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OPINION ARTICLE

The 'building paradox': research on building-related environmental effects requires global visibility and attention [version 1; peer review: 2 approved]

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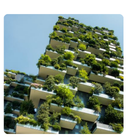
Abstract
The construction and operation of buildings is a major contributor to global energy demand, greenhouse gases emissions, resource depletion, waste generation, and associated environmental effects, such as climate change, pollution and habitat destruction. Despite its wide relevance, research on building-related environmental effects often fails to achieve global visibility and attention, particularly in premiere interdisciplinary journals – thus representing a major gap in the research these journals offer. In this article we review and reflect on the factors that are likely causing this lack of visibility for such a prominent research topic and emphasise the need to reconcile the construction and operational phases into the physical unity of a building, to contribute to the global environmental discourse using a lifecycle-based approach. This article also aims to act as a call for action and to raise awareness of this important gap. The evidence contained in the article can support institutional policies to improve the status quo and provide a practical help to researchers in the field to bring their work to wide interdisciplinary audiences.

Keywords
buildings, life cycle assessment, interdisciplinary research, climate change, global warming



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Introduction

Each discipline has its specialist audience, readership, and journals. It is expected that most of the research done in a field be aimed at those publishing venues and specialist readership. Still, significant advances in most disciplines regularly find their editorial light in top international, interdisciplinary scientific journals[a]. This might be due to the breakthrough the research represents for the field[1,2], the importance or impact it has on society[3,4], its timeliness compared to current socio-political-economic global trends[5–7] or the wider relevance it has in the overall scientific progress of human kind[8,9].

Research on building-related environmental effects is often an exception, although it fits the aforementioned criteria. While this is not a new field[10–12], it has relatively recently gained global traction as the growing number of published articles in specialist journals (Figure 1). This should not surprise, as buildings account for around 30–40% of global energy demand, greenhouse gases emissions, consumption of natural resources, and waste generation[13,14]. Parts of this agenda have been directly addressed by policy and regulation for decades, with the European Union Energy Performance of Buildings Directive first approved in 2002[15], and national regulatory efforts to limit energy use in new buildings going back at least as far as the 1960s[16]. Therefore, although some might think it is the relative novelty that keeps research on building-related environmental effects out of the most prestigious journals, this appears to not be the reason.

[a] *The meaning given to this phrasing within the scope of this article is fully defined, with supporting evidence, in the Extended data.*

At the time of writing (July 2019), in the entire suite of Nature and Science journals only 27 relevant entries (*Extended data:* Table S4[17]) were found matching the same keywords used for the graph in Figure 1. These cover works on urbanisation and cities[18–28], indoor ecosystems[29], autonomous architecture[30], and building materials and material efficiency[31–37].

This is paradoxical, particularly when the Nature journal *Eye* published an article in 2013 titled: 'The carbon footprint of cataract surgery'[38] based on a single component analysis for one patient in Britain, showing that the carbon footprint for one cataract surgery was 181.8 kg CO_2eq. It takes a mere 1 tonne of cement in a building to exceed that amount[39], and the sole structural frame of residential buildings can have a 'carbon footprint' in the range of 126-498 t CO_2eq[40]—three orders of magnitude higher than the carbon footprint of cataract surgery. Moreover, tonnes of cement produced around the world exceeds the number of cataract surgeries by more than 230 times, globally[41,42]. Why therefore does research on carbon footprint and environmental impacts linked to or caused by buildings not make it into premiere journals despite the undeniable magnitude of the problem and its wider societal relevance?

A reason, highly unlikely given the enormous pressure to publish that academics face, is that researchers in this field are uninterested in publishing in these top journals. Or there could be a targeted and selective rejection of articles in this field by prestigious publishers, but we struggled to find any reason why this would occur. So why does this happen? The reasons are several and not obvious—we believe—and both intrinsic and exogenous; we have reflected on them in the following sections.

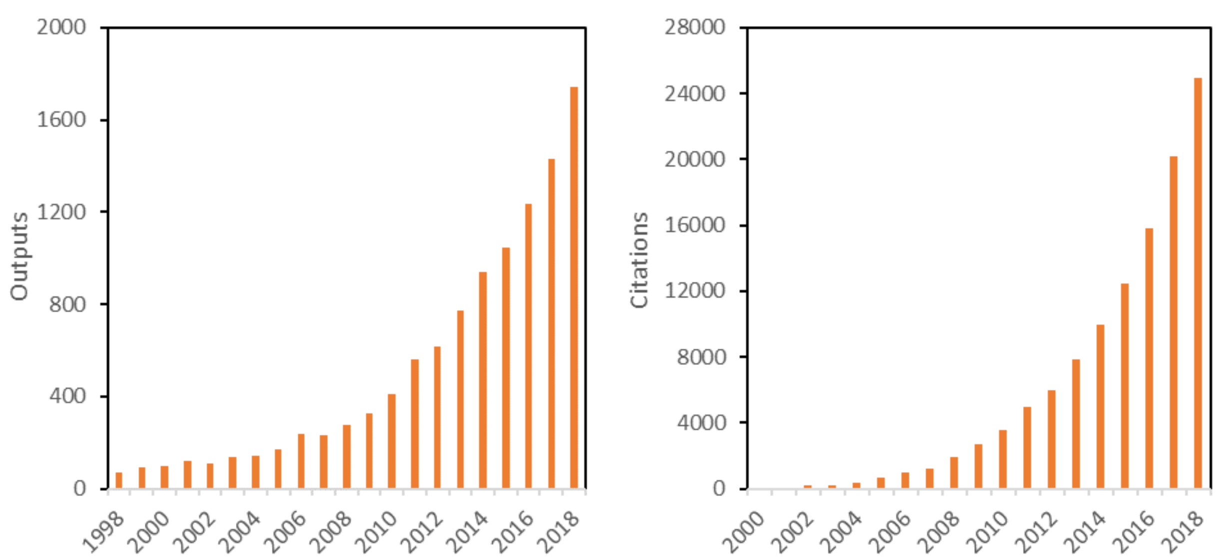

Figure 1. Bibliometric analysis for research outputs (n=10758) matching the keywords 'life cycle assessment buildings' OR 'environmental impacts buildings' OR 'embodied carbon buildings' in the last twenty years (1998–2018): total number of outputs per year (left); and sum of times cited by year (right). Citations start from year 2000 as no citations are recorded in the years 1998 and 1999. [Sources: Web of Knowledge and Dimensions AI].

The uniqueness factor

Albeit focussed on construction materials, one of the few papers that could broadly fit the 'building-related environmental effects' category is the recent work of Heeren and Fishman[43], which provides comprehensive and harmonised datasets and data structure for material intensity in buildings. This represents an important advance as it collates, validates, and enhances global data on material intensities in buildings. It is also a potentially excellent platform for global collaboration and offers highly sought-after data to many researchers. However, its primary focus is on materials rather than buildings, and if one were to look at the number of case studies behind the dataset (n=33) they would realise that it is well below some norms in other disciplines to produce a global database.

Is it just a data problem then? We do not think so. Buildings are unique entities made of hundreds-to-thousands of components that interact dynamically in space (through global, interconnected, and inter-sectoral supply chains) and time (they enter the life cycle of a building at various moments and stages, and stay for different lengths of time, over decades and even centuries). Grasping a good understanding and a complete picture of what occurs in a building requires a substantial amount of time. Apart from lengthy construction times, buildings require maintenance, repairs, material replacements, minor and major refurbishments, and demolition or dismantling, throughout their life and many decades into the future. This significantly adds complexity to modelling the environmental effects of buildings. More complexity is further added by the myriad of building codes (fire, safety, seismic, acoustic, etc.) and the interlinkages between different building systems that combine and interact with one another (glazing and ventilation, for instance).

The uniqueness of each building also reduces the possibility of bold generalisations of the results. As a consequence, a significant share of building-related research follows a case study approach, which is not, in our experience, widely supported by the publishing world. So much so that in writing, reading, and reviewing papers in this field Yin is always referred to[44] in order to justify and often *defend* the case study approach. But is this defence necessary? Other methodological avenues are taken for granted and only rarely in other disciplines do authors explain at length why they have chosen a specific technique used in their research. The building-field research community is therefore often looking for more buildings to analyse and strengthen the relevance of their findings. Not only does this require significant time, often beyond what is allowed or acceptable for a research project, but it also incurs an ironic counterargument on the part of some editors and reviewers along the lines of: 'the number of buildings is appropriate but the buildings are so different from one another that how can they be compared?'.

It is also worth noting that the same approach on diversity of population samples does not seem to apply in other fields. There might be cases in biomedical research where a heterogeneous population (e.g. zebrafish and mice[45]) is well received as it enables a demonstration of whether hypotheses and results hold (or not) regardless of the variation. In other disciplines, a small but homogenous sample (e.g. n=3 to 8 mice[46]) allows for substantial advancements to be made under the understanding that a bigger sample was not a viable option in that specific research project. But if three mice are a perfectly acceptable number to publish in top journals for biomedical researchers why does the same number not open the same doors for research on buildings? From our perspective, a mouse is not more complicated to monitor and analyse than a building. Further, it is unfeasible that two buildings, identical but for one variable, be constructed to test the influence of that one variable before moving on to the next one. Despite the impressive advancements in simulation tools and digital technologies, it appears unlikely that standard approaches in other fields of science will be fully applicable to research on building-related environmental effects.

Unless and until the uniqueness of buildings is better understood and acknowledged, the lack of large datasets and thousands of data points will continue to impede researchers in this field in the pursuit to have their work disseminated in top international journals. Big data can help, but—apart from some exceptions to date[47]—it seems more easily applicable to certain aspects of a building's life cycle, such as energy demand through real-time smart meter readings coupled with real-time building occupancy and weather data. However, this is a partial—and increasingly less preponderant[39,48–51]—aspect of building-related environmental effects, as explained in the next section.

The life-cycle factor

There is indeed an unnecessary and yet unresolved dichotomy in how buildings are seen, and this seems endemic. The IPCC[52], the Committee on Climate Change[53], and several other influential bodies, when focusing on buildings, tend to focus solely on the energy use and greenhouse gas emissions related to the use phase of a building, when it is occupied. This is certainly a large source of global impacts[54], but with more, and increasingly stringent, regulations driving towards Zero Energy Buildings (ZEB)[b], operational energy will progressively be less relevant, and in fact totally insignificant if the ZEB theoretical targets are ever achieved. What these bodies overwhelmingly ignore is the embodied energy (and the related embodied greenhouse gas emissions) linked to all other phases of a building's life-cycle: extraction and processing of raw materials, manufacturing, transportation, construction, maintenance, repair, refurbishment and end of life activities such as demolition, recycling and waste processing. In fairness, this energy is not ignored but it gets dispersed and diluted in a wider cluster of 'industrial sector' impacts, therefore breaking the functional unity of a building. This is shown in Figure 2.

To understawnd the paradox of disjoining embodied and operational impacts it is useful to try to apply the same reasoning to a car. It would imply that the petrol used by the car is attributed to the car, but the tyres are not. Does this make sense?

[b] *We contend this definition and the use of zero when in fact a ZEB is far from having zero energy consumption due to the embodied energy, but have used this definition for the common understanding it has.*

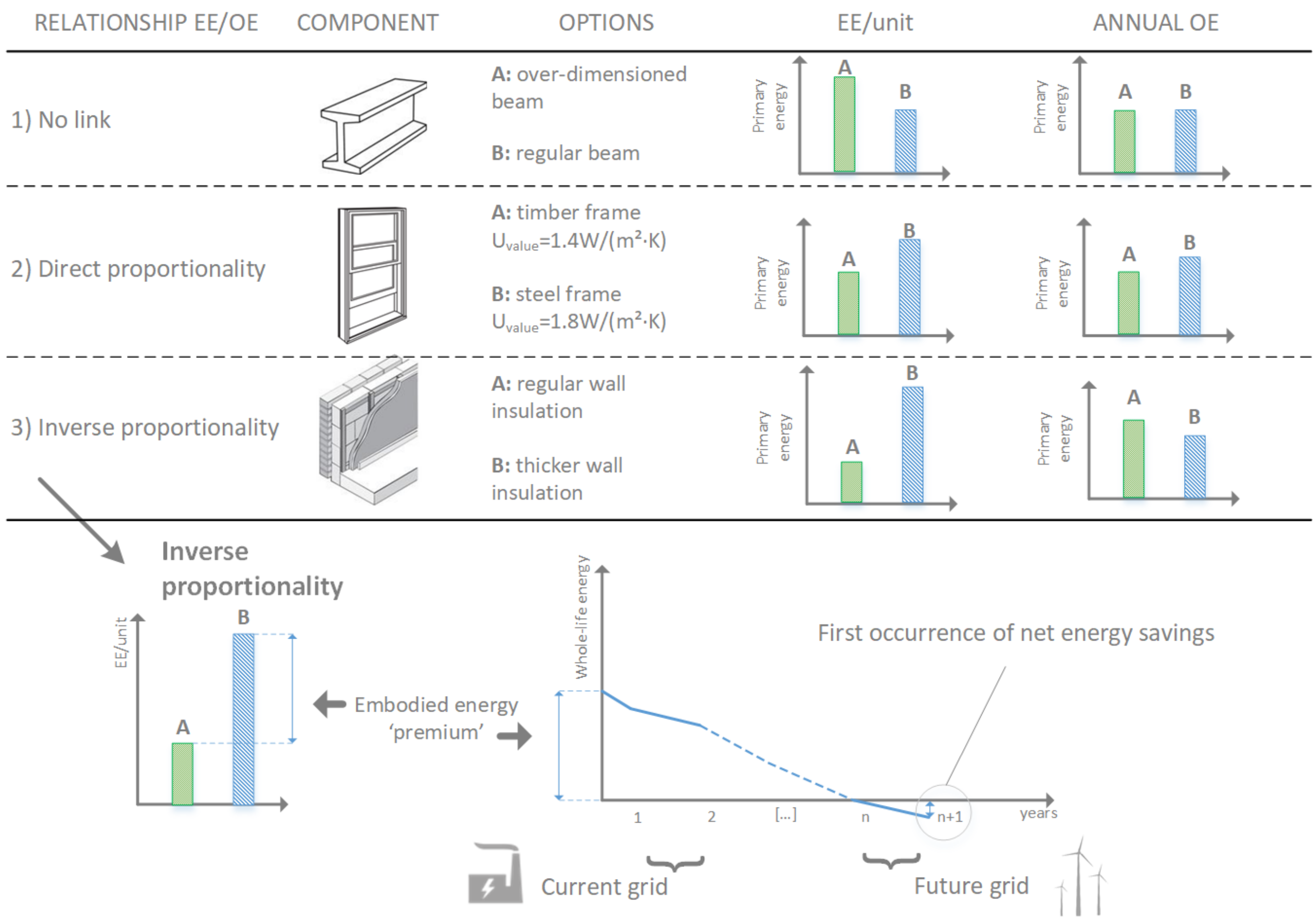

Figure 2. Relationship between embodied energy (EE) and operational energy (OE) in buildings depending on the component under examination. Options are: (1) no link, when a material with higher/lower embodied energy bears no implication over the operational energy consumption of the building; (2) direct proportionality, when a material with higher embodied energy also causes greater operational energy demand due to a worse thermal performance; and (3) inverse proportionality when a component with higher embodied energy reduces the operational energy demand. This latter case would be the only one where an increase in embodied energy can produce beneficial effects on operational energy. However, as the bottom part of the figure shows, operational energy savings do not materialise immediately. Instead, the whole life energy balance starts with the embodied energy 'premium', which is annually compensated by the lower operational energy demand of the option with higher embodied energy. It will take a number of years before the embodied energy premium is recovered. This means that the embodied energy 'premium' is causing a surge in emissions due to the current, carbon-intensive, energy grid to save emissions in the future on a likely decarbonised energy grid. [Source: authors' own].

Can a fully-fuelled but tyre-less car go anywhere? A powered building without walls would be equally useless. As much as the car is seen as the indivisible unit that provides a specific function, so is the building; or at least so it should be. The current mind-set would suggest that the industrial sectors push this energy and materials towards the building, but we would argue that it is quite the opposite. Just as a household pulls the energy demand for heating and cooling, the building—or in fact the people determining its features and construction fate—pulls the energy linked to the manufacturing and other activities related to the cement, glass, steel, and all the other materials it is made of. Until the unnecessary dichotomy of operational vs. embodied impacts gets reconciled, building-related effects will remain distributed and diluted across a number of existing categories and their magnitude will be seldom perceived. A lack of awareness of the magnitude of building-related impacts will impede appropriately targeted action that would yield beneficial outcomes more quickly and to a greater extent.

The paradoxical decomposition of a building can be observed in one of the most widely used tools for global sustainability analyses and sustainable production and consumption studies: input-output analysis (IOA)[55]. In IOA the physical unity of a building gets broken down into two main components treated substantially differently: the energy we use for heating, cooling, cooking, and hot water goes into the final energy demand of households while everything else linked to the building gets distributed and diluted across many industrial sectors. Recent ground-breaking research has developed the idea of city carbon maps[56] to allow for the complete and consistent reconciliation of direct and indirect greenhouse gas emissions from a city. But would it be feasible, or even desirable, to go one step further in this direction and try to develop 'building carbon maps' or is there a better way to reconcile impacts caused by buildings? There is already evidence of the successful application of environmentally-extended input-output databases to different scales of analysis, although this is limited to embodied impacts[57] and mostly focused on either micro (e.g. components[58]) or macro (e.g. nations[59]) scales.

The scale factor

In addition to the mainstream focus on operational energy efficiency, existing research on environmental effects within the built environment seems to fall mainly in two distinct and distant categories. The first could be described as *top-down* and would cover macro-economic and policy related studies that aim to understand current states and future consequences at national or international levels. One example is the work of Ramaswami and colleagues[60] who investigated cross-sectoral strategies to reduce greenhouse gas emissions from cities in China, finding a 15-36% improvement towards national greenhouse gas emissions targets compared to single-sector strategies. The second could instead fall in the *bottom-up* classification and would include studies in the material research area, and focus on improvements at small scale (nano, micro, or a single material) that would yield improvements given the large quantities of a specific material that are used globally. One example in this category is the work of Miller and colleagues[61] who investigated ways of mitigating the water demand of concrete production. Concrete is however only one of hundreds of materials in a building and while its global impacts are surely significant[62] they might well be rather modest in comparison to the broad range of impacts attributable to buildings.

Buildings are therefore not just unique, but they are also characterised by a specific scale that does not immediately match mainstream research approaches, mostly focused on macro or micro scales[63]. A focus on cities seems reasonable and accepted[64–67], perhaps because it instantly evokes an idea of utter complexity, but we could argue that a city is a complex conglomerate of buildings much as a building is a complex conglomerate of materials. However, city and material-based research is widely publicised in top international journals, unlike research at the whole building scale. There might be an underlying, unconscious assumption that by working at a problem from both ends—top-down and bottom-up—the research will meet in the middle and the problem would be solved. However, by analogy, we would not feel very comfortable if all medical knowledge was derived from research at the cellular and societal levels. Research on humans is equally fundamental, and so is research on buildings.

A wrongly perceived simplicity of the building scale might also be linked to the fact that many people look at a building and see their home or place of work, with which they might have empathy. Materials are less familiar and not as warming as a thought, as they can harm us and make us ill[68], and are often seen as parts of the industrial sphere. Cities on the other hand are chaotic, often polluted, interconnected and dynamic[69], and so the building remains in the middle, often ignored.

The human factor

Buildings are, at least in the large sense, designed not manufactured. Off-site construction can potentially change this[70] but this is yet to occur at a global scale. In addition, the growth of the concept of mass customisation in construction[71] seems to suggest that users will remain pivotal to defining the key design features, as well as the fate, of buildings. Buildings are quite an intimate thing for us humans. We spend two-thirds of our life indoors[72], and are keen to personalise our homes, tailor the desk arrangement and layout in our open plan office, create a unique and creative combination of plants, flowers, fruits, and vegetables in our gardens. No two homes are the same. These factors point to a large community of diverse stakeholders that play a pivotal role in the building industry. This seems an innocuous team, which however hides an intricate mix of professions that interact and contribute to the building design process at various and multiple stages. Building actors, broadly defined as those influencing what the finished building looks like, would potentially include owners, developers, architects, civil engineers, structural engineers, geotechnical engineers, building services engineers, interior designers, project managers, site managers and sub-contractors. This ensemble of expertise and professions is the main influencer of the overall environmental effects of a building (together with the user[73]). Decisions that determine these effects are made from the top down. For example, it is not the decision of the cement manufacturer that dictates how much concrete is used in a building. Rather, the architect decides first if concrete will be used for a specific building project or not. The geotechnical and structural engineer would then influence the amount and type of concrete depending on their approach on rationalisation and material redundancy[74–76], but would rarely oversee the procurement and supply of the material, which is left to managers and contractors. Whilst there are obviously rules of thumb developed over decades, and professional bodies and standards that guide best practices, the design process includes elements of unique subjectivity at each iteration and for each project. We believe these multiple human interventions are unique to, and strongly influential for, buildings and the research that is done on them. This should be borne in mind before adopting, suggesting, or promoting a single approach based on repeated iterations of the scientific method followed by rigorous statistical analysis. It might not always be that this is the best approach for building-related research. Interdisciplinary research that follows innovative paths should be encouraged, and the role of social sciences acknowledged and recognised in the pathway to effect real change[77]. Buildings are deeply social, and the solutions that will reduce their environmental effects to within acceptable limits, concordant with the rate of renewal of materials, are unlikely to come solely from technical analyses[63].

The systemic social factor

If one reads most PhD theses on building-related environmental effects, there will be few citations to articles in Nature or Science. This should not surprise, given the nearly non-existent body of literature published in such journals that is relevant to this field. However, this possibly also perpetuates the lack of research on building-related environmental effects in such journals and it might be explained by evidence from research on rational choice and social theory[78] because real or perceived environmental constraints drive a choice made by an agent (e.g. a person)[78].

A systemic theory on socialisation also argues that differences in environmental concern are the result of the implicit cultural training received[79,80]. If a PhD candidate in the field is trained without accessing premiere journals due to the lack of relevant research published in there, s/he might grow accustomed to thinking that such journals are not suitable publication venues for the research s/he does. However, we have already demonstrated this untrue as research on building-related environmental effects does fit the criteria that allows research in other fields to be published in these journals.

This therefore appears to be an endogenous barrier that researchers in the field of building-related environmental effects will need to overcome. Thus action is necessary by the whole community to ensure wider and more powerful dissemination of the work we do and the challenges it entails. It would also spur enormous opportunities for intra-, inter-, and trans-disciplinary collaborations, which would be likely to lead to more widespread and rapid change.

The methodological factor

If repeated applications of the scientific method followed by strict statistical analysis are not always or necessarily the best course of action, then what should be done? The honest answer is that the community is still identifying a course of action. Life cycle assessment (LCA) (in various forms) has been used for three to five decades[81], but its application to the built environment is more recent. LCA standards have initially—and intentionally—been generic and broadly applicable[82], and the first dedicated standard for the built environment dates back from 2011 only (8 years old at the time of writing)[83]. It suffered the same issue of broad definition as the first LCA standard and as a consequence national bodies have developed refined methodologies to clarify or adapt it[84].

Good datasets are few and far between and, without this being necessarily a negative criticism, most published studies are therefore partial and limited in scope[85]. Positive future avenues come from the field of hybrid LCA, whose application to—and usefulness for—the built environment is not new[86,87] but which has also not seen widespread uptake[88,89]. The building research community is also fragmented and still divided in the operational vs. embodied debate, and this has slowed progress towards a harmonised methodology that works across the building life cycle. This has also occurred in the Energy in Buildings and Communities (EBC) Programme of the International Energy Agency (IEA): the past annexes have either focused on operational energy efficiency and optimisation[90] or on embodied energy and greenhouse gas emissions[91,92]. As demonstrated in Figure 2, this fragmented approach is problematic in the building sector, where building performance is so intrinsically linked across the various life cycle stages.

In addition to the new dataset developed by Heeren and Fishman[43], the Annex 72 of the IEA[93] is advancing the research already conducted within EBC Annexes 56 and 57: it broadens the scope of both, and finally reconciles the operational and embodied effects. It aims to produce a harmonised, globally applicable and yet regionally differentiated, methodology to advance the assessment, and consequential mitigation potential, of life cycle environmental effects associated with buildings. There are also other promising avenues that are developing rapidly—in addition to the already mentioned hybrid LCA approach—such as a finer sectoral resolution in multi-regional input-output databases[94], and over 6,000 Environmental Product Declarations (EPD) for construction products at the beginning of 2019[95].

Additional observations and concluding remarks

Language is always very important and there could be an issue on the terminology used. The first instances of the term 'embodied energy' in academic literature date back more or less to the late 70s[96–98]. These early studies could all be attributed to the input-output research community, a field of research that unfortunately remains distant from most construction and building related research, as demonstrated in the following sections. To estimate the energy costs of goods and services, Bullard III and Herendeen[96] [p.268] proposed the idea of 'conservation of embodied energy', meaning that 'the energy burned or dissipated by a sector of the economy is passed on, embodied in the product'. (Interestingly, in the discussion of their method they conclude that their results 'are less useful for very detailed, micro questions (for example, the energy costs of different building materials)'[96] [p.268–269] and that for these, specific process analyses should be more accurate.) Arguably though, that energy—as well as the greenhouse gas emissions related to it—is all but embodied in the product. It has been used to generate heat and allow machinery to move and manufacture products, and the greenhouse gases have already been emitted into the atmosphere. Alternative suggestions that have been proposed are along the lines of "upfront carbon emissions"[99] or "capital carbon"[100]. Opponents of the 'embodied' terminology rightfully say that the term is misleading, but it is equally true that scientific communities in other fields have successfully used it. Additionally, the term carbon—whilst widely used—is scientifically incorrect to represent greenhouse gas emissions[101], and could increase confusion as much as it could ease understanding.

The open challenges are still many, but this is a time for hope. We have shown positive advancements in datasets and methodology, and the number of published studies and its growth rate testifies a global, and very active community, working in this field. However, the challenge of reliably assessing and effectively mitigating the environmental effects associated with buildings remains momentous, particularly in light of global trends of urbanisation and population growth. This is why research in this field must find a way to gain global visibility and attention and build a diverse and interdisciplinary community to orchestrate concerted actions, share and learn lessons, and accelerate impact.

Data availability

Underlying data

No data are associated with this article.

Extended data

Figshare: Extended data for Emerald Open Research, https://doi.org/10.6084/m9.figshare.12681419[17].

This project contains the following extended data:

- Table S1 – Top 10 international journals based on H-index values
- Table S2 – Top 25 international journals based on H-index values
- Table S3 – Top 20 journals in the field 'Construction and Building Technology
- Table S4 – Full list of outputs matching the keywords used for this article in the top interdisciplinary international journals as defined for the scope of this research

Data are available under the terms of the Creative Commons Zero "No rights reserved" data waiver (CC0 1.0 Public domain dedication).

References

1. Wang J, Zhao Y, Setzler BP, *et al.*: **Poly(aryl piperidinium) membranes and ionomers for hydroxide exchange membrane fuel cells.** *Nat Energy.* 2019; **4**: 392-398.
Publisher Full Text
2. Atkins JL, Long RA, Pansu J, *et al.*: **Cascading impacts of large-carnivore extirpation in an African ecosystem.** *Science.* 2019; **364**(6436): 173–177.
PubMed Abstract | Publisher Full Text
3. Thacker S, Adshead D, Fay M, *et al.*: **Infrastructure for sustainable development.** *Nat Sustain.* 2019; **2**: 324–331.
Publisher Full Text
4. Lenzen M, Sun YY, Faturay F, *et al.*: **The carbon footprint of global tourism.** *Nat Clim Chang.* 2018; **8**: 522–528.
Publisher Full Text
5. Wiedmann T, Lenzen M: **Environmental and social footprints of international trade.** *Nat Geosci.* 2018; **11**: 314–321.
Publisher Full Text
6. Zheng J, Suh S: **Strategies to reduce the global carbon footprint of plastics.** *Nat Clim Chang.* 2019; **9**: 374–378.
Publisher Full Text
7. Ansari E, Kaufmann RK: **The effect of oil and gas price and price volatility on rig activity in tight formations and OPEC strategy.** *Nat Energy.* 2019; **4**: 321–328.
Publisher Full Text
8. Vrselja Z, Daniele SG, Silbereis J, *et al.*: **Restoration of brain circulation and cellular functions hours post-mortem.** *Nature.* 2019; **568**(7752): 336–343.
PubMed Abstract | Publisher Full Text | Free Full Text
9. Clery D: **For the first time, you can see what a black hole looks like.** *Science AAAS.* 2019; (Accessed: 30th April 2019).
Reference Source
10. Hannon BM: **Energy use for building construction: final report for period March 1, 1976-December 31, 1976.** *CAC document; no. 228.* 1977.
Reference Source
11. Schmid JA: **The environmental impact of urbanization.** *Perspectives on Environment: Association of American Geographers, Commission on College Geography Publication.* 1974; **13**: 213–51.
12. Bekker PCF: **A life-cycle approach in building.** *Building and Environment.* 1982; **17**(1): 55–61.
Publisher Full Text
13. De Wolf C, Pomponi F, Moncaster A: **Measuring embodied carbon dioxide equivalent of buildings: A review and critique of current industry practice.** *Energy Build.* 2017; **140**: 68–80.
Publisher Full Text
14. Sbci U: **Buildings and climate change: Summary for decision-makers.** *United Nations Environmental Programme, Sustainable Buildings and Climate Initiative, Paris.* 2009; 1–62.
Reference Source
15. EU: **Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).** L153/13-L153/35. 2010.
Reference Source
16. DCLG: **Building Regulations - Statutory Instruments No. 1373**. 1965.
Reference Source
17. Pomponi F, Stephan A, Crawford R: **Extended data for Emerald Open Research.** *figshare.* Dataset. 2020.
http://www.doi.org/10.6084/m9.figshare.12681419.v1
18. Cumming GS, Buerkert A, Hoffmann EM, *et al.*: **Implications of agricultural transitions and urbanization for ecosystem services.** *Nature.* 2014; **515**(7525): 50–57.
PubMed Abstract | Publisher Full Text
19. Pichler PP, Zwickel T, Chavez A, *et al.*: **Reducing Urban Greenhouse Gas Footprints.** *Sci Rep.* 2017; **7**(1): 14659.
PubMed Abstract | Publisher Full Text | Free Full Text
20. Rosenzweig C, Solecki W, Hammer SA: **Cities lead the way in climate-change action.** *Nature.* 2010; **467**(7318): 909–911.
PubMed Abstract | Publisher Full Text
21. Kammen DM, Sunter DA: **City-integrated renewable energy for urban sustainability.** *Science.* 2016; **352**(6288): 922–928.
PubMed Abstract | Publisher Full Text
22. Parrish DD, Zhu T: **Clean Air for Megacities.** *Science.* 2009; **326**: 674–675.
Publisher Full Text
23. Ramaswami A, Russell AG, Culligan PJ, *et al.*: **Meta-principles for developing smart, sustainable, and healthy cities.** *Science.* 2016; **352**(6288): 940–943.
PubMed Abstract | Publisher Full Text
24. Brelsford C, Martin T, Hand J, *et al.*: **Toward cities without slums: Topology and the spatial evolution of neighborhoods.** *Sci Adv.* 2018; **4**(8): eaar4644.
PubMed Abstract | Publisher Full Text | Free Full Text
25. Grimm NB, Faeth SH, Golubiewski NE, *et al.*: **Global Change and the Ecology of Cities.** *Science.* 2008; **319**(5864): 756–760.
PubMed Abstract | Publisher Full Text
26. McDonald BC, de Gouw JA, Gilman JB, *et al.*: **Volatile chemical products emerging as largest petrochemical source of urban organic emissions.** *Science.* 2018; **359**(6377): 760–764.
PubMed Abstract | Publisher Full Text
27. Johnson MTJ, Munshi-South J: **Evolution of life in urban environments.** *Science.* 2017; **358**(6363): eaam8327.
PubMed Abstract | Publisher Full Text
28. Romero-Lankao P, McPhearson T, Davidson DJ: **The food-energy-water nexus and urban complexity.** *Nat Clim Chang.* 2017; **7**: 233–235.
Publisher Full Text
29. Humphries C: **Indoor Ecosystems.** *Science.* 2012; **335**(6069): 648–650.
PubMed Abstract | Publisher Full Text
30. Pawar VM, Stuart-Smith R, Scully P: **Toward autonomous architecture: The convergence of digital design, robotics, and the built environment.** *Sci Robot.* 2017; **2**(5): eaan3686.
Publisher Full Text
31. Xi F, Davis SJ, Ciais P, *et al.*: **Substantial global carbon uptake by cement carbonation.** *Nat Geosci.* 2016; **9**(14): 880–883.
Publisher Full Text
32. Wimmers G: **Wood: a construction material for tall buildings.** *Nat Rev Mater.* 2017; **2**: 17051.
Publisher Full Text
33. van Renssen S: **Making more with less.** *Nature Clim Change.* 2011; **1**: 137–138.
Publisher Full Text
34. Contreras JL, Lewis M, Roth HR: **Higher standards for sustainable building materials.** *Nature Clim Change.* 2012; **2**: 62–64.
Publisher Full Text
35. Song J, Chen C, Zhu S, *et al.*: **Processing bulk natural wood into a high-performance structural material.** *Nature.* 2018; **554**(7691): 224–228.
PubMed Abstract | Publisher Full Text
36. Fernández JE: **Materials for Aesthetic, Energy-Efficient, and Self-Diagnostic Buildings.** *Science.* 2007; **315**(5820): 1807–1810.
PubMed Abstract | Publisher Full Text

37. Wegst UGK, Bai H, Saiz E, *et al.*: **Bioinspired structural materials.** *Nat Mater.* 2015; **14**: 23–36.
PubMed Abstract | Publisher Full Text
38. Morris DS, Wright T, Somner JEA, *et al.*: **The carbon footprint of cataract surgery.** *Eye (Lond).* 2013; **27**(4): 495–501.
PubMed Abstract | Publisher Full Text | Free Full Text
39. Pomponi F, Moncaster AM: **Scrutinising embodied carbon in buildings: the next performance gap made manifest.** *Renewable & Sustainable Energy Reviews.* 2018; **81**: 2431–2442.
Publisher Full Text
40. Moncaster AM, Pomponi F, Symons KE, *et al.*: **Why method matters: Temporal, spatial and physical variations in LCA and their impact on choice of structural system.** *Energy Build.* 2018; **173**: 389–398.
Publisher Full Text
41. Lindstrom R: **Thoughts on Cataract Surgery: 2015.** *Review of Ophtalmology.* 2015.
Reference Source
42. CEMBUREAU: CEMBUREAU: **The European Cement Association - Activity Report.** 2017.
43. Heeren N, Fishman T: **A database seed for a community-driven material intensity research platform.** *Sci Data.* 2019; **6**(1): 23.
PubMed Abstract | Publisher Full Text | Free Full Text
44. Yin RK: **Applications of case study research.** (Sage, 2011).
Reference Source
45. El-Brolosy MA, Kontarakis Z, Rossi A, *et al.*: **Genetic compensation triggered by mutant mRNA degradation.** *Nature.* 2019; **568**(7751): 193–197.
PubMed Abstract | Publisher Full Text | Free Full Text
46. Tikhonova AN, Dolgalev I, Hu H, *et al.*: **The bone marrow microenvironment at single-cell resolution.** *Nature.* 2019; **569**(7755): 222–228.
PubMed Abstract | Publisher Full Text | Free Full Text
47. Stephan A, Athanassiadis A: **Quantifying and mapping embodied environmental requirements of urban building stocks.** *Build Environ.* 2017; **114**: 187–202.
Publisher Full Text
48. Giesekam J, Barrett JR, Taylor P: **Construction sector views on low carbon building materials.** *Building Research & Information.* 2016; **44**(4): 423–444.
Publisher Full Text
49. Ibn-Mohammed T, Greenough R, Taylor S, *et al.*: **Operational vs. embodied emissions in buildings—A review of current trends.** *Energy Build.* 2013; **66**: 232–245.
Publisher Full Text
50. Stephan A, Crawford RH: **The relationship between house size and life cycle energy demand: Implications for energy efficiency regulations for buildings.** *Energy.* 2016; **116**: 1158–1171.
Publisher Full Text
51. Stephan A, Crawford RH, de Myttenaere K: **A comprehensive assessment of the life cycle energy demand of passive houses.** *Applied Energy.* 2013; **112**: 23–34.
Publisher Full Text
52. IPCC: **Intergovernmental Panel on Climate Change - Climate Change 2014: Impacts, Adaptation, and Vulnerability.** (Cambridge University Press, 2014).
Reference Source
53. **Reducing UK emissions - 2018 Progress Report to Parliament.** *Committee on Climate Change.*
Reference Source
54. IEA: **Material efficiency in clean energy transitions.** 2019.
Reference Source
55. Wiedmann T, Wilting HC, Lenzen M, *et al.*: **Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis.** *Ecol Econ.* 2011; **70**: 1937–1945.
Publisher Full Text
56. Wiedmann TO, Chen G, Barrett J: **The Concept of City Carbon Maps: A Case Study of Melbourne, Australia.** *J Ind Ecol.* 2016; **20**(4): 676–691.
Publisher Full Text
57. Baynes TM, Crawford Robert H, Schinabeck Judith, *et al.*: **The Australian industrial ecology virtual laboratory and multi-scale assessment of buildings and construction.** *Energy Build.* 2018; **164**: 14–20.
Publisher Full Text
58. Hong J, Shen GQ, Mao C, *et al.*: **Life-cycle energy analysis of prefabricated building components: an input–output-based hybrid model.** *J Clean Prod.* 2016; **112**: 2198–2207.
Publisher Full Text
59. Guan J, Zhang Z, Chu C: **Quantification of building embodied energy in China using an input–output-based hybrid LCA model.** *Energy Build.* 2016; **110**: 443–452.
Publisher Full Text
60. Ramaswami A, Tong K, Fang A, *et al.*: **Urban cross-sector actions for carbon mitigation with local health co-benefits in China.** *Nat Clim Chang.* 2017; **7**: 736–742.
Publisher Full Text
61. Miller SA, Horvath A, Monteiro PJM: **Impacts of booming concrete production on water resources worldwide.** *Nat Sustain.* 2018; **1**(1): 69.
Publisher Full Text
62. Monteiro PJM, Miller SA, Horvath A: **Towards sustainable concrete.** *Nat Mater.* 2017; **16**(7): 698–699.
PubMed Abstract | Publisher Full Text
63. Pomponi F, Moncaster A: **Circular economy for the built environment: A research framework.** *J Clean Prod.* 2017; **143**: 710–718.
Publisher Full Text
64. Creutzig F, Agoston P, Minx JC, *et al.*: **Urban infrastructure choices structure climate solutions.** *Nature Clim Change.* 2016; **6**: 1054–1056.
Publisher Full Text
65. Rodriguez RS, Ürge-Vorsatz D, Barau AS: **Sustainable Development Goals and climate change adaptation in cities.** *Nat Clim Chang.* 2018; **8**: 181–183.
Publisher Full Text
66. Haberl H, Wiedenhofer D, Pauliuk S, *et al.*: **Contributions of sociometabolic research to sustainability science.** *Nat Sustain.* 2019; **2**: 173–184.
Publisher Full Text
67. Stephan A, Crawford RH, Bunster V, *et al.*: **A comprehensive model for quantifying the environmental and financial performance of cities.** In *Engaging Architectural Science: Meeting the Challenges of Higher Density.* 2018; **10**.
Reference Source
68. Frost G, Harding AH, Darnton A, *et al.*: **Occupational exposure to asbestos and mortality among asbestos removal workers: a Poisson regression analysis.** *Br J Cancer.* 2008; **99**(5): 822–829.
PubMed Abstract | Publisher Full Text | Free Full Text
69. Pollock K: **Policy: Urban physics.** *Nature.* 2016; **531**(7594): S64–S66.
PubMed Abstract | Publisher Full Text
70. Arif M, Egbu C: **Making a case for offsite construction in China.** *Engineering, Construction and Architectural Management.* 2010; **17**: 536–548.
Publisher Full Text
71. Piroozfar PA, Piller FT: **Mass customisation and personalisation in architecture and construction.** (Routledge, 2013).
Reference Source
72. Brasche S, Bischof W: **Daily time spent indoors in German homes - Baseline data for the assessment of indoor exposure of German occupants.** *Int J Hyg Environ Health.* 2005; **208**(4): 247–253.
PubMed Abstract | Publisher Full Text
73. Janda KB: **Buildings don't use energy: people do.** *Archit Sci Rev.* 2011; **54**(1): 15–22.
Publisher Full Text
74. Moynihan MC, Allwood JM: **Utilization of structural steel in buildings.** *Proc Math Phys Eng Sci.* 2014; **470**(2168): 20140170.
PubMed Abstract | Publisher Full Text | Free Full Text
75. D'Amico B, Pomponi F: **Accuracy and reliability: A computational tool to minimise steel mass and carbon emissions at early-stage structural design.** *Energy Build.* 2018; **168**: 236–250.
Publisher Full Text
76. Orr J, Pronk A, Ibell T: **Editorial Special Issue: Advanced Manufacturing and Materials for Innovative Structural Design.** *Structures.* 2019; **18**: 1.
Publisher Full Text
77. Gutowski TG: **A Critique of Life Cycle Assessment; Where Are the People?** *Procedia CIRP.* 2018; **69**: 11–15.
Publisher Full Text
78. Satz D, Ferejohn J: **Rational choice and social theory.** *J Philos.* 1994; **91**(2): 71–87.
Publisher Full Text
79. Vollan B, Henry AD: **Diversity in decision-making.** *Nat Clim Chang.* 2019; **9**: 258.
Reference Source
80. Bryant CD, Peck DL: **21st century sociology: A reference handbook.1**: (Sage, 2007).
Reference Source
81. Guinée JB, Heijungs R,Huppes G, *et al.*: **Life Cycle Assessment: Past, Present, and Future†.** *Environ Sci Technol.* 2011; **45**(1): 90–96.
Publisher Full Text
82. ISO: **BSI EN ISO 14040: 2006 Environmental management - life cycle assessment - principles and framework.** British Standard Insitution, 2006.
Reference Source
83. BSI: **BS EN 15978: 2011. Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method.** 2011.
Reference Source
84. RICS: **Whole Life Carbon Assessment for the Built Environment, 1st edition.** 2017.
Reference Source
85. Pomponi F, Moncaster AM: **Embodied carbon mitigation and reduction in the built environment - What does the evidence say?** *J Environ Manage.* 2016; **181**: 687–700.
PubMed Abstract | Publisher Full Text
86. Treloar GJ: **Extracting embodied energy paths from input-output tables: towards an input-output-based hybrid energy analysis method.** *Econ Syst Res.*

1997; **9**(4): 375–391.
Publisher Full Text

87. Lenzen M, Treloar G: **Embodied energy in buildings: wood versus concrete—reply to Börjesson and Gustavsson.** *Energy Policy.* 2002; **30**(3): 249–255.
Publisher Full Text

88. Crawford RH: **Life Cycle Assessment in the Built Environment.** Spon Press, 2011.
Publisher Full Text

89. Stephan A, Crawford RH, Bontinck PA: **A model for streamlining and automating path exchange hybrid life cycle assessment.** *Int J Life Cycle Assess.* 2019; **24**: 237–252.
Publisher Full Text

90. IEA: **Annex 53 IEA EBC**. (Accessed: 1st May 2019).
Reference Source

91. Birgisdottir H, Moncaster A. Wiberg HA, *et al.*: **IEA EBC annex 57 'evaluation of embodied energy and CO2eq for building construction'.** *Energy Build.* 2017; **154**: 72–80.
Publisher Full Text

92. IEA: **Annex 57 IEA EBC**. (Accessed: 1st May 2019).
Reference Source

93. IEA: **Annex 72 IEA EBC**. (Accessed: 1st May 2019).
Reference Source

94. Malik A, McBain D, Wiedmann TO, *et al.*: **Advancements in Input-Output Models and Indicators for Consumption-Based Accounting.** *J Ind Ecol.* 2019; **23**(2): 300–312.
Publisher Full Text

95. Anderson J: **Construction LCA's 2019 guide to EPD by jane anderson - Infogram**. (Accessed: 1st May 2019).
Reference Source

96. Bullard CW, Herendeen RA: **The energy cost of goods and services.** *Energy policy.* 1975; **3**(4): 268–278.
Reference Source

97. Wright DJ: **Good and services: an input-output analysis.** *Energy Policy.* 1974; **2**(4): 307–315.
Publisher Full Text

98. Costanza R: **Embodied Energy and Economic Valuation.** *Science.* 1980; **210**(4475): 1219–1224.
PubMed Abstract | Publisher Full Text

99. Let's rename 'Embodied Carbon' to 'Upfront Carbon Emissions' TreeHugger. (Accessed: 1st May 2019).
Reference Source.

100. Bionova Ltd: **Embodied_Carbon_Review_ 2018.pdf.** 2018.
Reference Source

101. Wiedmann T, Minx J: **A definition of 'carbon footprint'.** *Ecological economics research trends.* 2008; **1**: 1–11.
Reference Source

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✔ **Michal P. Drewniok**
Department of Engineering, University of Cambridge, Cambridge, United Kingdom

This paper presents a very interesting and important review on the factors that are likely causing the lack of research visibility of studies on the environmental impact of buildings (construction) in interdisciplinary journals.

Interesting, but not surprising is the fact that the research outputs in this area significantly increased over the last decade.

The paper includes literature review on this topic. Reviewer found however, difficulties in finding the structure that define a problem, problem importance, how the problem can be solved and what impact can have the solution. The Authors identified 6 weak areas that might improve research visibility (The uniqueness factor, The life-cycle factor, The scale factor, The human factor, The systemic social factor, The methodological factor) non of these were pointed to be more or less important, or how these might help to increase the visibility.

The Authors concluded: "This is why research in this field must find a way to gain global visibility and attention and build a diverse and interdisciplinary community to orchestrate concerted actions, share and learn lessons, and accelerate impact." The main and the most important question arises: What should be done to make the research more visible? Is it not interesting (and if yes, why?)? Not important? What are the Authors ideas? It would be the greatest Author's achievement and output from this research.

Some more detailed comments below:
Please note that that the environmental impact of buildings should be considered by building typology (e.g. office building - analogy to a mouse) and the best option is to have more than one that is analysed. Reviewer know a few papers that analyse only one building using 3 different technologies (concrete, timber and steel - analogy to 3 mice) in Energy and Buildings (H: 147, IF: 4.867) **- "**Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules". But indeed, Energy and Buildings is not in the *10 international journals based on H-index values. Reviewer would like to mention softly that the m*ain difference between biology and

engineering science is that in the engineering research no animals or humans are used to provide experiments.

Indeed over the last 2 decades the operational energy was mainly assessed to provide building performance score. Over the last decade however, when construction materials demand dramatically increased, the more attention is paid to embodied energy/carbon in materials used in buildings. Already in 2011 approved standard BS EN 15978:2011 "Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method" introduced a method that combines embodied and operational energy (carbon). This methodology is further developed and also accepted to be mandatory by the Royal Institution of Chartered Surveyors in the UK. But as the Authors noticed, there is still lack of the data that allows to make complete whole life carbon assessment and indication the importance of embodied and operational carbon.
Authors correctly presented that the impact should be accessed both from the building, district, city, country and global point of view.

It should be highlighted, that buildings, no mater if they are constructed on-site or off-site (manufactured) are (had to be) designed and then created. Complete whole life assessment might be an excellent decision making tool, if only we have enough data to make a complete assessment. The other aspect is that prefabrication accounts for a small share in the UK construction. However, the share is much larger in other countries, e.g. Denmark, Norway, Poland. The question is what presents some countries to use off-site manufacturing?

Indeed "No two homes are the same" This is true if we look from the house arrangement. However, from a structural point of view, many buildings (including British Victorian houses) are identical. In Europe (especially in Eastern Europe) we can find entire estates with many identical blocks with identical flats.

Overall, in my opinion, the article can be pass peer review.

Is the topic of the opinion article discussed accurately in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?

Yes

Are arguments sufficiently supported by evidence from the published literature?

Partly

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Partly

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Partly

Does the piece present solutions to actual real world challenges?
Partly

Is real-world evidence provided to support any conclusions made?
Partly

Could any solutions being offered be effectively implemented in practice?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: LCA in construction, construction technology, structural engineering, material science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 25 August 2020

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Antonio Garcia Martinez
Department of Building Construction, Universidad de Sevilla, Seville, Spain

The paper investigates the profound reasons that could be found behind the lack of visibility of studies on the environmental consequences of buildings within the scientific world in general and in that of high-impact publications in particular. It provides an original point of view of great value and relevance that will undoubtedly help a better understanding of this complex research object. The authors show a high knowledge of the methodological circumstances, and the theoretical and practical barriers that surround research in this field. Through solid evidence, they construct a well-articulated argument about the factors that determine scientific research in the field of environmental evaluation of buildings and progressively they reach interesting conclusions. From my point of view, the article deserves to be indexed.

Is the topic of the opinion article discussed accurately in the context of the current literature?
Yes

Are all factual statements correct and adequately supported by citations?
Yes

Are arguments sufficiently supported by evidence from the published literature?

Yes

Are the conclusions drawn balanced and justified on the basis of the presented arguments?
Yes

Is the argument information presented in such a way that it can be understood by a non-academic audience?
Yes

Does the piece present solutions to actual real world challenges?
Yes

Is real-world evidence provided to support any conclusions made?
Yes

Could any solutions being offered be effectively implemented in practice?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Life Cycle Assessment of Buildings. Environmental impacts in Construction Sector.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.