two living spaces instead of the entire apartment, or overly simplified assumptions regarding the thermal envelope quality of buildings, where default values are used in the HWB calculation instead of real constructions (Sunikka-Blank and Galvin 2020).

4.3 Is it all done with the renovation?

Housez et al. (2014) analyzed the renovations of seven existing residential buildings, mostly apartment buildings for older adults with multiple units. In this study, the actual energy performance before and after the renovation was assessed using data from bills and compared with calculations and simulations of the status quo as well as the planned renovations. The buildings were constructed between 1968 and 1985 and were renovated between 2005 and 2009. The planned target values for the specific heating demand after the renovations, which were designed for high energy efficiency, ranged according to the standards for energy certificate calculations at that time from 6.7 to 17 kilowatt-hours per square meter of gross floor area per year (abbreviated: $kWh.^{m-2.a-1}$). These values were and are extraordinarily low energy metrics for residential buildings. The actual specific heating demand (determined from energy bills) was only close to the planned value for one building; for the others, the determined values ranged between 40 and 55 $kWh.m^{-2}.a^{-1}$, meaning in some cases four to five times higher than the anticipated energy performance. Subsequently, parametric estimates were conducted to find out how the deviation occurred: higher indoor temperatures and differing real weather data were quickly ruled out as strong influencing parameters, as the available measurements of indoor temperatures and weather records showed that there were no significant deviations. In terms of adjusting ventilation behavior, it became evident that increased air exchange through more extensive ventilation (e.g., consistently "tilting" windows) served as a very good explanation. Interestingly, in the building where the anticipated and actual performance largely matched, the users directly paid the energy cost bills, while in the other properties, the energy costs were proportionally allocated to the units based on their floor area, meaning that the users could not recognize whether their behavior was causing the "worse" energy performance.

4.4 Building Energy certificates – the solution or the box of Pandora?

In another research effort, the practical creation of energy certificates was examined. Although there are a number of laws (EAVG 2012), guidelines from various institutions (guidelines from the Austrian Institute of Construction Technology, Ö-Normen from Austrian Standards International), and supporting documents for this purpose, there remains a significant interpretive degree of freedon regarding how to handle existing buildings. Since the issuance of energy certificates is not particularly well compensated and there are no clear training requirements for issuers, the lack of accuracy in energy certificates is likely to be quite high. As part of a research project (see Sommer and Pont 2017, Pont et al. 2016), it was shown that there are significant differences in the results of energy certificates. Two groups of previously identically trained issuer groups each calculated the energy certificates for buildings. The differences in the results were sometimes enormous – at times, the difference in heating demand results was 100 $kWh.^{m-2.a-1}$ (!). Upon closer examination of the calculations from the two groups of issuers, differences in the assumed calculation data were identified: While both groups similarly determined gross floor areas and gross volumes, as well as area calculations and glazing ratios, there were striking differences in the assumed U-values (thermal transmittance coefficients) of the building components. Apparently, components that were not accurately described in the existing building documentation were approximated using default values according to the OIB guideline 6. Unfortunately, there is a significant interpretive degree of freedom for these default values, which means that the described deviations could arise “to the best of the issuers’ knowledge and belief.” It should also be noted that the energy certificate would certainly be an excellent idea for comparing different buildings if the aforementioned problems did not occur. However, it is fundamentally advisable to refrain from assuming that the energy certificate accurately reflects the actual behavior of occupants (e.g., regarding heating, internal gains from the presence of people, operating devices, artificial lighting, or ventilation behavior). In another project, it was investigated (Pont et al. 2019) how the energy certificate procedure can be used in evaluating large real estate portfolios and making decisions with limited budgetary scope to find the 'best' renovation option that can achieve maximum savings effects. What has been described should be kept in mind when conducting the thermo-energetic assessment of the building stock. In short: just because a certain energy key performance indicator (KPI) is assumed for an existing building through a calculation, it does not necessarily reflect reality. Besides the fact that the calculation or simulation is based on sometimes rough assumptions (especially regarding user behavior), the manner in which the calculations or simulations are conducted is also significant, as it is subject to a variety of uncertainties.

5 WHAT WOULD WE BUILD ANYWAY?

Until now, this article has primarily dealt with aspects of proof for buildings, innovative retrofitting technologies, and similar topics. This leads directly to the question: “Should nothing more be built anew?” This can be answered relatively simply, but it unfolds into a series of partial answers. First: It will definitely be necessary to create additional (or altered) residential spaces as the population grows, but this should only be accompanied by measures that make better use of existing structures or sensibly expand them. In a project aimed at reorganizing living space, it was shown that – no matter how absurd a reorganization may sound at first – a win-win situation for residents and energy performance could be achieved with the same or improved living comfort in the existing building stock through organizational and (small-scale) structural modifications in the (historic) building stock (Mahdavi et al. 2012). Of course, legal and ownership-related aspects are significant hurdles here, but the project demonstrates the vast potential of this approach. The idea of sufficiency, meaning a limitation of, for example, living space per person, also comes to mind. Improved utilization of the 'still' available urban area is another aspect that is conceivable in the context of 'new' building. Assuming that many building regulations today have developed prescriptively from a long cascade of evolutionary steps, it is unlikely that the existing “negative space” that still exists will actually be efficiently utilized through core densification. In the course of another project (Pirstinger et al. 2017), it was investigated which core densification potentials could be unlocked with which methods.

A major theme for new buildings will be measures for climate change adaptation. Historical, urban areas with their very limited offerings of green-blue infrastructure and conditionally available root space for trees could benefit from 'artificial' structures for shading and cooling.

As part of a recently completed research project, the essential aspects of artificial tree structures (dubbed Smart & Urban Trees) were examined for urban cooling purposes. It is important to note that such structures do not compete with trees and plantings but are intended to complement areas where natural plantings cannot be implemented or are difficult to implement for technical or organizational reasons. Figure 5 shows result visualizations from this project. The corresponding structures were also examined for their shading effects and cooling potentials through numerical simulations and were confirmed in their effectiveness. The multitude of legal, organizational, technical, and socio-economic questions associated with such structures indicates that new construction in the future may need to be conceived in a much more holistic and integrative manner than is currently the case.

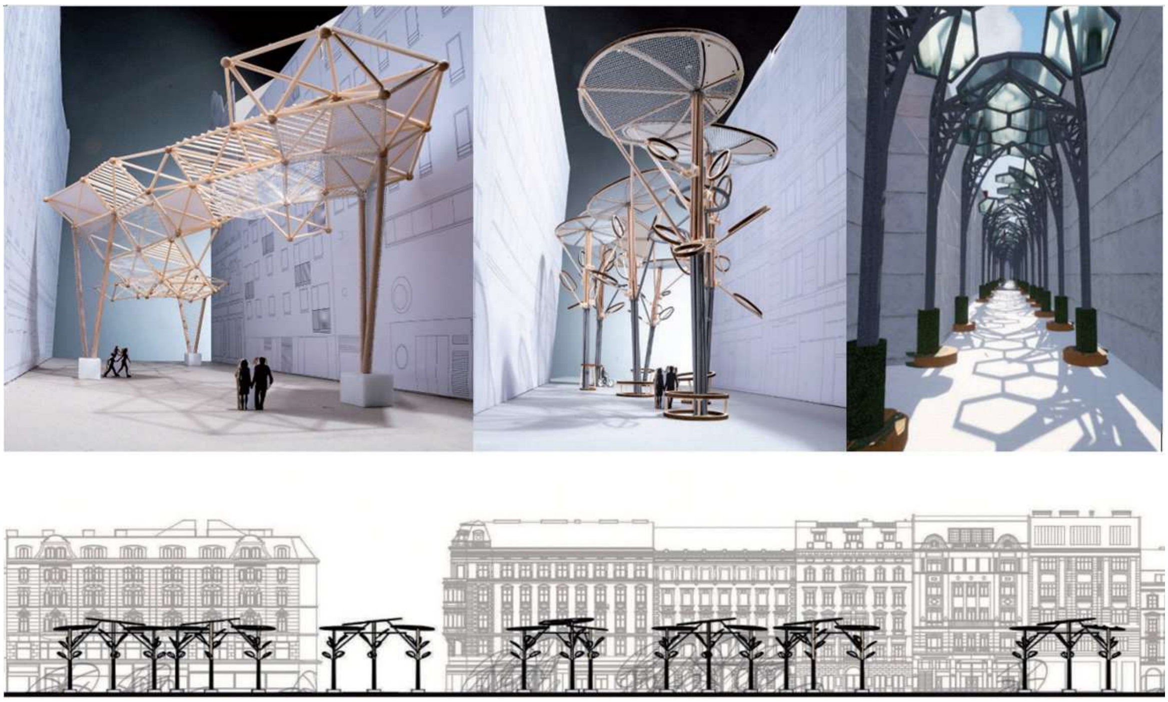

Fig. 5: Visualisations of artificial tree structures for urban cooling (Pont et al. 2025)

6 INNOVATIVE TECHNOLOGIES FOR IMPROVING THE THERMO-ENERGETIC PERFORMANCE OF THE BUILDING STOCK

It has already been suggested that the city, as the largest manifestation of building stock, may also require new organizational approaches for densification and expansion. Therefore, the following will address a whole range of research and development efforts on the topic of 'innovation in optimizing existing structures. When asked how to energetically upgrade existing buildings, the standard response is always “insulation”. What is typically meant by this is the additive (external) application of insulating materials. While this may seem feasible for the unadorned facades of post-war buildings – though even here, a sometimes questionable cultural impact is often hard to deny – this solution often appears not readily applicable to richly decorated cultural heritage buildings. As an alternative, aside from no intervention, internal insulation is mentioned. However, from the perspective of the Central European winter climate, this poses problems: the temperature drop is shifted to the interior side of the load-bearing components, making condensation and mold formation likely, which must be avoided, for example, through diffusion-tight membrane materials or capillary-active insulating materials. The interior ceilings that connect to the load-bearing exterior walls become thermal bridges, and the altered temperature characteristics in this detail area can lead to the rotting of wooden beam ceilings, resulting in a shortened lifespan of the structures and potentially leading to collapse. The significant reduction of interior spaces due to corresponding insulation thicknesses should also be noted as an economic and living space issue.

6.1 Thermal insulation made with Aerogel Plasters and Subtracive Insulating

For the innovative external insulation of culturally significant buildings, plaster systems with insulating characteristics are suitable, provided that the exterior plaster does not represent the preservable cultural asset. In a research project (AGelFa), the insulation potential of the still relatively expensive aerogel plasters was demonstrated (Proskurnina et al. 2015). Aerogels are solid, highly porous gel structures (with up to 97 percent air pore content) that are highly insulating even at low thicknesses. Not only was the benign nature and durability of the material for top plaster systems explored through extensive monitoring, but it was also shown that for average Gründerzeit facades, with an appropriate offset of the facade structure and plaster system thickness, and with accompanying measures on other components (e.g., window upgrades, avoidance of thermal bridges in ceiling connection areas), savings of up to 70 percent in heating energy demand can be achieved. This makes Gründerzeit buildings 'competitive' in terms of heating energy demand (cf. Proskurnina et al. 2015). Figure 6 shows a test area for aerogel plasters as produced and observed in this project.

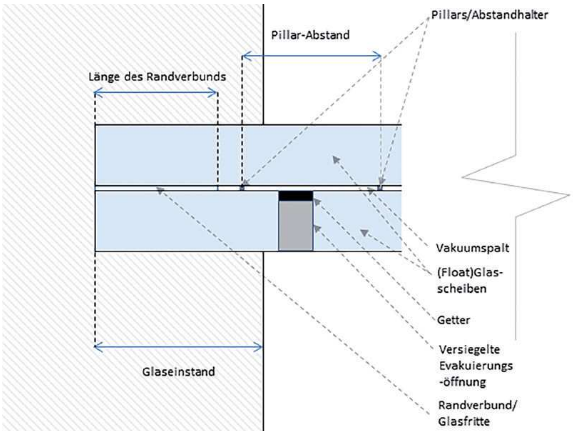

Fig. 6: Aerogel-plaster test surfaces (Image by the Author), fig. 7: Schematic Constituents of vacuum glazing products (Image by the Author)

Another approach regarding the "insulation" of opaque parts of existing facades was recently explored in a preliminary project: The idea here is to insulate "subtractively", meaning to thermally improve the static reserve of Gründerzeit walls by introducing suitable drill holes (and corresponding "caps") with insulating, standing air inclusions. The U-values of Gründerzeit walls could be improved by up to twelve percent concerning the thermal transmittance coefficient (U-Value). In combination with other concepts, such as phase change materials (PCM), the characteristics of heat transfer, especially during cold winter nights, could be positively manipulated. Moreover, an interesting approach to renovation is that it should not be carried out as usual by construction workers on scaffolding, but rather that autonomous robots should gradually upgrade the facade whenever resources (energy, money, time) are available. Future music? It is certainly true that such highly innovative concepts must reach a level of maturity and face challenges (robot technology, appropriate modeling of the facade to clarify where "drilling" is allowed, suitable drill heads/drilling techniques). However, it has become evident, especially in recent years, that such ideas are no longer mere science fiction with the advent of digitalization (Sommer et al. 2021).

6.2 Historic casement windows and their retrofit via innovative glazing products

Buildings are not only made up of opaque components but also of transparent elements like windows. Windows are still considered a weak point in building envelopes, through which a significant amount of heat is lost during the cold season. The existing building stock is often characterized by very elegant window constructions, which, however, do not necessarily meet the current standards for thermal insulation. Unfortunately, the unsustainable practice of "window replacement" has become the primary form of renovation for windows. In this way, and under the false argument of an alleged lack of alternatives regarding improved thermal building performance, thousands of box window constructions are unnecessarily lost each year, and the appearance of the valuable building stock is often negatively altered.

The old casement window constructions represent fundamentally well-thought-out and high-quality window designs that utilize an air cushion between the inner and outer sashes for thermal insulation. However, due to leaks and the high thermal conductivity of float glass compared to multi-pane insulating glass, the thermal insulation effect is often limited. While adjusting the windows and fittings, adding seals, and maintaining the windows can generally counteract leaks and drafts, the heat losses through float glass are difficult to modify. Heavy double or triple glazing with several millimeters of gas inclusions is not feasible as a glass alternative due to the delicacy of box window constructions (often very thin wooden strips as muntins and delicate beams for the window frame). Since box windows also represent an excellent construction from a circular economy perspective (easy separability of materials, durability), a glass alternative would be a great opportunity to make box windows 'fit' for the present time. In fact, there have been durable vacuum glass products for about ten years that meet the requirements regarding glass thickness and weight (vacuum glasses are available from about five millimeters of glass thickness) for box windows. Vacuum glasses are highly insulating due to the thin, less than one millimeter thick vacuum gap, which largely eliminates the heat transport mechanisms of conduction and convection (see Figure 7).

The author has been leading several research and development projects in recent years that focus on the use of vacuum glass in new and existing window constructions. Due to the characteristics of vacuum glass, which have a significant "thermal bridge" at the edge connection of the glass, it was necessary to pull out all the stops regarding the evaluation of the performance of box windows reinforced with vacuum glass: Not only through simulations and laboratory tests, but also through monitoring under real conditions in buildings, it could be demonstrated that box windows reinforced with vacuum glass do not show any tendency for condensation or mold even under harsh winter conditions. In six heritage-related objects, box windows with vacuum glass were implemented for demonstration purposes and subjected to intensive performance monitoring for over a year using high-end measurement equipment. In each of the objects, a control window in its original state was monitored alongside two reinforced windows that were sensorily observed. For the reinforced windows, one window had its outer layer of float glass replaced with vacuum glass, while the same was done for the inner layer.

Ultimately, it was demonstrated that box windows, when carefully planned for structural renovation (in addition to glass replacement, also correct adjustment of fittings and, if necessary, adding seals in the rebate), can achieve a significant performance improvement compared to the original. The use of vacuum glass can be planned so that the windows do not show any signs of condensation or ice formation. If the vacuum glass is used for the inner sash, the energy performance of the renovated window is better; if the vacuum glass is installed in the outer sash, a slightly poorer thermal insulation property results in a warmer space between the panes (thus protecting against condensation formation). With such a minimally invasive renovation option (sash replacement, adjusting the window and fittings, adding a sealing layer), a 10 percent reduction in heating energy demand was found in Gründerzeit houses without large construction sites. The window U-value for box windows reinforced with vacuum glass could be reduced from 2.5 $W{\bullet}m^{-2}K^{-1}$ to below 1.0 $W{\bullet}m^{-2}K^{-1}$ (Pont et al. 2016).

7 WHAT INSTRUMENTS DO WE NEED FOR IMPROVING THE BUILDING STOCK?

This article described concepts and showcased exemplary projects that either address the meaningful enhancement of built space for additional effects (e.g., mitigating summer overheating) or focus on the innovative improvement of existing structures with minimally invasive measures. It should be noted that these projects – although often with a built 'demonstration character' – have largely utilized digital tools: For example, numerical thermal bridge simulations were employed for the development of vacuum glass box windows, as well as light and temperature simulations. The use of such technologies plays a key role in the success of evaluations of the potential of ideas, especially given the impossibility of experimentally testing a multitude of variants. Verification and validation of results through monitoring, as in the case of box windows, is also of utmost importance.

In fact, the digital tools available today do not represent the "ceiling" for supporting planners, end users, or decision-makers. A decision support system for renovations was developed ten years ago, aimed at making the overwhelming amount of information for stakeholders involved in renovation processes more "manageable" through "multi-objective optimization" and semantic web technologies (Heurix et al. 2013). The enormous amounts of information needed for building renovations (e.g., building material/product data, subsidies, legislative information, zoning regulations, etc.) often have to be painstakingly compiled manually. This overload often leads to the seemingly 'simplest' but not necessarily "most sensible" path being taken. This problem resulted in the tool SEMERGY (2023), which can still be used today for planning building renovations while considering the parameters of energy performance, ecological footprint, and costs, evaluating several hundred thousand variants regarding optimal performance in typical renovation projects (cf. Pont 2014). In times of artificial intelligence, robotics, and other disruptive technologies, such tools will likely be expanded and utilized even better for the purposes of optimizing existing structures, provided there is the political will to focus on much more efficient and sufficient optimization of existing buildings.

8 CONCLUSIONS

This article presented different approaches to optimizing the existing building stock. They highlighted various points: (a) A holistic approach is required for the optimization of existing buildings, with the involvement of as many relevant stakeholders as possible. It is of no use, for example, if the renovation of windows through minimally invasive measures is only scientifically proven to be sensible. The industry (small and medium-sized carpentry businesses and guilds) as well as the administration (moving away from funding regimes that only support window replacement as a sole measure) must be involved here – just as civil society must be willing to participate. (b) The existing building stock is somewhat like an 'undiscovered' land: In fact, we still do not know many details about the existing building stock today, particularly concerning thermal building envelope qualities, etc. Further research, development, demonstration, and communication are required. What we do know suggests that the existing stock can do much more than is often acknowledged. (c) The existing building stock must be recognized as a valuable asset that needs to be maintained and improved. The cultural significance of the existing stock already constitutes a large part of the identity, image, and quality of life in many cities. At the same time, we must move away from romanticizing it. Just as in the area of new construction, there are areas where the existing stock has weaknesses: It is necessary to find technologies and approaches that allow for optimization. There is also a building stock that may not be as “presentable” as the historic city centers from the Gründerzeit. Improvements can address the aesthetic and technical problems that may exist there. (d) While a respectful approach to the (historical) existing building stock is a conditio sine qua non, one should remain open to new technologies and methods for its improvement. In times of digitization, 'assemble to order' custom manufacturing, and high-tech materials, addressing the existing stock can not only help rapidly reduce energy consumption and emissions but can also be used to bring the somewhat outdated construction industry into the present and compensate for economic losses due to reduced new construction activity.

No matter how you look at it: Yes, we have already built enough, even in a growing world, and yes, it is necessary, in the spirit of Karl Polanyi (1944), to initiate a 'Great Transformation': The existing building stock can play a key role in this.

9 DISCLAIMER AND ACKNOWLEDGEMENTS

This article is based on a recently published contribution to a book in German language (Pont 2024) that is the written and extented form of a presentation held in 2022. The research presented in this article is always a co-production with colleagues from the fields of building physics and building ecology at TU Wien, as well as from partner institutions in academia and industry. Notable contributors include Magdalena Wölzl and Matthias Schuss from TU, Peter Schober and his team from Holzforschung Austria, Bernhard Sommer and his team from the University of Applied Arts, as well as numerous companies that have particularly collaborated on projects directly related to structural elements. Without the generous support of the Austrian Research Promotion Agency, the projects on which this article is based could not have been carried out.

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