Dear Editors, dear Reviewers,

First of all, I want to thank you for the prompt handling of our submission by the editors, and for the very constructive comments and suggestions by the reviewers. We actually agree to all points raised, and our responses can be found below, numbered by reviewer, partly in tabular form, partly in non-tabular form.

In addition to the points raised, we made the following changes:

* We changed the title as we found it more appropriate to write about “random selection of samples” instead of “semi-statistical analysis”.
* We included a new figure (Figure 2) that shows the population of buildings, as well as the spatial distribution of the randomly selected samples (=objects). For this and an in-depth analysis of our geo-data digital building model, we asked our GIS-expert Andreas Gassner (who already published is last article in JoIE) to join the team, also as co-author.
* Even though not claimed by the reviewers, we sent the manuscript to English proofreading. We think that the result is no an even much better readable paper.
* Even though we were gratitude for the supporting materials, we extended it, but also improved their readability and structure. Otherwise, readers get lost in all the heap of data. Therefore, we have now one supporting\_document. The manuscript only refers to this. In the supporting\_document, calculations are better explained, but also the supporting\_data (3 files, Excel).

In case of questions, please don’t hesitate to contact us. We are looking forward to your responses.

With best regards

Jakob Lederer (in the name of the authors)

# Reviewer 1:

## Comment Reviewer 1:

This study focused on material intensity quantification by taking samples in Vienna. The authors considered more detailed structure information of buildings than previous studies and used it to refine the estimation of MI. This process can improve the rationality of MI quantification but increases the complexity of material stock/flow assessment on buildings. I suggest this manuscript can be further revised by the following two alternative approaches:

1. Based on the results of refined MI estimation, authors could do more in-depth research by combing with MFA-GIS. Maybe Vienna is a good choice because authors could compare their results with Kleemann’s. Following this approach, this manuscript can attract more audiences and have broader implications.

2. Keeping focusing on MI quantification but need more samples from a broader geographical scope. As a trade-off, refining MI can improve the accuracy of material stock/flow estimation but increases the complexity of MFA. Authors’ samples from Vienna can not represent the situation of a region (e.g., Europe or western/eastern Europe), resulting in their method would not or very difficult to apply to other cases due to the data availability (e.g., architectural structure information for each building). In this context, authors may need to sample from more cities and summarize regular patterns (e.g., a ratio of refined MI vs. previous values), leading to scaling-up of MI information from sites to a region.

## Response of authors to Reviewer 1:

Dear Reviewer, we are grateful for the two suggestions. Considering how long it takes to collect more samples from another area as suggested in alternative approach 2, we decided to use alternative approach 1.

For approach 1, we highlighted that using MIs differently generated to the same research object, in our case the material stocks in buildings in the city of Vienna, may lead to different results. Therefore, we inserted a new research question and objective on the influence of different MIs on material stock estimates (page 5, line 1104 and lines 110-112). Based on that, we decided to use the newly generated data set to re-estimate the material stock in buildings in Vienna and compare them to the results from Kleemann et al. (2017). Therefore, we use the same GIS-dataset. The methodology is described in a new subsubsection 2.4, on page 12, lines 249-256. The result is shown in a new section in both, the results (subsection 3.4., page 15, line 332-341) and the discussion (subsection 4.4, page 19, line 442-458). The underlying calculations are presented in a new online supporting\_data 3 file.

With respect to approach 2, we hope that our research inspires other groups so that they may increase the database by case studies from other world cities and regions using a similar approach as the one presented in this study. In such a case, we will provide our help if desired.

# Reviewer 2:

## Comments Reviewer 2:

The authors present a well-written and clearly presented study on the determination of material intensities (MI) for buildings, using the city of Vienna, Austria, as a case. To broaden the evidence base on buildings (MIs), they address two of the key limitations of existing MIs: unclear definitions of what is actually seen as “building” and the lack/unclear representativeness of these MIs in relation to the entire building stock of a region/city/country. The paper is very clear and provides useful reflections on the pro’s, con’s, method and results. I have only very minor suggestions for editing/finetuning. I also want to highly applaud the authors for providing such an extensive supplementary data file, which will definitely be very useful for other researchers. I suggest that the authors/editor consider the JIE transparency badge for this paper?

## Response of authors to Reviewer 2:

Dear Reviewer, many thanks not only for your very valuable comments, but also for your very positive judgment of our article and the supplementary data presented. Indeed, I can’t remember an article of mine in which I presented so much of the material and data I used, and in fact, the only possible step ahead would be to supply also the scans of the plan documents of the sampled buildings. However, we crosschecked with the intellectual property lawyer of our University, and she clearly said that for all plan documents of younger buildings, we would have to seek permission from the architect to provide the scans for open download. We thus decided not to do that.

We will respond to each point in Table 1:

Table 1: Response to Reviewer 2

|  |  |  |
| --- | --- | --- |
| Comment reviewer | Response authors | Referred text in revised manuscript |
| Abstract, line 10-12: Completely agree; could be written even more directly, e.g.  1) “reference values on their size” -- rather than size, maybe dimensions is a better  term (?), as you also use on page 9?  2) “many studies lack a clear ...” – they also often lack a clear/transparent  definition of “building” and its dimensions? | We agree, we changed to “dimension”, also due to homogeneity in the manuscript. We also included “definition of buildings. | Page 1, line 11-14:  “Many studies calculate the material stock of buildings using material intensities and reference values on building dimensions. Often, they lack a clear definition of and transparency in the selection of buildings to be analyzed, as well as adequate description for the determination of the material intensities of buildings.” |
| P3: you could add a sentence somewhere early in the intro, that the “reference  value” of a building is the direct link to building stock energy research (and many  other applications); therefore it is crucial that transparent definitions are given and  where feasible, different reference values are provided so that MIs can be reestimated by other researchers for their purposes? (as you do in this paper!) | We agree and included the sentence, and also one reference investigating materials and energy of building stocks. | Page 2, lines 44-45:  “The RV thus provides the link between material stocks and energy demand, for instance for heating and cooling of buildings (Stephan and Athanassiadis 2017).” |
| P5, line 86: section header: “expression of MIs and comparability of studies”  Section-header not really clear that the building definition is actually the issue here;  maybe add “Limitations to comparability due to expression of MI based on unclear  and differing building defintions” | We agree and used more or less the phrase suggested, as we did not found a better one. | P4, Line 91:  “1.2.3 Limitations to comparability due to expression of MI based on unclear building definitions” |
| P5, line 87-92 … because often national statistics use differing and changing  definitions, so researchers adapt to their national specifics also, not always taking  into account that others might different base-definitions? | I totally agree, and we currently experience that in Austria, namely a shift from using useable floor area (determined from surveys) to net- or gross-floor area (determined by calculation). Furthermore, different accounting systems exist in different countries. I added two sources on that. | Page 4, lines 93-94:  “This due to different accounting systems across countries as well as changes in national statistical procedures (Trabucco and Miranda 2019; Statistics Austria 2010).” |

# Reviewer 3:

## Comments Reviewer 3:

This paper presents a semi-statistical method for collecting and analyzing the buildings to calculate the material intensity. Based on a digital building model, it allows the detailed estimation of the material uses in the building components. This study contribute to the material stock and flow analysis by accurately determining the material intensity in a city scale. The manuscript is well structed. The data and methods are clearly illustrated. The only suggestion is to add some discussion that how can reproduce or apply the method in those cities without digital building models or data. And the possibility of improving the data collecting and calculating efficiency by using the emerging big-data technology.

## Response of authors to Reviewer 3:

Dear Reviewer, many thanks for your appreciation of our work and your suggestion. We took the point you raised and discuss in Subsection 4.1.1 extensively (see page 16, lines 346-362). To summarize that, we distinguish between two situations with respect to data availability:

Situation 1 is a situation in which digital building models, like digital 3-D cadaster plans, are available. According to our knowledge, this would be the case for instance in the cities like Melbourne (Stephan and Athanassiadis 2017), Hamburg (Schiller et al., 2020), Odense (Lanau and Liu 2020), Padua (Miatto et al. 2019), Manchester and Wakayama (Tanikawa et al. 2009). In these cities, a similar approach as the one described in our manuscript can be used (see page 16, lines 346-351).

Situation 2 is a situation where these digital building models are not available or existing. In these cases, we proposed two approaches, both based on open accessible geo-datasets. Approach 1 refers to open geo-datasets giving information on buildings. Examples are available for cities like Canberra (Schandl et al., 2020) or Beijing (Mao et al., 2020). Here, the total population of buildings can be generated based on the open geo-datasets, and from these, samples can be randomly selected. To do so, big geo-based datasets are used, as you highlighted in your review. Approach 2 refers to open geo-datasets giving information on streets, like open street map. In this case, random points on streets can be selected and the buildings closest to these points can be selected as samples. Examples for the applicability of this approach, which derives from household surveys mainly in developing countries where houses often not even have a postal address, might be Jakarta and Bandung in Indonesia (Surahman et al., 2017) (see page 16, lines 352-362).

In both situations, the randomly selected buildings have to be analyzed, either based on plan documents available, or, as done by Surahman et al. (2017), Schebek et al. (2017), or Kleemann et al. (2016), by site-specific investigation, which is obviously the more laborious approach (see page 16, lines 363-367). Like with geo-datasets, big data technology, as you suggested, can also be used here, for instance when building information modelling (BIM) data on buildings is used to extract certain building properties, particularly building dimensions and material quantities and thus composition. In a current research project called M-DAB, we also investigate the opportunities of BIM in material stock estimates ([Link](https://www.researchgate.net/project/Analyzation-Digitalization-and-Sustainable-Management-of-Anthropogenic-Resources-within-the-City-M-DAB)), using the case study of Vienna. The reason why I did not highlight this point too much in the manuscript is that hitherto, our experiences in doing so are rather disappointing, and I simply don’t know yet in which direction our further experiences and thus conclusions will go. BIM would have great opportunities, but the data on building dimensions and built-in material quantities I got was rather of poor quality. For instance, in one case, I got reasonable data on material quantities, but only the net-floor area, and not the gross-floor area or the gross volume. In another case, it was exactly the other way round. In an older study (of course Kleemann et al. 2017), we got BIM data from 12 newly built buildings, and we could only use the material quantities after going through the plan documents by ourselves (manually), as many of these estimates were simply wrong. And this is the situation for new buildings. For existing and particularly older buildings, which make the bulk of the material stock in buildings in cities like Vienna (or Paris, Berlin, Milano, Barcelona, ……), no BIM datasets are available at all. In a stakeholder workshop on the impacts of digitalization in the building industry on CD waste and resource management, the CEO of a construction company pointed it out like this: “BIM can be a useful tool, and there’s a big hype. However, our experience is that it is currently overrated for new buildings, and completely useless for old buildings as their irregular nature does simply not fit in the BIM framework.” Having seen the development of AutoCad from 2D via 3D to 4 and more D (=BIM) since I started my education (and practical experience) in civil engineering in 1994, I would not go that far, as I see the rapid progress in BIM, big data management, and machine learning. However, before I would make a strong statement in an article as the one we have submitted, I’d rather see which further challenges and highlights we will experience in the course of the M-DAB project.

# Reviewer 4:

## Comments Reviewer 4:

The authors have presented a semi-statistical approach to collect and determine material intensities (MIs) of buildings, using the case study of Vienna. This work constitutes an important contribution to the field. Since MIs play a crucial role on the calculation of material stock, C&D waste, etc., the scope of this study meets the need of establishing a systematic procedure for the generation of these indicators. From a methodological and technical viewpoint, the paper is very good. The manuscript is very well written and clearly structured. Some minor comments are listed below; when they are addressed, I would recommend this article for publication.

## Response of authors to Reviewer 4:

We are very grateful for these very helpful comments, and we want to respond to them in Table 2:

Table 2: Response to Reviewer 4

|  |  |  |
| --- | --- | --- |
| Comment reviewer | Response authors | Referred text in revised manuscript |
| Keywords: I would suggest removing “statistical analysis” from the list | We agree and use “random sampling” | Page 1, lines 26:  “random sampling” |
| p8, line 154-155: “… they were filled-up with randomly selected samples from the corresponding categories, leading to in total 256 objects”. Could the authors  comment more explicitly about this? | For some buildings categories, only 1 or 2 objects were in the sample. We wanted to increase the number of samples (i.e. objects) for these categories, so we added some objects which we randomly selected, but only from these building categories. For instance, if we had only 1 industrial building object from the age category 1919-1945 and the size category <1,000 m³ GV, we randomly selected 2 more of these objects. | Page 7, lines 152ff:  “As the number of samples were fairly small for some building categories, additional samples from these categories were randomly selected and added to the sample, leading to 256 objects to be analyzed in total.” |
| p13, line 246: “could not” instead of “couldn’t” | Agree, we changed that. | Page 11, line 234:  “…the MI could not…” |
| p13, line 26: “Equation 10” instead of “Equation 1” | Agree, we corrected that | Page 11, line 2644 |
| p13, line 263: m3 instead of m2 | Agree, we corrected that | Page 12, line 259 |
| p17, line 359: The authors indicate that buildings <1,000m³ GVeaves were  overrepresented. Since figure 2 and supplementary\_data\_1 show that the share (in  number and GV) of this category is the lowest (when comparing with their  associated reduced population), it is not clear if this comment is related to the  entire population or not. Could the authors comment more explicitly about this? | This means that each object was a sampling unit, and each object had an equal chance to be selected. Considering the large number of small objects, and their small contribution to the total gross volume of all buildings, the consequence is that one m³ gross volume of a small building had a higher chance to be selected than one m³ gross volume of a larger building. However, as this point caused some confusion, we decided to describe it more generally. This was also necessary, as I had to maintain the length of the article. | Page 17, line 368ff:  “More attention could be given to get a more representative sample with a higher representation of larger buildings.”. |
| 4 Discussion: although MIs mean-values are commonly used to calculate material  stocks, I would encourage the authors to include a discussion about the  uncertainties in the MIs obtained in this study. | We agree and we introduce a discussion point on this topic (4.3.4 Consideration of uncertainties in MIs). | Page 219, lines 432ff:  The MIs determined in this study are generally mean values, and for some building categories that contain a sufficient number of objects, like residential buildings, it is possible to calculate statistical uncertainties. For most other building categories, this is not possible as the number of samples per category is between one and seven objects (supporting\_document, Section 3.1.1, Table S9). The reasons for this are the large number of building categories, on the one hand, and the still small number of samples if compared to the population, on the other. If the statistical uncertainties of all building categories are desired, there are two options for obtaining them: either some sub-categories of buildings must be merged to one category, or many more plan documents of building categories with currently low sample sizes must be collected. Obviously, the latter makes more sense. |
| Figure S4: there is not a dotted green line on the right side of the image as the text  indicates | Agree, the line is dotted, but not green. We changed to solely dotted line. |  |

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