ON-SITE STRUCTURAL RECONFIGURATION AS THE ALTERNATIVE FOR DEMOLISHING STEEL FRAME BUILDINGS

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ABSTRACT

The world steel demand and production are constantly growing parallelly to the world economic growth. Even though steel is fully recyclable, there is still a vast amount of virgin production which put tremendous pressure on the natural scarcity of natural resources. Steel recycling only mitigates the impacts since it alone requires a significant amount of energy (including re-manufacturing process) and it produces more greenhouse gases into the atmosphere. Therefore, assumptions suggest that the market of reclaimed material will play a progressively more important role in the future. This research paper presents the limitations which currently make the reuse scenario very unlikely to occur excluding industrial uses which is a relatively narrow sector. Through this, it will investigate the relevance of on-situ frame structural reconfiguration as a potential alternative for demolishing steel frame buildings.

KEYWORDS: *reuse, recycling, steel, flow, demolition, deconstruction, design for disassembly, steel frame, structural reconfiguration, reclaimed material, end of life-cycle*

I. INTRODUCTION

It is generally believed that our consumption of non-renewable material resources and creation of wastes is one of the crucial points that our society has to urgently address, and building industry plays a significant role in term of energy use and waste production. The construction market is dominated by three materials: steel, concrete and brick constitute currently 90% of all building materials. But steel itself generate 50% of embodied energy in the building industry[1], and the world steel demand and production are constantly growing since mid of the XX century reaching 1.7 Mt this year (it was 1.2 Mt in 2007 in comparison)[2]

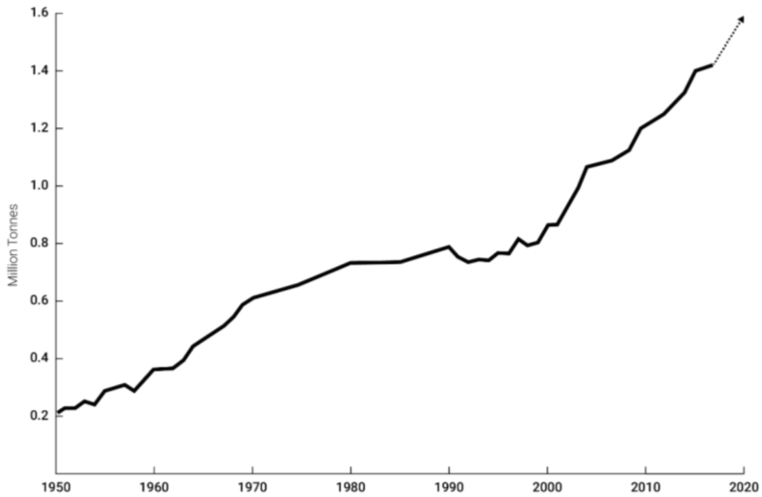

Figure 1. World steel demand, 1950 – 2017, source: worldsteel.org, own illustration

The steel industry is frequently associated with the economic growth, the reason behind is that steel has a crucial role in the infrastructural and constructions developments. The last decades of steel production were totally dominated by Chinese market (the predictions don't expect changes in this matter), it was due to the economic boom when China experienced a massive increase in the need for steel construction in last years. The country has developed into by far the largest world's producer and consumer of steel with estimated 50% (Europe production equals about 10%) of world production in 2016. The growth has been driven by the fast modernization of the country economy, manufacturing, infrastructure and construction industries.

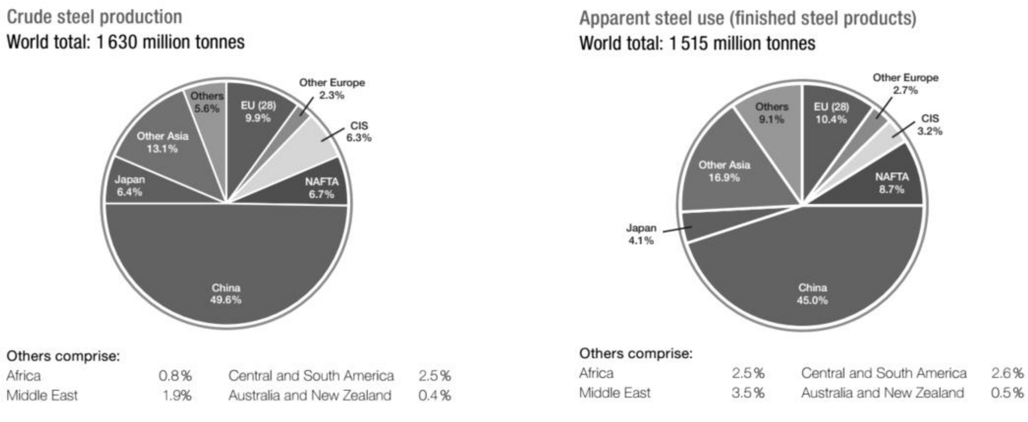

Figure 2. Steel production and use - 2016, source: worldsteel.org

[1] Allwood, J., Cullen, J. and Carruth, M. (2012). Sustainable materials. Cambridge: UIT Cambridge.
[2] Worldsteel.org. (2017). Cite a Website - Cite This For Me. [online] Available at: https://www.worldsteel.org/en/

Even though only a minimal amount of construction steel goes to landfill (estimated less than 1%, the part which is difficult to extract from the waste stream), new steel production and even recycling process product significant amount of greenhouse gases. Global warming is surely one of main concern connected with growing materials productions; nonetheless, another factor involved is the rapid depletion of mineral resources and creation of waste which requires urgent disposal due to growing prices of landfilling. The construction industry is always connected with the constant expansion of populations and economies; therefore, it has a major role to play in term of energy reduction. It is especially relevant currently since the world's needs for almost every construction materials are increasing which create a tremendous pressure on natural resources. The example here can be continually increased of oil prices which demonstrates the incredible scarcity of this resource. It exposes the fact that even the commodities once seemingly taken for granted might suddenly become in shortage. Hence, all these circumstances will make reusing existing resources exceptionally important in the coming future.

Reusing structural components theoretically is the most and sustainable solution for steel construction, and it is broadly acknowledged that the whole industry should aim to increase the percentage of using reclaimed steel structure, which in the end might become a mainstream for future construction method. However, there are many aspects causing difficulties for this solution; for instance lack of a structure and organization of available steel components for construction companies, designers and other subjects who are eager to use such elements in their new project. For now, the amount of available information about reuse sector is very limited, there is a shortage of well-established system of components exchange. Thus, it is generally challenging to identify suitable materials in the local context at the appropriate time frame. Furthermore, currently it is hard to precisely estimate a final cost of reused or recycled implication, which makes the choice difficult and unclear until the end. The limitations of reusing steel construction elements were one of sub-subject of the research and it is elaborated more in the point 3.5.

This paper aims to expand understanding of different processes within the steel construction industry, in order to suggest possible alternatives and creates a framework for design principles for next project phases. It explores the challenges which lie in the integration reused components to new constructions, but also shows different techniques which foster reuse strategies and analyze on-site structural transformation as a potential possibility to increase the percentage of reusing steel structural components. Through responding to sub-questions (point III), interviews making, literature and case studying, it will answer to the question if is it relevant to develop an integrated system of on-site structural reconfiguration in order to facilitate greater reuse of construction steel.

II. METHODOLOGY

The research consisted mainly three inter-related methods: literature study, case study and interviews. Mail and phone interviews with developer and architect. Another method was a case study of a deconstructed building of former Youth Hostel designed by Dutch architect, Jan Van Klingeren in the Hague. Currently, the steel components from this building are stocked at a private plot waiting for next steps. This case will be the base for creating flow diagrams. The first one is built on the history of this building; whereas, the second represents the alternative scenario, based on the imaginative situation when the structure of the hostel was not deconstructed but transformed. These two diagrams together aim to provide the overview and comparison of different flows involved in the steel structure deconstruction and reconfiguration. It is also one of the research tool (diagramming method) for a better understanding of project site and can form a framework for design principles and decisions in next the phase. The last research method used in this paper was literature study. The list of all titles can be found in the Bibliography chapter.

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III. RESEARCH QUESTION AND SUB-QUESTIONS

Can on-site structural transformation of steel frame buildings be one of the relevant solutions for increasing reuse of reclaimed steel construction elements?

SUB QUESTIONS

In order to generate the needed knowledge for the intended project the following questions need to be answered:

1. *How currently the flow of construction steel looks like and what improvement can be implemented?*

2. *How much more sustainable and profitable might be reuse than recycle of steel?*

3. *What amount of steel is reused presently and how much steel reuse might be increased in the future?*

4. *What are existing steel reuse models?*

5. *What are current main limitations of steel structural reuse?*

6. *What are current strategies for improving the situation?*

Ad.1

How currently the flow of construction steel looks like and what improvement can be implemented?

In order to understand the flow of construction steel in the European steel industry, I have created this loop diagram based on different researches and literature studies. Is it rather a simplified diagram, the actual network might have more intermediaries within the whole production, each of the arrows represents also a transportation need. We can already see the potential of reuse scenario, which could exclude some of the processes such as transportation needs, material separation, storage and processing. These all are connected with energy use and additional environmental impacts making recycle process less desirable then reuse. Although the one which is the most desirable is through adaptation but is usually not available scenario. Each component of the chain is briefly described on the next page.

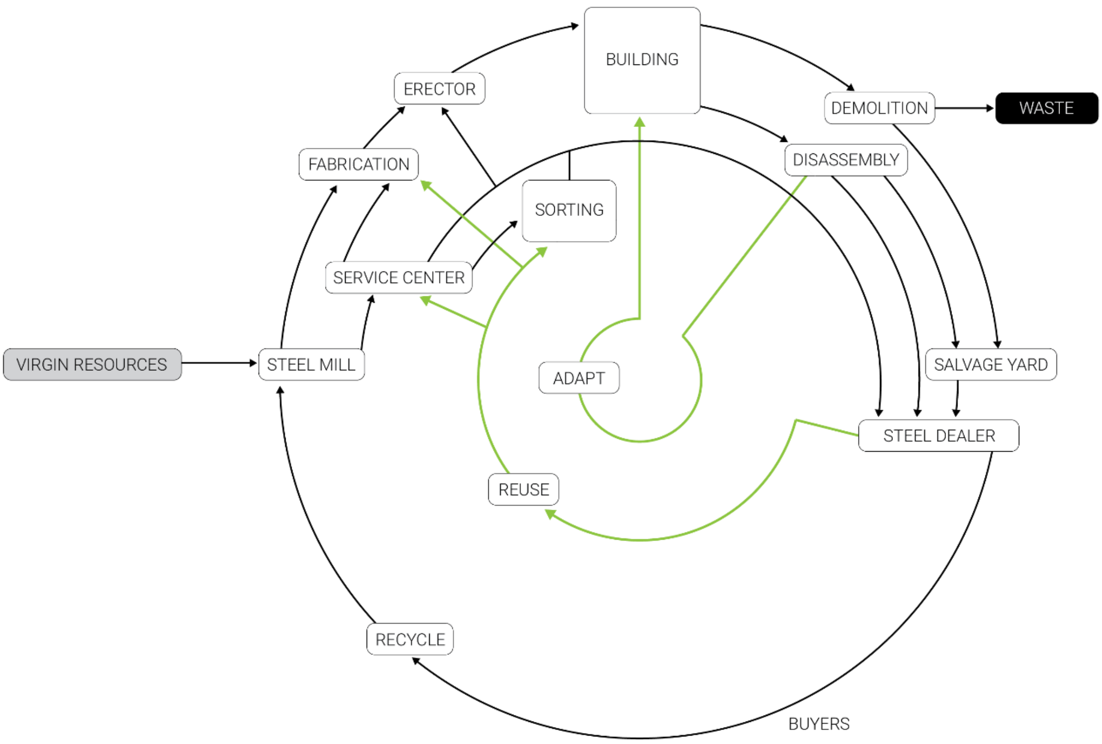

Figure 3. Network of steel flow in construction, own illustration

VIRGIN RESOURCES - The primary virgin resources in the manufacturing of steel iron ore. The growing world demand for material caused by expanding population and economy put high pressure on natural resources.

STEEL MILL - Steel mills manufacture steel from both virgin resources and recycled materials.

SERVICE CENTER - It performs as first stage processing and distributing steel. Services centers are intermediaries between steel mills and fabricators, but also shoring companies and other clients need steel from immediate source. Some service centers stock both new and used steel.

SHORING – Shoring contractors require significant amounts of steel for a temporary support structure for below-ground construction and are large users of reclaimed steel. They generally look for large sections and lengths and often are able to take a significant amount of materials.

FABRICATOR AND ERECTOR - Fabricators purchase steel from service centers or steel mills and fabricate the component which is then assembled into a building by erectors. Often both exist within one company which might also have small stocking place for reclaimed steel waiting for an opportunity to be reused. Any offcuts or waste usually is sent back to mills for recycling.

BUILDING - It can be designed to be more readily deconstructed, increasing the potential for reuse and thereby maximize the of life value of the materials. Thus, the obsolescence of the building and ways of maximization financial and environmental value should be addressed at the design and construction phases.

DEMOLITION - Demolition companies are responsible for the removal of buildings that are no longer required. Nowadays most of the buildings are demolished using destructive methods and heavy machinery. There is a perception that other methods of keeping steel undamaged create additional costs and problems. Due to the high value of scrap and a relatively easy process of distracting, almost all steel is removed from the site.

DISASSEMBLING - Some demolition companies are maximizing the reuse value of the components through disassembly. In the case of disassembling the connections are unbolted or torch cut (little damage). It is generally estimated that the demand for reclaimed steel will increase in the nearly future.

WASTE - Only a minimal amount perhaps about 1% goes to landfill in the European context, it is a part which is difficult to extract from the waste stream.

SALVAGE YARDS - The role of salvage yards is to store steel for reuse and recycling purpose. Some of them might be able to extract steel components if a potential for reuse will be recognized. Although currently due to a high value of scrap steel and a safety concern, most of the steel goes directly to melt again.

STEEL DEALER - Steel that emerges from the demolition process is often sold to scrap steel dealers or salvage yards that will cut, grade, batch and sell the steel back to steel mills for recycling. Dealers often also buy scrap steel from fabrication process and other available sources. These companies also prefer to sell reuse steel directly from demolition sites.

RECYCLE - Recycled steel is an essential feedstock for the manufacture of new steel and there is a large world market for scrap steel. It is generally calculated that about 90% of steel from demolished building goes to steel mills to be recycled. During recycle process steel does not virtually lose any of its physical properties.

REUSE - Sourcing steel components from an old building and using them in a new project minimal re-processing. The most sustainable way is reusing the whole steel frames and adapt them in situ to new requirements. The elements might need to be cleaned and sometime they require additional fabrication work, although there is no need to re-manufacture the steel.

ADAPT – Adoptable building is a concept that incorporates the ability to make future changes easily and with minimum expense, to meet the evolving needs of occupants. It is based on the principle that a building should allow its layers to change in the hierarchical way, where a structure is the element which lasts the longest. Incorporation of this adaptive aspect could save in the longer perspective money, time and difficulties when needs of changes will come.

Ad.2

How much more sustainable and profitable might be reuse than recycle of steel?

It is very challenging task to estimate exact profits of reuse above recycling because the whole steel industry involves many different intermediaries. However, I have made a simple assessment form on the available database[3] of steel in the Netherlands and based on a system of proportions, scaling and relations (as well as some assumptions) comparable set of data was generated.

The diagram from the Appendix 1 describes the situation of steel demand in the context of the Netherlands. First by relating to the European scale (7Mt - 4%), then it shows the relation between construction steel (3.92 Mt - 56%) and other steel usages; finally, the third column presents the amount of structural steel for building (0.77Mt - 11%). Using this final calculation the next diagram was created - Appendix 2. For this diagram, the assumption of reusing 1/4 of current percentage of recycling steel was taken (growth of 20% of steel reuse). Based on that series of CO2 emission comparisons was made to visualize the potential impact. If we reuse 1/4 of the recycled steel we could save around 33 880 tCO2 only in the Netherlands, it is equivalent of taking 6700 cars off the road every year or production of 2600 tons of beef.

Ad.3

What amount of steel is reused presently and how much steel reuse might be increased in the future?

Generally, 90% is recycled back to steel mills. About 10% is reused (mainly portal frame system, industrial building, warehouses). It is estimated that only less than 1% of the material goes to landfill, the part which is difficult and not profitable to extract from the demolition. This statistic does not include in-situ reuse and adaptive reuse.

The prediction are that reasonable potential of increasing reuse sector of steel structural component. Some sources suggest even the raise from 10% to 20-25%[4], that would be achievable if the market

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[3] Worldsteel.org. (2017). Cite a Website - Cite This For Me. [online] Available at: https://www.worldsteel.org/en/

[4] Gorgolewski, M. (1999). The role of steel in environmentally responsible buildings. Ascot: Steel Construction Institute.

improves in a way which fosters this scenario. In the past, the steel reuse percentage was higher, and there is no reason not to do it again. Additionally, there might be a greater possibility for steel frame building to be reused on the same site, without major disassembling and cutting.

Moreover, it is generally predicted that in the future the motivation of pursuing reuse steel will grow. Together with the current improvements in building heating, ventilation and insulation, the average annual energy consumption will significantly decrease. This fact combining with shorter building lifespan estimated on 20-25 years will cause that the embodied energy of the building component will have more impact on the total use of energy during the whole building lifecycle. Obviously, that will have an impact on energy certification systems such as BREEAM in the UK and LEED in the US. Investors and developers are already aware of this trend. Hence they look ahead for possibilities of reducing embodied energy and apparently the reuse of material offers the greatest impact.

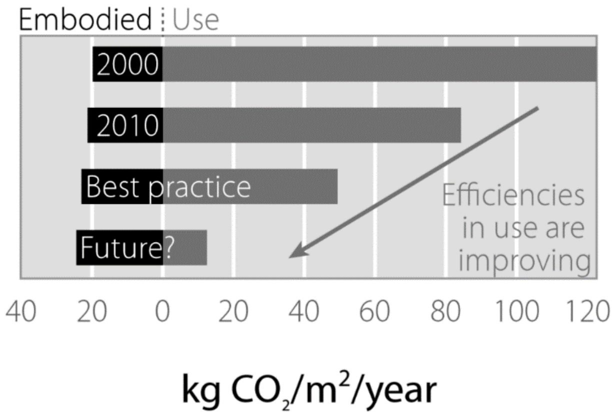

Figure 4. Embodied energy vs energy use, source: Allwood, J, Sustainable materials.

Ad.4

What are existing steel reuse models?

Based mainly on the literature study I was able to distinguish five different steel reuse models which are currently established (see Appendix 3). Different factors such as information and certification, design and project management affect the decision to use one or another in the specific circumstances. The first reuse model is *Direct exchange* which bases on the direct trade between steel seller and buyer without any immediate, usually the buyers are several so the dismantled structures are sold partly and separately. The second is *Stockholding*, which is basically stocking sections, steel frames or modules until a buyer will be found. The third model is called *Scrap manufacturing*, in this case building does not to be necessarily deconstructed, it can be demolished, since steel is cut to regular sizes, remanufactured and sell as second-hand products. The fourth reuse model is *In-situ Reuse* where the building after it is bought is adapted (possible also with structural changes, and additions). The last model is *Relocation*, it occurs when a building is dismantled and relocated to a new site (happen typically with portal frame buildings).

For the need of this study, two other models were added. The first one is the personal proposal - reuse by reconfiguration the steel structure. This method assumes that at the time when the old building is not sufficient anymore to host the existing function or the function changes, the structure could be able to change and adjust together with the needs. By this, it provides an extra possibility for investors to consider. The second added alternative is constructing by new steel, which is taken from the case study of van Klingeren hostel, when the investor, having all reclaimed components, is still considering to purchase new steel for the construction purpose.

Therefore, seven models were put together and evaluated using seven different criteria (Appendix 3): certification, design, time and management, energy use, waste production and adaptivity. The assessment and grading system is based mainly on the literature study, supported by conclusion from case study and interviews but it is considered to be a qualitative comparison. One of the main conclusion from this exercise is that probably the most efficient option is not surprisingly *In-situ Reuse*, due to the simple fact of the minimal amount of operations required. Obviously this model grates very low in term of adaptivity, that is the reason why *Reconfiguration* might offer a relevant alternative. *Relocation* also scores very high, although in reality, this works almost only in case of industrial buildings, rarely happening in other types. Building by new steel is certainly the most efficient way, but it involves much more energy use, which is the European context is not the main concern since labour is expensive and energy is relatively cheap. The three first models - *Direct exchange, Stockholding and Scrap manufacturing* - are in principle based on distributing steel apart to different clients, it involves a higher amount of waste and energy in the end; however, it should be prioritized if no more immediate reuse solution is possible.

Ad.5

What are current main limitations of steel structural reuse?

Based on the case studies, phone interview with Jos van Boxtel form Stebru company (the developer of the van Klingeren reconstruction) and literature researches series of reclaimed steel construction limitations were identified. At the present moment, they efficiently make the process of reuse very challenging. This point presents some of the main limitations, whereas the next point will talk about types of currently available and future desirable possible improvements.

High value of scrap

Currently, even the value of scrap steel on the market is very high, and it is estimated to grow. This fact discouraged steel components to be reused. The reason is that the value of the scrap steel is directly linked with the cost of new steel since steel can be almost 100% recycled without losing any properties. Therefore salvage yards and demolition contractors can ask about high prices for steel which goes directly to mills to be recycled. In most cases, they will not be eager to make an additional effort to sustain the extra cost of extracting the steel element without damaged that they are able to be reused after work.

Difficult or costly demolition process

The extracting process itself is one of main issue stopping reusing scenario, to extract steel from demolition building in a careful way creates extra costs and problems. Even when connections are bolted the deconstruction occurs mainly in term of larger components, in any other case connections are cut using torch cutting or scissor shears. It is estimated by Rotor deconstruction takes about 4 times longer than demolition, and it is 2-3 times more expensive.

Pre-engineered building

It seems to be generally accepted that steel reuse at this moment has place only at the pre-engineered industry- warehouse, industrial and agricultural use. These structures are in most cases base on Portal Frame system, they are easy to construct and deconstruct, thus they are resold as a whole structural system for re-erection at another location. The advantages of this solution are that there is no testing required for the use, because a function remains the same or is even downgraded.

Time consumption

Designer, engineers and builders are more confident with the way they work with a standard steel inventory, when they know in advance what type, profile, size and amount are available for them. A well-established system of reclaimed material ready to be supplied at realistic time frame will be something they look for when designing with second-hand materials. Unfortunately, it is unlikely that supply platform will wildly available in a reliable way for designers and others in the nearly future; therefore, they have to look for alternative approaches which will involve more improvisation and flexible design in order to fit availability of the reclaimed steel market at the time.

Storage insecurity

Another major issue is coordination difficulty, steel need to be available at certain time and place, which often is not a case, it creates delays in the construction process. At the early stages of the project, the design team needs to identify specific reclaimed components they want to integrate into the new project. That needs to be coordinated with the client, who commits to buy these particular pieces, it is often even before a general contractor is chosen, which requires storing the steel for a long time (for instance the case of van Klingeren building).

Liability

One of the main limitation is the issue of component liability and insurance. The problem of how to establish steel structural characteristic of particular reclaimed components can be difficult to solve without knowing the period of manufacture and steel origin. Although with this knowledge and with the precise section dimensions, it would be possible to make a basic assumption of the strength of steel based on historical data.

Trend for customized construction

Currently, we can observe a growing popularity of customization approach, this shift from standardization of steel structure towards customized design will make future reuse more difficult since might be generally challenging to integrate old components to new buildings.

Lack of motivation

Besides technical limitations, there is also a motivational aspect which is considered to be a key component of greater reuse. Without the true involvement of client, contractor and design team, there will not be a change to overcome before mentioned limitations. Some aspect such as heritage and cultural value, sustainable certifications might make the motivation stronger.

Ad.6
What are current strategies for improving the situation?

Relatively recently we can observe the growing interest in calculating the entire lifecycle of the building, instead of only its only operational time. It seems that the notion of embodied energy is more present in the consciousness of designers, that constituted further to development of several strategies which aim to foster the growth of using reclaimed materials. I have decided to identify four of them and briefly present here.

The first one is a *new business model*[5], it could be a realistic solution for big companies owning significant amount of buildings. The current expectation of buildings lifespan is only 20 years, these companies could keep the ownership of the building components in order to reconfigure them and reuse elsewhere. In this case, minimum number or intermediaries are involved which faster the construction process and maintain the value of the elements. Alternatively, we could focus on developing a *new joining system*, the new approach of connecting steel components should facilitate remote deconstruction. Moreover, a problem of separating steel beams and columns with reinforced concrete

[5] 1. Allwood, J., Cullen, J. and Carruth, M. (2012). Sustainable materials. Cambridge: UIT Cambridge, p. 225

should be addressed. Another improvement which should go parallelly is *creating more efficient testing and guaranteeing system*, several ways are possible here. It might lead through the establishment of an affordable set of standard testing methods which will be acceptable for insurance companies. Other possibilities are developing a simple and available information record-system about all new steel components in the market or providing a permanent system of marking for each steel section specifying its properties. Last but not least it is crucial to *promote the use of reclaimed materials*, people need to understand that combination of new and reuse elements can provide an extra value and at the same time reduces embodied energy and additional emissions.

Unfortunately, at the present moment, it seems that the available improvements are either not strong enough or possible to be implemented to have a real changing impact for the reuse steel construction market. Having this knowledge, a proposal of an entirely different construction operation by structural reconfiguration could be a relevant alternative to keep the building at the same place

IV. CASE STUDY – VAN KLINGEREN'S YOUTH HOSTEL IN THE HAGUE

The youth hostel by van Klingeren in The Hague was, in fact an extension of hotel complex located in the middle of the forest area and in a proximity the sea. The building was designed by architect between 1971 and 1973, it was constructed within one year making the official opening in 1974. Originally the structure of the building supposed to be concrete, the change to the steel had the place at last moment. Even though the architect designed that in the way which allowed for a flexibility of programmatic layout. The combination of steel and large glass windows has created a seamless transition between indoor and outdoor space. Additionally, the building was a representation of the architect's thoughts and his ideas, it celebrated the functional ambiguity and constantly unfinished process that van Klingeren strongly believed. According to him, architecture should foster people encounters and interactions, should stimulate them and give them a possibility to influence a building, even by "taking the control" of the space.

In 1997, the hostel was left empty and become a vacant space, that finally led to the situation when the municipality of the Hague started making a plan of a transformation of the object into a new conference hotel. Nonetheless, ten years have passed until some actions were taken towards this direction. The demolition of the hostel was suggested since it was decided that the building is not suitable to be integrated into the new development, it was considered unsatisfactorily both in term of aesthetic and functionality. Shortly after a plan to rescue and reconstruct the building in a new place was put forward under the supervision of architect Leon Thier. The structure was dismantled within a period of 6 months, after disassembling the steel was transported to Pijnacker located 25 km away. The reconstruction of the building supposed to take a place a year after, but today the rusty steel elements remain still outside at the private plot, awaiting for decision-making and legislation acceptances to be reassembly.

The diagram from Appendix 4 presents the timeline of van Klingeren hostel including the crucial events for the building. Additionally, it shows three possible future scenarios which might occur - rebuilding by old steel, rebuilding by new steel and limbo continuation. Appendix 5 and 6 present together the comparison of different resources - transportation, on-site human labour, heavy machinery, energy, waste, design & engineering, maintenance & renewal, other activities. Appendix 5 depicts the present scenario, where the building was deconstructed and it is awaiting for reassembling in the new location, also hosting a new function (luxury hotel or housing), whereas the Appendix 6 displays an imaginative scenario which presumes that the building has never been fully dismantled and moved away, but the structure was on-site transformed to adapt to new function of a conference hotel

Analyzing these diagrams, two main conclusions might be drawn. Firstly, the timelines differ from each other. In the existing situation, the whole process of building reconstruction takes years due to the involvement of different actors and complicated process of reassembling the structures when once it was fully taken apart. The steel beams and columns are kept outside unprotected during that time which faster the corrosion process. The alternative time-line anticipates that the whole process in case of structural alteration could be significantly shorter (takes about 2-3 years in total), it is due to the fact that the main construction elements are already on site and the general sequence of operation is already known in advance, by this different construction operations would be able to happen simultaneously at the same time (following main architectural ideas of van Klingeren). Obviously, this option assumes the ideal scenario where the whole procedure is tested, established and integrated with all other construction aspects such as material deliveries, logistic, labour, machinery, legislation etc. Secondly, as mentioned, fewer actors are connected with the whole operational chain, this means (again, ideally) that there are fewer resources, waste, labour, need of transportation, energy and money involved. This could provide economic, environmental and time benefits making all sides of the investments satisfied, and at the time this option provides the solution which reuses main construction components.

V. CONCLUSIONS

The overall aim of this paper is to verify the feasibility of on-site structural reconfiguration of as a relevant alternative for demolition steel frame buildings. The general ambition of this solution would be a potential increase of reclaimed steel construction elements. Literature and case studies, as well as interviews, were used as main methodologies in the research process.

The main part of this paper is divided into six sub-questions and case study, which gradually explore the research topic. It starts with presenting the network of construction steel flow in the industry to give the overview of different operations and intermediaries involved in the whole process. The diagram also suggests the possible intervention area, not by interrupting and changing the network but rather giving the additional alternative path of keeping building on site and transforming the structure. Subsequently, the comparison between reuse and recycle, along with the potential future growth of steel reuse were presented – they show the potential benefits of reusing above recycling scenarios. There is also the qualitative assessment of available reuse models including reconfiguration option, it analyzes the advantages and disadvantages of each solution. The end of chapter IV presents current limitations of reusing structural steel, but also provides some of the possible improvements. Lastly, based on the case study of van Klingeren Youth Hostel two scenarios were compared, the existing situation and the once possible alternative of structural transformation and adaptation to the new function of the conference hotel at the same place. The second scenario has clearly more potential advantages such as time and energy use since it follows the clear logic that longer lasting building components like structure can be altered to adapt to new conditions, whereas shorter lasting like facade and building facilities might be easily updated or replaced.

On the basis of the results of this research, it can be concluded that currently the limitations of reusing steel components make the whole operation very challenging, usually it is too complicated for investors and designers to choose this path. Most of the possible improvements proposed for now have a theoretical character. Therefore almost all steel structures which are entirely reused come from industrial sector (pre-engineered portal frame system). The challenges of reusing the steel structure for other function are clearly represented by the case of van Klingeren's Youth Hostel, where having the pre-dismantled building, perfectly sorted and stocked at one place just 15 kilometers away from the construction site, it is still difficult to make the reconstruction successful. At the present moment, the components are still waiting for decision-making. During the phone interview, the client's representative has admitted that using new steel is still an option. Additionally, they certainly would not process such project based one reusing that amount of reclaimed steel if not the name of the architect, which is still known enough to brings cultural and heritage value to the generic development. Based on this case and the previous research part, the conclusion which might be drawn is that even a careful disassembling of buildings does not give a high change for a steel structure to be reused again (in the European context, in Canada and USA the sector of reclaimed steel component is better established). Therefore, reusing existing building in their current form with refurbishment to new use should be the most desirable scenario. However, if this is not possible, there should be still one more solution considered. The on-site structural reconfiguration can provide both, functional adaptability and a new image of the building, with keeping the old structure (Appendix 8). This should be seen as a new business opportunity which adds values such as culture and heritage to reuse materials, consequently leading also to significant economic benefits.

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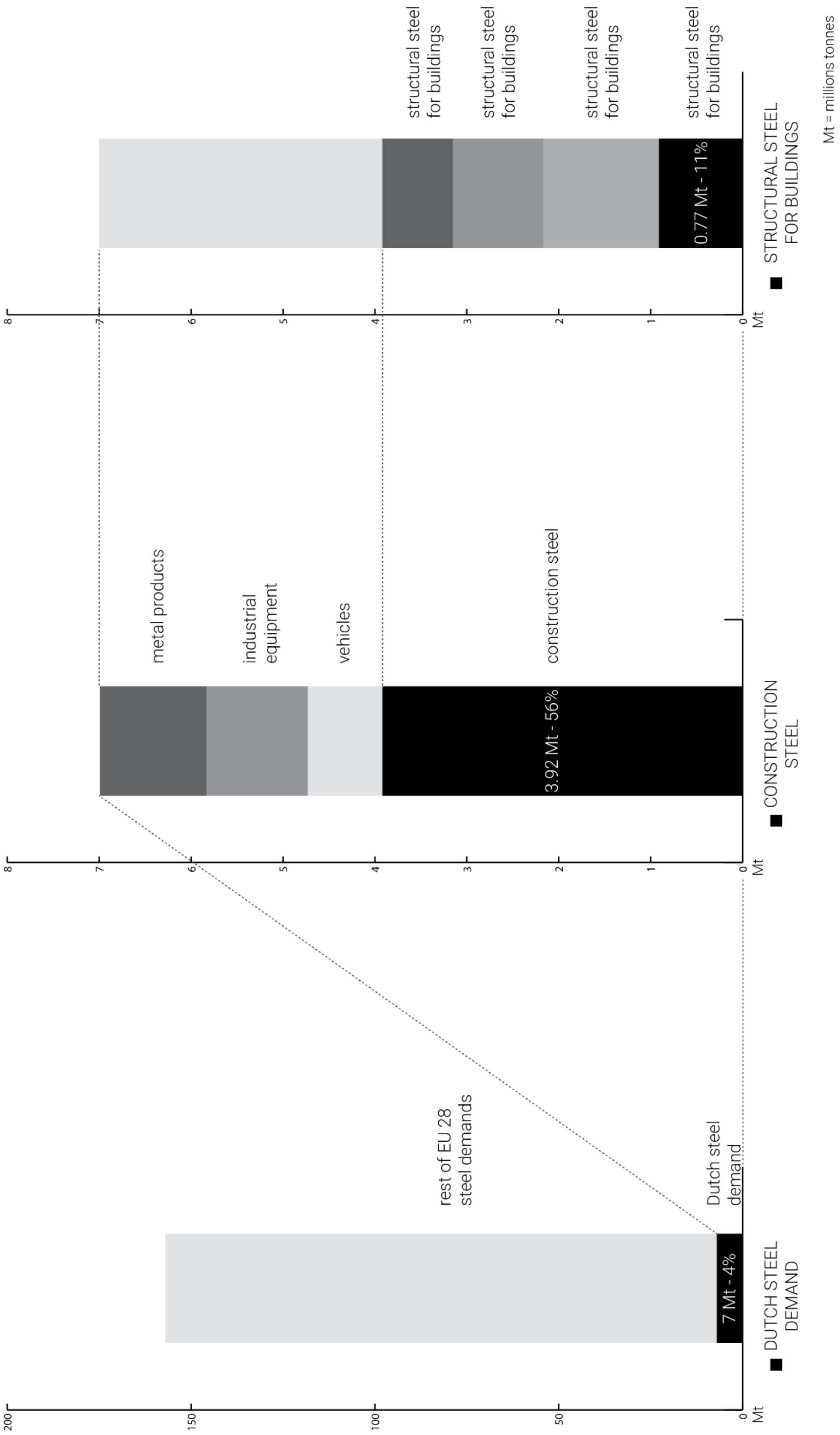
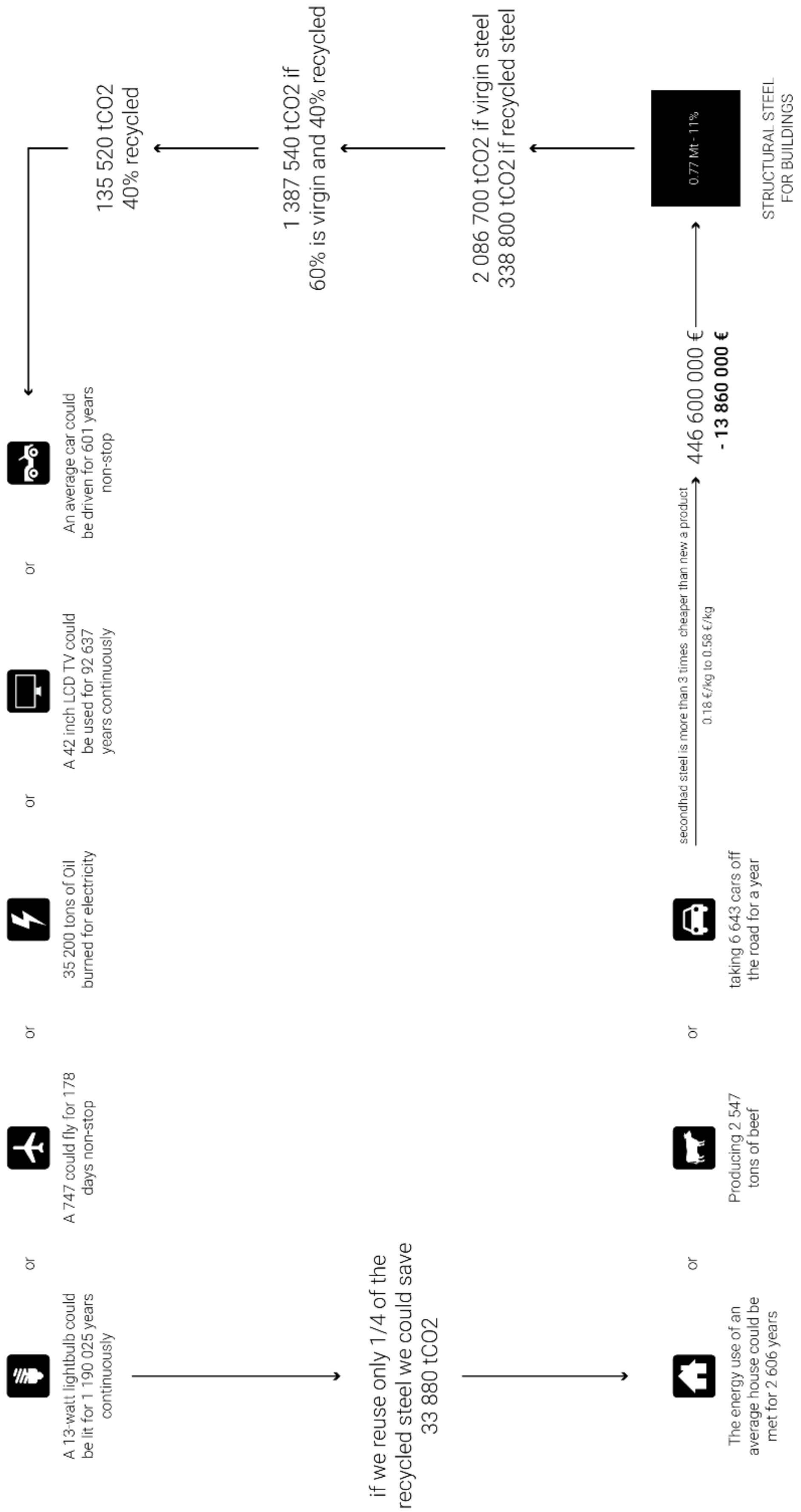
VII. APPENDIX



Appendix 1. Structural steel for buildings in the Netherlands, source: Worldsteel.org, own illustration

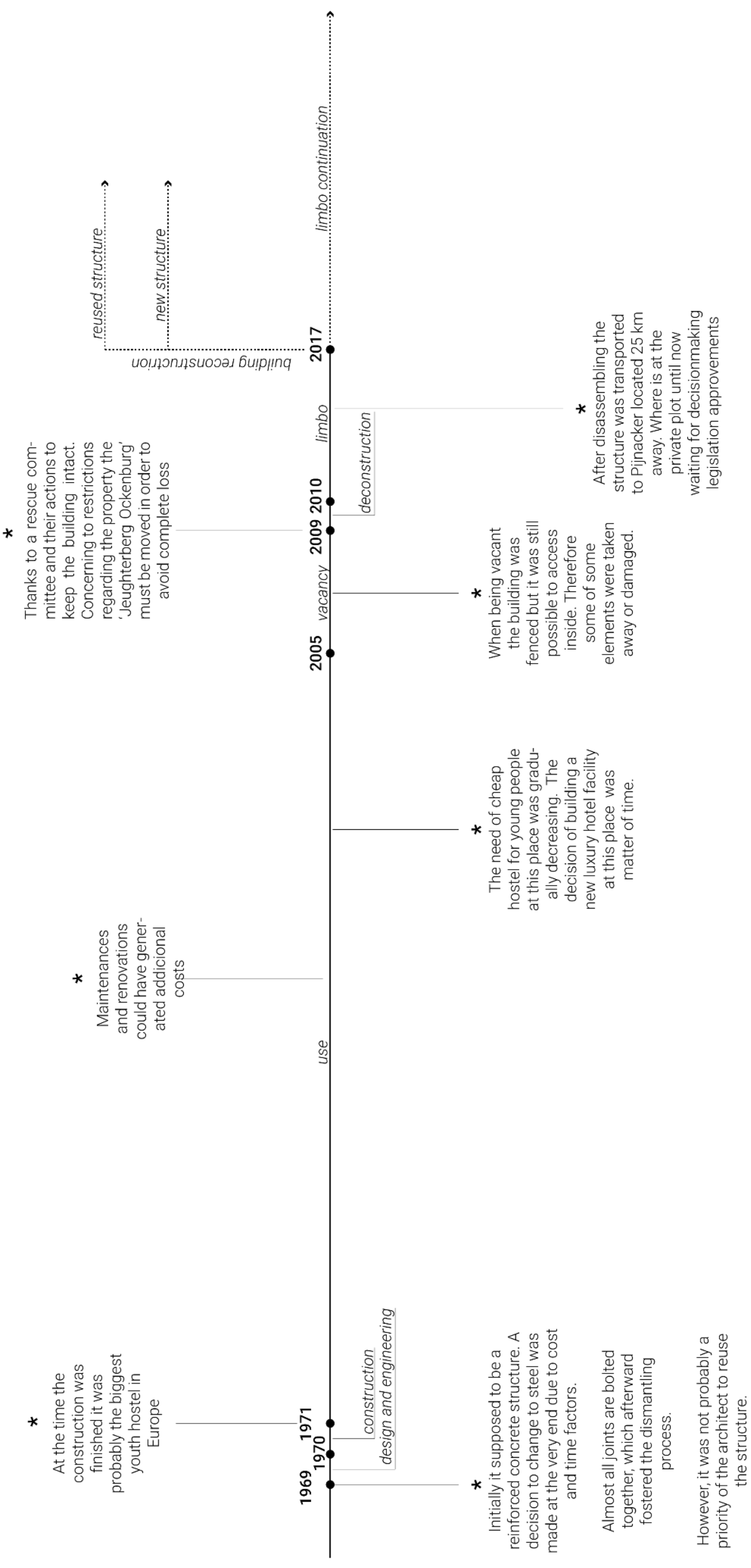


Appendix 2. Reuse and recycle environmental impact comparison, own illustration

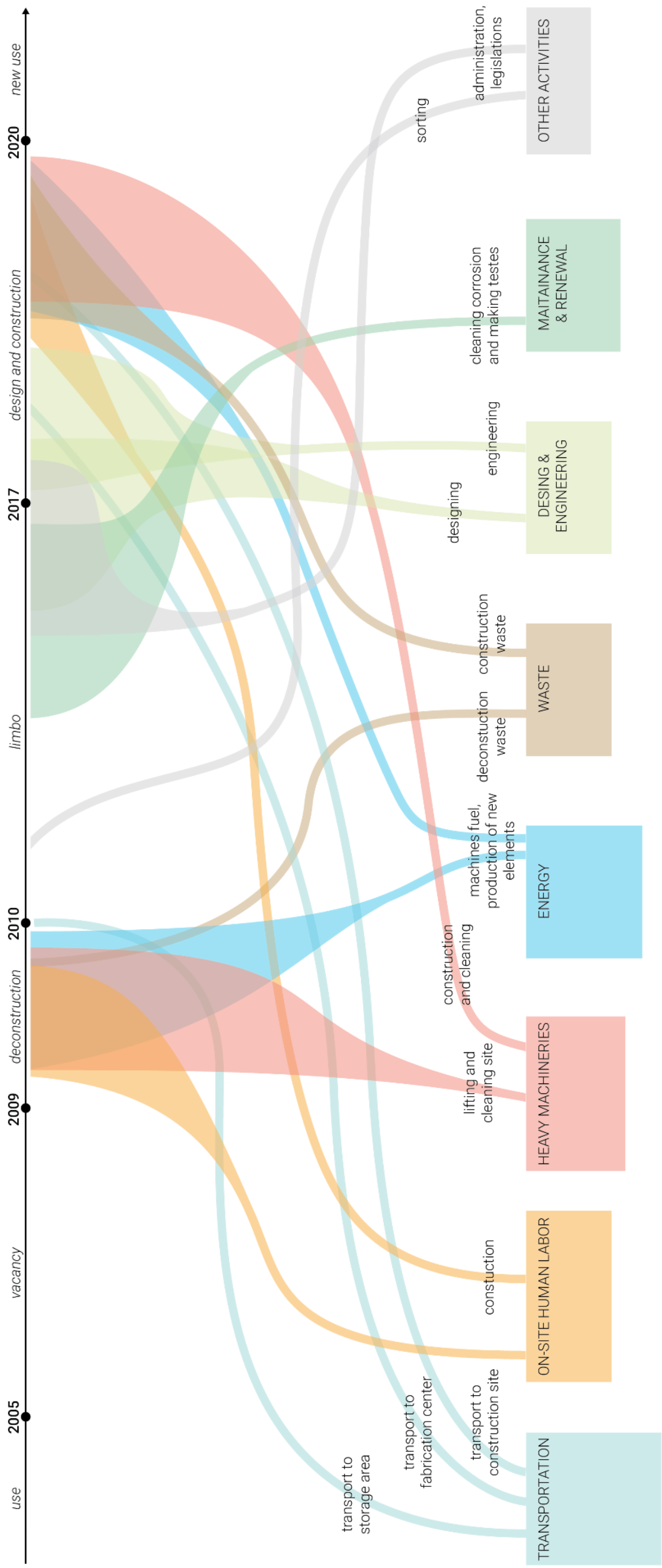
	Existing reuse models	*Certification*	*Design*	*Time and management*	*Energy use*	*Waste*	*Adaptibility*
2.33	**DIRECT EXCHANGE** Steel sections or modules are sold for reuse without an intermediary.	●● Testing and certification required unless beams are downgraded or buyers trust sellers.	●● Material pre-ordered or design drawn up with a flexible specification in order to increase likelihood or finding suitable stock.	●● Buyer is tied to seller's project schedule possibility of delay.	●●● Energy is used for one way transportation and integration with new structure.	●● Waste depends on needs and requirements of a new construction. Material from elements which don't fit go to recycling process.	●●● Depends on an integration with a new structure.
2.16	**STOCKHOLDER** Sections, steel frames or modules are brought, remediated and stocked until a demand presents itself.	● Testing and certification required unless beams are downgraded. May only accept standard products.	●● Material pre-ordered or design drawn up with a flexible specification in order to increase likelihood or finding suitable stock.	●● Delays can be avoided as stock is supplemented with new material if necessary in order to guarantee supply.	●● Energy is used for transportation, assembling and potentially maintaining	●●● Material is stocked and waits for resseling, there will be a part which does not match to the market needs.	●●● Depends on an integration with a new structure.
2.86	**SCRAP MANUFACTURING** The steel is bought, cut to regular sizes and sold for reuse.	●●●● Material properties known. No additional testing. Sold for non-critical parts.	●●●●● Unaffected as irregular offal is cut into standard sizes.	●● Delays can be avoided as stock is supplemented with new material if necessary in order to guarantee supply.	● Energy is used for disassembling transportation, cutting and assembling.	● All joints and specific parts are wasted (recycled), only generic sections are reused.	●●●● The outputs are standard steel profiles, the only limitation lies on lenghts of elements.
4.16	**IN-SITU REUSE** An obsolete building is bought and either adapted, or decosntructed so that components can be reused.	●●●● Reduced need for testing: possible access to engineering drawings, current loads know.	●●●●● Adaptive design based on known materials purchased up front. Possibility to reuse entirely building system.	●●●●● Single client manages deconstruction, design and construction. Timing naturally aligned.	●●●●● Almost non energy is used if the building is adapted.	●●●●● There should be literally no waste of the structural components.	● Restricted to a former stucture and building layout.
3.83	▶ **RELOCATION** A steel structure is dismatled is dismantled and re-erected elsewhere.	●●●● Reduced need for testing: same configuration, same loads.	●●●●● No significant need of designing.	●●●● Buyer is tied to seller's project schedule possibility of delay.	●●●● Energy is used for disassembling transportation and reassembling.	●●●●● No waste if all elements are reused.	● Restricted to a former stucture and building layout.
3.50	▶ **TRANSFORMATION** Structure relocation and rearrangement in order to fulfil new functional needs.	●●● New connections might need testes and certifications.	●●● Need of designing new joints, but also new spatial layout.	●●● Possible delays, counting, testing and certificating. Additional structural design required.	●●●● Energy is used for disassembling transportation and assembling.	●●●● The aim is to reuse possible all steel, but there might be a minor amount of unsuitable elements.	●●●● Structural transformation allows more space flexibility in order to match new needs.
	Alternative						
3.00	▶ **REBUILD BY NEW** Building the same volume and structure configuration using new steel.	●●●●● Using new steel and possible new structural profiles, therefore no need of extra testing.	●●●● Need of updating with the current steel profiles and types of connection. New calculations.	●●●●● Regular building process unrelated to the old structure.	● Additional energy is required for new steel production and manufacturing.	●● All old steel will be probably melted and recycled.	● Restricted to a former volume a spatial organization.

▶ Scenarios for van Klingeren's Youth Hostel

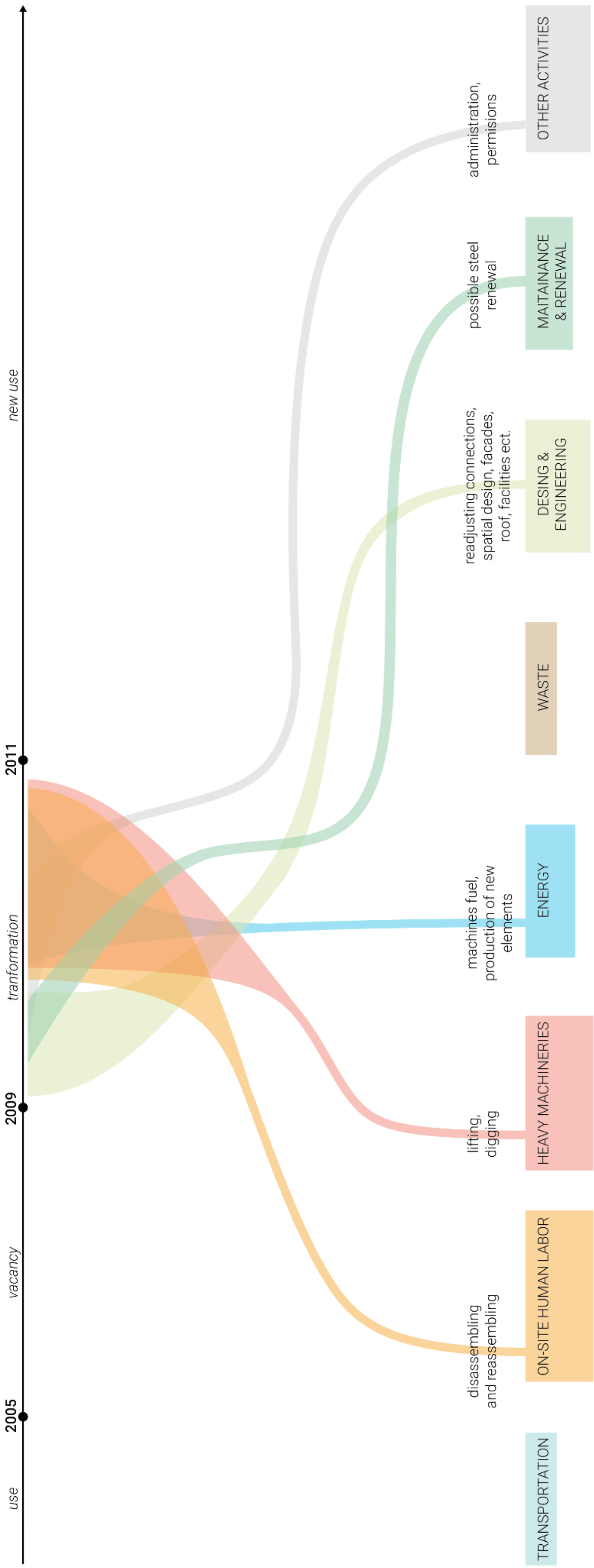
Appendix 3. Steel reuse models comparison, own illustration



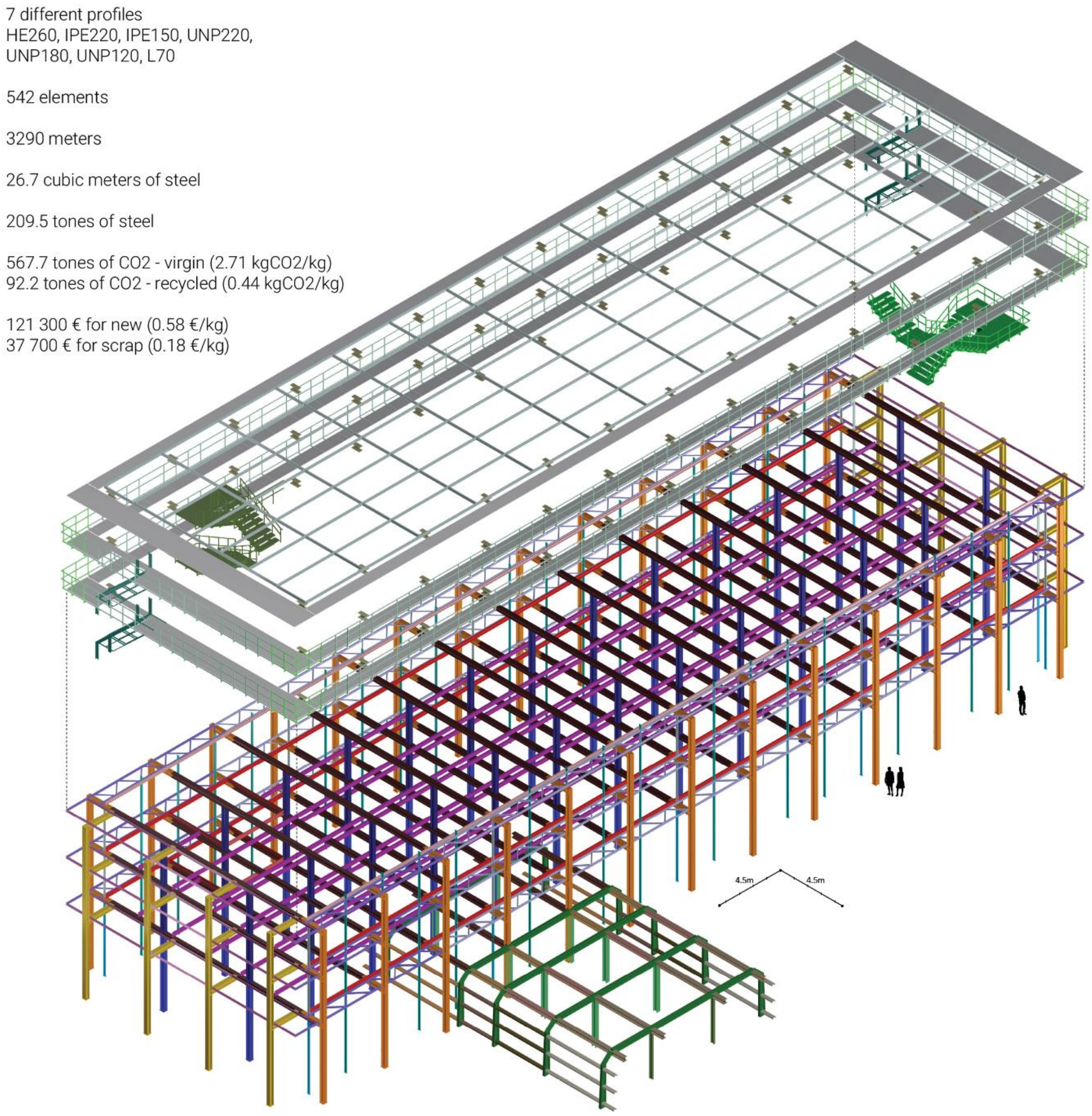
Appendix 4. Timeline of van Klinegeren's Youth Hostel building, own illustration



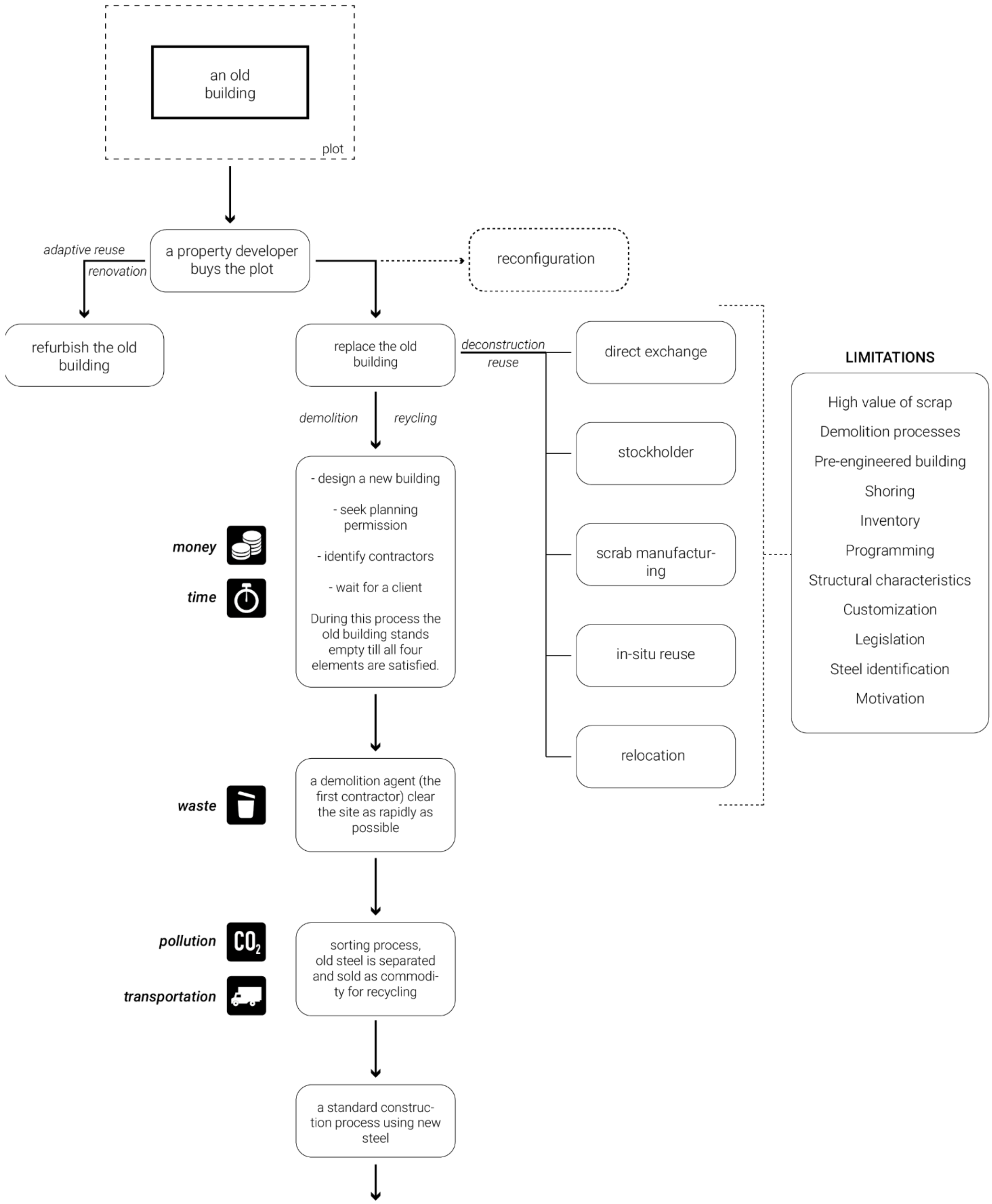
Appendix 5. van Klingeren Youth Hostel - current situation, own illustration



Appendix 6. van Klingeren Youth Hostel - alternative scenario, own illustration



Appendix 7. van Klingeren Youth Hostel – structural overview and calculations, own illustration



Appendix 8. Possible current scenarios for construction of steel building and
suggested additional alternative of on-site structural reconfiguration, own illustration