BUKTI KORESPONDENSI

Jurnal Internasional Bereputasi terindeks Scopus dan SJR

Judul paper:

“Up on the roof: a review of design, construction, and technology trends in vertical extensions”

Nama jurnal:

Architectural Science Review, Vol. 67, No. 1, January 2024, halaman 63-77

sebelumnya Architectural Science Review (online), Agustus 2023

Daftar korespondensi:

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2. Informasi bahwa paper sedang dalam proses review - 7 Feb 2023
3. Notifikasi hasil review dan deadline submit revisi paper - 27 Feb 2023
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5. Permintaan perubahan format untuk paper dapat direview - 21 Apr 2023
6. Konfirmasi bahwa paper sedang dalam proses review - 25 Mei 2023
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9. Notifikasi online proofing system and paper DOI - 21 Jul 2023
10. Permintaan untuk mereview author publising agreement - 22 Jul 2023
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12. Permintaan untuk mereview paper proof & mengirim koreksi - 25 Jul 2023
13. Konfirmasi bahwa koreksi proof telah diterima & snapshot koreksi - 26 Jul 2023
14. Permintaan mengirim revisi gambar - 27 Jul 2023
15. Notifikasi bahwa paper telah publish online open access - 1 Agt 2023
16. Notifikasi bahwa paper dipublish di Vol. 67 - 13 Des 2023

1. Konfirmasi submit paper - 25 Okt 2022

From: Architectural Science Review
To: Eunike Kristi Julistiono
Subject: Architectural Science Review - Manuscript ID ASRE-2022-0158
Date: Tuesday, 25 October 2022 6:13:46 PM

25-Oct-2022

Dear Ms. Julistiono:

Your manuscript entitled "Up on the Roof: A Review of Design, Construction, and Technology Trends in Vertical Extensions" has been successfully submitted online and is presently being given full consideration for publication in the Architectural Science Review.

Your manuscript ID is ASRE-2022-0158.

Please mention the above manuscript ID in all future correspondence or when calling the office for questions. If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at https://mc.manuscriptcentral.com/asre and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Center after logging in to https://mc.manuscriptcentral.com/asre.

Thank you for submitting your manuscript to the Architectural Science Review.

Sincerely,
Architectural Science Review Editorial Office

2. Informasi bahwa paper sedang dalam proses review - 7 Feb 2023

From:	TASR-peerreview@journals.tandf.co.uk
To:	Eunike Kristi Julistiono
Subject:	Re: Submission update #TrackingId:14147034
Date:	Tuesday, 7 February 2023 3:44:29 AM

You don't often get email from tasr-peerreview@journals.tandf.co.uk. Learn why this is important

Dear Eunike Kristi Julistiono,

Thank you for your email!

I have checked the status of your manuscript within our online submission system and I can confirm we have one review returned and another who is due to return their comments to us within the next fortnight. We will arrive at a decision as soon as possible, thereafter.

I am unable to provide any more specific information regarding your submission at this time, aside from assuring you that we will do our best to deliver a decision to you as soon as possible.

Please do not hesitate to contact me if you have any further questions or concerns.

Best,

Marissa

Marissa Nania - Journal Editorial Office

Taylor & Francis Group

Web: www.tandfonline.com

BIG_11081_OpenAccess_banner_600x150_1.png

TransferScheme_email sig_650x150px.png

Architectural Science Review

From:onbehalfof@manuscriptcentral.com
Sent:04-02-2023 12:24
To: Marissa.nania@gwinc.com
Cc:
Subject: Re: Submission update

Dear Sir/Madam,

I would like to ask regarding the progress of my paper (manuscript ID is ASRE-2022-0158). It was submitted on October 2022 and currently the status is under review.
Is there any updates on the status? Is there anything which I need to add to the submission?

I'm really looking forward to hearing some updates.

Best regards,

Eunike Kristi Julistiono

3. Notifikasi hasil review dan deadline submit revisi paper - 27 Feb 2023

From: Architectural Science Review
To: Eunike Kristi Julistiono
Cc: francesco.fiorito@poliba.it; Francesco Fiorito
Subject: Architectural Science Review - Decision on Manuscript ID ASRE-2022-0158
Date: Monday, 27 February 2023 10:56:43 PM

27-Feb-2023

Dear Ms. Julistiono:

Manuscript ID ASRE-2022-0158 entitled "Up on the Roof: A Review of Design, Construction, and Technology Trends in Vertical Extensions" which you submitted to the Architectural Science Review, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter. In addition to written comments, the reviewers have been invited to answer a number of questions on a 1 to 5 scale (5 being the most favourable), and these questions and responses have been included for your information.

The reviewer(s) have recommended publication, but also suggest some minor revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript.

To revise your manuscript, log into https://mc.manuscriptcentral.com/asre and enter your Author Center, where you will find your manuscript title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision.

You may also click the below link to start the revision process (or continue the process if you have already started your revision) for your manuscript. If you use the below link you will not be required to login to ScholarOne Manuscripts.

*** PLEASE NOTE: This is a two-step process. After clicking on the link, you will be directed to a webpage to confirm. ***

https://mc.manuscriptcentral.com/asre?URL_MASK=612b7c1b3ed847ef8786ff1d5f325782

You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript using a word processing program and save it on your computer. Please also highlight the changes to your manuscript within the document by using the track changes mode in MS Word or by using bold or colored text.

Once the revised manuscript is prepared, you can upload it and submit it through your Author Center.

When submitting your revised manuscript, you will be able to respond to the comments made by the reviewer(s) in the space provided. You can use this space to document any changes you make to the original manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the reviewer(s).

IMPORTANT: Your original files are available to you when you upload your revised manuscript. Please delete any redundant files before completing the submission.

Because we are trying to facilitate timely publication of manuscripts submitted to the Architectural Science Review, your revised manuscript should be submitted by 29-Mar-2023. If it is not possible for you to submit your revision by this date, we may have to consider your paper as a new submission.

Once again, thank you for submitting your manuscript to the Architectural Science Review and I look forward to receiving your revision.

Sincerely,
Prof. Darren Robinson
Editor in Chief, Architectural Science Review
d.robinson1@sheffield.ac.uk

Referee(s)' Comments to Author:

Referee: 1

Recommendation: Minor Revision

Comments:
This paper is about in detail the classification of the technological approaches of vertical extensions implemented in existing buildings. The paper contains an interesting database of 172 VE examples from around the world with the greatest number of projects from the United Kingdom, the United States, and Australia. In this research, a mixed method approach of literature review, documentary research, and stakeholder interviews was used.
The research conducted focused on the following issues:
- the global trends on the evolution of the VE structure;
- types of VE;
- different architectural, structural, and constructional technologies used in VE projects.
The base buildings of the projects reviewed were classified into five functions:
(a) industrial, (b) other commercial/public, (c) office; (d) education, (e) residential.
The authors analyzed architectural, structural, and construction strategies.
Taking into account the architectural approach, two strategies were analyzed: form (extruded, setback, roof form, rooftop cottages, freeform) and façade design (unified, similar, distinct) of VEs.
The analysis of structural strategies considered two factors: planned/unplanned VE and
structural support strategies (fully supported, supported by the existing structure, supported by a separate structure).
In terms of construction strategies, two trends were examined: structural materials.
used and the occupation condition of the base building while the VE is constructed.

On evaluating the paper positively, I have a few minor comments:
- In the paper there is information about 172 examples of VE, while in several figures the number is different:
There are 171 projects in total in Figure 3 (Project locations by country);
Figure 4 shows a total of 180 base buildings and 172 VE;
Figure 9 shows a total of 180 base buildings and 172 VE;
Figure 12 shows a total of 183 VE;
Figure 14 shows a total of 175 VE;
Table 4 shows that there are 180 of all the buildings analyzed buildings (Industrial + office + residential =140, and where are the rest of the buildings?);
- Does it make sense to consider a 21-30 storey vertical extension to the base building (is this still a VE or a completely new building)
- what is meant by VE with demolition in Table 4.

Additional Questions:
1. Is the topic relevant to ASR, ie, to the science of architecture and the built environment.: 5

2. Is the research problem important and/or is the methodological approach innovative?: 3

3. Is the literature review comprehensive and reviewed in an integrative and critical manner?: 4

4. Are the research methods clearly stated and appropriate for the questions being addressed?: 5

5. Are the findings, interpretations and conclusions warranted from the research and data collected?: 4

6. Will the findings have applicability beyond the particular situation studied?: 3

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 4

8. Overall rating: Does the paper contribute to new knowledge in the field?: 4

Referee: 2

Recommendation: Accept

Comments:
The paper deals with a very important topic and provides a worthwhile review of vertical extension of buildings.
The manuscript is well written and the figures are clear.
This reviewer encourages the authors of the paper to go on in this research direction, and, after this overall overview, to deepen some specific aspects and/or paradigmatic projects

Additional Questions:
1. Is the topic relevant to ASR, ie, to the science of architecture and the built environment.: 5

2. Is the research problem important and/or is the methodological approach innovative?: 4

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4. Are the research methods clearly stated and appropriate for the questions being addressed?: 3

5. Are the findings, interpretations and conclusions warranted from the research and data collected?: 3

6. Will the findings have applicability beyond the particular situation studied?: 4

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 4

8. Overall rating: Does the paper contribute to new knowledge in the field?: 4

Referee: 3

Recommendation: Reject & Resubmit

Comments:
The topic of vertical extension of existing buildings as a method to densify the city which has been proved a positive strategy to reduce global energy use and energy related GHG emissions reducing commuting times, is relevant for the realization of sustainable cities and societies. It is also important then that the realization of vertical extensions is performed with the scope to reduce building lifecycle carbon emissions.
The article analyses different construction and functional aspects of the 172 vertical extension considered as number of stories, functional changes, extension formal strategies, and types of façade used. These data are interesting, however the main (expected) scope of the research is missing: an investigation about the potential of vertical extensions to reduce building lifecycle carbon emissions in comparison with conventional new buildings on empty areas. The reviewer thinks that without the analysis and relative results related to energy and carbon emission the research is not providing important new knowledge. Adding an analysis related to energy use and carbon emission in relation to different aspects of vertical extensions could help planners and designers in realize new low energy and carbon vertical extensions and could help researchers in developing further the knowledge.
The research methodology should be expanded. It is very simple almost a bullet points list of the different aspects and methods used. A more in depth explanation of each of these should be given also in consideration of the additional aspects to consider given in the previous point.

Additional Questions:
1. Is the topic relevant to ASR, ie, to the science of architecture and the built environment.: 3

2. Is the research problem important and/or is the methodological approach innovative?: 2

3. Is the literature review comprehensive and reviewed in an integrative and critical manner?: 4

4. Are the research methods clearly stated and appropriate for the questions being addressed?: 3

5. Are the findings, interpretations and conclusions warranted from the research and data collected?: 4

6. Will the findings have applicability beyond the particular situation studied?: 2

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 3

8. Overall rating: Does the paper contribute to new knowledge in the field?: 2

Editor's Comments to Author:
This manuscript addresses an important issue - that vertical extensions can be a highly advantageous strategy to densify urban settings in a low Carbon manner. I agree with reviewer 3 that some form of assessment of decarbonisation potential would be valuable, but understand that this might be reserved for future work. If feasible, I wonder whether you would be able to propose a tentative decision making process diagram to determine whether, for a specific case, VE was viable and, better yet, the form that this should take, depending upon a particular project's starting point and requirements? Just a thought...
Otherwise, I agree with the Associate Editor that you should respond to amendments suggested by reviewer 1.

Associate Editor
Comments to the Author:
The article is on an interesting topic for the journal, it is well written and it can be published after the minor revisions asked by the reviewers will be made.

4. Reminder untuk submit revisi paper - 16 Mar 2023

From: Architectural Science Review
To: Eunike Kristi Julistiono
Subject: Reminder: Architectural Science Review
Date: Thursday, 16 March 2023 5:05:08 PM

16-Mar-2023

Dear Ms. Eunike Kristi Julistiono:

Recently, you received a decision on your manuscript entitled "Up on the Roof: A Review of Design, Construction, and Technology Trends in Vertical Extensions."

This e-mail is simply a reminder that your revision is due on 29-Mar-2023. If it is not possible for you to submit your revision by this date, we will consider your paper as a new submission.

Please see a copy of the decision letter below which contains details of how to submit your revision and any comments from the editor/reviewers:

27-Feb-2023

Dear Ms. Julistiono:

Manuscript ID ASRE-2022-0158 entitled "Up on the Roof: A Review of Design, Construction, and Technology Trends in Vertical Extensions" which you submitted to the Architectural Science Review, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter. In addition to written comments, the reviewers have been invited to answer a number of questions on a 1 to 5 scale (5 being the most favourable), and these questions and responses have been included for your information.

The reviewer(s) have recommended publication, but also suggest some minor revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript.

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Once again, thank you for submitting your manuscript to the Architectural Science Review and I look forward to receiving your revision.

Sincerely,
Prof. Darren Robinson
Editor in Chief, Architectural Science Review
d.robinson1@sheffield.ac.uk

Referee(s)' Comments to Author:

Referee: 1

Recommendation: Minor Revision

Comments:
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Additional Questions:
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3. Is the literature review comprehensive and reviewed in an integrative and critical manner?: 4

4. Are the research methods clearly stated and appropriate for the questions being addressed?: 5

5. Are the findings, interpretations and conclusions warranted from the research and data collected?: 4

6. Will the findings have applicability beyond the particular situation studied?: 3

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 4

8. Overall rating: Does the paper contribute to new knowledge in the field?: 4

Referee: 2

Recommendation: Accept

Comments:
The paper deals with a very important topic and provides a worthwhile review of vertical extension of buildings.
The manuscript is well written and the figures are clear.
This reviewer encourages the authors of the paper to go on in this research direction, and, after this overall overview, to deepen some specific aspects and/or paradigmatic projects

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6. Will the findings have applicability beyond the particular situation studied?: 4

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 4

8. Overall rating: Does the paper contribute to new knowledge in the field?: 4

Referee: 3

Recommendation: Reject & Resubmit

Comments:
The topic of vertical extension of existing buildings as a method to densify the city which has been proved a positive strategy to reduce global energy use and energy related GHG emissions reducing commuting times, is relevant for the realization of sustainable cities and societies. It is also important then that the realization of vertical extensions is performed with the scope to reduce building lifecycle carbon emissions.
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2. Is the research problem important and/or is the methodological approach innovative?: 2

3. Is the literature review comprehensive and reviewed in an integrative and critical manner?: 4

4. Are the research methods clearly stated and appropriate for the questions being addressed?: 3

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6. Will the findings have applicability beyond the particular situation studied?: 2

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 3

8. Overall rating: Does the paper contribute to new knowledge in the field?: 2

Editor's Comments to Author:
This manuscript addresses an important issue - that vertical extensions can be a highly advantageous strategy to densify urban settings in a low Carbon manner. I agree with reviewer 3 that some form of assessment of decarbonisation potential would be valuable, but understand that this might be reserved for future work. If feasible, I wonder whether you would be able to propose a tentative decision making process diagram to determine whether, for a specific case, VE was viable and, better yet, the form that this should take, depending upon a particular project's starting point and requirements? Just a thought...
Otherwise, I agree with the Associate Editor that you should respond to amendments suggested by reviewer 1.

Associate Editor
Comments to the Author:
The article is on an interesting topic for the journal, it is well written and it can be published after the minor revisions asked by the reviewers will be made.

If you have any questions or experience any difficulties submitting your revised manuscript, please contact the journal's editorial office at TASR-peerreview@journals.tandf.co.uk.

Sincerely,
Marissa Nania
Architectural Science Review Editorial Office
TASR-peerreview@journals.tandf.co.uk

5. Permintaan perubahan format untuk paper dapat direview - 21 Apr 2023

From:	Architectural Science Review
To:	Eunike Kristi Julistiono
Subject:	Unable to Display Letter Tag (##DOCUMENT_ID_EXTERNAL##) (Architectural Science Review) - changes required to your submission
Date:	Friday, 21 April 2023 4:05:59 AM

20-Apr-2023
Re: Unable to Display Letter Tag (##DOCUMENT_ID_EXTERNAL##)

Dear Ms. Eunike Kristi Julistiono:

Your manuscript, entitled "Up on the Roof: A Review of Design, Construction, and Technology Trends in Vertical Extensions", requires some further changes before it is ready for review in Architectural Science Review:

1. Please provide individual figure files with high-resolution (minimum 300 DPI) for Figures 11, 13, 16, and 20. Figure files should be supplied in one of our preferred file formats: EPS, PS, JPEG, or TIFF. Microsoft Word (DOC or DOCX) files are only acceptable for figures that have been created using Word.

2. Please ensure your Response to Reviewers is anonymous. Currently, your Response to Reviewers identifies the authors by referencing their previous work - "Our previous research (Julistiono et al. 2023)".

3. Please remove the Appendix from your main manuscript file, uploading it in a separate file.

Please visit the instructions to authors to complete your submission and re-submit the manuscript for consideration of publication.

To re-submit your manuscript, please go to your author dashboard at https://rp.tandfonline.com/dashboard/, locate the manuscript and click 'Resume'.

Kind regards,
Marissa Nania
Architectural Science Review Editorial Office
TASR-peerreview@journals.tandf.co.uk

6. Konfirmasi bahwa paper sedang dalam proses review - 25 Mei 2023

From: TASR-peerreview@journals.tandf.co.uk
To: Eunike Kristi Julistiono
Subject: Re: Update on ASRE-2022-0158.R1 #TrackingId:15254511
Date: Thursday, 25 May 2023 6:20:46 AM

> You don't often get email from tasr-peerreview@journals.tandf.co.uk. Learn why this is important

Dear Eunike Kristi Julistiono,

Thank you for your email!

I have checked the status of your manuscript within our online submission system and I can confirm we are awaiting feedback from one reviewer who is due to return their comments to us within the next fortnight. We will arrive at a decision as soon as possible, thereafter.

I am unable to provide any more specific information regarding your submission at this time, aside from assuring you that we will do our best to deliver a decision to you as soon as possible.

Please do not hesitate to contact me if you have any further questions or concerns.

Best,

Marissa

Marissa Nania - Journal Editorial Office

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Architectural Science Review

From:onbehalfof@manuscriptcentral.com
Sent:22-05-2023 06:43
To: Marissa.nania@gwinc.com
Cc:
Subject: Re: Update on ASRE-2022-0158.R1

Dear Architectural Science Review Editor,

I would like to ask regarding my paper - ASRE-2022-0158.R1.
It's been a month since I last submitted the corrections of some images as requested. Is there any updates on the review process? If there is anything else I need to submit, please let me know.

Looking forward to hearing good news from you.

Best regards,

Eunike Kristi Julistiono

7. Konfirmasi bahwa review telah selesai, paper sedang dievaluasi editor - 6 Jul 2023

From: TASR-peerreview@journals.tandf.co.uk
To: Eunike Kristi Julistiono
Subject: Re: Update on ASRE-2022-0158.R1 #TrackingId:15672683
Date: Thursday, 6 July 2023 3:14:04 AM

You don't often get email from tasr-peerreview@journals.tandf.co.uk. Learn why this is important

Dear Eunike,

Thank you for checking in. I can confirm that your manuscript ASRE-2022-0158.R1 has undergone peer review and is now with the editors for evaluation. We will notify you of a decision as soon as one is reached. Thanks for your patience and let me know if you have any other questions!
Best,

Ashley Indelicato (she/her/ella) - Journal Editorial Office

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Architectural Science Review

From:onbehalfof@manuscriptcentral.com
Sent:02-07-2023 06:55
To: Ashley.Indelicato@gwinc.com
Cc:
Subject: Re: Update on ASRE-2022-0158.R1

Dear Editor,

It has been more than 1 month since I received the last update from you that my paper was still under review. Is there any new update now?

I'm looking forward to hearing from you.

Best regards,

Eunike Kristi Julistiono

8. Notifikasi paper 'accepted for publication' - 14 Jul 2023

From:	Architectural Science Review
To:	Eunike Kristi Julistiono
Cc:	francesco.fiorito@poliba.it; Francesco Fiorito
Subject:	Architectural Science Review - Decision on Manuscript ID ASRE-2022-0158.R1
Date:	Friday, 14 July 2023 6:37:29 PM

14-Jul-2023

Dear Ms. Eunike Kristi Julistiono:

It is a pleasure to accept your manuscript entitled "Up on the Roof: A Review of Design, Construction, and Technology Trends in Vertical Extensions" in its current form for publication in the Architectural Science Review. The comments of the reviewers who reviewed your manuscript are included at the foot of this letter. In addition to written comments, the reviewers have been invited to answer a number of questions on a 1 to 5 scale (5 being the most favourable), and these questions and responses have been included for your information.

Thank you for your fine contribution. On behalf of the Editors of the Architectural Science Review, we look forward to your continued contributions to the Journal.

Sincerely,
Prof. Darren Robinson
Editor in Chief, Architectural Science Review
d.robinson1@sheffield.ac.uk

Referee(s)' Comments to Author:

Referee: 1

Recommendation: Reject

Comments:
The reviewer comments related to the original manuscript have not been taken into account.

Additional Questions:
1. Is the topic relevant to ASR, ie, to the science of architecture and the built environment.: 3

2. Is the research problem important and/or is the methodological approach innovative?: 2

3. Is the literature review comprehensive and reviewed in an integrative and critical manner?: 3

4. Are the research methods clearly stated and appropriate for the questions being addressed?: 3

5. Are the findings, interpretations and conclusions warranted from the research and data collected?: 3

6. Will the findings have applicability beyond the particular situation studied?: 3

7. Is the quality of presentation clear and suitable (structure, English, illustrations, tables, references)?: 3

8. Overall rating: Does the paper contribute to new knowledge in the field?: 2

Referee: 2

Recommendation: Accept

Comments:
As already stated by this reviewer, the manuscript deals with a very important topic, is clear and well written, and should be published.

Additional Questions:
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Up on the roof: a review of design, construction, and technology trends in vertical extensions

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History : received : 2022-10-25 accepted : 2023-7-14

ABSTRACT

~~The creation of n~~New spaces to accommodate growing urban populations ~~needs to take place~~ should be created in a way that also reduces building lifecycle carbon emissions. In this context, the vertical extension (VE) has emerged as a novel building typology that can increase space in cities through the construction of additional floor area atop existing base buildings. This paper presents a review of 172 VE projects worldwide to provide an understanding of their design and construction trends, and to classify the technologies applied. Results show that VE construction has accelerated significantly over the past decade. Although most VEs consist of only small vertical additions, often one to two storeys, higher VEs can be built ~~by utilising~~ with innovative structural strategies and lightweight materials. Industrial buildings ~~in particular~~ are often found to provide significant opportunities for VE due to their higher structural capacity. By comparing the characteristics and design of VEs, typologies based on architectural, structural, and construction technologies are presented **[Q3]**.

KEYWORDS

- Vertical extension
- urban densification
- space demand
- technologies
- construction trends
- sustainable development

FUNDING

This work was supported by the Australia Awards Scholarship.

Introduction

Minimising whole lifecycle carbon emissions from the building sector is a global necessity, since building-related emissions are responsible for 37% of energy-related greenhouse gas emissions (UNEP 2021). The need to reduce embodied carbon, which is the greenhouse gas emissions associated with materials, construction, maintenance and demolition, disposal and recycling of a building, is becoming increasingly influential (De Wolf, Pomponi, and Moncaster 2017; Helal, Stephan, and Crawford 2020; Nadoushani, Moussavi, and Akbarnezhad 2015; Röck et al. 2020) with embodied carbon being shown to be responsible for 27-70% of a typical building's lifecycle emissions (Pomponi and Moncaster 2016; Robati et al. 2021). Such figures are likely to increase, as new building development in many regions aspired for net-zero operational performance by 2030, meaning embodied
carbon could be responsible for 100% of lifecycle emissions in many new buildings, in only a few years.

Simultaneously, there is a demand for increased space in urban areas. Urban growth is fuelled by population increases, rapid urbani~~z~~sation, globali~~z~~sation
, economic development, and wealth. In 2018, roughly 55% of the world's population were urban dwellers, but this was predicted to increase to 60% in 2030 and 68% in 2050 (United Nations 2019). To accommodate this growth, it is suggested an additional 230 billion square metres of floor area is needed, doubling existing floorspace by 2060 (UNE and IEA 2017). Between 2010 and 2020, a 12.5% increase in the global population caused a 22.5% rise in floor area (UNEP 2021) not only to satisfy the space demand but also economic growth. While much of this growth is fuelled by increases in wealth and the demand for larger living spaces, there **[Q1] [Q2]** is also a legitimate demand for new buildings to support the health and well-being of society, with some 1.6 billion people living without adequate shelter (Habitat for Humanity 2022).

Acknowledging the negative impacts of urban sprawl, future space demand should be met in a way that supports urban densification and compact city forms as part of sustainable urban development models (Broitman and Koomen 2015; Hernandez-Palacio 2014; Mouratidis 2019; Neuman 2005; Oldfield 2019; Stevenson et al. 2016; United Nations 2017). Since preserving green and rural regions is crucial to ensure a healthy urban environment, creating new floorspace in a sustainable manner often relies on brownfield development (Cappai, Forgues, and Glaus 2019; Dulić and Krklješ 2014; Smith 2008).

Nonetheless, if this development includes the demolition of existing buildings and creation of new construction, significant waste and carbon emissions will be produced.

The Vertical Extension (VE), in which an extra storey(s) is built atop an existing base building, has emerged as a novel solution to increase urban floor area while preserving existing buildings, thus minimising whole lifecycle emissions. While VE can be found as early as the eighteenth or nineteenth century (Artés ~~, and~~ Wadel , Marti 2017; González-Redondo 2022)[2] , a holistic understanding of the design, construction, and technological trends of VEs at global scale is limited. This paper aims to document and classify in detail technological approaches of VEs through a comprehensive review of 172 VE projects worldwide. In doing so, the following research questions are answered:

- What are the trends associated with VE construction?
- What different types of VE are being built?
- What are the different architectural, structural, and constructional technologies used in VE projects in different contexts?

Vertical extension (VE) as an emerging typology

Existing terms, definitions, and benefits

Some studies use the term 'vertical extension' (VE) to represent[20] the additional floor(s) atop existing buildings (Argenziano et al. 2021; Artés ~~, and~~ Wadel , Marti 2017; Bergsten 2005; Dind, Lufkin, and Rey 2018). Others call this 'vertical expansion' (Jellen and Memari 2018; Thornton, Hungspruke, and DeScenza 1991), 'rooftop extension' (Aparicio-Gonzalez, Domingo-Irigoyen, and Sánchez-Ostiz 2020; Floerke et al. 2014; Wijnants, Allacker, and De Troyer 2019), 'roof stacking' (Amer et al. 2017; Amer, Mustafa, and Attia 2019), 'upward extension' (Morris 2021.), 'aufstockung' (Eliason 2014; Floerke et al. 2014), or simply 'adding floors to existing buildings' (Soikkeli 2016; Uwimana 2011).

A few studies present specific definitions of VE. For instance, Floerke et al.(2014) define VE as *'a structure that is constructed upon the top floor-space – generally the roof – of an existing building, adding one or more storeys'* and suggest that VE is a 're-densification solution' in the urban environment. The existing literature also documents a variety of environmental, social, and economic benefits of VE, as listed in Table 1.

Table 1. Benefits of VEs recognised by existing literature.

Benefits of VE		References
Environmental benefits	• Increasing urban density (while preserving green spaces and reducing urban sprawl) • Avoiding or reducing demolition of existing buildings therefore reducing embodied carbon emissions • Improving the performance of the base building (that beneath a VE), by using financial gain of the extension to fund a retrofit	(Ambrosini and Callegari 2021; Amer et al. 2017; Aparicio-Gonzalez, Domingo-Irigoyen, and Sánchez-Ostiz 2020; Argenziano et al. 2021; Artés ~~, and~~ Wadel , and Marti 2017; Dind, Lufkin, and Rey 2018; Eliason 2014; Hermens, Visscher, and Kraus 2014; Jellen and Memari 2014; Pattison 2021; Soikkeli 2016; Sundling 2019)

Social benefits	• Preserving cities' historical character (as compared to demolish and rebuild) • Improving safety in the city centre by increasing urban density	(Eliason 2014; Hermens, Visscher, and Kraus 2014; Jellen and Memari 2014)
Economic benefits	• Increasing the income potential of the base building • Financing refurbishment of the base building • Reducing cost of land and new foundations (as compared to a new building) • Faster construction (as compared to demolish and rebuild)	(Eliason 2014; Jellen and Memari 2014; Kussin 2016; Pattison 2021; Sundling 2019; Soikkeli 2016)

Development of vertical extensions

VEs have been constructed for centuries, especially in Europe (Eliason 2014; González-Redondo 2022), but they have become more frequent with the urgency of urban densification and a growing concern about building emissions. Hence, most literature [21] on this topic has emerged in the twenty-first century. At the building scale, most studies examine low-rise VE solutions (one to three storeys high) (Aparicio-Gonzalez, Domingo-Irigoyen, and Sánchez-Ostiz 2020; Argenziano et al. 2021; Artés~~, and~~ Wadel, Marti 2017; Dind, Lufkin, and Rey 2018; Jellen and Memari 2018; Soikkeli 2016), with fewer studies examining multi-storey or high-rise VEs (Hermens, Visscher, and Kraus 2014; Uwimana 2011). VEs have also been investigated at a neighbourhood level (Amer et al. 2017; Aparicio-Gonzalez, Domingo-Irigoyen, and Sánchez-Ostiz 2020) and component level (Lešnik et al. 2020; Wijnants, Allacker, and De Troyer 2019). Among these studies, some looked at specific building functions, such as residential VEs (Amer, Mustafa, and Attia 2019; Jellen and Memari 2018; Soikkeli 2016), and office VEs (Dind, Lufkin, and Rey 2018). Most research suggests that offsite construction and modular building systems are the most suitable construction methods for VEs, with lightweight materials (steel/timber) seen as preferable (Amer, Mustafa, and Attia 2019; Bergsten 2005; Dind, Lufkin, and Rey 2018; Hermens, Visscher, and Kraus 2014; Jellen and Memari 2018).

Some studies have reviewed and classified VEs (Table 2), in terms of their construction methods (Amer, Mustafa, and Attia 2019), form (Floerke et al. 2014), function (Ambrosini and Callegari 2021), and structural strategies (Hermens, Visscher, and Kraus 2014; Sundling 2019). However, most studies are in the European context, with little knowledge in other regions. Furthermore, most classifications are based on a single criterion (i.e. construction method, form, structural strategy) and focus on low-rise VEs. This study looks at VE implementations from a wider context and provides a review of VE technologies from multiple perspectives comprehensively. Through reviewing 172 VE projects worldwide, this paper presents the global trends on the evolution of VEs while documenting different designs and technologies from real projects, and classifies VEs based on architectural, structural, and constructional aspects. It presents what kinds of buildings are being extended and what strategies are applied.

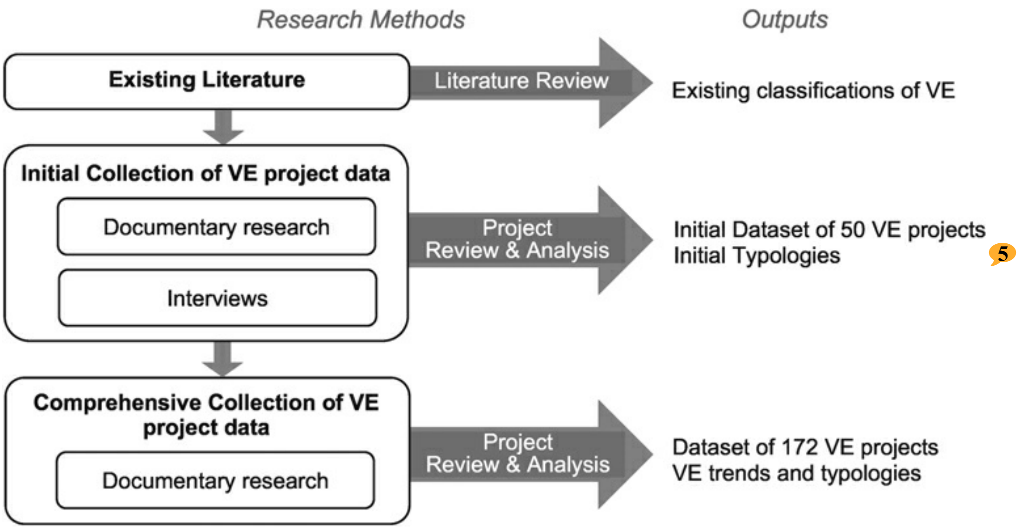
Table 2. Existing Classification of VEs.

Author(s)	Publication Type	Classification Types	VE Classifications	Study Scope
Amer, Mustafa, and Attia (2019)	Journal paper	Based on offsite construction methods of VE	(1) load bearing methods: • direct loading • indirect loading (2) assembly methods: • modular assembly (3D) • panels assembly (2D) • component assembly (1D) (3) building materials of the • base buildings: masonry (81%), RC (13%), steel (6%) • VEs: steel, timber, RC	136 VE projects in Europe, residential function, 1–3 storeys VE
Ambrosini and Callegari (2021)	Book	Based on the function of VE	historical residential buildings, social housings, factory reuse, service buildings	25 VE projects (80% in Europe), 1–3 storeys VE
Floerke et al. (2014)	Report	Based on the form of VE	roof, cube, inserted, free form, add on, gap	154 VE projects (97% in Europe)
Hermens, Visscher, and Kraus (2014)	Conference paper	Based on structural strategies of VE	spanning, building through, building on top of other buildings and infrastructure	7 VE project examples (6 in Europe)
Sundling (2019)	Journal paper	Based on structural strategies of VE	no reinforcement is required, reinforcement is required, no solution for reinforcement can be found	4 VE projects in Sweden (2 built, 2 unbuilt), 1–2 storeys VE

Research methodology

A mixed method approach of literature review, documentary research, and stakeholder interviews was utilised in this research (Figure 1). First, a literature review was performed to identify the existing knowledge and classifications of VE. Then, VE projects worldwide were collected through a documentary research process(Bowen 2009; Tight 2019), in which information about a particular project was gathered from multiple sources – academic documents (journal/conference papers and reports), official documents (government records, development application documents), popular resources (newspaper/magazine articles), and institutional resources (company website, press release). Semi-structured interviews and correspondence with professionals involved in some projects (architects, structural engineers, developers, contractors) were also undertaken to obtain project information.

Figure 1. Research methodology.



A final dataset of VE projects w as~~ere~~ created based on information obtained. A predefined template was used to determine what types of information should be retrieved, then information on each project was assembled based on this template. Due to the complex and diverse characteristics of VE, this template was adapted during the data collection. The final template is provided in Appendix. For each project, information collected includes project location, organi s~~z~~ations involved, information about the base building and its VE (i.e. year built, number of storeys, function, structural material), alongside architectural, structural, and construction approaches. In this research, VE is defined as constructing one or more storeys of new permanent inhabitable space on top of an existing base building. Thus, project inclusion and exclusion criteria are predefined to decide whether a specific VE project would be included or not in the dataset (Table 3).

Table 3. Project inclusion and exclusion criteria.

Project Inclusion Criteria	Project Inclusion Criteria
• Minimum 1 storey of permanent occupiable VE is built on top of the base building • VE's footprint is more than 25% of the base building's footprint area (estimated from project drawings) • There is evidence that the project has been built or is currently under construction	• Minimum 1 storey of permanent occupiable VE is built on top of the base building • VE's footprint is more than 25% of the base building's footprint area (estimated from project drawings) • There is evidence that the project has been built or is currently under construction

Results

A total of 172 VE projects were reviewed as part of this research. They are located across four regions: 36 in America (21%), 17 in Asia (10%), 97 in Europe (56%), and 22 in Oceania (13%) (Figure2), and spread over 27 countries (Figure 3). The three countries with the greatest number of projects are the United Kingdom, the United States and Australia with 52 (30%), 33 (19%), and 22 (13%) projects.

Figure 2. Project locations by region.

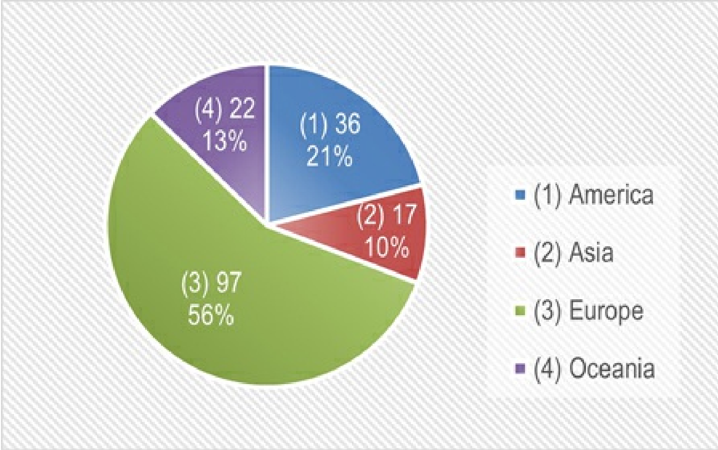
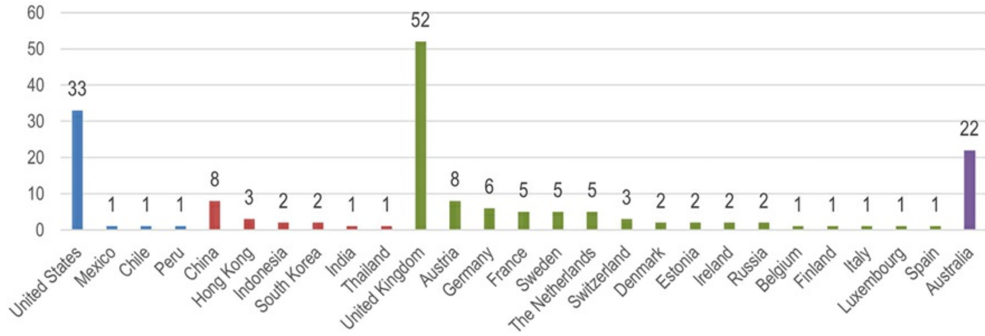


Figure 3. Project locations by country



Construction period and time gap

The construction periods of VEs and the base buildings (i.e. the original buildings that sit beneath VEs) were gathered to understand whether buildings from certain eras were extended more frequently. Figure 4(a). shows the completion periods for the base buildings. A total of 180 buildings are shown, because in seven projects, the VE was built atop two/three buildings. The chart shows that most base buildings were built in the twentieth century (125 out of 180 buildings, 69%), with a quite even split across the century (i.e. 19–30 buildings every 20 years). This suggests a wide array of buildings from different eras can facilitate VEs, with little limitation of construction period. There was a small drop in frequency of base buildings between 1940-1979. This is likely due to both the second world war (and subsequent reduced construction), and some buildings from the post-war era being less suited to VE economically. In an interview a developer revealed that:

> Buildings from the sixties and seventies are not very good to be extended, often there was a lot of postmodern design, the structures weren't as repetitive, they didn't have good floor-to-ceiling heights. So, the economics in trying to extend vertically those buildings is very different…

Figure 4. Construction periods of: a. base buildings (left); b. VEs (right). Note: There are 180 base buildings and 172 VEs, because in 7 projects, VEs were built atop 2–3 base buildings.

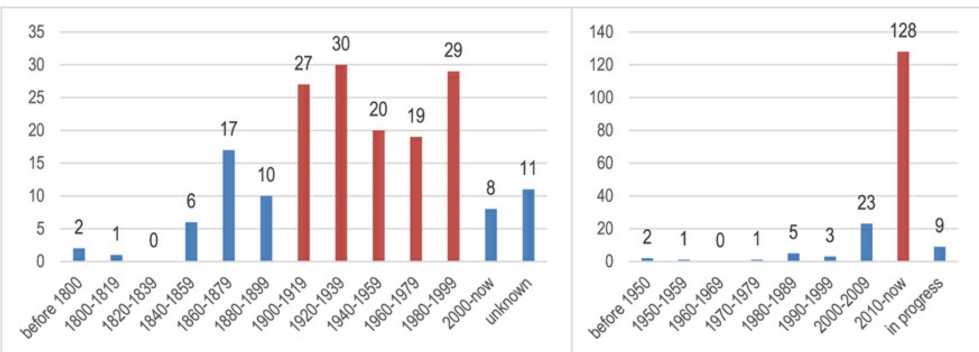
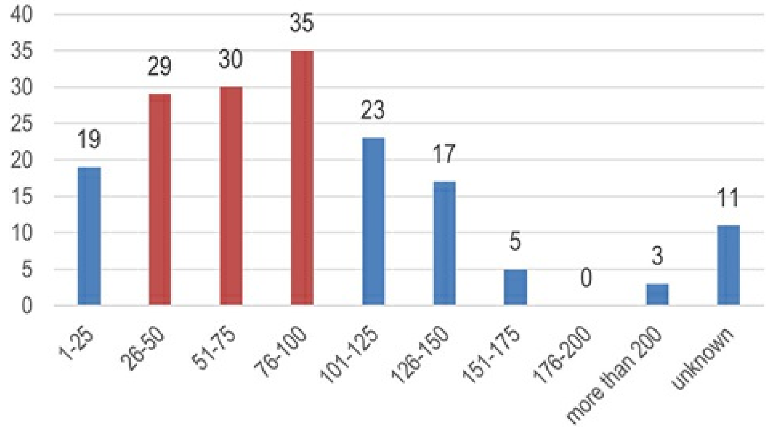


Figure 4(b) presents when the VEs were constructed. The graph shows that although there is a record of VE stretching back before 1950, it is very much a contemporary trend, with 137 of 172 projects (80%) completed/in progress since 2010.

By comparing the construction periods of base buildings and their VEs, time gaps can be determined. Figure 5 shows that the most common time gap is 76–100 years (35 projects, 20%), followed by 51–75 years (30 projects, 17.4%) and 26–50 years (29 projects, 16.9%). Moreover, the time gaps are more than 50 years for 113 projects (66%), and more than 100 years for 48 projects (28%), showing that VEs are often built atop historic/old buildings, rather than more contemporary ones.

Figure 5. Construction time gaps between base buildings and VEs.



Number of storeys and percentage of storeys added

The numbers of storeys of base buildings and their VEs were collected to understand to what extent VEs have been utilised to create additional space, and whether VEs were mostly built atop low-rise or high-rise buildings. Among 172 projects reviewed, the height of the base buildings above grade ranges from one storey up to more than 30 storeys (Figure 6). The blue line shows that the base buildings are mostly 1–6 storeys (132 out of 172 projects, 77%) with 3–4 storeys (59 projects, 34%) as the most common, followed by 5–6 storeys (45 projects, 26%). The highest base building is in the South Bank Tower in London (31 storeys), which had 11 storeys added on. The red line shows that most VEs are 1–2 storeys (66%). This highlights that most VEs do not add significant extra capacity. Nevertheless, there are examples of taller VEs among the projects reviewed. The tallest VE found was the Greenland Centre in Sydney, in which a 40-storey VE was built atop a 26-storey building. In addition, the Blue Cross Blue Shield in Chicago (Figure 13(1)), consists of a 24-storey VE built atop a 30-storey building (albeit this extension was pre-planned – see also Structural Strategies section).

Figure 6. The number of storeys of base buildings and VEs.

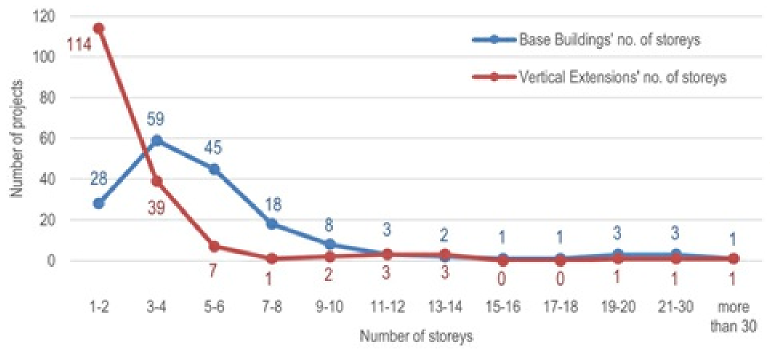
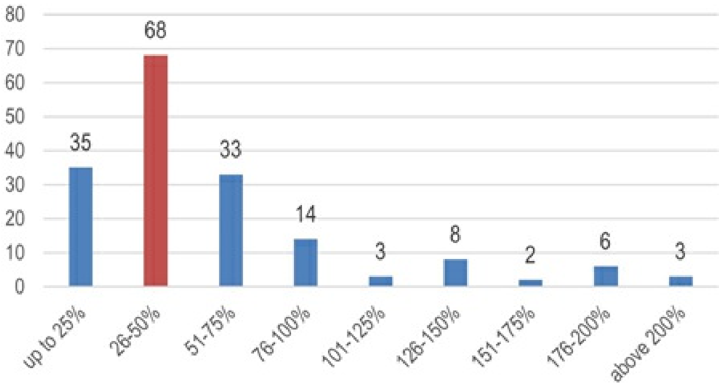


Figure 7 shows the percentage of storeys added (VE's number of storeys) compared to the base building's number of storeys. This percentage varies from below 25% to above 200%, with 26-50% as the percentage for most projects (68 projects, 40%). The highest percentage is found in The Hero in New York, where a 19-storey VE was built atop a 5-storey building, resulting a 380% of storey addition.

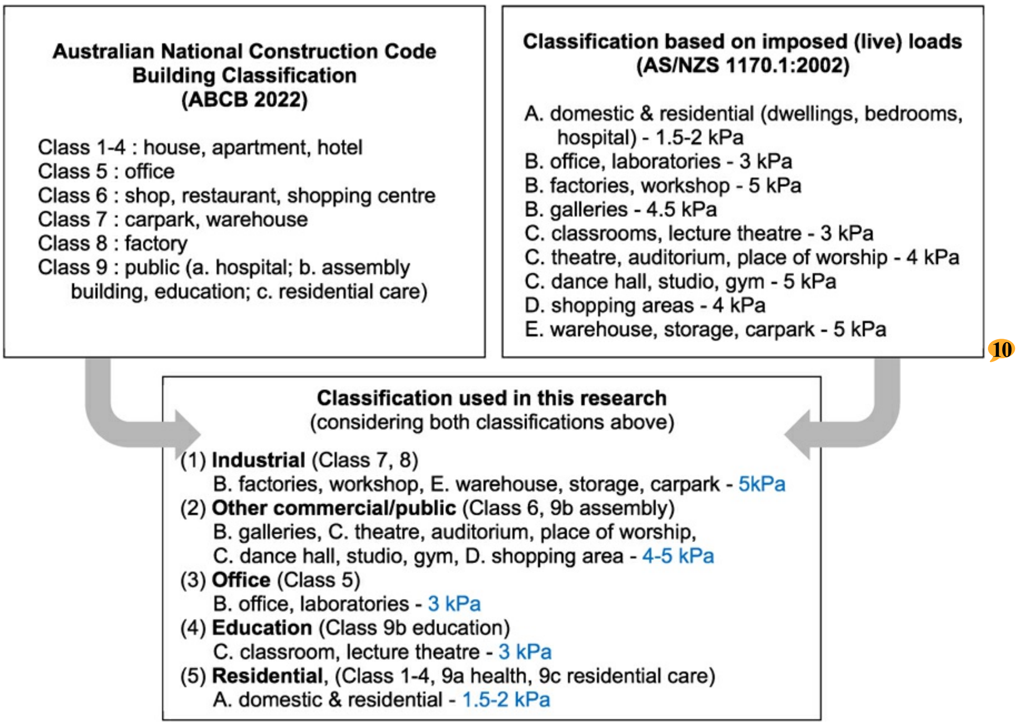
Figure 7. Percentages of storeys added.



Project function and functional change

To classify the projects based on functions of the base buildings and their VEs, a functional classification was predefined by considering the classification from the Australian National Construction Code(A B C B2022) and the imposed load requirements of each building type (AS/ NZS 1170.1:2002) (Figure8). Classification based on imposed loads (typical live loads) was used to examine whether different load requirements of specific building functions influence the realiszation of VEs.

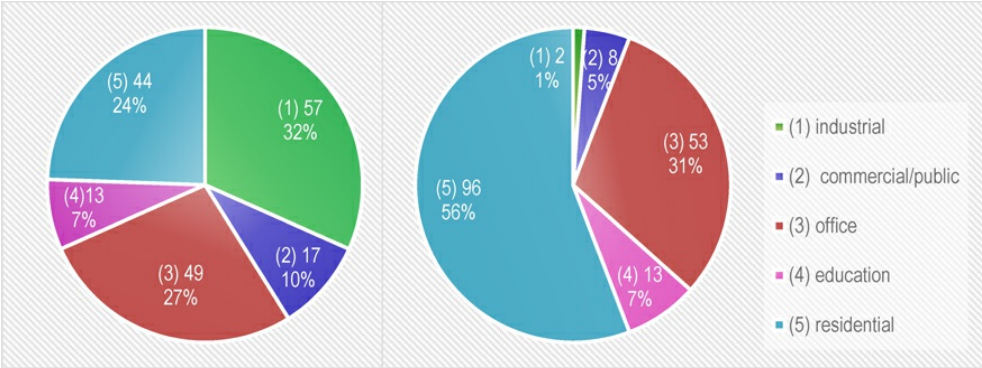
Figure 8. The functional classification used and its references.



The base buildings of the projects reviewed were classified into five distinct functions based on the typical live loads the typology requires (Figure 9(a)): (1) industrial (factory, warehouse, car park, showroom, military facility); (2) other commercial/public (shopping centre, retail, gallery, museum, church, restaurant); (3) office; (4) education (school, university); (5) residential

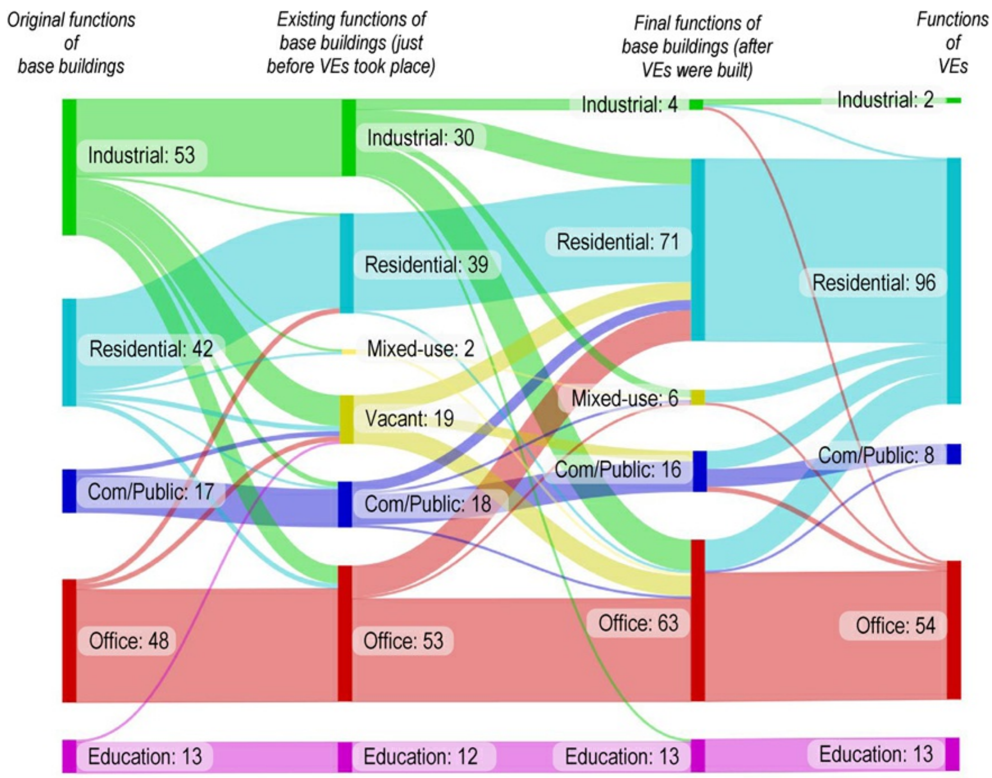
(single-family house, apartment, hotel, hospital). The most common building type found as the bases of VEs were industrial buildings (57 out of 180 buildings, 32%), followed by office (27%) and residential (24%). Figure 9(b). shows that most VEs were built to accommodate residential functions (96 out of 172 projects, 56%), followed by office purposes (53 projects, 31%).

Figure 9. Functions of: a. base buildings (left); b. VEs (right). Note: There are 180 base buildings and 172 VEs, because in 7 projects, VEs were built atop 2–3 base buildings.



Observing the functional changes of the base buildings, in 50% of the projects, the original function remained, while in 50% it changed. Figure 10 shows that most industrial buildings experienced a change of function (both before and during the VE process). Whereas, for base buildings with other functions (office, education, other commercial/public, residential) the original function mostly remained. In 115 out of 172 projects (67%), VEs were performed alongside the refurbishment of the base buildings, either to accommodate functional changes or to adjust them to the current building standard/requirements.

Figure 10. Functional changes of base buildings and VEs' functions. Note: Each node shows '[building function]: [no. of buildings]'. In this diagram, the number of buildings considered has been adjusted. Where multiple base buildings were located beneath a VE, these have been counted as a single building to ensure consistency in the Sankey diagram, except if they had different functions, resulting a total of 173 buildings in the graph.



Architectural strategies

Two distinct architectural strategies were examined: form and facade design of VEs. It was found that heritage status of the base building and VE's footprint ratio often influenced the selection of architectural strategies. In the case where the base building was heritage-significant, VE development would likely need to comply with certain restrictions, e.g. facade preservation, setback requirements. Regarding VE's footprint ratio (ratio of VE's footprint compared to the base building's footprint), most projects generally aimed to maximise additional space created and achieve a footprint ratio close to 100%, but due to some functional considerations or setback provisions, this was not always possible. Hence an average footprint ratio for 172 projects is 91%.

Form of VE

When considering the form of the VE as compared to the base building, five different strategies are identified (Figure 11):

1 *Extruded* form, in which VE has the same form as the base building, and the VE's footprint ratio is nearly 100%.
2 *Setback* form, in which VE has the same form as the base building but with a setback on the front elevation, on two/more faces, or has some recessed areas.
3 *Roof* form, in which VE appears as the roof of the base building.
4 *Rooftop cottages*, in which VE appears as a few/cluster of small houses/cottages atop the base building.
5 *Freeform*, in which VE has a distinct form, footprint, or axis with the base building, cantilevered from the base building, or connected with a horizontal extension.

Figure 12 shows that most frequently used form is the *extruded* form (72 projects, 42%), followed by the *setback* form (62 projects, 36%). In 11 projects, the combination of two strategies was applied, e.g. both *extruded* and *roof* forms were applied in Trikafabriken 9 (Figure 11(3)). In 51 projects (30%) where the base building(s) was considered of heritage significance or located in a historic district, the most common form used is *setback* (19 out of 51 projects, 37%).

Figure 11. Five forms of VEs identified along with examples of projects: (1) extruded – Adina Apartment Hotel, Melbourne; (2) setback – Deco Building, Sydney; (3) roof – Trikafabriken 9, Hammarby Sjostad; (4) rooftop village – Didden Village, Rotterdam; (5) freeform – Substation 164, Sydney ~~(published with permissions from: (1) Peter Clarke; (2) Brett Boardman; (3) Tengbom; (4) MVRDV; (5) Nuveen)~~ [images courtesy of: (1) © Peter Clarke; (2) © Brett Boardman; (3) © Felix Gerlach for Tengbom; (4) © Rob t Hart for MVRDV; (5) © author].

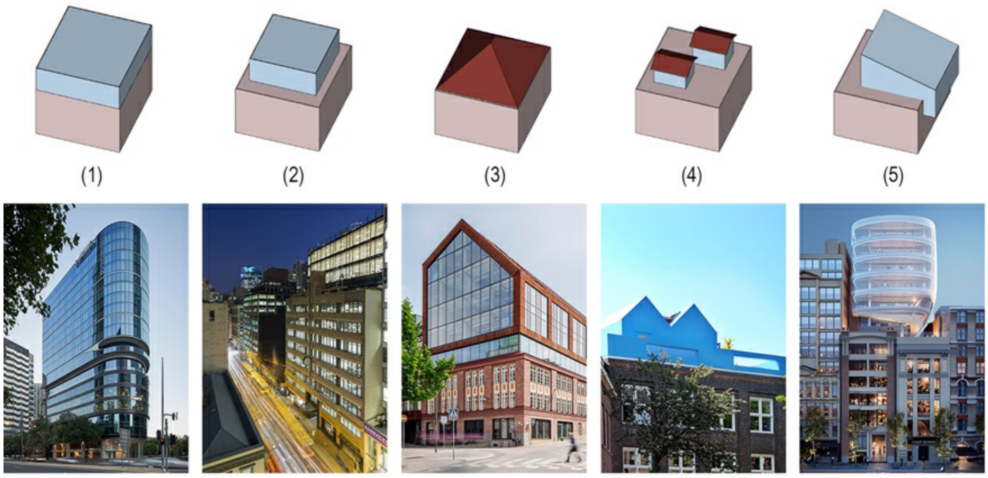
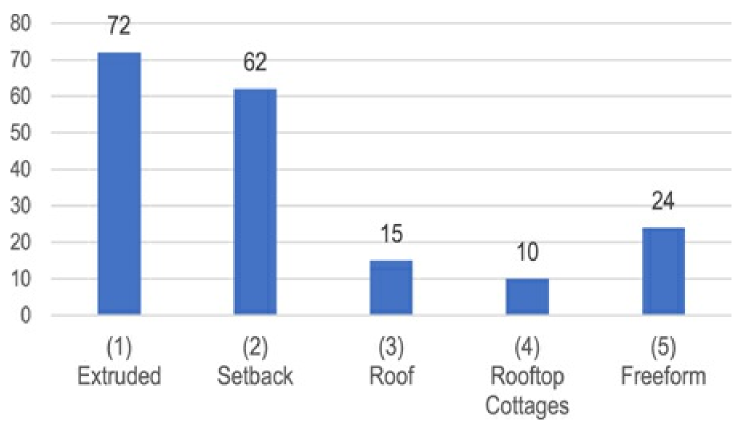


Figure 12. Project classification based on forms of VEs. Note: Combination of two forms was applied in 11 out of 172 VE projects.



Facade design of VE

By comparing the facade of the VE with its base building, three facade design strategies are identified:

1 *Unified* facade, in which VE has the same facade as the base building, so that it is difficult to distinguish between the old and new.
2 *Similar* facade, where VE's facade adopts some characteristics of the base building's facade (i.e. same/similar rhythm, colour, and/or material), but the VE can still be identified as a new addition.
3 *Distinct* facade, where VE's facade has a different rhythm, colour, or material, and is easily differentiated from the

base building.

Examples of these approaches are shown in Figure 13. Figure 14 shows that among the projects reviewed, a *distinct* facade appearance is the most applied (123 projects, 72%) whereas *unified* appearance is the least (14 projects, 8%). In three projects, combined strategies were applied. In 18 projects, the base building's facade was demolished, and the building was reclad (most commonly to achieve *unified* facade, but in some projects, *similar*/*distinct* appearance was used).

Figure 13. Examples of VE projects and their facade strategies: (1) unified facade at Blue Cross Blue Shield; Chicago; (2) similar facade at Midtown Centre, Brisbane; (3) distinct facade at De Karel Doorman; Rotterdam ~~(published with permissions from: (1) Goettsch Partners; (2) AM Brisbane CBD Investments &DMC Projects; (3) Ibelings van Tilburg architecten)~~ [images courtesy of: (1) © James Steinkamp Photography for Goettsch Partners; (2) © AM Brisbane CBD Investments & DMC Projects; (3) © Ibelings van Tilburg architecten, Ossip van Duivenbode] .

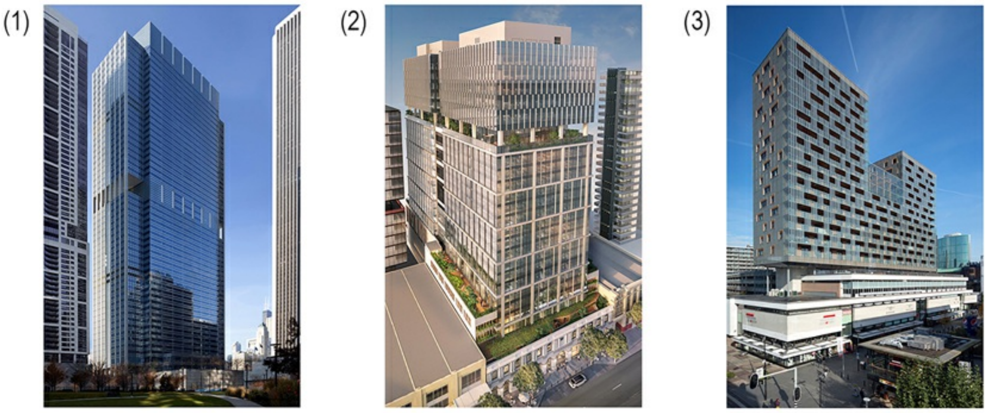
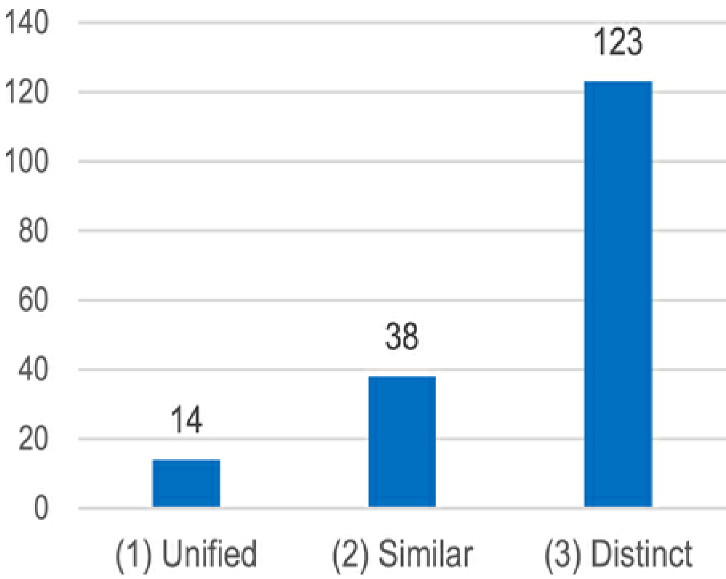


Figure 14. Project classification based on fa cçade designs of VEs. Note: Combined facade designs were applied in 3 out of 172 VE projects.



Structural strategies

The analysis of structural strategies considered two factors: planned/unplanned VE and structural support strategies.

Planned/unplanned VE

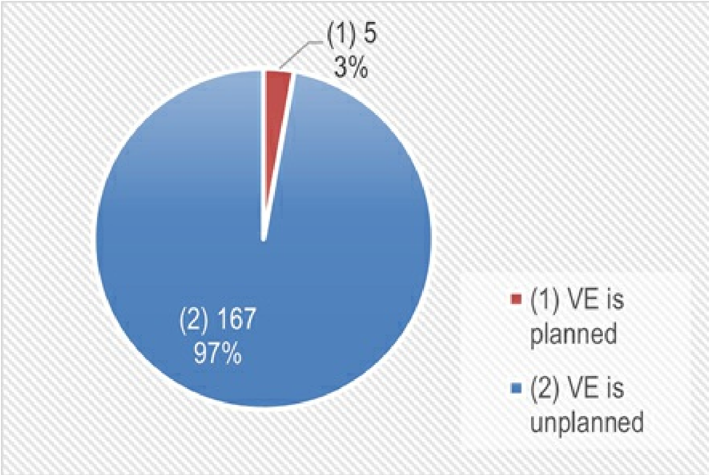
Two distinct typologies are identified (Figure 15):

1 *Planned VE*, in which the VE is purposely planned at the time of initial design of the base building. Blue Cross Blue Shield (Figure 13(1)) is an example of this where a 24-storey VE was planned as part of a long-term expansion of the 30-storey office building. Among 172 projects, only five (3%) have planned VEs, and in two of them, the reali szation of VE exceeded the originally planned height. The Adina Apartment Hotel in Melbourne is an example of this (Figure 11(1)), where the base building was designed to support a 6-storey VE, but in the end a 10-storey VE was built using CLT. The architect shared:

> The developers knew that they could build 6 levels extension with concrete, but they were looking for 220 hotel rooms to get their best return from investment. So, anything smaller probably would have meant that the project wouldn't have gone ahead. With timber, we could get 10 levels …

2 *Unplanned VE*, where there is no plan for future VE in the initial design of the base building. Most VE projects (167 out of 172 projects, 97%) fall into this category. It should be noted that during data collection, a project was only considered to have a planned VE when specific information identified it as such.

Figure 15. Project classification based on plan for VEs.



Structural support strategies

To support VE, three structural support typologies are identified (Figure 16):

1 VE is *fully supported by the existing structure*
2 VE is *supported by the existing structure with some additional reinforcement*
3 VE is *supported by a separate structure*

Figure 17 shows that strategy 2 was the most frequently used approach (40%), followed by strategy 1 (35%). A partial demolition of the base building took place in 41 out of 172 projects (24%). The demolition varied from roof and floor demolition, replacing the roof or one/more of the base building's floor(s) of heavy construction with more floors of lightweight construction. Floor and roof demolition was found in 21 and 19 projects respectively. In six projects, the base building's slabs were cut throughout the building height and replaced with new construction with more strength to support the VE.

Figure 16. Three structural support strategies for VE (Julistiono , Oldfield, Cardellicchio ~~et al.~~ 2023).

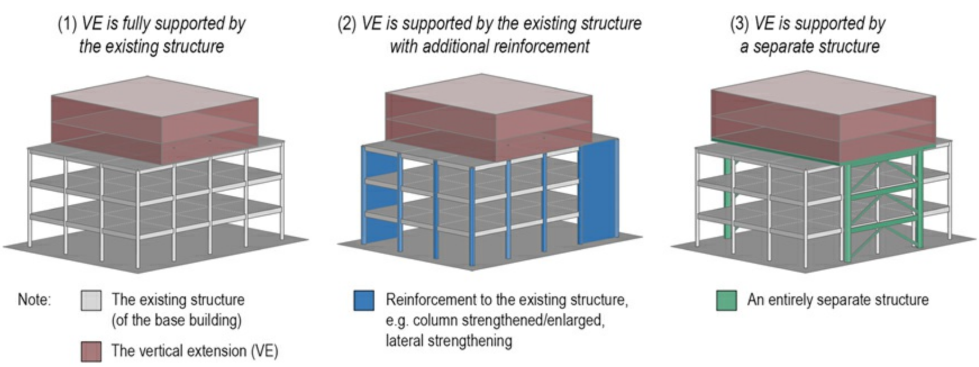
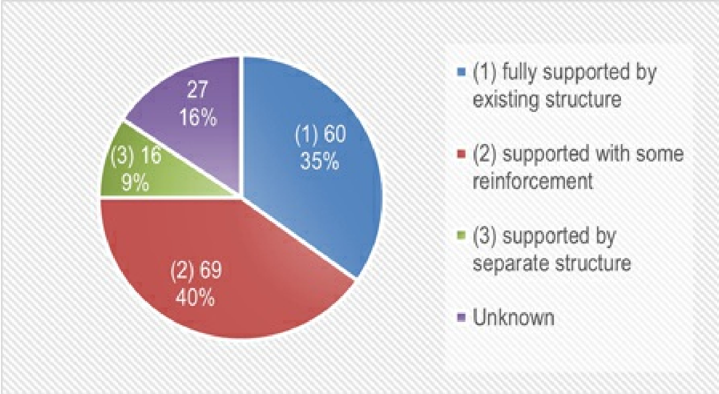


Figure 17. Project classification based on structural support strategies.



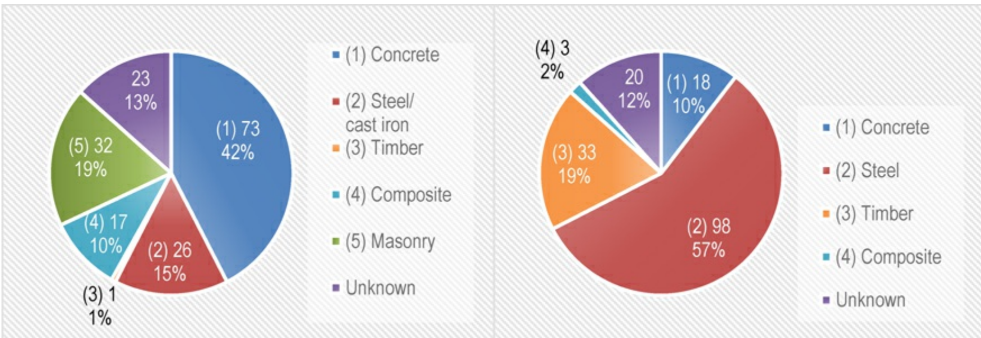
Construction strategies

In terms of construction strategies, two trends were examined: the structural materials used and the base building's occupation condition while the VE is constructed.

Primary structural materials

Figure 18 presents classifications of VE projects based on the structural materials of the base buildings and the VEs. If multiple materials were used in the project, the primary structural material is defined by the vertical structural component as the main load bearer (i.e. columns or vertical load-bearing walls). Concrete is the base buildings' primary structural material for most projects (42%), followed by masonry (19%) and steel/cast-iron (15%). In 17 projects (10%), two or more materials were used, e.g. masonry bearing wall with cast iron/timber frame. Regarding structural material of VEs, steel is the most frequently used (57%), followed by timber (19%).

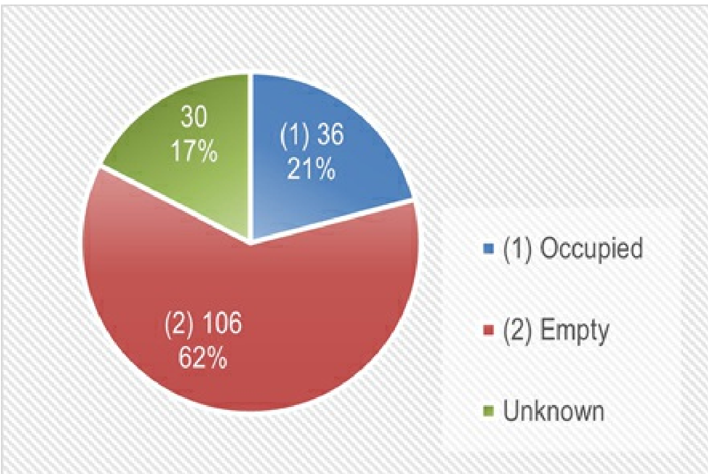
Figure 18. Project classifications based on: a. primary structural materials of base buildings (left); b. primary structural material of VEs (right).



Base building's occupation condition while VE is constructed

Two different occupation conditions were identified during the construction of VE – empty and occupied (Figure 19).

Figure 19. Project classification based on occupation conditions while VE is built.

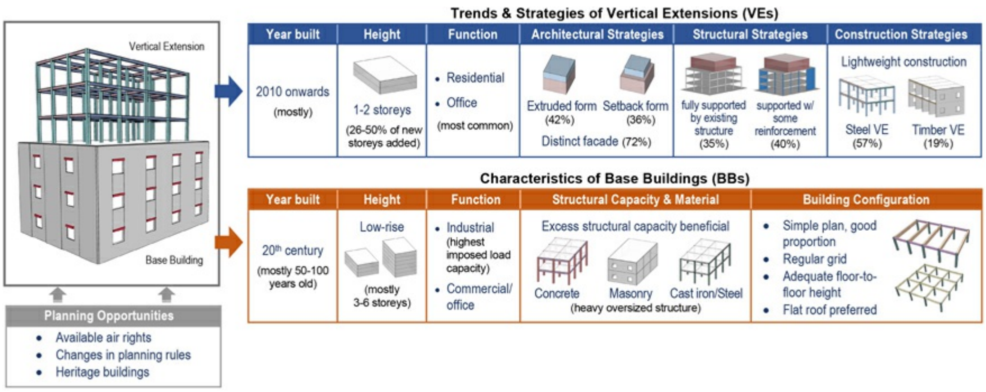


For 106 projects (62%), the base building was empty during the construction of VE, either it has been abandoned or it was vacant due to the VE being built alongside a refurbishment and/or strengthening to the existing structures was required. For 36 projects (21%), the VE was constructed while the base building remained in operation. This was possible when no extensive structural work occurred in the base building, or in *planned VE* projects.

Discussion

This research constitutes the largest review of VEs globally, with 172 projects analysed across four main geographical regions. Figure 20 summarises the key findings, including the most frequent base building and VE characteristics, trends, and approaches. As such, this diagram could be used to identify potentials for VE in a specific case, based on common factors found in this research. The following discussion points are highlighted.

Figure 20. Summary of the most frequent trends and characteristics of VE development.



Construction trends: an accelerating phenomenon

Based on location, Europe is the region with the most projects (56%). This aligns with the existing literature, with 19 out of 21 VE studies (90%) set within the European context, and evidence that VE has a long history in Europe(Eliason 2014). However, by including 44% of the projects from other regions, especially Asia and Oceania, which are rarely discussed, this research presents a more global review of VEs. Based on country, the UK has the most projects. In here, 33 out of the 52 projects identified (63%) are in London. The US is the next to have most projects, in which 26 out of 33 projects (79%) are in New York. This confirms that VEs are most economically viable in dense megacities such as London and New York, where land is hard to come by. In an interview, an architect noted:

> Finding an area to build in a city as dense as New York is very, very hard, so the only thing you can do is building on top of other places. It's starting to happen a lot more and more.

Construction periods of VEs confirm that VE trends have gained significant momentum in the last decade worldwide, with 80% of the projects reviewed here built since 2010. The construction periods of VE's base buildings show that while most base buildings were built in the twentieth century (69%), it is possible to build atop buildings from any era (the oldest base buildings were from the fifteenth century, while the most recent was built in 2016).

Structural capacity: small interventions

Based on 172 projects reviewed, most VEs are 1–2 storeys (66%), with only 11% of projects (19 out of 172) above 4 storeys. Likewise, the percentage of storeys added for most projects is between 26-50%. This shows that most VEs are relatively short as compared to their base buildings – they add relatively modest amounts of extra capacity. This limitation of VE is found to be caused by most extensions relying (to at least some extent) on the excess capacity in the base buildings to support additional loads – a fact recognised by other research (Jellen and Memari 2014; Julistiono , Oldfield, Cardellicchio ~~et al.~~ 2023; Thornton, Hungspruke, and DeScenza 1991)

. This also aligns with results on structural support strategies, i.e. in 75% of the projects, VE was supported by the base building's existing structure, either fully (35%) or with some reinforcement (40%). An entirely new structure supporting VE is less common (9%).

In terms of the base buildings' original functions, an industrial building is the most frequent (32%), followed by office (27%) and residential (24%). Analysis of these three base building types in Table 4 shows that projects with industrial buildings as the base of VEs have the highest average percentage of storeys added (67%). Also, they have the highest refurbishment rate and change of function (87% and 92%), and the lowest partial demolition rate (15%). All of this reveals that industrial buildings have a significant opportunity to accommodate VEs as they are typically designed to accommodate higher loads (see Figure 8), and thus there is excess load capacity to support VE. In the interviews, an engineer shared that:

> Very often old buildings have more capacity than people expect, especially in the case where they've changed use. The best example is the buildings that were once warehouse buildings, machine shops, industrial buildings, that are converted into flats. There, the loading goes from heavy loading to light loading.

Three structural support strategies are recognised (Figure 16), similar to previous research (Hermens, Visscher, and Kraus 2014; Sundling 2019).

- For *planned VEs*, since the existing structure is designed to support a future extension, strategy 1 (*fully supported*) is the most obvious strategy. However, this research found that in three out of five planned VE projects, *additional reinforcement* to the existing structure was applied (strategy 2) since the time difference has caused a change in needs and the demand for VE to be realised with more storeys.
- For *unplanned VEs*, the selection of structural strategies depends on the excess capacity in base buildings' structure. Strategy 1 was used in 58 out of 167 unplanned projects (35%). Strategy 2 and 3 were used in 82 projects (49%) since the excess capacity was inadequate or lateral strengthening was required.

For 36 projects with occupied base buildings during VE construction, strategy 1 was most frequently applied (21 projects, 58%) to prevent disturbance to base building operation.

Table 4. Comparison of VE projects with three most frequent base building functions (industrial, office, residential).

Base building function (no. of projects)	Average percentage of storeys added	VE alongside refurbishment	Original function changes	VE with demolition*	Occupied
All (172)	63%	115 (67%)	86 (50%)	41 (24%)	36 (21%)
Industrial (53)**	67%	46 (87%)	49 (92%)	8 (15%)	3 (6%)
Office (48)**	54%	34 (71%)	19 (40%)	15 (31%)	9 (19%)
Residential (42)	57%	23 (55%)	10 (24%)	13 (31%)	10 (24%)

Note: *VE was built alongside partial demolition in the base building.

**There is one project in which the VE was built atop two base buildings – industrial and office, hence this project is counted in both industrial and office base building function.

Standing out: diverse form and facade design

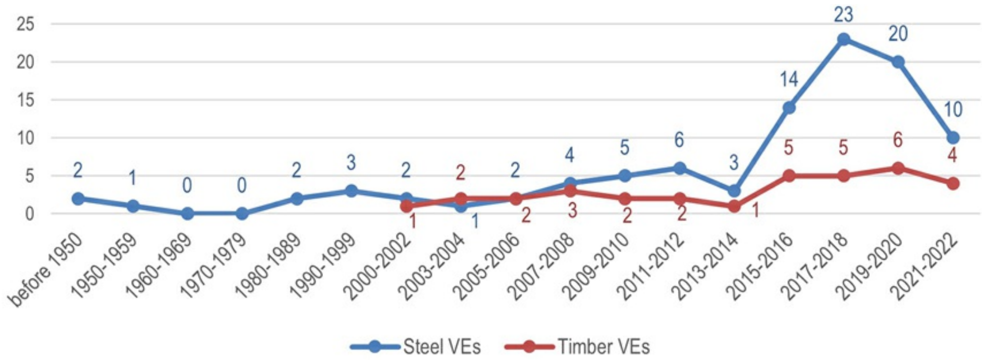
Considering the form of VE, as compared to its base building, five distinct typologies are identified – *extruded*, *setback*, *roof*, *rooftop cottages*, *freeform*. Floerke et al. (2014) presented six different forms (Table 2). In both studies, it is found that the *extruded* form is most frequently used, likely to maximise the potential space created. However, this research finds that the *setback* form is most commonly applied if the base building has a heritage value. Moreover, *rooftop cottages* ~~are~~ is a new form typology identified here, where multiple smaller individual buildings are placed atop a base building.

Regarding facade design, a *distinct* appearance between VEs and base buildings was found to be the most frequent strategy used. This aligns with heritage conservation principles (NSW Heritage 1999) in which a building should reflect its era, and thus any new addition should be visually distinctive. In contrast, a *unified* appearance is used the least, with there being technological and logistical challenges to ensure the new extension appears the same as the old building. Where it is used, this strategy often requires the base building to be reclad as part of a refurbishment.

Material technologies: steel dominates, but timber is growing

Results show that most VEs were built with steel (57%), followed by timber (19%). This reinforces that lightweight structural materials are preferable for VE to reduce loads on base buildings. Observation of the construction periods of steel and timber VEs (Figure 21) shows that steel has been increasingly used in the past decade as VEs gain momentum, while timber has started to be used since 2000 and with a slower growth over the last seven years.

Figure 21. Construction periods of steel VEs and timber VEs.



Comparing steel and timber VE projects (Table 5), it is found that timber VEs have a lower average percentage of storeys added, but more frequently use structural strategy 1 (*fully supported* by the existing structure) (52%) and are more often occupied during construction (30%). Since timber is lighter (Foster and Reynolds 2018), using timber VE can minimise the base structure's required strengthening and disturbance to the building occupants.

Table 5. Comparison of VE projects with steel and timber VEs.

VE material (no. of VE projects)	Average percentage of storeys added	Structural strategy 1 (*fully supported*)	Structural strategy 2 (*supported w/ reinforcement*)	Base building occupied during VE construction
All (172)	63%	60 (35%)	69 (40%)	36 (21%)
Steel (98)	64%	36 (37%)	43 (44%)	22 (22%)
Timber (33)	52%	17 (52%)	12 (36%)	10 (30%)

Note: This table only compares steel and timber VEs (projects with VEs constructed using other materials are excluded).

Mass timber has emerged as a lightweight and efficient material, and is cost-effective due to being prefabricated for rapid assembly (Evison, Kremer, and Guiver 2018; Jelec, Varevac, and Rajcic 2018; Ramage et al. 2017). Timber is a low-carbon material, benefits from long-term carbon storage or sequestration (Churkina et al. 2020; Parajuli et al. 2018). Hence, the use of timber for VEs can maximise the environmental benefits of VEs and has been studied by existing research(Dind, Lufkin, and Rey 2018; Foster and Reynolds 2018; Soikkeli 2016; Wijnants, Allacker, and De Troyer 2019). Despite the potential of timber, Figure 21 indicates that the use of timber for VE has not been fully utilised. This might be due to low awareness of timber potential, availability of technical information and regulatory limitations (Espinoza et al. 2015). For example, if projects in UK are excluded, from the remaining 45 projects in Europe, 18 have timber VEs (40%), while 20 have steel VEs (44%). If UK is included, the percentage of timber VEs is reduced to 27% (26 out of 97 projects) with 62% of projects having a steel VE. The lack of timber VEs in the UK is likely to be caused by restrictions for timber wall use in multi-storey buildings (Barker 2022; Carpenter 2020; Pacheco 2020).

Although most VEs are short, there are a few projects in this study that have taller VEs. 9 out of 172 projects (5%) have VEs higher than 10 storeys. These taller VEs were possible since the VE was either pre-planned, or by harnessing innovative construction methods such as lightweight materials and modular construction, alongside structural support strategy 2 or 3 (VE is *supported by the existing structure with some reinforcement* or *by a separate structure*). An example of this is De Karel Doorman (Figure 13(3)), where a 16-storey VE was built atop an originally 3-storey building by adding two new cores for lateral stability and applying ultra-lightweight materials. The engineers shared:

> … we came up with the lightweight innovative structure: a lightweight steel frame, a timber flooring, gypsum ceilings and partition walls, timber facade. So, this building weighs only

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260 kg/m2 gross floor area, whereas the traditional building in the Netherlands for housing weighs 5.5-6 times more.
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Research limitations and future works

Several limitations are acknowledged in this research. Firstly, the sample size is unknown. Nevertheless, by including 172 projects with 44% outside Europe, this study represents the largest review of VE with the widest context. However, sample bias may still exist given a reliance on English language sources for data collection, for example. Hence, some regions may still be underrepresented as compared to the number of VEs that may exist. Also, while some project information was easily obtained, other data was more challenging to acquire, e.g. information on structural strategies and building materials. Thus, there is unknown data in some typologies, although efforts have been made to minimise this by gathering data from multiple sources and contacting relevant consultants and stakeholders.

In terms of future work, a gap in the knowledge seems to be what is the structural capacity of existing buildings – how much of a contribution can VE make to growth in cities at an urban scale? Is VE just for novel one-off projects, or can it make a real contribution to urban growth? Amer et al. (2017) have partially addressed this by mapping urban densification potential through VE in Brussels and found that VE can accommodate 30% of expected population increase by 2040. However, the study only considered residential VEs and did not examine the base buildings' structural capacity which this research finds is a key driver to VE. Future studies can be built to assess this capacity based on various building types. Moreover, excess structural capacity is a theme that emerged multiple times and considered crucial in the feasibility of VEs. While some studies presented a structural analysis of VEs, mostly are single project-based. Future research could seek to develop benchmarks for buildings' capacity for VE, to provide cities with an understanding of the VE potential within their existing building stock to inform growth policies and support a retrofit first approach over demolish and rebuild.

While it is suggested repeatedly in the literature and many built project descriptions, the carbon benefit of VE as compared to conventional approaches to achieve additional floorspace are rarely measured. Pattison (2021) and Papageorgiou (2016) compare the environmental benefit of VE with demolish and rebuilt scenario, but only consider steel VEs. As such, future studies are required to measure the quantitative environmental benefits of VE compared to conventional approaches to densification across different materials, at a building or urban scale. Future research should also focus on VE in Asia where urban space shortages are an escalating phenomenon in many densely populated countries such as Macau, Singapore, and Hong Kong (World Bank 2022).

Conclusions

VE is an emerging novel approach to accommodate the rising demand for space while reducing the need for demolition of existing structures. By reviewing 172 VE projects worldwide, this research presents a holistic understanding of VE trends and technologies at a global level. Several significant conclusions are highlighted below:

- Although VE has occurred across time, the evidence suggests it as a trend that is accelerating significantly in the past decade, especially in densely populated cities.
- While most VEs are relatively small, one to two storeys in height, there is an opportunity to expand this capacity by employing lightweight materials and innovative structural strategies.
- Industrial buildings are common base buildings for VE due to their higher structural capacity, and subsequently represent a significant opportunity for adaptive reuse, expansion, and densification of cities.
- While the *extruded* form of VE is the most common to maximise VE's footprint ratio, *setback* form is often chosen related to heritage preservation. Also, *distinct* facade of VEs is the most frequently applied to differentiate from the base buildings.
- Most VEs are *supported by the existing structures with some reinforcement*, because although excess capacity in the existing structure can support additional vertical loads, lateral strengthening is sometimes required. In the case where the base building remains occupied, VEs are often *fully supported by the existing structure* and timber is often used to prevent disturbance to the occupants.
- With the promotion of biomaterials to facilitate low-carbon architecture, increasing development of timber VE could potentially contribute to low whole lifecycle carbon buildings with less demolition, although the quantification of such carbon-saving is lacking in the literature.[18]

Data availability statement

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials **[Q4]**.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix. Project information template

[Project Title]			[Code]
~~[project picture/s]~~			Location:
			[address]
			[city, country]
			Professionals involved:
			Architect:
[project picture/s]			[architect name]
			Developer/Owner:
			[developer/owner name]
			Structural engineer:
			[structural engineer name]
			Contractor:
			[contractor name]
Base Building (BB):		Vertical Extension (VE):	
Year built	[year built]	*Year built*	[year built]
Storeys	[no. of storeys]	*Storeys*	[no. of storeys]
Function	original: [original function] existing: [before extended] final: [after extended]	*Function*	[function of VE]
Structure	[primary structural material]	*Structure*	[primary structural material]
Structural strategies:		Architectural strategies:	
[planned/ unplanned]		Facade: [unified/ similar/ distinct]	
[supported by existing structure/ supported w/ reinforcement/ separate structure]		Form: [extruded/ setback/ roof/ rooftop cottages/ freeform]	
		VE footprint ratio: [VE footprint/EB footprint]	
Construction strategies:		Additional notes:	

[occupied/ empty] while VE being constructed		Is the BB heritage significant? [Yes/No]
Any demolition involved? [Yes/No]		Was VE performed w/ refurbishment? [Yes/No]
		Was VE built w/ horizontal extension? [Yes/No]
Other information:		
– [context story/a brief history]		
– [additional information on strategies implemented to extend the base building]		
References:		

Attachment Files

1 Figure 1.jpg *: Please use this file, since there is uneven shade in the current figure, the font size has also been adjusted*

2 Table 3.docx *: The right column of Table 3 is wrong, please change as this attachment*

3 Figure 8.jpg *: The font size has been reduced to make it more comparable with the article main text*

4 Figure 11_Jul 23.jpg *: Some project photos are changed according to the copyright permissions*

5 Additional References Corrections.docx *: Please add these corrections to the References, since we cannot revise them in EditGenie*

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