Building the future using the existing building stock: the environmental potential of reuse

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Abstract. Immense amounts of natural resources are consumed and processed by the construction sector every year resulting in a significant climate impact. In return, the resource and environmental value of these resources is lost due to the vast amounts of construction and demolition waste (C&DW) that is down-cycled. Thus, the potential of transitioning the construction sector from a linear to a circular economy (CE) are expected to be significant. In Denmark, C&DW make up 40% of all waste. Although 88% of the C&DW is recycled only 36% is upcycled (i.e. recycled with an equal or higher quality than the original resource) while 52% is down-cycled (e.g. crushed for road filling). More recently interest in direct reuse has increased as better way of exploiting the remaining technical service life of the materials and retaining the inherent value of the materials and avoid environmentally heavy material processing. In coming years, a large number of homes on Denmark’s ‘ghetto list’ (i.e. socio-economically disadvantaged residential areas) corresponding to 1,360,300 m² are to be demolished. At the same time, a large number of new buildings is to be built in the same affected areas. The Resource Block project seeks scalable reuse solutions that can link the large amount of resources in the existing buildings to be demolished with the need for resources to build the new buildings in these areas. On the basis of a life cycle assessment (LCA), the paper at hand assesses the environmental benefit of the reuse solutions found from the Resource Block project. The results show that reuse of these elements may on average potentially save 49% of the new buildings' greenhouse gas emissions compared to building solely with virgin materials depending on the availability and degree of reuse and which types of virgin materials the reuse is combined with.

Keywords: Circular Economy (CE), life cycle assessment (LCA), reuse, construction and demolition waste (C&DW), embodied greenhouse gas emission (EG)

1. Introduction

The building sector annually consumes 40% of all resources extracted and processed globally [1] resulting in a significant climate impact of 39% of the total human induced greenhouse gas emissions [2]. These issues are especially concerning when considering that by 2050 it is expected that the built environment will double [2]: where are all these resources going to come from? Circular ways of sourcing and managing resources are needed in order for the building sector to keep up with the needs of a growing world population, urbanisation and increasing living standards without adding to the climate challenge.
At the same time great amounts of resources are leaked from the building sector: 40% of the worlds waste by volume comes from building activities such as construction, demolition and renovation of which large amounts end up at landfills or are down-cycled (i.e. recycled with a lower quality than the original resource) [1]. This means that the (remaining) resource value, and thereby also the inherent environmental impacts ‘invested’ in the consumption and processing of these resources is not fully exploited and even lost. Circular Economy (CE) i.e. looping these resources at a high quality back into the built environment to retain the resource and environmental value e.g. through reuse (i.e. when a material or component is reused for the same or equal purpose it was originally made for) has therefore become of great interest in recent year [3,4].

In Denmark, C&DW make up 40% of all waste [5]. Although 88% of the C&DW is recycled only 36% is upcycled (i.e. recycled with an equal or higher quality than the original resource) while 52% is down-cycled (e.g. crushed for road filling) [5]. Denmark is legally obligated to meet a 70% CO₂ reduction in 2030 [6]. Realising the significant role that the building sector plays in reaching this goal, as it emits 30% of Denmark’s CO₂ emissions, the Danish government is phasing-in and stepwise tightening CO₂ requirements for new buildings in the building regulations towards 2030. Several studies suggest that building refurbishment (i.e. avoiding demolition) is preferable from a climate and resource perspective [7]. However, when refurbishment is not an option then reuse should be considered as it has a great potential to reduce new buildings’ CO₂ emissions [8–10]. However, reuse cases are often singular cases that lack a potential for upscaling. This is among others due to the unreliable, diverse and undocumented secondary material flows: i.e. lack of knowledge on the type, amount and quality as well as at which time these materials will become available from the existing building stock makes it difficult to create a big enough volume of secondary material supply to substitute the virgin material demand on a large scale [11].

In 2018 the Danish government published a ‘ghetto list’ of socio-economically disadvantaged residential areas that are subject to development requirements towards 2030. The list requires that a large number of buildings in these residential areas, corresponding to 1,360,300 m², are to be demolished and in their stead a similar or larger number of new buildings are to be built to transform these areas in coming years. From a technical point of view many of these residential buildings and their inherent materials are in good shape. Many of these buildings are built within the same time window of 20 years (1960-1980) using an industrialized montage building method that was developed to erect many buildings very quickly due to lack of housing, resources and skilled work force after the second world war [12]. Because these buildings are built using a simple modular and standardized system using mass-produced prefabricated reinforced concrete elements that are cast together on site they can upon their demolition provide a large volume of relatively homogeneous secondary building elements. This indicates that there is a large potential for reuse to replace virgin materials on a larger scale when refurbishment is not an option. Finding ways to exploit the existing buildings stock of secondary materials to build the new buildings replacing them thereby reducing resource consumption, waste and environmental impacts is obvious.

The Resource Block (in Danish: Resource Blokken) is a joint research project between industry partners (architects: 3XN, JAJA, Spektrum, ReVærk, Panum&Kappel, Effekt; engineers: Regnestuen; contractors: Enemærke & Petersen, Søndergaard and housing association: Ungdomsbo) and research institutions (Aalborg University Department of the Built Environment and the Danish Technological Institute) funded by Realdania running from 2020-2022 [13]. The project is working with two residential areas on the ghetto list and maps the existing resource stock, tests and documents the quality of the secondary materials in the buildings and investigates the potential to disassemble and reuse the secondary materials in new buildings. The aim is to develop scalable reuse solutions.

The paper at hand assesses the embodied greenhouse gas emission (EG) reduction potential of the reuse solutions from the Resource Block: when virgin materials in the new buildings are substituted with secondary materials from the existing buildings. The papers conclude by discussing the practical challenges of upscaling the reuse solutions from the Resource Block.
2. Method

2.1. Existing buildings stock

The study is based on three building blocks from two ‘ghetto areas’ that are listed as some of Denmark’s toughest ghettos soon to be demolished: Stengårdsvej and Vollsmose in Esbjerg and Odense municipality respectively. The existing stock of materials within the three building blocks Stengårdsvej 8, Stengårdsvej 10 and Birkeparken 65 have been mapped (see Table 1). The buildings predominantly consist of prefabricated concrete elements that have been casted together on site.

Table 1. Existing stock of materials in building blocks. Image of buildings from [13].

|                   | Stengårdsvej 8 | Stengårdsvej 10 | Birkeparken 65 |
|-------------------|----------------|----------------|---------------|
| Year of construction | 1967           | 1967           | 1967          |
| Number of floors   | 8              | 3              | 8             |
| Concrete floor slabs [m³] | 393          | 630           | 3296          |
| Concrete primary walls [m³] | 343          | 312           | 1463          |
| Internal concrete walls [m³] | 27           | 38            | 346           |
| Window wood frames [m³] | 29            | 4             | 78            |
| Glass [m³]         | 3              | 3             | 44            |
| Concrete façade [m³] | 105           | 57            | 444           |
| Brick façade [m³]  | 75             | 118           | 22            |
| Facade stone wool insulation [m³] | 443          | 326           | 474           |
| Concrete roof slab [m³] | 54            | 163           | 286           |
| Roof stone wool insulation [m³] | 126          | 190           | 343           |
| Roof felt [m³]     | 5.65           | 3             | 8.75          |
| Concrete stairs [m³] | 9              | 25            | 91            |
| Internal wood doors [m³] | 13            | 14            | -             |
| Steel plate, 2mm [m³] | -              | -             | 4             |

The Danish Technological Institute tested the concrete for its composition, strength and potential pollution and found that the majority of the building elements are clean of toxic chemical compounds and can thus be reused. However, the concrete elements are only suitable for use in passive environments (i.e. non-loadbearing functions) as their composition and the strength do not live up to current standards.

Disassembly of the buildings will happen in steps: as in a traditional demolition the existing buildings will be stripped down to the structure, the structure is then cut with a diamond cutter into box modules and deck/wall elements that are lifted out with a crane. The advantage of demounting the building into larger modules and elements is that the monetary and environmental cost of cutting and crane lifting can be reduced.

2.2. Design sprints

Based on the development plans for the ghetto areas Stengårdsvej and Vollsmose, six Danish architects: Effekt, Panum & Kappel, Spektrum, Reverk, JaJa and 3XN were asked to come up with designs and technical solutions for how to reuse the existing building stock to build new row houses in these areas. Each architect designed one housing unit each. As the concrete elements cannot be reused in load bearing functions the designers had to find other solutions to fulfil the loadbearing requirements e.g. using steel frames. Effekt designed a unit of 360m² for disassembly combining reuse concrete elements
with cross laminated timber elements. Panum & Kappel combined reuse concrete box modules and elements and a reuse window facade to design a two storey 104m² unit on a pillar foundation. Spektrum designed a two storey 290m² unit using reuse concrete box modules on the first floor, reuse concrete wall elements and a new steel frame in the ground floor, reuse wood as flooring and reuse windows for greenhouses on the roof terrace. Reværk designed a 2 storey 130m² unit on top of a foam glass foundation using reuse concrete hollow core slabs as floor slabs and reuse brick walls and halved concrete hollow core slabs as facades with reuse windows. JaJa used reuse concrete box modules and concrete wall elements and halved concrete hollow core slabs as facades in their design of a 160m² two storey unit. 3XN designed a two storey 134m² unit for disassembly on top of a pillar foundation using reuse concrete box modules, slab and wall elements. The designs are described in more detail with illustrations in the Resource Block design catalogue available online [13]. Figure 1 shows the amount of virgin and reuse materials used in each design sprint. The relationship between virgin and reuse materials differ across the design sprints: in the majority of the design sprints the amount of virgin material is equal or higher than the amount of reuse materials except for Panum & Kappel who use more reuse material than virgin material. The difference occurs as the designs vary in size and technical solutions. Note that these material amounts reflect the preliminary design and not the final design.

**Figure 1.** Amount of virgin and reuse materials used in each design sprint.

### 2.3. Life cycle assessment

In this study, we estimate the EG reduction potential of: 1) the existing building stock compared to if corresponding building blocks were to be built today using virgin materials and 2) the design sprints compared to CO₂ reference values for twelve Danish row houses from [14] and building a corresponding row house using virgin materials.

To do this we used life cycle assessment (LCA). LCA is increasingly used in the building sector to assess the environmental impact potentials of buildings. Several LCA software tools and environmental impact databases exist. While many conventional building materials and solutions are well-documented in these tools and databases, a deficiency of well documented reuse solutions exist. Thus, the study at hand builds on the findings from Andersen et al. 2019 [15] who documented the environmental
performance of different reuse and recycling solutions for e.g. bricks, concrete elements, windows etc. that are currently being used by the Danish building industry so that they may be included in the LCA. Figure 2 gives an overview of the EG of each reuse or recycling solution per m³ material.

Figure 2. Embodied greenhouse gas emission of different reuse and recycling solutions compared to a corresponding conventional solution calculated for 1 m³ material based on [15]. Note that the y-axis differs between the three graphs.

Andersen et al. 2019 [15] follows the LCA method decribed In ISO 14044, ISO 14044 and EN 15804, using a simple functional unit (FU) of 1m², 1m³ or 1 kg for a given material or component for a conventional reference scenario in comparison to a reuse scenario. In the study at hand we have converted the functional unit to m³ (see Figure 2). The system boundaries include modules A1-A3 (production of the materials including assumed transport of 50 km, 10% assumed waste and disposal of waste) and C3-C4 (waste treatment and disposal) and D (credits for potential future reuse, recycling and energy recovery at end of life in a next product system). However, module D has been excluded from our study as it is too uncertain. As the existing building elements primarily comprise of concrete elements that have a long technical lifespan it is expected that these will last the lifespan of the new buildings. In the study at hand we also estimated the EG for cutting the concrete elements i.e. replacement of saw blades and energy consumption for cutting based on information from the manufacturer. As circular economy is a relatively new concept within the building sector environmental data is lacking. Therefore, Andersen et al. 2019 [15] combines several environmental data sources to close the gap: environmental performance declarations, the ökobau.dat and Ecoinvent 3.4 cut-off database focusing on a Danish or European representativeness. The assessments using Ecoinvent v3.4 were conducted in the SimaPro LCA software tool using the characterisation method ILCD 2011 Midpoint+. Although several environmental impact indicators have been calculated, we only used the environmental impact indicator global warming potential expressed in kg CO₂ eq. in accordance with the scope of our study. The material amounts in Figure 1 are multiplied by the kg CO₂ eq./m³ materials from Andersen et. al 2019 [15].

As the design sprints vary in size the EG is calculated in kg CO₂ eq./m² floor area to enable comparison of the design sprints. Reference EG values for the twelve Danish row houses from [14] have also been calculated in kg CO₂ eq./m² floor area in order to compare them with the design sprints. The
EG reduction potential of the existing buildings is estimated for the full material stock and is therefore calculated in tonne CO$_2$ eq.

Figure 2 shows that reuse without heavy processing often results in the largest EG reduction compared to the corresponding conventional solution (e.g. aluminium, galvanized steel and steel) while recycling often has a lower reduction potential (e.g. chip board, concrete). For more details see [15].

It varies from the different solutions in what life cycle stage the EG reduction happens. For example, the metal related reuse solutions reduce the production related EG but increased the EG from waste treatment. Although some solutions result in lower reduction potentials e.g. brick wall reuse compared to other solutions e.g. aluminium plate reuse, the absolute effect can be larger in situations where these solutions exist in large volumes. Recycled concrete does not result in a large EG reductions but can still reduce the demand for sand and gravel. Some solutions, such as recycled chip board does not result in an EG reduction compared to the corresponding conventional solution. Overall, the graph suggests that EG reductions can be expected if secondary resources from demolition are exploited to a larger degree in new buildings.

3. Result

Note that the result shown herein have been updated since they were first published and may therefore slightly differ from the results in the design catalogue of the Resource Block project [13]. However, the conclusions remain the same.

3.1. Existing building stock

Figure 3 shows a comparison of the EG when the material stock in the building blocks Stengårdsvej 8 and 10 and Birkeparken 65 today using virgin materials. Note the difference in the y-axis values between the graphs.

Figure 3 shows that if the Stengårdsvej 8, Stengårdsvej 10 and Birkeparken 65 were to be built today using virgin materials it would leave a significant EG footprint of 410, 524 and 2286 tonne CO$_2$ eq. respectively. The highest EG comes from the concrete floor slabs, concrete primary walls and bricks as these exist in large amounts as seen in Table 1 and are EG intensive to produce today. In comparison, only a minor EG is connected to the reuse of the building materials and elements inherent within Stengårdsvej 8, Stengårdsvej 10 and Birkeparken 65: 41, 55 and 118 tonnes CO$_2$ eq. respectively. In other words, a
significant potential to avoid a substantial amount of EG exist: 3006 tonne CO2 eq. if 100% of these materials and elements are reused. This corresponds to saving the annual CO2 emission of approximately 273 Danes assuming that one Dane emits approximately 11 tonne CO2/year [16]. As seen from Figure 3, reuse is not completely burden free due to processing of the materials and elements for reuse. EG related to the cutting of the concrete elements in order to retrieve them for reuse i.e. replacement of saw blades and energy consumption for cutting only corresponds to 5%, 3% and 10% of the EG for reusing the building stock in Stengårdsvej 8, Stengårdsvej 10 and Birkeparken 65 respectively.

3.2. Design sprints

Figure 4 compares the EG of two scenarios for each design sprint: 1) using some degree of reuse materials in combination with virgin materials to build the design sprints (see Figure 1) and 2) using only virgin materials to build the design sprints.

![Figure 4](image_url)

**Figure 4.** Embodied greenhouse gas emission of each design sprint when using ‘reuse’ materials compared to using only ‘virgin’ materials measured against Danish row house reference values. Percentage saving of the reuse scenario compared to the corresponding virgin materials scenario are displayed at each ‘reuse’ scenario.

Figure 4 shows high EG savings when the design sprint substitute some of the virgin materials with reuse materials compared to only building the design sprints using virgin materials: 49%, 80%, 56%, 18%, 52% and 49% saving for Effekt, Panum & Kappel, Spektrum, Reaer, JaJa and 3XN respectively – on average a 49% EG saving across all of the design sprints. As seen from the green bars in all the design sprints, the saving primarily comes from reusing concrete elements that thereby avoid the burdensome production of virgin concrete. Because Panum & Kappel has the smallest unit size of 104m² and predominantly use reuse materials their design by far achieves the highest EG reduction of 80%. Effekt, Spektrum, JaJa and 3XN achieve similar savings of ranging from 49%-56%. Reaer only achieves a 18% EG saving because a high amount (180.5 m³) of EG intensive virgin materials such as foam glass, wood fibre insulation, steel and concrete that is distributed out on a small unit size of 130m². In comparison, Effekt uses an even higher amount of virgin materials (240.1 m³) compared to Reaer but the amount is distributed out on a larger unit size of 360m², hence the kg CO2 eq./m² is smaller and the EG saving higher (49%) for Effekt compared to Reaer. Thus, the EG reduction depend on the amount and type of virgin materials that the reuse solutions are combined with. Higher savings can be
achieved by combining reuse with low EG virgin materials or reducing the amount of EG intensive virgin materials.

If the design sprints were built using only virgin materials only Effekt and JJa is below the lower reference value, Spektrum is below the median reference value and Panum & Kappel is below the upper reference value. With reuse, this brings all design sprints, except Reværk, below all the reference values. Hence, reuse holds a great potential to help reduce the EG of new buildings.

4. Discussion

The industrialized montage building method that was used to build Stengårdsvej 8, Stengårdsvej 10 and Birkeparken 65 in 1967 has been used all over Europe due to a critical lack of housing after World War II. It is therefore expected that the reuse solutions and concepts from the Resource Blok can be translated to other similar buildings around Europe. However, several challenges pertain to building future buildings using the existing building stock.

As previously mentioned, it was found in the Resource Block project that 1:1 reuse of the concrete elements in the existing building blocks e.g. using a loadbearing concrete wall from the existing building as a loadbearing wall in the new building is not possible because the elements’ composition and strength do not live up to current standards. Therefore, these elements are only suitable for use in passive environments (i.e. non-loadbearing functions) as demonstrated in the design sprints (e.g. non-loadbearing façade covering, partition walls etc.). As concrete is often used in loadbearing functions in new buildings, this limits the extent to which we can substitute virgin concrete elements in new buildings with concrete elements from existing buildings. Albeit the design sprints demonstrate that it is possible to find suitable uses for the concrete elements that will provide a significant potential to lower the buildings EG through reuse of these elements in non-loadbearing functions.

As the concrete elements were produced at a time when strength requirements were less strict some of the concrete elements have little to no reinforcement within them making it difficult to lift them out with a crane and even transport them for reuse elsewhere at the risk of damaging them. Thus, careful handling and temporary bracing may be needed to move the concrete elements. After extraction the elements cannot be stored outside as they must not be exposed to humid and cold weather. With the risk of damaging the building materials and elements as well as the risk of pollution e.g. PCB it is unlikely that the full EG reduction potential (i.e. 100% reuse of the existing stock) from Figure 3 can be realized. However, even if only a 50% reuse of the existing building stock is realized it would still provide good EG benefits. To realize a higher EG saving and resource efficiency refurbishment, where polluted building materials and elements are removed, should be prioritized over element reuse as these buildings are in good shape.

The availability of secondary resources is limited: more buildings are being built than demolished. For that reason, we can only to a limited extent build future building by reusing the existing building stock. This means that the built environment will still rely on virgin materials. For that reason, other building related climate and resource actions are needed to build future buildings environmentally responsible e.g. using renewable biomaterials.

A study of the Danish legislation found no legal barriers hindering reuse of building elements but also found that the legislation does not promote it [17]. It is a challenge that the technical and documentation requirements for products in the Danish Building Act also apply to reuse materials and elements. At the same time there are no harmonized standards or guidelines for how to test and document secondary building materials. Hence, extensive testing and documentation is required in order to reuse existing building materials and elements.

The varied data sources used by Andersen et al 2019 [15], upon which our EG reduction estimates rely on, is a source of uncertainty. Hence, this study should only be viewed as a screening and first steps to quantify the EG of reuse solutions on a building level. Expanding existing environmental impact databases with the environmental performance of CE (including reuse) solutions is essential to drive the circular transition in the building sector. It is also questionable if the basis for comparison that results in the estimated EG reduction potential is representative of the real-life situation. For example, we compare
the benefit of reusing a halved concrete hollow core slab as a façade on the new building with that of using a virgin concrete hollow core slab as a facade. In reality it would be too costly to produce a concrete hollow core slab simply for the use as a façade. The halved concrete hollow core slab would most likely substitute a commonly used façade product e.g. fiber cement plates which would be more representative to compare with. However, the comparisons are made in the absence of better environmental performance data for reuse solutions.

Concrete, the primary focus of the Resource Block project, has a very long technical lifespan that can last for several hundred years. As buildings often reach obsolescence prematurely for various reasons [18,19] the building sector potentially fails to exploit the full technical lifespan of long-lasting building materials such as concrete. At the same time immense amounts of concrete are being produced globally every year emitting 8% of the world’s greenhouse gas emissions [20]. Determining the exact remaining technical lifespan of the concrete elements is challenging, however, due to the good condition of the existing concrete elements it is expected that they will have a very long remaining technical lifespan that can last the full lifespan of a subsequent building. In light of both the resource and climate challenge, it is very likely that society will be forced to maintain buildings, components and materials much longer in the future than is the current practice.

The individual steps of the reuse process are currently not well described or well documented. Hence, the next step of the Resource Block project is to develop methods, test, document and demonstrate each step of the process. This includes disassembly, documentation and test, preparation for reuse in new buildings, construction and potential for future disassembly. The Resource Block project will focus on concrete hollow core slabs as they were and still are a commonly used element across building types and periods, thus existing in large quantities providing a large potential for upscaled reuse.

5. Conclusion

Lack of knowledge on the type, amount and quality as well as at which time these materials will become available from the existing building stock makes it difficult to create a big enough volume of secondary material supply to substitute the virgin material demand on a large scale in the built environment. However, the demolition of 1,360,300 m² ghetto areas in Denmark in coming years will make a large volume of secondary materials available to be reused in the new buildings to be built in these areas. In this paper we assessed the EG reduction potential of the reuse solutions from the Resource Block project: when virgin materials in the new buildings are substituted with secondary materials from the existing buildings. Although, 1:1 reuse is not possible (e.g. using an existing loadbearing concrete wall as a loadbearing wall in the new building) as the existing concrete elements’ composition and strength do not meet current standards the study found that reuse in non-loadbearing functions can still provide a significant potential to lower new buildings’ EG. The design of six different row houses applying different solutions on how to reuse the building elements from three existing ghetto buildings showed a potential to save on average 49% of the row houses’ EG emissions (provided that these materials are available) compared to building them solely with virgin materials. The size of EG savings depend on the amount and type of virgin materials that the reuse solutions are combined with. Combining reuse with low EG virgin materials or reducing the amount of EG intensive virgin materials can increase the EG saving. Furthermore, not all reuse solutions will result in EG savings compared to a corresponding conventional solution as processing for reuse may in some cases outweigh the EG benefits. It is expected that the reuse solutions and concepts from the Resource Blok project can be adopted in other similar buildings around Europe providing further opportunities to reduce some of the virgin material consumption and EG related to the built environment in coming years.

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