In the matter of simulation and buildings: some critical reflections

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ABSTRACT

Is there firm evidence suggesting that the deployment of building performance simulation in the design process has actually a significant impact on buildings’ subsequent long-term environmentally relevant performance? More importantly, do we have conclusive evidence for the frequently stated environmental mitigation potential of the building sector, given a number of essential global boundary conditions, including, for instance, population and urbanization growth? The pursuit of these questions could contribute to a more realistic appraisal of the environmentally relevant potential and limitations of both performance simulation deployment and sustainable building practices.

What’s the matter?

In various gatherings of building design, assessment, construction, and operation professionals, certain assertions are made on a regular basis. A typical sequence of such assertions unfolds as follows:

The ramifications of environmentally relevant developments and phenomena (energy and resource depletion, climate change) for people and the planet are likely to be disastrous and irreversible (IPPC 2019). Buildings have a considerable role in causing and hence also in effectively countering such developments (EPA 2009). Building performance simulation represents an essential instrument for mitigating buildings’ environmentally relevant impact (Beausoleil-Morrison 2016).

Such assertions are often taken at face value and rarely examined in detail. Rather, they are frequently followed by presentations of some specific instances of ‘green’ or ‘sustainable’ building design and operation such as integration of renewable energy harvesting equipment, smart controls, and simulation-supported design optimization.

The present contribution does not dispute the first assertion above, but intends to have a closer look at the second and the third. Building simulation can be plausibly argued to improve certain qualities of building designs, but is there empirical evidence suggesting that it actually has a unique and significant impact on buildings’ long-term environmentally relevant performance?

More importantly, what evidence do we have for the frequently postulated key role of the building sector toward effective and timely mitigation of environmental challenges such as climate change? Specifically, what exactly is the mitigation potential of the building sector, given a number of relevant local and global boundary conditions pertaining to, for instance, population and urbanization growth?

The main objective of this contribution is to encourage a more informed, responsible, and realistic discussion of the environmentally relevant potential and limitations of both performance simulation deployment and ‘sustainable’ buildings in the broader context of relevant boundary conditions. As such, the contribution raises a number of critical questions and offers a number of observations. However, cognizant of the subject’s formidable complexity, it does not claim to provide ultimate answers and final proofs. In fact, the contribution does not follow the methods and structure of a typical research study. Nor is it organized in terms of a classical paper in a technical proceeding.

Nonetheless, to pursue the problem in an organized manner, the treatment follows two high-level – and somewhat broadly formulated – null-hypotheses. There are to be rejected, before we give credence to the aforementioned frequently stated assertions regarding the effectivity of buildings and simulation:

H0,1 There is no conclusive evidence suggesting that the application of building performance simulation in the design process significantly improves the subsequent long-term energy and environmental performance of buildings.

H0,2 Given buildings’ relative standing within the multitude of drivers for anthropogenic environmental impact (including population and urbanization growth as well as life style considerations), efforts to improve their design and operation do not necessarily represent a decisive mitigation strategy for global environmental calamities such as climate change.

The next two sections of this contribution (labelled ‘Does simulation matter?’ and ‘Do buildings matter?’) address these two hypotheses and consider the case for their rejection. The contribution’s final section (‘Does it matter?’) entails a summary of the arguments and concluding thoughts on the subject.
**Does simulation matter?**

Let us now consider $H_{0,1}$ above. It may initially appear odd to even assume that such a null-hypothesis could be rejected. After all, there is something circular about the simulation effectiveness argument. In other words, if simulation models – as it is commonly assumed – can capture buildings’ behaviour, and if they are expertly applied, then it trivially follows that they can be used to:

(a) unambiguously identify the best performing variant in a set of building design (or operation) options and
(b) reliably predict future performance of buildings.

Yet the matter is not as straightforward, as highlighted, for instance, by the two ‘if’ occurrences in the above statement.

There is extensive body of literature dealing with various takes on the multi-aspect and complex nature of the simulation methods’ development and deployment processes (Hensen and Lamberts 2011; De Wilde 2018; Mahdavi 2011, 2003). What follows, is a terse treatment of this complexity in as much as it is relevant to contribution’s arguments:

- **Simulation algorithms** (mathematical representations of physical processes) and derivative code implementations may be erroneous. Computational solutions may be oversimplified, or opaque (involving hidden assumptions, shortcuts, coefficients, etc.). They may require input data and model parameter that are unavailable in many practical application scenarios. They may be only partially applicable (i.e. for specific purposes or specific levels of model abstraction and resolution). They might have not gone through a proper validation process (Mahdavi and Tahmasebi 2017).

- **The effectiveness of simulation deployment** may be reduced due to a lack of integration in the overall design support media. Building performance simulation applications may come with subpar, cumbersome, or confusing interfaces. Integration problems and poor interfaces may thus not only hamper the generation of complete and error-free models, but also the transparent and purposive viewing and representation of the results.

- **In actual workflow situations, users’ background and level of expertise** may be insufficient. Users might not be in a position to generate and test hi-fidelity and complex simulation models. They may be also unable to properly interpret simulation results, making thus false inferences and misguided decisions.

- **Assumptions pertaining to the input variables of simulation models** are prone to all kinds of uncertainties. Uncertainties apply not only to building geometry, fabric, construction, and systems, but also to external and internal boundary conditions. These include microclimatic and contextual variables as well as assumptions regarding patterns of user presence and behaviour in buildings. Specially the latter two categories (weather conditions and user-related processes and events) represent serious challenges for the efforts to increase the reliability of predictions concerning buildings’ long-term energy and environmental performance.

In the light of these largely non-trivial challenges and uncertainties, it may not be unreasonable to demand that empirical evidence should corroborate claims with regard to simulation effectiveness. But how is such evidence to be provided? The review of the pertinent literature reveals mostly plausibility arguments, anecdotal evidence, and specific case studies. However, such material typically does not arise to the level of what would earn the label of empirical evidence. But then again, what standard of evidence do we expect before we grant that the effectiveness doubts contained in hypothesis ($H_{0,1}$) are conclusively rejected? Do we really expect some kind of random controlled test? And what would such a test look like?

In order to conduct a random test in the present context, a large enough sample of buildings would be required, representing different types, scales, and locations. We would then need to randomly divide this sample into an experimental group, to be subjected to the postulated cause (use of simulation in the design process) and a control group (which has not benefited from simulation deployment). We would then need to monitor the post-commissioning performance of these two groups over a sufficiently long period of time. Subsequently, the values of the respective performance indicators of the two groups would have to be made comparable (e.g. via normalization). Finally, a detailed statistical analysis would have to be performed to provide solid evidence for the existence of a discernible (statistically significant) difference.

A moment of reflection discloses the highly difficult obstacles toward conducting such an experiment. A somewhat more feasible research design could perhaps pursue a retrospective causal study. In that case, the assumption would be that the experimental group has been already subjected to the suspected cause (i.e. performance simulation deployment in the design phase), but not the control group. Aside from practical challenges associated with obtaining sufficient information for such a study, we would have to also deal with the problem of other causal effects. This problem could be perhaps alleviated somewhat through some systematic backward matching; however, the results would still remain rather tentative. But suppose we are able to meet all of these challenges and can confirm that an ideal simulation deployment scenario would increase the likelihood that the target building would perform better in the long run. Even so, we still have not established that a similar level of improvement could not have been achieved via other means. Such means could include, on the side of the planners, heuristic knowledge, practical experience, technically refined common sense. Moreover, the planner could also benefit from sound prescriptive standards and design guides. Especially when dealing with the aggregate energy and environmental performance of larger populations of buildings (for example, at the urban level), the potential of appropriate and well-conceived design guidelines and prescriptive codes cannot be simply dismissed (Markovic, Pont, and Mahdavi 2019; Pessenlehner and Mahdavi 2003). Granted, such codes and guidelines themselves could be based not only on empirical observations and physical testing, but also on extensive sets of prior-parametric simulations. However, this indirect utility of simulation is clearly not at the heart of the contention in $H_{0,1}$.

Note that these observations are by no means meant to undervalue the utility of building performance simulation as
such. As already implied, it is quite reasonable to assume that systemically developed, carefully tested, and judiciously deployed simulation tools can effectively support the building design and operation processes. Nevertheless, such effectiveness is probably easier to demonstrate in the case of application with well-defined temporal, contextual, and operational boundary conditions. Well-known instances of highly useful simulation models pertain to domains such as thermal bridge analysis, lighting systems design, and room acoustics optimization (Mahdavi and Dervishi 2009; Engedy, Lechleitner, and Mahdavi 2019). Interestingly, in these instances – and in numerous comparable cases – simulation studies have often a snapshot character, meaning they focus on analysing the artefact at a specific temporal instance rather than providing long-term forecasts of artefacts’ behaviour under dynamically changing internal and external boundary conditions.

The above assertion is not necessarily contradicted by the successful incorporation of simulation engines in dynamic settings such as model-predictive building systems control (Sterl, Schuss, and Mahdavi 2016; Mahdavi 2008). In applications to building operation scenarios, predictions are commonly made for relatively short time horizons (typically matching the reliable time horizons as pertinent to weather predictions), not to derive long-term building performance indicators. Moreover, in such cases models’ predictive capacity can be enhanced using system feedback. In other words, models can be regularly calibrated via processing of monitored data (Tahmasebi and Mahdavi 2014).

Generally speaking, the building simulation community is quite familiar with the uncertainties concerning external boundary conditions (weather conditions, microclimatic factors) and has more experience in accommodating such uncertainties when conducting performance simulation studies (Barnaby and Crawley 2011; Mahdavi and Dervishi 2013). The following discussion thus focuses on the second important class of highly dynamic boundary conditions in performance simulation, namely those associated with people’s presence and control-oriented actions in buildings. In the general context of the foregoing analysis of simulation deployment effectiveness, it is perhaps particularly instructive to scrutinize a number of recent efforts toward incorporating detailed – mostly stochastic – occupancy-related models in performance simulation.

The starting point of a large fraction of such efforts was a “performance gap” assertion extrapolated from a number of case studies. Thereby, it was suggested that the frequently observed discrepancy between buildings’ predicted and actual energy performance is chiefly due to simplified (typically schedule- and rule-based) representations of inhabitants’ presence and control-oriented behaviour in buildings. The relevant point of discussion here is not so much the question of if this suggestion consistently applies: In fact, a good many – but not all – discrepancies between a priori predictions of buildings’ energy demand and their actual energy performance may be at least partially attributable to people’s behavioural patterns (Housz, Pont, and Mahdavi 2014). Likewise, we do not wish to enter into a debate here if the principal objective of simulation studies is always the prediction of specific outcomes at specific instances of time in future (as opposed to, for example, comparative assessment of alternative design options). Rather, we are interested in the aforementioned efforts’ approach to address the inhabitants’ representation in building simulation models. Thereby, the dependability of behavioural models has been frequently reduced to the question of using the ‘right’ algorithmic formalism, i.e. the choice between various mathematical/statistical modelling methods. Such formalisms were mapped into a – typically limited – set of observational data to optimize the fit.

However, independent of the deployed statistical technique, a locally established fit does not constitute a model’s generality and scalability. As such, data-driven models that are applied to populations not included in their developmental stage, do not necessarily perform satisfactorily in all cases (Mahdavi 2015; Mahdavi and Tahmasebi 2016). Consequently, there is no evidence that any amount of formalism handling or uncertainty analysis could compensate for the lack of underlying – and sufficiently representative – empirical data sets. Obtaining vast quantities of observational data would be of course no mean feat. But even if available, comprehensive empirical data repositories do not provide a guaranty for the long-term predictability of individual buildings’ energy and environmental performance. They could, however, provide at least a dependable basis for the formulation of meaningful uncertainty ranges attributed to computed values of key building performance indicators.

One can try to extend the applicability range of locally derived data-driven models by inclusion of additional variables that are meant to account for attributes applicable to larger populations. For instance, if a model was initially derived based on data from the specific climatic context of x, for example, and the specific building type of y, say residential, additional variables may be identified and introduced to capture other climatic and functional circumstances relevant to, for example, cold climates and commercial buildings. However, in such a process, potential gains in coverage may be accompanied by losses in precision. Introduction of ever more variables may address influence factors beyond those initially considered in model development. But with every new variable a new source of variance and uncertainty is introduced in the process.

It may be of course argued that the simulation-based generation of distributions of performance indicator values via probabilistic modelling methods – as opposed to single values resulting from schedule and rule-based representation of inhabitants – is actually meant to address some of the aforementioned challenges. For instance, it is supposedly better to provide ranges of performance results rather than single values, given the fact that the exact composition of building users and their behavioural tendencies is seldom known in the design phase. But this suggestion entails a conflation of different levels of argument. There is the level of the much quoted “performance gap” attributed to occupancy, and there is the level of uncertainty. Provision of ranges for performance indicators does not necessarily solve the problem of false predictions. And the so-called single-value performance simulation results are not necessarily wrong or misleading.

As such, one can flunk every performance indicator result with such a broad uncertainty range that, trivially, it would be always correct. But such a result would be hardly of any use for decision making. Neither would it be particularly useful if
computed values of building performance indicators are flanked by arbitrary uncertainty ranges.

We can thus summarize the implications of these arguments as follows:

- Providing simulation results in terms of single values is not automatically fallacious, if such results are not meant to imply accurate predictions of future circumstances but are used, for example, to gauge designs against applicable benchmarks or compare different designs.
- Provision of uncertainty ranges of computed values of performance indicators can be highly useful (even necessary), but should be derived from statistically processed actual observational data in the relevant domain.

But what is the upshot of all this discussion? Why is it not only prudent, but may be even critical to exercise caution when proclaiming the power and merits of building performance simulation, particularly its long-term prediction potential? Well, there is the scientific angle. The lack of evidence for the constrained predictability of buildings’ long term energy and environmental performance is not accidental. It is consistent with the predictability limits of all systems that are subject to widely dynamic and stochastic internal and external boundary conditions. There is also the didactic angle. The judicious deployment of any kinds of analysis tools arguably requires a deep understanding of the scientific models’ potential and limitations. This means also to be able to understand the difference between the problem of a model’s precision (i.e. the consistent reproducibility of computed model’s behaviour) versus its accuracy (i.e. the consistent replication of real systems’ behaviour via computed model’s behaviour).

The circumstance that we cannot reject the null-hypothesis H0,1 does not contradict the fact that carefully developed, systematically tested, and competently deployed building performance simulation methods and applications represent a great asset to building design and engineering professionals. Robust simulation methods can, given hi-fidelity input assumptions and well-defined boundary conditions, provide reliable digital replica of real systems and facilitate thus a host of instructive virtual experiments. In the light of this, there is surely no need to engage in or fall for hyperboles when commenting on and promoting the virtues of building performance simulation.

**Do buildings matter?**

Let us now turn our attention to H0,2, the second null-hypothesis listed in the introduction. It essentially questions the extent of the frequently purported environmental mitigation potential attributed to improved building design and operation practices. To reject this null-hypothesis, it would be necessary, but not sufficient, to demonstrate the building sector’s high relative standing amongst the multitude of other anthropogenic causes of environmental degradation. We would also need to show that the sector’s mitigation potential can be effectively exploited, even if other or related anthropogenic drivers of environmental crisis remained unchallenged. Instances of such drivers are, for instance, population and urbanization growth and life style matters.

Here again, the null-hypothesis formulation and the attempt to reject it may appear peculiar. After all, buildings evidently do have a large share in negative environmentally relevant developments, including depletion of non-renewable energy and other resources, emission of atmospheric pollutants, and generation of waste. But this is not what H0,2 disputes. Rather, what is being questioned is the advertised potential of building-related mitigation efforts. The essence of the implied contention in this hypothesis can be stated as follows. As service-providing ventures, building-related interventions may be moulded in such a way so as to become more efficient. The question is if the ensuing efficiency gains can compensate for higher-level forces, factors, and developments that bring about, amongst other things, an incessant rate of increase in the magnitude of required services.

Before an all-out attempt to reject H0,2, it may be useful to pose, as a kind of a plausibility test, a couple of exploratory questions. One such question may be formulated as follows: Looking at people’s various requirements and activities (living, work, mobility, entertainment), what are the respective magnitudes of environmentally relevant impacts (such as energy use or waste generation) and how do these magnitudes compare? In the context of such requirements and activities, the relative quantities of environmental loads associated with buildings can provide an initial indication if H0,2 is to be taken seriously or not.

To illustrate this point, consider the mean daily energy required in different categories for a random individual living in a Central European city such as Vienna, Austria. This can be estimated based on some basic information (Mahdavi 2010; MacKay 2009). Assuming the individual lives in an average (thermal) quality apartment, the daily heating and hot water energy use would be roughly 18 kWh. Energy use associated with various ‘gadgets’ (phones, electronic equipment) could be estimated to be around 4 kWh. Assuming the individual drives a car (30 km per day), the required energy would be about 24 kWh. Assuming the individual completes the equivalent of one transatlantic flight every year, the respective energy use would be approximately 30 kWh. Given this partial portfolio, the fraction of the individual’s home energy use amounts to roughly 20% of the sum total.

Now assume we retrofit the apartment to reach a higher thermal quality standard (resulting in a mean daily energy use of, say, 12 kWh). Consequently, the respective share of the apartment in the total energy use portfolio falls from 20% to 15% and the total energy use is reduced by 7%. As an aside, it would be also interesting to estimate, for the above scenario, the order of magnitude potential of building-integrated renewable energy harvesting. If for every inhabitant of Vienna, 6 m² of solar panel area (with an effective efficiency of 20%) would be installed, a per capita mean daily energy harvesting potential of approximately 4 kWh could be expected, amounting to about 5% of the total portfolio or barely covering the virtual inhabitant’s gadget energy need in the above example.

Granted, many aspects of the above back-of-the-envelope calculation exercise can be criticized. The individual is not representative of even Vienna’s inhabitants, let alone those in other locations, where residential energy expenditures might be much higher than those associated with flights. Likewise, the energy use portfolio is in this case glaringly incomplete, and
the corresponding energy estimates obviously coarse. Yet the arguably modest relative effect of apartment’s thermal retrofit does not readily render H0.2 as a spurious contention. Is it indeed conceivable, that our expectations concerning both the environmental mitigation efficacy of building-centric (design and operation optimization) measures and the building-integrated renewable energy gain potential are overstated?

Let us consider a second exploratory question regarding the basic plausibility of H0.2. As compared to improved building design and operation category, what building-related factors could be more critical from the environmental impact standpoint? One such instance is implied by the suggestion that circumstances and decisions regarding buildings’ location and situation may be indeed more consequential. To pick again an example relevant to the Austrian context (Hagelversicherung 2019), the land use (transformation of agricultural land to build areas) grew about 25% from 2001 to 2017, a rate much higher than the population growth in the same period (9.1%). Over the past ten years, the area of agricultural land sealed in Austria every day amounts to about 20 hectares (equivalent to 30 soccer fields) or roughly 10 m² per capita per year. On the other hand, 40 hectares of already sealed land (formerly used in industry, commercial, and residential sectors) remain abandoned. This area could replace the need for further conversion of agricultural land to sealed land for 2 years at the current excessive rate and for 20 years if the daily rate of 20 hectares would be reduced to a more responsible 2 hectares.

This observation sheds additional light on null-hypothesis H0.2. Given the well-known negative effects of sealing more and more land areas (global warming, urban heat islands, water runoff problems, eco-diversity losses, etc.). Thus, the answer to our second exploratory question seems also to suggest that H0.2 cannot be simply dismissed. In much of our conversations in the building sector domain, we might have not only overstated the relative environmental mitigation potential of better building design practices, we might have also downplayed or downright ignored potentially decisive boundary conditions surrounding the building design and delivery process.

Since we cannot simply put H0.2 aside, we need to look for a more systematic procedure, if we intend to reject this null-hypothesis. Thereby, while searching for an adequate approach, it might be useful to consider the analogy to the previously discussed building simulation. As is generally known, building simulation can facilitate the ranking process of design options in view of performance indicators such as energy demand or environmental emissions. However, to assess H0.2 in an analogous manner, we would need a kind of world simulation capability, such that we could predict the environmentally relevant implications of all kinds of alternative mitigation measures in different domains (e.g. buildings, industry, transportation, policy, education, etc.). Also in this case, we would have to express the simulation results in terms of pertinent performance indicators such as the reduction of global energy use, or reduction of the greenhouse gas emissions.

Deeper domain knowledge and advanced computational methods have increased the scope and scale of building simulation, extending from building components, to individual spaces, whole buildings, districts, and even cities. External (climatic) boundary conditions around buildings can now be consistently nested in multiple hierarchical modelling levels from neighbourhood to district, urban, regional, and global levels. But it should not come as surprise to anyone to suggest that the kind of world simulation capability needed for testing a hypothesis such as H0.2 is far from what can be done with today’s technology. We would not only need climatic models of multiple scale and levels of resolution, but many other models representing relevant domains and activities covering industry, agriculture, transportation, and tourism, to name a few. We would have to also remember that our world model would need to integrate not only energy and mass flows, but also information-centric processes at individual, group, national, and global levels. In other words, aside from the sciences of the physical environment and life processes (physics and chemistry, meteorology, biology, botany, physiology), we would need also to include psychological, social, and economic models, given their critical role with regard to the effectiveness and success probability of candidate mitigation measures. Even if we could assemble a coherent multi-domain model of at least some of the phenomena involved, obtaining dependable values for the respective – and highly extensive – input variables would be a herculean task.

Whereas a world simulation platform remains a distant vision, there have been a considerable number of efforts to estimate and evaluate the magnitude and consequences of anthropogenic interventions in the natural environment (IPCC 2019; IPPR 2019; IEA-ETP 2019; Club of Rome 2019). The results of such efforts might provide, in lieu of a global simulation model, a provisional basis, at least for a preliminary examination of H0.2.

Toward this end, we refer, in the following, to some of the results of one such effort (Drawdown 2019). The objective of this international collaboration was to project and compare (rank) the mitigation potential of some eighty candidate ‘solutions’ organized in seven different categories (Buildings and Cities, Electricity Generation, Food, Land Use, Materials, Transport, Women and Girls). This resulted in estimations of cumulative greenhouse emission reduction of greenhouse gases (expressed as CO₂-eq. gigatons) over a thirty-year period (2020–2050) for three scenarios labelled as plausible, drawdown, and optimum. Moreover, when possible, the net realization costs and net expected savings were calculated. The calculations entail, according to the authors, no double counting, but they concede that the study has limitations concerning systems dynamics and rebound effects (Hawken (Ed.) 2017).

What do the estimations generated in this project tell us about our inquiry? To obtain a first general impression, consider the comparison of the aforementioned seven categories in view of CO₂-eq. reduction potential (plausible scenario, medium population growth scenario). Expressing the comparison in terms of percentages of the total (of all categories), the following ranking emerges: Food (31.1%), Electricity Generation (23.8%), Land Use (14.5%), Materials (10.8%), Women and Girls (10.1%), Buildings and Cities (5.3%), Transport (4.4%). Note that the category Buildings and Cities entails eight ‘solutions’ under the Buildings subcategory (building automation, green roofs, heat pumps, insulation, LED lighting commercial, LED lighting household, smart glass, and smart thermostats) and five solutions under the Cities subcategory (bike infrastructure, district heating, landfill methane, walkable cities, water distribution). If we consider only the Buildings subcategory (assuming it is more likely to be
influenced by building design and operation professionals), then
the share of CO2-eq. reduction potential falls to 3.5%.

These results do not imply a promising gambit to reject our
null-hypothesis $H_{0,2}$. In fact, if we look for the top seven most
effective individual solutions – which constitute half of the total
CO2-eq. reduction potential of all 80 solutions considered – the
following ranking emerges (percentage of the total reduction): Educating Girls and Family Planning (10.1%), Refrigerant Man-
agement (8.7%), Onshore Wind Turbines (8.2%), Reduced Food
Waste (6.8%), Plant-Rich Diet (6.4%), Tropical Forests (5.9%),
Solar Farms (3.6%). None of the above solutions is in the Build-
ings and Cities category. The highest ranked solution (27th) in
that category is District Heating (0.9%) and the highest ranked
directly building-related solution (31st) is Insulation (0.8%).

As mentioned before, in the absence of any realistic prospect
of an emerging robust, comprehensive, dynamic, ‘world simu-
lation’ platform, we may have to operate based on the kinds of
data generated by efforts such as the one referred to above. We
may have quibbles about the terminology and methodology of
the study and the format and reliability of the projections. But
it seems unlikely that the detected signal in the study’s results
could be masked by the noise caused by uncertainties of the
study’s approach and assumptions. As such, it should not come
as a surprise, if the population growth (the main factor influ-
enced in the solutions’ subcategory ‘Women and Girls’) and a
number of population-related factors in the ‘Food’ category rep-
resent both the leading contributors to environmental problems
and the domains where mitigating measures could be most
effective.

Let us further reflect on these points briefly. As it was alluded
to before, proclamations under the label of ‘sustainable build-
ings’ often start by a reference to the world population and
additional demands its growth generates, but they typically fail
to mention and consider the deeper implications of pop-
ulation dynamics. Estimations of population development (UN
2017, median scenario) in the period from 2000 to 2050 to mas-
sive rates of increase in Asia (41%), Africa (209%), South/Central
America and Caribbean (48%), North America (39%), Oceania
(84%) and world at large (60%). The population of Africa –
slightly over 200 million around 1950 – is projected to approach
two billion by 2050. Population increase appears to be taken as
a fact of fate. Even if the population growth is going to be regarded
as an inevitable and unalterable process, at least the implica-
tions for resources, environment, as well as ecological and social
systems should be frankly discussed, rather than evaded. The
affordance of an ecosystem can sustainably support only a finite
number of people of a given life style. Transgressing that limit
invariably results in environmental degradation.

The ecological strain resulting from population increase is
aggravated by a parallel process involving the improvement of
living standards for some populations around the world. This cir-
cumstances explains the significant net increase in per capita
environmental impact even in those countries, where some level
of population control has been achieved. For instance, in the
45-year period between 1960 and 2015, the total fertility rate
(children per woman) decreased from 6.1 to 1.3 in South Korea,
from 6.2 to 1.5 in Thailand, from 5.5 to 2.1 in Sri Lanka, and
from 6.8 to 1.9 in Colombia (TFR 2019). However, in the same
period, GDP per capita in these countries rose roughly 171 times
in South Korea, 58 times in Thailand, 27 times in Sri Lanka, and
25 times in Colombia (WBG 2019).

Lest these assertions are misunderstood, rise in people’s stan-
dard of living is of course desirable socially and ethically. How-
ever, even though not a necessity, per capita improvement in
living standard (partially reflected in per capita GDP) is typically
mirrored in per capita increase in resource depletion and envi-
ronmental impact (expressed, for instance, in terms of per capita
ecological footprint in hectares). Whereas in the last twenty years
the per capita energy use has been stagnating (albeit at a very
high level) in countries such as United States and Germany,
both per capita energy use and Gross National Income (GNI)
have been increasing in China, India, and Brazil. Specifically, the
Gross National Product (GNP) of China and India is projected to
increase within a period of 40 years (2009–2049) roughly by a
factor of 6 and 9 respectively. Primary energy use in China has
been suggested to increase around 230% by the year 2035 as
compared to the 2008 value (Mahdavi 2016).

One of the life style changes associated with economic
growth pertains to the nations’ nutritional habits. For example,
within a short period of about 25 years (1976–2001) per capita
meat consumption in China increased by a factor of 5 to reach
a value of roughly 50 kilograms of meat per person per year
(Mahdavi 2016). The environmental ramifications of such devel-
opments can be easily exemplified, if one is reminded of the high
animal feed conversion, i.e. kilogram animal feed to kilogram
animal product.

The increase is the population’s capacity to rapidly exploit
natural resources and to intervene in the working of natural
systems result in all too familiar negative consequences. The
combined ecological and environmental consequences of con-
current population growth and the rise of the so-called standard
of living can rapidly outrun incremental advances in efficiency
improvement effects in the building sector. In other words, as
compared to the anthropogenic impact factors’ associated with
the population growth and lifestyle change, efforts to improve
the design and operation of buildings do not necessarily consti-
tute the most critical mitigation strategy vis-à-vis global environ-
mental problems.

The upshot of this is that we have not been able to make a
case for rejecting $H_{0,2}$. Of course we can always argue that, even if
the environmental mitigation potential of building-centric mea-
sures is comparatively modest, it is still important and worthy
of utilization. Perhaps we can even strengthen the argument by
highlighting the economic saving potential of building-centric
mitigation solutions.

In fact, it was mentioned before that the cited study of mitiga-
tion solutions (Drawdown 2019) included also, for the most part,
their net cost and saving potential. It is thus possible to express
the economic attribute of each solution in terms of net costs
and savings per reduced gigaton of CO2-eq. emissions. Let us
compare the solutions’ relative costs to achieve the same mag-
nitude of CO2-eq. reduction. Compared to a unit cost of one for
‘Land Use’, we would have 2.8 for ‘Food’, 11.5 for ‘Materials’, 22.7
for ‘Electrical Energy’, 99.7 for ‘Buildings and Cities’, and 440.6
for ‘Transport’ (no estimations are provided for the Women and
Girls category). While these numbers identify the ‘Building and
Cities’ category as the second most expensive, they do not tell
the whole story. Looking at the savings in a similar manner, a
different pictures emerges. Compared to a value of one for net saving due to solutions in the 'Land Use' category, we obtain, for the same reduction level of CO₂-eq. emissions, 1.6 for 'Materials', 1.8 for ‘Food’, 6.6 ‘Electrical Energy’, 112.5 ‘Buildings and Cities’, and 201.8 for ‘Transport’. This suggests that while Buildings and Cities category may be the second most expensive amongst the rated measures, it is also the second highest in terms of saving potential.

Building-centric mitigation scenarios may be thus neither the most effective nor the cheapest. However, they are not negligible in terms of impact and are quite attractive considering their net savings potential. It would be thus quite reasonable, if not compulsory, for professionals in the building sector to energetically promote, pursue, and implement such scenarios. Yet in this case too, it would be prudent to abstain from engaging in (or to fall for) hyperboles when elaborating on the environmentally relevant virtues and benefits of the so-called sustainable building design, retrofit, and operation strategies.

**Does it matter?**

Let us recapitulate:

- Robust building performance simulation tools, in competent hands, offer many potentially useful building design and operation improvement opportunities. All the same, their application does not necessarily and automatically result in subsequent superior long-term energy and environmental performance of buildings.
- The building sector’s share of negative global environmental impact is large. However, in the face of boundary conditions – pertaining mostly – to population growth and life style issues, improved building design and operation strategies have comparatively a rather limited potential toward effective reduction of global environmental impact.

Some may not find these conclusions convincing. That is of course alright. So much the better, if more reliable data and stronger arguments are presented that contradict and ultimately falsify the above assertions. But at times, even those who concede the validity of the present contribution’s conclusions, still question their deeper meaning and the ultimate purpose. Frecuenctly the tenor of the implied discontent with the discourse boils down to the following objection: After all is said and done, does the world simulation platform to figure out that problems we evade tend to remain unresolved, and may well turn into hopeless ones – if they have not already.

**Disclosure statement**

No potential conflict of interest was reported by the author.

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