COMBINING DEEP RETROFIT WITH TOPPING UP IN WOOD
The sustainable densification and transformation of the Amsterdam Navy Area

Thematic Research Paper
Architectural Engineering and Technology
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Abstract
Keywords: top-up, optoppen, densification, deep retrofit, renovation, transformation, wood construction, lightweight construction.

How to densify Amsterdam using vacant office space, while improving energy performance with sustainable materials? The paper focuses on combining the strategies of densification, deep retrofit, office transformation and the use of wood to do so in a sustainable matter. The location of research is Amsterdam, where population is rising, but space is scarce. Therefore the city needs a densification process, the paper proposes to do so partly by topping up: adding extra levels to existing buildings. Another focus of Amsterdam as well as the Dutch government is an energy neutral built environment in 2050. To realize this goal, we need to drastically increase renovation works to make existing buildings perform better. A third problem is a structural vacancy of offices. Their functional life does not match their technical life, being vacant they take up space needed for dwellings. Transforming offices into dwellings could be an option, this transformation can be combined with a deep retrofit to increase the buildings performance and lifetime. Adding extra levels makes these interventions financially possible with extra floor space. All additions to the office should be done in wood, to decrease the project’s energy and carbon footprint.

The design assignment consists out of a complex currently used as an office building for the Dutch Navy, located in the city centre of Amsterdam. The complex features a concrete skeleton structure and an outdated façade with concrete sandwich panels. The objective is to transform this office building to dwellings. Therefore it needs a deep retrofit, to improve its energy performance, climate comfort and to extend the lifetime of the building. To make these interventions financially possible, and to respond to Amsterdam’s densification policy, extra levels are added to the building. All additions are done in timber frame construction where possible, to minimize the amount of embodied energy in the building and to reduce its carbon foot-print.
1. INTRODUCTION
Many cities face an increasing population, but often it lacks the space to accommodate the people within the physical boundaries of the city. Amsterdam is planning 70,000 new dwellings within the next 20 years, but the question remains where. One of Amsterdam’s strategies to cope with sparsity in space is to densify the city, for example by transforming or topping up buildings.

Next to planning an amount of dwellings, they also need to be sustainable. An energy neutral built environment in 2050 is the aim of local and national policymaking. Because we don’t renew our built environment every now and then, this means a huge challenge to improve our existing building stock. A high level renovation or deep retrofit can update old buildings to nowadays standards of energy performance and comfort.

Where the demand for dwellings is rocketing, the market for office buildings copes with a structural vacancy. Amsterdam has one of the highest vacancy rates in the Netherlands. Transformation of functionally obsolete buildings could be a sustainable way of dealing with the inflated market for offices, but it is often regarded as too expensive. Topping up can motivate owners of vacant buildings to transform their office into dwellings, as it increases the amount of floor space, and thus increases revenue.

Having mentioned three challenges for Amsterdam’s building stock, would it make sense to combine the possible strategies to cope with them? To top-up and retrofit existing buildings is not new; French architect Anne Lacaton proved it to be a successful strategy on many depreciated buildings. However, she mainly uses conventional construction materials with a big energy and carbon footprint (concrete, steel and glass). Hence, the fourth and last focus of this paper is on the use of timber construction for sustainable building. This makes sense to top-up buildings, as wood can be a very light construction material. It minimises loads on the existing structure. My goal is not to prove that one specific building can be transformed using the aforementioned methods; the combination of strategies aims to give an integrated answer to the stated social, spatial, environmental and financial issues. Some are specific for growing and high populated areas as Amsterdam, part of the research can be applied on a bigger scale.

The main research question is how to densify Amsterdam using vacant office space, while improving energy performance with sustainable materials? The following specified questions are extracted out of the main question:

- Which methods can be applied for densification, and is topping up a feasible method to contribute to the densification of Amsterdam?
- What is a good balance between renewing and retrofitting building stock in order to meet our energy ambitions?
- What are the benefits and challenges of transforming offices into dwellings?
- When adding extra volume and building elements, which sustainable material causes the lowest energy and carbon footprint?
- Which construction method results in the lowest building mass?
- Can the several strategies answering to the questions above be combined into one building?
2. PROBLEM STATEMENT

2.1 GROWTH AMBITION
The population of Amsterdam is steadily increasing. With an average of 1.4% the last five years, the growth of Amsterdam is much higher than the average of 0.4% of other municipalities. Within this timeframe, the city grew with roughly 10,000 people each year.\(^1\) To accommodate the increase of inhabitants, extra dwellings need to be built, as well as accompanying amenities. The city of Amsterdam is planning an additional 70,000 dwellings in the next 20 years, an enormous increase of 18% of its current stock. In its policy for 2040, the city government explicates that in order to deal with this spatial challenge, Amsterdam needs to **densify** current urban forms and **transform** monotone industrial areas into mixed use neighbourhoods for both work and living.\(^2\)

Density, as a term in urbanism, is described as the relation between an area and its number of people, dwellings, services or the total amount of floor space. A higher density can be achieved by adding buildings within the same area, or making better, more efficient use of existing stock. For the last decades population density declined significantly in Amsterdam, in a trend originating from late 19th century. From well over 500 inhabitants per hectare, the footprint of each inhabitant has been growing, and density declined to just 60 inhabitants per hectare in 2000. However, this trend is slowing down, influenced by policy and because Amsterdam reached the physical limits of its administrative boundaries.\(^3\) According to Pierre van Rossum, manager of the city governments urban development department, 'easy' or ready to develop plots are gone in 2018.\(^4\) As future building plots are more complicated to develop, building within the city's boundaries might stagnate unless other strategies are given a chance.

Transforming industrial or office buildings to dwellings is one of these strategies. For example, it is estimated that 13,000 dwellings can be realized on (former) industrial sites alongside the west IJ river.\(^5\) This development also fits the city's policy for mixed use areas. However, to reach Amsterdam's goal of 70,000 dwellings, we also need to change the trend of an ever decreasing density per inhabitant. And to change, we need to know why the trend went down in the first place.

In the late 19th century, population growth combined with a huge migration towards the cities led to overcrowded cities, causing health problems and other misery. The unhealthy industrial cities eventually made scientists, urbanists and the government work together, leading to the Dutch Housing Act (Woningwet) in 1901. This resulted in urban expansion plans from Berlage for example. In the first half of the 20th century the footprint of Amsterdam grew rapidly with added areas of relatively low density. In the second half, this changed to a process of suburbanization after car ownership and commuting raised in popularity, further decreasing Amsterdam’s density. In the last ten years, the decreasing density is stagnating. A steadily growing population combined with the physical boundaries of Amsterdam’s footprint forces the city to make better and smart use of its space.\(^6\)

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1. Centraal Bureau voor de Statistiek, 2017. Bevolking; ontwikkeling per gemeente
2. Gemeente Amsterdam, 2011. Structuurvisie 2040
4. Damen, 2015
5. Gemeente Amsterdam, 2011. Structuurvisie 2040. Stedelijke ontwikkeling Haven-Stad (scenario 2)
To make better use of Amsterdam’s area, existing parts of the city will have to become more dense. For this densification process, there are multiple strategies, which can be combined as well to achieve an even higher efficiency for the area. These strategies are partly based on a research to densify the city centre of Rotterdam.\footnote{Tillie, et al., 2012}

**Create**

Build on the few open and vacant spaces left within the city. The easiest solution, but there are almost no vacant spaces left within Amsterdam. A lot of vacant space is untouched for a reason, for example areas right next to highways and other polluting infrastructure, or areas around Schiphol airport (noise pollution).

**Infill**

Build on areas in between or around existing buildings. For example, connect two perpendicular housing blocks by building a corner block. Might not be accepted by current residents, as it can decrease the amount of greenery and parking space. As this strategy uses extra floor space in existing neighbourhoods, it can affect the quality of these areas.

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\footnote{Tillie, et al., 2012}
Top-up
Build on top of existing buildings, add extra levels to apartment blocks or office buildings. A flat roof and good supporting structure is required. Difficulties may be legal restrictions, accessibility of the newly added levels, and building while apartments are still inhabited.

Transform
Convert existing office or industrial buildings into dwellings. Vacant office or industrial space often needs drastic changes and improvements of both the building and the surrounding area, as these were not designed for residential purposes. The strategy might be well combined with an infill or replace approach in typical office or industrial areas, matching Amsterdam’s policy to stimulate mixed use neighbourhoods for both work and living. Also, when buildings already get a significant overhaul, the possibility to top-up could be considered, to add even more floor space.

Replace
Areas or buildings with low density are demolished and replaced, using bigger/higher apartment blocks. For example: poor quality social housing blocks get replaced. Industrial areas with buildings which cannot be easily transformed to dwellings also apply to this strategy.

Relating these strategies to the site of this research, the Marineterrein, all of them could be applied. Referring to Amsterdam’s policy for 2040, for the Marineterrein the city focusses on quality of public space. The former navy site could be a publicly accessible park, combined with residential buildings. The current site features a lot of vacant, green space. However, taking Amsterdam’s policy into consideration, to build on this vacant space using the create approach, does not seem fit. Also, the site seems to have little options to fill up obvious spaces in between buildings. To replace some of the current buildings might be a possibility, especially for the low-rise storage buildings. Looking more specifically to the building scale of the former signal school building, the focus of this paper, two strategies seem fit in particular. The building features a flat roof, which could make it possible to add extra levels on top of the building. Also, the structural design seems flexible enough to transform the current office building for other uses. The application of these two strategies combined in an approach to transform, improve and add space to the signal school building can serve as an example for other buildings in Amsterdam.

2.2 ENERGY NEUTRAL AMBITION
In the Energy agreement for sustainable growth, as accepted by the Dutch government in 2013, the ambitions are clearly stated: an energy neutral built environment in 2050. To achieve this, already in 2020 new buildings have to perform as (near) zero energy buildings. Zero energy buildings (or ZEB) are generally interpreted to have a net zero energy, an equilibrium between the used and produced energy. They make use of the Trias Energetica principle, in order of importance: reduce energy use, maximize the use of renewable energy sources and use fossil energy as efficient as possible. Other terms which are common in the Netherlands and Belgium are passive house, near zero energy building (nZEB) or EPC[...]. Building legislation demands new dwellings to be nearly zero energy in 2020, however, the agreement also states an energy neutral built environment: the existing stock should get an overhaul to make its energy performance up to current standards. With government ambitions to have the entire countries building stock energy neutral in 2050,

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8 Gemeente Amsterdam, 2011. P31 & 43. Visie wonen/werken & visie Oosterdok/zuidelijke IJ-oever
9 SER, 2013. p16
10 Mlecnik, 2012
11 In Dutch: passiefhuis, nul energie woning en nul op de meter (NOM) woning
there is an enormous challenge to convert existing, poor performing buildings into energy neutral ones. If we want to make big steps in our energy and emission goals, it is the huge majority of our building stock that we have to focus on in order to meet our ambitions.

Within the European Union, the existing building stock accounts for over 40% of the final energy consumption. 50% of this stock is built before 1970, mostly with very a bad energy performance, since insulation only became common after this period. The low energy performance of our stock is confirmed by looking at the energy labels of dwellings: 75% of all labelled dwellings have a label lower than B.

![Number of dwellings, produced in the Netherlands between 1925 - 2015](image)

The current speed in which we renew our building stock in the Netherlands is 0.4% yearly. In this pace, only 12% of our building stock will be renewed by 2050. Meanwhile, outdated buildings are further deteriorating in quality and energy performance. Both our energy ambitions and the current state of our building stock require that we take drastic action. We have to renew and renovate, and we have to choose a right balance between both strategies.

When choosing between a high level renovation (also called deep retrofit) and replacement (demolition), there are more factors to keep into account than just measuring the current energy performance of a building. When you take material usage and waste into account, the environmental impact of renovation, and thus life cycle extension, is less than demolition and new construction. Everything we make has embodied energy in it, the energy consumed during the production and transport of materials is eventually stored in our products and buildings.

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12 Poel, Cruchten, & Balaras, 2006
13 CBS, PBL, Wageningen UR, 2016
14 Mulder, et al., 2015
15 Dutch: Hoog niveau renovatie. Buildings are stripped and retrofitted for better energy performance
16 Thomsen & Flier, 2008
17 Konstantinou, 2014
If you strip an average office to the core of its construction, 32% of its embodied energy is still saved in the structure and initial site work.\textsuperscript{18} This is a huge advantage compared to new buildings. Next to embodied energy, buildings also store capital, both of which are entirely wasted when buildings are demolished.\textsuperscript{19} Moreover, thorough renovations result in higher property value. Also, renovation and/or transformation leads to more differentiation in housing stock.\textsuperscript{20} This matches Amsterdam’s policy for diverse urban spaces for combined living and working. Taking multiple aspects into consideration, we can conclude that whenever technically and financially possible, improving the energy performance and living standards should be achieved by thorough renovation and retrofitting of our existing building stock, instead of demolishing and building new dwellings. Even when building new dwellings there is a possibility of using the embodied energy of the current building stock. In case of adding extra levels, the foundation, site work and infrastructure can still be used.

\textsuperscript{18} Cole & Kernan, 1996. Around 27% of the initial embodied energy goes into structure (the average between concrete and steel, wood has a lower value). Over 5% goes into site work (i.e. flattening, infrastructure)
\textsuperscript{19} Konstantinou, 2014
\textsuperscript{20} Thomsen & Flier, 2008
2.3 OFFICE BUILDING VACANCY

In this paper we already concluded the necessity to densify in Amsterdam, and to retrofit instead of renew whenever possible. This chapter focuses on office vacancy, and why we should transform offices into dwellings.

In the Netherlands, 7,387,000m² of office space is vacant, which is 15% of the total office space in our building stock. There is a structural vacancy of 36% of the vacant space, meaning that these offices have a low chance of being rented out soon, since they are already vacant for more than three years. Amsterdam is the biggest market for office space in the Netherlands, however this office market is not comparable to Amsterdam’s booming housing market: although demand for housing and housing prices are high and rising compared the rest of the Netherlands, office vacancy complies to the national average with 15%. A healthy vacancy rate for the office market is 5 to 6%. Called frictional vacancy, this amount of free space is needed for a good interaction between supply and demand. Currently, we have an overcapacity of around 10% in office space. Part of our existing office stock is simply not needed for its function (functional obsolescence). Some office buildings are already obsolete after their first lease period. This creates a mismatch between the technical and the functional life span of a building: designed and built according to Dutch building legislation, an office building is expected to have a technical life span of 80 years. By transforming and thus changing the function of a building, the functional lifespan can be prolonged to better suit the technical and economical lifespan.

Figure 4: increasing overcapacity of office space in the Netherlands (CBS, PBL, Wageningen UR, 2017)

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21 DTZ Zadelhoff, 2016
22 Remøy & Koppels, 2012
23 DTZ Zadelhoff, 2016
24 Remøy, 2010
2.4 WOOD AS BUILDING MATERIAL

When focussing on measures to minimize impact on our environment, just preventing unnecessary use of energy is not enough. The production, maintenance and recycling of buildings also uses significant amounts of energy and resources. Earlier on in this paper, embodied energy is mentioned: the amount of energy stored into a material or product. Wood constructions have a considerably lower embodied energy than concrete and steel.25

“Relative to the wood design, the steel and concrete designs embody 26% and 57% more energy relative to the wood design, emit 34% and 81% more greenhouse gases, release 24% and 47% more pollutants into the air, discharge 400% and 350% more water pollution, produce 8% and 23% more solid waste, and use 11% and 81% more resources.” (Canadian Wood Council, 2016)

Wood as a building material has various advantages. Wood is a renewable resource, withdrawn material can be reproduced by nature when conducting sustainable forestry. Also, wood plays an important role in reducing greenhouse gas, as it stores CO2 inside the material, and the production of wood takes only a fraction of the energy used to produce conventional building materials. Therefore, wood has a very small or even negative carbon footprint.26

Stored carbon, however, is not very relevant on the total savings compared to the savings in emissions during manufacturing. In new designs, replacing energy intensive, big carbon footprint building materials with wood drastically decreases the carbon footprint and embodied energy of a building. For example, if the use of wood in housing is increased at the expense of energy intensive materials, the emission reduction can be up to fifteen times the amount of carbon stored in the extra wood products.27 When looking at the entire life of a building, wood buildings also take the least amount of energy to dismantle. On the total sum of embodied energy within a building, demolishing it takes 1% with wood construction, but up until 3% with steel and concrete (where the total amount of embodied energy is already higher).28

<table>
<thead>
<tr>
<th>House type</th>
<th>Maximum impact</th>
<th>Most common</th>
<th>Minimum impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Timber</td>
</tr>
<tr>
<td>Exterior walls</td>
<td>Brick</td>
<td>Concrete block</td>
<td>Weatherboard</td>
</tr>
<tr>
<td>Roof</td>
<td>Corrugated galvanized steel</td>
<td>Corrugated galvanized steel</td>
<td>Concrete tiles</td>
</tr>
<tr>
<td>Framing</td>
<td>Steel</td>
<td>Timber</td>
<td>Timber</td>
</tr>
<tr>
<td>Windows</td>
<td>Aluminium</td>
<td>Aluminium</td>
<td>Wood</td>
</tr>
<tr>
<td>Energy (GJ)</td>
<td>520</td>
<td>372</td>
<td>218</td>
</tr>
<tr>
<td>Carbon emissions (t)</td>
<td>9,6</td>
<td>6,3</td>
<td>0,9</td>
</tr>
</tbody>
</table>

Figure 5: Different housing construction types compared (Buchanan & Honey, 1994)

25 Cole & Kernan, 1996
26 Buchanan & Honey, 1994
27 Buchanan & Levine, 1999
28 Cole & Kernan, 1996
Wood seems to be a much better choice for building material than other, more energy intensive or fossil materials. In some markets, timber frame construction makes up for a traditional, much used building method, usually when large areas of forest are easily available (i.e. Canada, New Zealand, Scandinavia). However, in the Netherlands the market share of timber frame construction is a steady 5% for over years, increasing in a slow pace.\textsuperscript{29} Why are we not rapidly increasing the use of wood materials in buildings? Building tradition and a conservative building market seem to be of major importance. After the Second World War, demand for new housing increased rapidly, which led to the necessity for optimization and rationalization of the building process. Both a shortage on the conventional building materials wood and brick, and the urge to speed up construction time soon stimulated research of cast and prefabricated concrete structures (i.e. the British Airey system, imported by the Dutch government in 1948).\textsuperscript{30} A following tradition in building in concrete still marks a significant part of the Dutch building stock, effectively displacing the use of timber frame construction. Since 1945, the quantity of wood per building is reduced by half in the Netherlands.\textsuperscript{31}

As the Second World war marked a tipping point in building tradition, perhaps our increasing awareness combined with political agreements regarding climate change can mark a tipping point for a new age in building: the age of smart, sustainable wood constructions.

\textsuperscript{29} De Houtkrant, 2016 (5 to 10%) and Lichtenberg, 2015 (a few percent)
\textsuperscript{30} Blom, 2004, p25-26
\textsuperscript{31} Fraanje, 1999
3. RESEARCH ON RENOVATION, EXTRA LEVELS & MATERIAL

3.1 RENOVATION

Chances and threats for office renovation

In different articles of Voordt, Geraedts, Remoy, & Oudijk, a variety of topics on office transformation can be found. The following information is based on these articles.

Technical information

Office floors are often in a multitude of 1.8m, usually 5.4m or 7.2m. In dwellings, 5.5m is a standard, this seems to fit well to common office dimensions. Floors are usually dimensioned to a static weight of 300kg/m² where dwellings are dimensioned to 175kg/m². Live loads in offices are 2.5 - 5kN/m² depending on the amount of freedom in arranging the floorplan. When archives are present (common practice in older offices), these loads go up to 10kN/m². The live loads of dwellings are 1.75kN/m² (NEN6702), considerably lower. These figures give some perspective in the possibility to add extra levels to the existing structure.

Pre-tensioned floors offer little space to make openings in it. Vertical ducts are therefore difficult. Office floors and walls are usually not suited for building legislation on acoustics and sound proofing for dwellings. For sound proofing, a floating screed floor can be used, and there are several lightweight separating wall systems.

Connecting dwellings to elevators or stairs is often difficult. Most offices don’t have balconies or outside space. An outside space is not obligated by building regulation, but preferred by many possible target groups. Interventions in the façade are of a costly matter, but have a big influence on the building’s performance, in energy, comfort and aesthetics.

Targeting inhabitants

Possible target groups are students, starters, dual earner couples without children, empty nesters and elderly people. One condition is the location of the office building. All target groups prefer to live close to amenities. Many office buildings are placed in an industrial or office area, making them less appealing for transformation to dwellings.

Financial

Often, selling a vacant office building is not very appealing for the owner. If vacancy occurs on a longer term, the selling price of the building will decrease. If the owner is a developer or investor it might be an option to transform the building themselves.\(^{32}\)

Regulations

Although it is not obligatory by building legislation to conform to the governments ambitions of zero energy buildings in case of a transformation (since 2012 a change in function is not regarded as a new built structure, and therefore it has to comply to the legislation for existing buildings)\(^{33}\), to convert an office building into an attractive place to live probably requires a high level renovation in the first place. When new parts are added during renovation works, for example new glazing or an entirely new façade, these parts have to conform to building legislation for new buildings, and thus they also need to conform to current standards of insulation, ventilation and so on.

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\(^{32}\) Voordt, Geraedts, Remoy, & Oudijk, 2007

\(^{33}\) Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013
3.2 TOPPING UP
Before designing additional levels on existing buildings, the following prerequisites should be taken into account. These are partly based on the work of Gooijer, Heilker, Velde, & Cüsters, 1999.

Building lifetime
A careful assessment of the current building's expected lifetime should be made before planning new levels on old buildings. Usually, topping up is done in coherence with other interventions like deep retrofit, in order to increase the building lifetime.

Fits urban plan
The current plan should be able to host the additional dwellings, if necessary with minor changes. Enough parking space should be available, and a shading study should be done to see if a higher volume blocks any sun on unforeseen places.

Financially possible
Adding extra levels can be of high costs, especially unforeseen interventions and advisory costs are high in an unconventional building method. Some buildings are better suited than others to add extra levels. An financial assessment should include costs per unit (both old and new), subsidies, and 'land use' costs.

Technically possible
A technical assessment of the foundation and building structure can reveal whether it is dimensioned well enough to support extra levels, or that extra improvements and reinforcements should be made before adding extra weight on top of the building. An additional 12% of the total building mass is mentioned as a rule of thumb for the extra weight which can be added.

With older buildings, precise measurements of the state and quality of the foundation can be done by a cone penetration test. For each foundation pole, an estimate can be made of the load it can bear.

Co-operating municipality
Is the municipality willing to be flexible with land use and costs? How do they handle building legislation? What are the municipalities plans for the neighbourhood?

Co-operating inhabitants
A successful plan to top up is only possible if the inhabitants in and around the building agree with the addition and the nuisance it will cause during construction time. They can be convinced by possible benefits like an added elevator, renovation of the entire building (lower energy costs) or some expenses for the nuisance.

Architectural conditions
The appearance of the added volume should fit the overall appearance of the neighbourhood. Are there practical possibilities for access to the new levels? Does the existing building have storage room an can is be reassigned to host the extra dwellings as well?

Regulations
For extremely light structures, meeting the fire regulations can be a challenge. Emergency staircases are expensive building elements.

34 In Dutch: sonderingsonderzoek
3.3 EXTRA WEIGHT: LIGHT CONSTRUCTION

Adding extra levels to a building means adding a lot of weight to a structure which is usually not designed to support this. However, the construction of old buildings is usually over dimensioned, as they did not account for the possibility for load reduction for multiple floors before 1990. As a rule of thumb, the extra weight most old buildings can support can be calculated:

Old load: \( F_g + F_e \) \( R \)

New load: \( 1,2 \times (F_g + \Delta F_g) + 1,5 \times F_e' \)

Where the extra permanent load is \( \Delta F_g \). Examples of multiple constructions can be found in the reader of Kamerling and Daane.\(^{35}\)

As the scope for adding extra weight is small, additions cannot be built in traditional, heavy building methods. Steel frame building and timber frame construction seem to fit best. In literature about lightweight constructions, steel frame building is often considered the 'best' option.\(^{36}\) However, in the recent years, there has been quite some innovation in engineered wood products. With smart application of composed wood strains, typical disadvantages of wood such as strength depending on grain direction are improved. Also, all of these products are prefabricated, decreasing building time on site to a minimum. Examples of innovation in wood products are Cross Laminated Timber (CLT) for massive, load bearing panels or beams (also called Kerto), Finnjoist for its resemblance with a steel I-beam, Lignatur for hollow core floor/roof elements and Kielsteg for big span elements. The Dutch company BIA makes interior walls out of a smart cardboard and OSB construction.

In the following table, some of these products are compared to the lightest possible steel frame construction:

<table>
<thead>
<tr>
<th></th>
<th>kN/m²</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Floors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel frame</td>
<td>0,74</td>
<td>Star frame floor (without concrete finish)</td>
</tr>
<tr>
<td>Regular TFC</td>
<td>0,69</td>
<td>Conventional timber frame construction</td>
</tr>
<tr>
<td>Finnjoist</td>
<td>0,5</td>
<td>Wooden I-beams</td>
</tr>
<tr>
<td>Lignatur</td>
<td>0,37</td>
<td>Timber hollow core slab</td>
</tr>
<tr>
<td><strong>Walls</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel frame</td>
<td>0,20</td>
<td>Metalstud plasterboard wall</td>
</tr>
<tr>
<td>Regular TFC</td>
<td>0,23</td>
<td>GyProc</td>
</tr>
<tr>
<td>OSB/Cardboard</td>
<td>0,16</td>
<td>BIA</td>
</tr>
<tr>
<td><strong>Walls, separating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel frame</td>
<td>0,41</td>
<td>GyProc</td>
</tr>
<tr>
<td>Regular TFC</td>
<td>0,49</td>
<td>GyProc</td>
</tr>
<tr>
<td>OSB/Cardboard</td>
<td>0,33?</td>
<td>BIA</td>
</tr>
<tr>
<td><strong>Roof</strong></td>
<td></td>
<td></td>
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<tr>
<td>Similar values to floors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Minimum specification as found in tables. Products might not be suitable for bigger spans, a specified calculation has to be made for each design

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\(^{35}\) Kamerling & Daane, 2015

\(^{36}\) Verburg & Barendsz, 2000, Gooijer, Heilker, Velde, & Cüsters, 1999
4. Conclusions

4.1 REFLECTION ON RESEARCH QUESTIONS

Answering to Amsterdam’s call for densification, and applying it to the buildings scale of the former Navy office complex, two of the mentioned densification methods seem fit: transformation and topping up. Both methods create new dwellings and therefore a higher density, without extra land use. Transforming the building cannot be done without a high level of renovation if we want to make the building future proof. The rate of renewal within the built environment is too low to meet international energy performance ambitions. New dwellings consume (almost) zero energy, but these buildings will still be in the minority for a long time. The challenge lies in improving the existing building stock. The combination of a deep retrofit and topping up might be applicable for many more (vacant) buildings in Amsterdam and other cities which are confronted with space issues.

Combining the transformation of office space with beforementioned densification and retrofit strategies seems to make sense. A deep retrofit is desirable to meet energy and emission goals, and to conform to the clients expectations. Adding extra levels seems necessary to make both transformation and the retrofit financially feasible. Extra space by topping up the building increases the amount of rentable space, and therefore leads to a higher revenue and lower land prices per dwelling.

In consulted literature, wood outweighs any other conventional building material in the field of sustainability. It has the lowest embodied energy, and by far the lowest carbon footprint. New products in engineered wood also proof to be competitive to steel frame construction. Looking at the values for steel frame construction and engineered wood products, we can conclude that by using wood, especially on flooring and roofing constructions, a significant save in weight can be made. This could mean the difference between one or two levels extra: the added floor space has a big influence on the financial feasibility of the project.

4.2 IMPLICATIONS FOR FUTURE BUILDINGS

The combination of strategies aims to give an integrated answer to social, spatial, environmental and financial issues, applied on a building scale. Some are specific for growing and high populated areas as Amsterdam, part of the research can be applied on a bigger scale. As an example for similar projects, it can have a positive effect on transformation and topping up with wood construction. During research in current literature, no projects where evaluated using recent engineered wood products. Most research is done in steel frame construction. The use of lightweight timber products can have a big effect on the technical and financial feasibility of a project.

4.3 LIMITATIONS

Most applied literature about topping up is already 17 years old. The costs of the projects used as reference are not applicable anymore, estimations are difficult to make. Until today, topping up is still a rare phenomenon. Many assumptions will have to be proofed by tests and measuring in practice.

4.4 FUTURE RESEARCH

This paper is a good start for any of the mentioned methods, but in its diversity of topics, in depth information is left for future research. The use of lightweight timber products for topping up is very promising, and calculations have to be made of the entire building block.

37 Greco, et al., 2016
38 Voordt, Geraedts, Remoy, & Oudijk, 2007
REFERENCES


