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Evaluation of potential reuse and recycle of residential construction material in the city of Gothenburg

Master's thesis in Infrastructure and Environment Engineering

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URBAN METABOLISM

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ABSTRACT

According to the United Nations, cities house 56.2 percent of the worldwide population, with 23% of the global population expected to reside in cities by 2050. Cities play a vital role in the transition to a circular economy, and all stakeholders have a unique role in it. Cities have a large amount of secondary material stock in the form of built environment stock, such as buildings. The building industry currently generates one-third of all global waste. While the industry is notorious for the waste creation the businesses are stepping up their efforts to address the problem. The identified sustainable approaches to manage waste is by recovering stock through reuse, recycling from urban mines. The approach is to mine the existing material rather than extracting it. A city-wide circular framework to recycle and reuse not only reduces the number of raw resources used in the system, but also allows for sustainable consumption and waste reduction by looping the stock. Though the built environment in an urban ecosystem holds most of the material stock, the extent of mining in urban environments has yet to be explored. There is a huge possibility of using the waste as resource material and promoting circularity.

While the strategic application of circular economy in the context of building stock is still in its infancy, the following study focuses on building a database of material and elements available in city of Gothenburg. It also predicts possible demolition of residential building over time and develops a material database with material and elements that will be available after possible demolition. The study quantifies the material and provides spatial information of material stock using digital tools. Finally, the study looks into future construction between 2035 to 2050 and maps the amount of different material and element required and available for the given time. The study reimagines city of Gothenburg as circular resource systems through reuse and recycle of residential construction materials. It also presents the location of material and elements for circular construction process with the aim to reduce resource extraction while promoting sustainable infrastructure development.

Keywords: database, demolition, recycle, reuse, residential

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The study has instilled the authors with comprehensive knowledge on urban metabolism and circular economy. We believe the study will be an important corner stone to aid in transition of residential construction from linear to circular system while promoting sustainable development.

Mose Adamu & Shashank Raj Bhattarai

2022-05-24, Gothenburg

1. Introduction

As per the United Nations, 56.2% of the global population live in the cities and it is estimated that ⅔ of the world population will live in cities by 2050(United Nations, n.d.). This increase in urbanization reinforced with growth in population will have a direct effect on the consumption resources, liveability, equitability within the cities (The International Bank for Reconstruction and Development/The World Bank, 2009) (Satterthwaite, 2009; World Health Organization, 2003). Further, countries also have an added obligation to achieve the United Nations SDG target explicitly SDG 11"make cities and human settlements inclusive, safe, resilient and sustainable," and SDG 12 "ensure sustainable consumption and production patterns." The Circular Economy Action Plan was adopted by the European Commission in March 2020 as part of the European Green Deal, with the objective of achieving a carbon-neutral, sustainable, non-toxic, and fully circular economy by 2050 (European Commission, n.d.). As a part of the plan, 70 percent of all construction waste must be recycled from 2020 onwards. This deal has galvanized the industry and catalysed the switch from a linear to a circular strategy.

Circular economy is an ambiguous concept in its rudimentary stage, it is very important to define certain framework so that the current linear system transforms into an innovative circular system. The urgency for this transition was underscored by Walter Stahel in 1982 (Bertino, Kisser, Zeilinger, Langergraber, Fischer, Österreicher, 2021). Cities are an important part towards the transition to a circular system and all the stakeholders have an important role to play. Cities have a huge amount of secondary material stock in form of built environment stock such as buildings which can be looped back into the system (Jacobs, 1961). A city-wide circular framework helps not only minimizes the raw resources which is input in the system, but also provides an opportunity for sustainable consumption while reducing the waste by looping the stock back into the system. Waste production in construction industry is a burning agenda and industries are stepping up their efforts to response to the troubling aspect. Currently, one third of the global waste is generated by construction industry ("BBC, the buildings made of rubbish" n.d). Moreover, in an urban area, the built environments such as buildings and infrastructure hold the bulk of all materials stock. With the increase of population, economy and material accumulation is also quickening in many countries (Modolo, Ferreira, Machado, Rodrigues, M, Coelho, 2011). Nevertheless, though the major usage of construction material is concentrated in the urban area, the scope within the mining of urban environment is not explored and is still in a fledgling stage along with the strategical implementation of circular economy (Adams, Osmani, Thorpe, Thornback, 2017). One of the identified sustainable ways to manage waste is to recover trash are through reuse, recycling, and waste reduction of the urban mine however there is still much space for improvement in this avenue. Reusing and recycling construction materials can assist the building industry and local governments in their efforts to become more environmentally friendly. This circular process can reduce resource extraction as well as emissions from infrastructure development activities by re-imagining cities as circular resource systems and developing action plans to bring this vision to life. It is also noted that reuse and recycling have the potential to reduce carbon emissions by up to 59 percent as direct consequence from minimizing the production of construction material such as concrete, metal and so on (U. Umar, N. Shafiq, F. Ahmad, 2019).

While Sweden has long been synonymous to sustainability nevertheless the construction and demolition waste accounts for one third of the waste volume ("Swedish environmental research institution", n.d). The built environment aspect within the society remains largely unshattered. Though the process of recycling has garnered some momentum over the years there is still a lot to progress with. It is strongly believed that the lopping of the process is cumbersome and undoable however it is also found that recycling and reusing of material could save up to millions of SEK per year for the Swedish construction industry. Currently, there is a huge limitation of digital information on quantity and quality of available material, information on elements which play as a barrier for the circularity of building stock.

The following study presents a case study from City of Gothenburg in Sweden. The study will focus on possibility of the circular use of construction materials through recycle and reuse in residential buildings.

1.1 Aim

The aim of the study is to evaluate potential of reusing and recycling of residential construction material in the city of Gothenburg.

1.2 Research questions

- How much material stock is in residential buildings (single and multi-family) of Gothenburg?
- How many residential buildings will be potentially demolished in the future?
- How can the circularity of Gothenburg be increased by reuse and recycle strategy between 2035-2050?

1.3 Goals

The study will focus on achieving the following goals.

- To develop a material database of residential building in Gothenburg
- To map the construction materials using GIS
- To promote circular economy by displaying opportunities for reuse and recycle of materials from existing material stock in Gothenburg.

1.4 Scope

The scope of the study will only investigate the city of Gothenburg and its urban mining potential. As the single family and multifamily residential building cover a huge amount of material stock these building will be the focus of the study. The study will only focus on four elements within the building i.e.: roof, bottom slab, window and external wall and the material database will only document material from these four elements in a house. The result will only present weight of following materials; wood, concrete, metal and brick. Finally, for the future construction scenario only the residential construction between 2035-2050 will be studied.

1.5 Case study description

The city of Gothenburg is situated in the west coast and are the second biggest city in Sweden as shown in figure 1. The current population of Gothenburg are at 5,78,327 and the population just are expected to grow just like other major cities around the world (Stad, G, 2014).

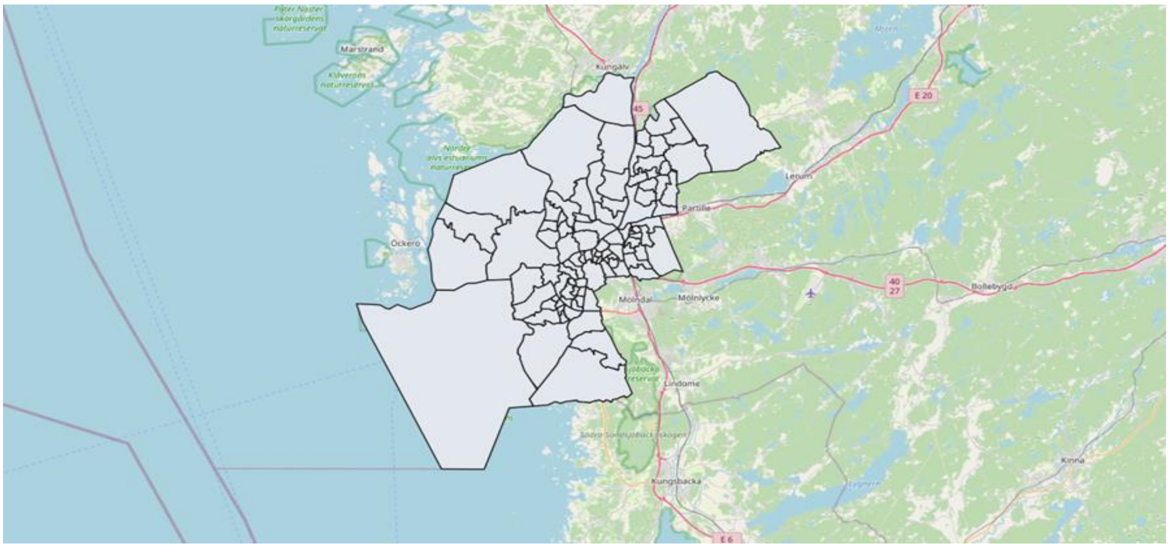

Figure 1. City of Gothenburg, Sweden.

According to a study, the population of Gothenburg is expected to grow by 100 000 by 2035 (Berntsson, S, 2018). As of today, there is roughly 290334 residential buildings (Gothenburg, statestik och analys, n.d) however these residential buildings will not be enough to accommodate the growing population. The typical design of current single and multifamily residential building is presented in figure 2. The following figure 3 represents the development planned by city of Gothenburg over the years in and around central areas whereas figure 4 represents the population density growth between 2022 to 2035.

Figure 2. Typical single and multifamily residential buildings in Gothenburg. Source: Wikimedia

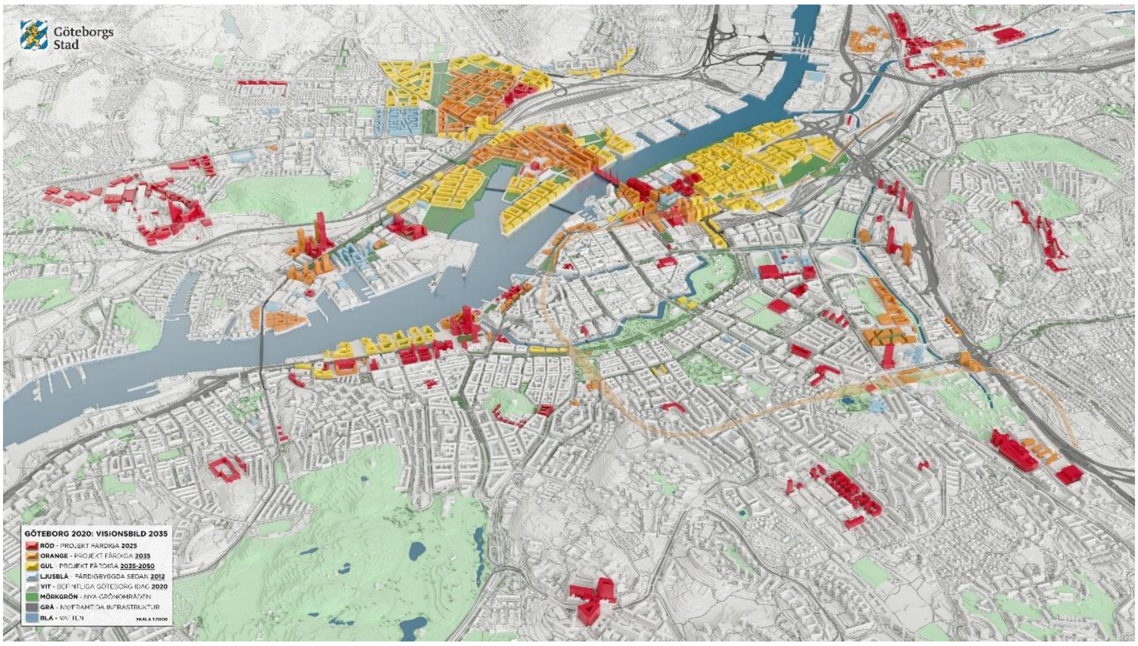

Figure 3. City development plan in and around centre of Gothenburg. Source: SBK

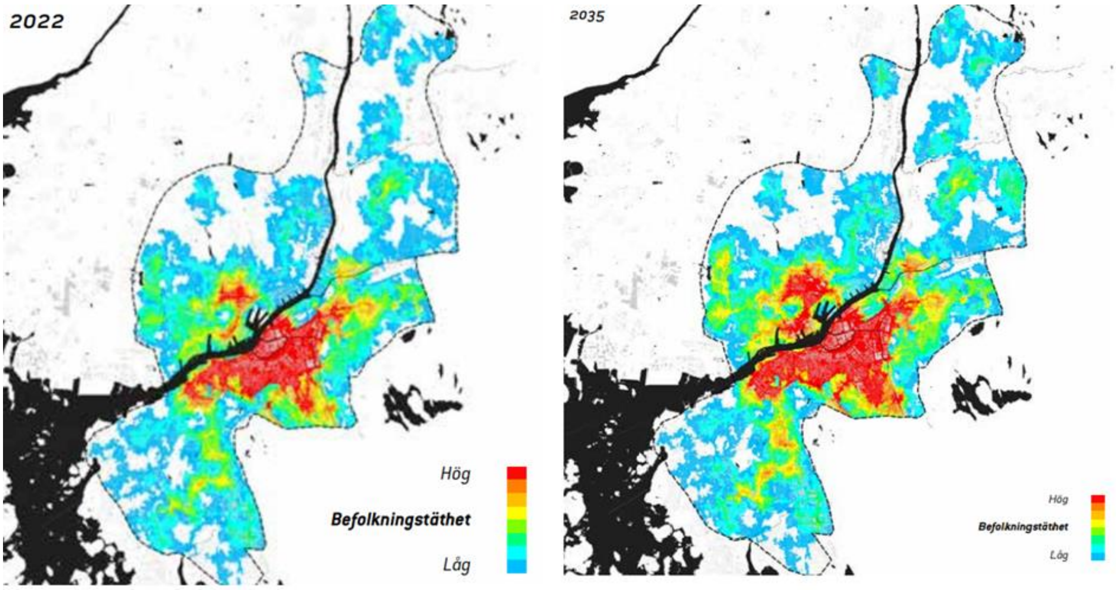

Figure 4. The population density of central Gothenburg over time. Source

To achieve sustainable development, the city of Gothenburg has drafted four strategy papers that provide an overview of how the city will advance in terms of both its infrastructure and its urban development. The main objective is to make life in a metropolitan area greener and liveable (Stad, G. 2014). The primary goal is to reduce the amount of traffic and to expand the number of homes and local city centres that can help make daily living easier for the population. The masterplan also includes creating roughly 9000 residential buildings in the central parts of Gothenburg and 15000 new residential buildings are estimated to be built in the middle city. Some major areas for construction are Hisingen, Angered, Gamlestan and Frölunda where there will be 5000 new residential buildings. The figure presents Finally, as per Stadsbyggnadskontoret there will also be constructions of 7500 new city centres which are under plan to be constructed (Stad, G. 2014). It is important to know that the plans do not only focus on building new structures, but Gothenburg city also aims to enhance already existing city centres by renovation. It is evident that numerous numbers of residential housing will be constructed in Gothenburg in days to come and the city could close the material loop by incorporating circularity strategy of recycle and reuse while developing the city sustainably (Berntsson, S, 2018).

2. Literature Review

2.1 Material stock

A material stocks could be defined as resource bank which could be used for understanding different distributions of units or a consumption source which could be used (Kleemann, Lederer, Rechberger, & Fellner, 2017). The study "Analysis of Vienna's Material stock in building" explains that in the perspective of construction and city metabolism stocks are usually created to understand the material distribution of the city. By understanding the composition of materials in the city more emphasis on promoting circularity of in city could be applied, a circular economy's ability to close material loops and reduce polluting emissions depends on the stock arrangement and stock amount (Wittmer, Lichtensteiger, & Wittmer 2007). The ability to use material stock for promoting circularity is something that is a relatively new concept and there have been several challenges to promote usage of already existing material stocks in the city (Langergraber, Castellar, Pucher, Baganz, Milosevic, Andreucci, Atanasova, 2021). In the study "Residential buildings material stock and component level circularity: The case of Singapore" it is mentioned that residential buildings are demanding a greater number of materials to be built while the materials existing in the market are being more scares because of limit of raw material, economic and environmental factors (Arora, Raspall, Cheah, & Silva, 2019). In the study a database was created and an understanding of buildings which are reaching the end of life was conducted, most of the buildings still have large quantities of materials which will be able to be reusable. Understanding the material stock of the buildings will minimize the amount of waste generated after demolition and understand the potential of reusable and recycle material. Overall, to create the material stock a material intensity coefficient is produced to understand how each single material had a place in the overall structure weight (Tanikawa, Fishman, Okuoka, Sugimoto, 2015). There are a multitude of different approaches that could be used to gather information to build a material stock the chosen method is based on the amount of information available and how the information is expected to be used. Among several methods developed to estimate material stock (Tanikawa et all, 2015) presents top down and bottom-up approach. Studies present the usage of these approaches to material stock evaluation as the two basic approaches for material stock assessment.

Top-down approach

Top-down analysis is a term that refers to the process of making decisions based on a complete set of criteria. To identify the large picture with all its elements, the top-down strategy must be used. This involves developing an overall system of data collecting and processing prior to describing and figuring things out the subsystems that will fall under it. This allows for additional greater extensive and sophisticated subsystems to be built on top of these components in the future (E.M Meslin, 2010). The research conducted by Arora and the team in the case study regarding Singapore further explains how to combine the top-down and bottom-up flow analysis methodologies. As a result of the research, the authors believe that top-down and bottom-up approaches have different maximum and lower bounds on the flow of information (Arora et all, 2019).

Bottom-up approach

Bottom-up approach follows the process of decision making from grass root level to the top level in a hierarchical chart. The study "The weight of society over time and space: comprehensive plan of the construction materials stock of Japan, 1945-2010" informs about bottom-up approach for information collection on the material stock of Japan (Tanikawa et all, 2015). The study explores different types of materials within in different structures such as roads and households. It informs the benefits with using the bottom-up approach for visualization of the studied objects as well as extensive insight into the connection regarding the structure and the creativity through structural integration. Also, the study, conducted in Denmark (Lanau, & Liu, 2020). Aimed to promote circularity by material reuse from already existing material stocks in houses and infrastructure underscores the bottom-up approach. Bottom-up approach consists of inventorying all items containing materials of data and multiplying each item amount by its relevant material intensity coefficient. Previous studies done to develop urban resources conducted in Denmark choose the bottom-up approach because it allowed for creating a sufficient inventory data with the help of small data for a specific area (Lanau, & Liu, 2020). The precision of this procedure is dependent on the material that is being investigated, the section that is selected, and the availability of information regarding the material composition. Due to the pool of information required, the access to data could become a severe restriction or relief depending on the quantity of material information gathered (Lanau, & Liu, 2020). The biggest uncertainty with using the bottom- up approach according to the study in Japan is the rehabilitee of the material intensity coefficient (Tanikawa et all, 2015). How the material intensity has been documented and what control groups was used to validate the values is debatable. A large quantity of data would be required for a study with a broad scope if there were limited data or data of low quality, the study would provide a significant degree of ambiguity and erroneous stock estimates (Tanikawa et all, 2015). The study conducted in Denmark also mentions similar uncertainties with the bottom-up approach, the condition of the material intensity and the realistic sizes of structures is necessary for creating a credible material stock. The usage of stock (MS) could be calculated with multiplying the material intensity coefficient (MIC) with the inventory of the item size (IND).

$$MS = MIC \times INV \qquad \text{Equation (1)}$$

2.2 Material intensity coefficient

According to "Material-intensity database of residential buildings: a case study of Sweden in the international context" a building could be broken down to elements and the elements are comprised of different materials (Gontia, Nägeli, Rosado, Kalmykova & Österbring, 2018). Elements are usually comprised of several different materials, the quantity of these materials could vary on bases of different factors such as manufacturers, year of construction and much more (Gontia, Nägeli, Rosado, Kalmykova & Österbring, 2018). The mass produced by a typical construction unit on a per-square-meter basis is referred to as the material intensity coefficient, and it is measured in terms of the phrase material intensity coefficient. In the study that was carried out in Sweden with the goal of knowing the specific material intensity trends and the element weight of various buildings located throughout the entirety of Sweden, the research was done. The research aimed to contributed to a better understanding of how the proportions of structures affected the amount of material that was required (Gontia, Nägeli, Rosado, Kalmykova & Österbring, 2018). In another study conducted in China to understand the material stock in the nation over time, the material intensity coefficient with the aid of bottom-up method was used to calculate the material stock in the nation (Zhang, Liu & Lv, 2019). The material intensity coefficient helps to provide the weight of a particular material in a structure if the dimensions are provided (Zhang, Liu & Lv, 2019). The unit could differ depending on where the study is done and what kind of parameters are mostly fitting for the studies. There have been several studies aimed to understand the urban metabolism that have been using the material intensity coefficient. A study done in China to create a material stock analysis data base for material intensity coefficient was created as a foundation to understand the building metabolism in the nation (Yang, Guo, Sun, Shi, Liu, & Tanikawa, 2020). The information was mainly gained by different Chinese construction companies from different cities that had documents from buildings constructed in the years between 1949 – 2015 (Yang, Guo, Sun, Shi, Liu, & Tanikawa, 2020). In the study of Sweden, the material intensity coefficient was extracted from "Så byggdes villain: Svenska villa arkitektur från 1890 till 2010" which is an architectural book of buildings around Sweden (Gontia, Nägeli, Rosado, Kalmykova & Österbring, 2018).

2.3 Circular economy strategy for cities

The authors (Bolger, Doyon, 2019), investigates and presents the framework on how a city can exist in a circular way in terms of resource flow within the city. It also provides a framework for conceptualizing core aspects of circular economy within the city. The study informs that CE strategy can be implemented in various part of functioning economy including in meso level which involves cities. The implementation of CE strategies will close the material loop and help in rejuvenating resources within the planet's boundary while also helping to restore the existing natural system by not diminishing it further. Further, the study (Gravagnuolo, Angrisano, Fusco Girard, 2019), presents the framework for CE in cities adopting "closed" metabolism is urban ecosystem. The paper presents various strategic areas of focus for circularity of building. The framework focuses specifically on aspect such as "reuse of material from old building". The paper firstly suggests a systematic review of existing strategies by identifying implication in the area of interest such as building construction, waste management and so on. Consequently, the selection of cities and more specifically selection of circular economy action with focus on recycle and reuse of building material is done. Finally, key performance indicators devised for monitoring is implemented. The study concludes that to have a sustainable economic development there is a lot of limitation within the current framework as it doesn't represent actual implementation in real life. It also informs that for economy to function in a circular way the aspects such as built material within the buildings plays a very vital role. It highlights the process is slow and challenging yet fulfilling and cities are uniquely positioned to drive the change as there is sufficient economical, geographical, and technical aspects to drive it towards the goal. Figure 5 presents the circular framework within the built environment used in the study.

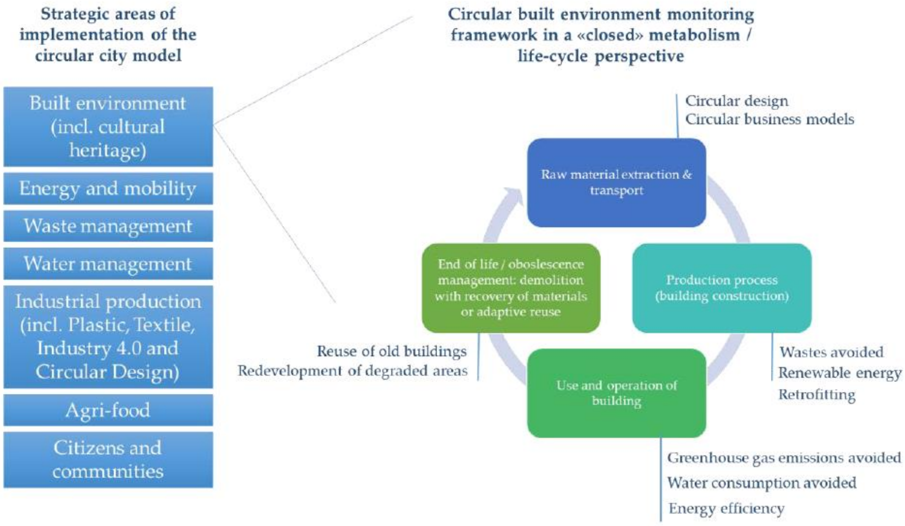

Figure 5. Circular city framework with focus on built environment. Source: (Gravagnuolo, Angrisano, Fusco Girard, 2019).

The first countries to implement the concept of circular economy were China and Japan and there has been plethora of cities that have been following the lead. The practise from the Japanese model have been used in ports of European cities Kalundbor-Denmark, Dunkerque-France, London, Amsterdam and so on focusing on aspects such as waste material recycling, industrial symbiosis, circular financial market and so on which uses the same framework (Bertino, Kisser, Zeilinger, Langergraber, Fischer, Österreicher, 2021). Moreover, study is also funded by the EU Horizon 2020 CLIC projects (2017–2020) also provides a roadmap to adaptive reuse as an important aspect of circular economy for buildings. As per (Bertino, Kisser, Zeilinger, Langergraber, Fischer, Österreicher, 2021), for a city to be circular business models need to be innovative with improved method which provides an overall reduction of resource, reduce the amount of waste ending up in landfill. It also highlights that urban symbiosis and industrial symbiosis are the major activities of CE in an urban ecosystem. The activities require synergy among different actors and the exchange could help minimize waste. The process will impact the overall life cycle starting of extraction, manpower, transportation and so on leading to improved environmental quality. The paper also uses the term "Deconstruction" which refers to dismantling of various building components for future use by reusing, repurposing, or recycling. It argues that with the implementation of such strategies, though the conventional demolition process might be cheaper with a lot of waste associated with it, would be beneficial in long term. The paper focuses and discusses on applying circular strategy to reduce the impact on urban environment by focussing on design and planning phase. The paper also presents the following sustainability hierarchy as seen in figure 6. The hierarchy helps with navigating through the process of circularity along with its associated impact in circular process.

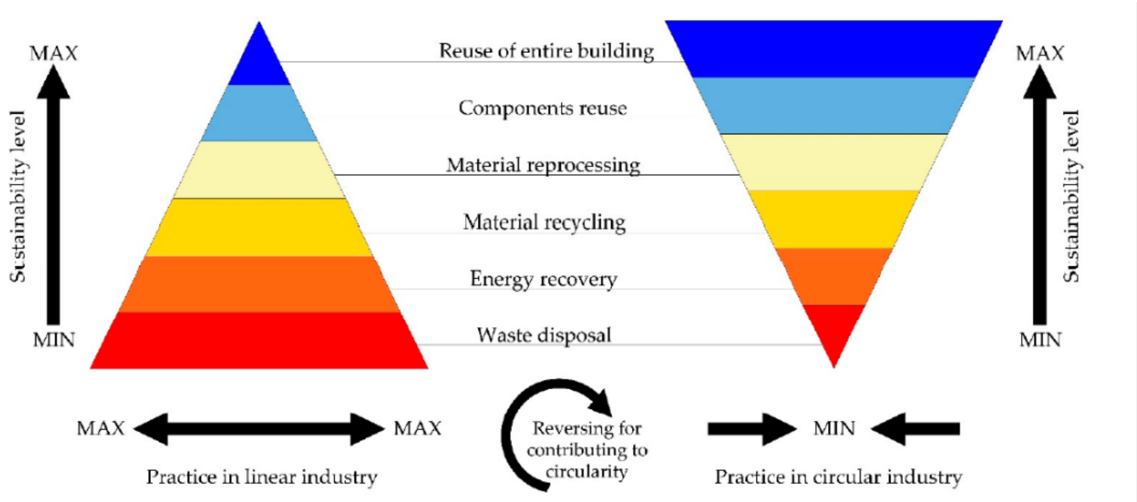

Figure 6. Sustainability hierarchy of a building (Bertino, Kisser, Zeilinger, Langergraber, Fischer, Österreicher, 2021)

2.4 Use of GIS in stock modelling

Technology can aid towards a more efficient implementation of CE. A digital tool can provide a medium to tackle solutions in a positive way making transition towards circularity more pragmatic (Bolger, Doyon, 2019). Currently, there is a huge gap between availability of spatial data and attribute of buildings associated with it. As informed by (Tanikawa, Hashimoto, 2009), the usage of spatial material stock analysis in combination of material flow accounting would give a holistic view on urban metabolism and could aid the policy makers working towards creating a circular society. However, over the years, the usage of Geographical Information System (GIS) as a tool to aid CE has been used widely. GIS assists with visualisation of spatial distribution of Material stock in the study area. GIS has also been used in various approaches including the bottom-Up approach for stock modelling as well as resource identification along with material intensity coefficient. The attributes of individuals buildings such as area, location, material and elements are documented. The process allows to analyse the inventoried buildings database which have been built using the material intensity coefficient. This process allows to visually identify the material stock within a boundary and assist in recycling and reuse of material. The usage of GIS for stock modelling was recorded in 2009 in United Kingdom, Salford in Manchester and Japan, Wakayama City Centre and later followed by many cities around the globe (Tanikawa, Hashimoto, 2009). The following framework as presented in figure 7 has been used by (Tanikawa, Hashimoto, 2009) to estimate material stock using GIS in the cities.

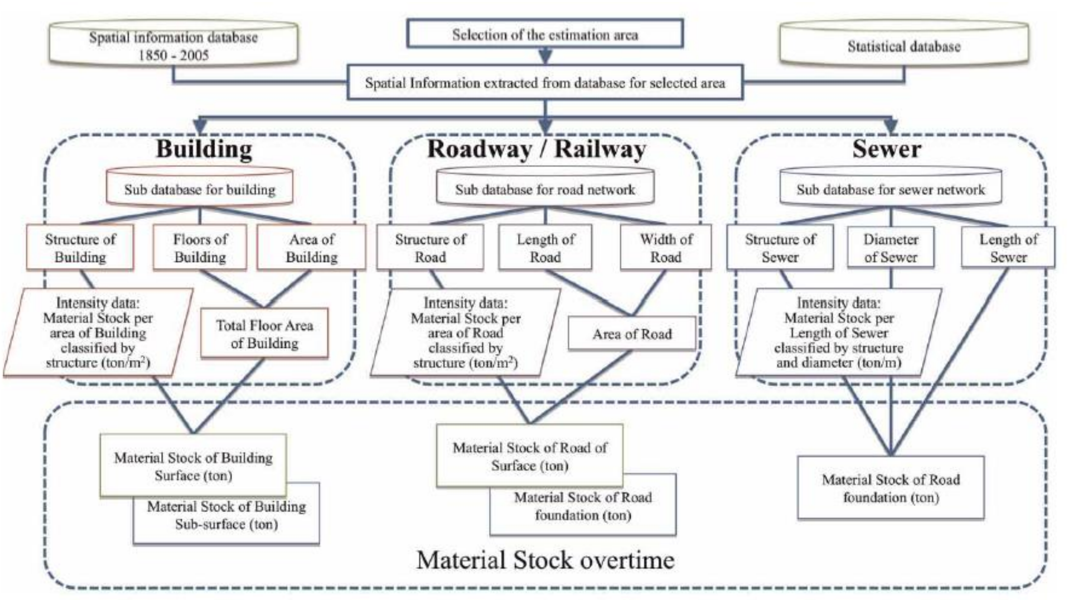

Figure 7. Material Stock Calculation framework. Source: (Tanikawa, Hashimoto, 2009)

Over the years though there have been a lot of studies where the statistical data have been used to document and estimate the stock size however this process has its limitation. It doesn't allow to pinpoint the location of the stock without using a tool such as GIS. The biggest challenge is not only having adequate information on stock but also mapping out the resource tagging it with the location. A spatial and temporal assessment of building material was conducted by (Kleemann, Lederer, Rechberger, Fellner, 2017) for monitoring settlement and open space development. Other applications mentioned are using GIS for track flow of construction material stock in a LEED certified building to make the process as energy efficient as possible as well as achieve recycle ability. The study also provides information on usage of GIS in USA for characterisation of building based on land type. These all cases aimed at integrating the information with the GIS system to optimise the flow and develop a dynamic database. This in turn strengthens the overall process of urban development and circularity involved within it.

2.5 Building cycle and demolition prediction

Overtime, a building goes through various cyclic process starting from design, construction, usage and finally end of life. As the building reaches the end of life, the material is dumped in a landfill as waste. This is not limited to environmental challenge but also waste of resource which could be used otherwise (Bertino, Kisser, Zeilinger, Langergraber, Fischer, Österreicher, 2021). If only the waste could be circled back into the production stage, it would hugely help in reducing the extraction of raw material while also managing the material in hand. The "self-replenishing system" strategy would help in extending the end life of the material by reuse or recycle in use or production phase (Stahel,1982). There are a lot of efforts and studies that have been made to understand the impact of recycling and quantifying the material that will be available overtime through demolition. It is crucial to measure the amount of construction waste that will be generated in order to manage and reuse the material properly. As informed by (Tanikawa, Hashimoto, 2009), for urban planning, future development and demolition of building it is also very crucial to understand the urban metabolism characteristics. The study provides information of the building construction and demolition projects in Japan and United Kingdom and their influence by factors such as economic interest, government plans, and usage of land and so on. Among various other mathematical function, (Tanikawa, Hashimoto, 2009) uses a simple logistics curve to fit the demolition curve to predict the building demolition.

$$N = \frac{K}{1 + a \cdot \exp(-bx)}$$ Equation (2)

In the above equation, the N represents the demolition rate of x-year old buildings, K is the carrying capacity, a,b are parameters to be fitted. There are various challenges to measure the demolition based on the curve i.e., the parameters for the recently constructed buildings cannot be calculated due to a smaller number of sample and multiple timelines. The study (Tanikawa, Hashimoto, 2009), has found the life span in United Kingdom for the middle and low-density residential housing which it refers to as detached and semi-detached houses have a life span of 102 years while that of high-density residential housing such as apartments have a life span of 96 years.

3. Methodology

The methodology section has been divided into various aspect as shown in figure 8. Firstly, the study starts with data collection which explains where the data for the study has been collected from. Secondly, the process section which explains how the geodatabase was developed with the help of different tools (QGIS and Microsoft Excel). It also follows steps within process which has been used in the study to find the result as show in figure 9. And finally, the last part of the study, result, which will be presented in another section of the study.

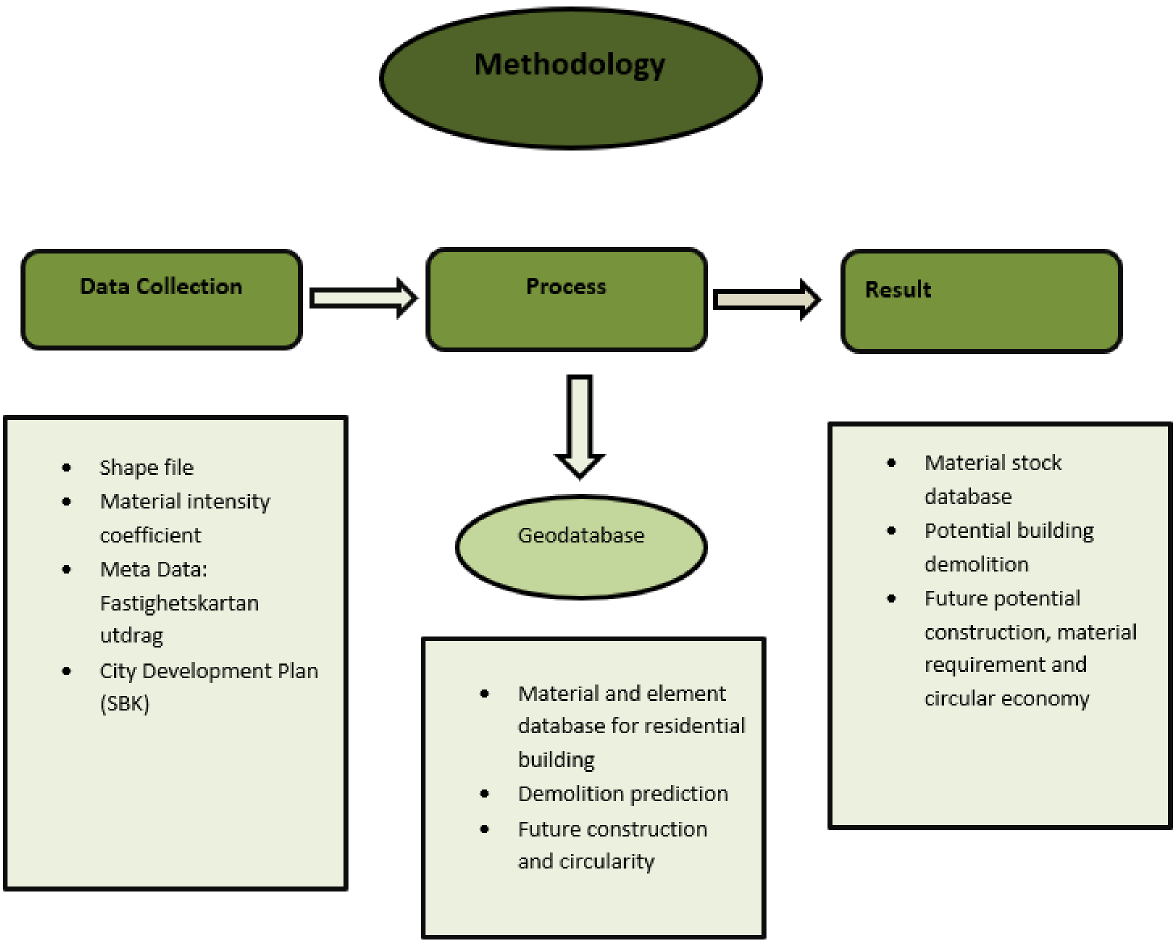

Figure 8. Aspects within the methodology process of the study.

3.1 Data collection

The study has been conducted based on the following information as presented in Annex 1. The various sources include literature, past studies, lantmateriet, Gothenburg municipality and so on. The study also relied heavily on secondhand sources from previous studies conducted in Gothenburg to gather data on material which eventually has been the foundation the entire material stock database presented in the study. The GIS data with polygon of buildings in Gothenburg from Landmäteriet. For the material coefficient the following study was used as the primary source for the building the database (Gontia, Nägeli, Rosado, Kalmykova, Österbring, 2018). The existing study provided the material intensity coefficient in terms of raw data for the residential buildings. Also, the document named fastighetsutdrag was used as a meta data to sort out the residential building among the pool of data. This document also enabled to categorize which buildings was defined as residential buildings in Gothenburg as well as separate the single-family and multi-family residential buildings. For the future development scenario, the study has used future development plan provided by Stadsbyggnadskontoret. The document included future construction plans in images form. Also, some judgements in the study regarding the future construction of 2035-2050 have been made based on the interview with the city architect ("stadsbyggnadskontoret, detaljplaner".n.d) who shared potential ideas for future construction sites in Gothenburg and for what purpose the new construction sites will hold. Furthermore, the study also analyzed the detail plans as provided by Gothenburg stad in order to identify details about infrastructure to be built in days to come. However, the lack of detail plans for residential buildings made it challenging to predict the exact structure type and amount for the new construction locations. Hence, in order to make as precise prediction as possible the detail plans collected from ("stadsbyggnadskontoret, detaljplaner".n.d) was studied to identify current buildings in the surrounding areas and assume the future construction archetype. Finally, a separate GIS shape file with the building heights of different buildings in Gothenburg was also used for the study.

3.2 Process

The following figure 9 presents the different process that was conducted in the study to followed in the methodology section. The details of the process have been explained in the following sections.

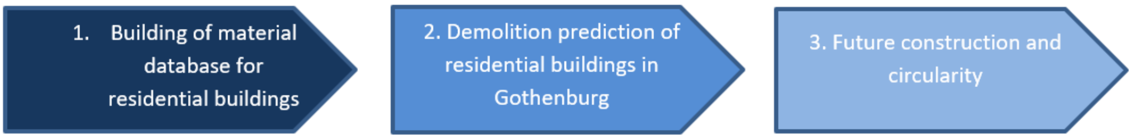

Figure 9. Procedure followed within the process section of methodology.

3.2.1 Building of material database for residential buildings in Gothenburg

The study developed a material database for all the residential buildings (Multi and Single Family) buildings in Gothenburg. The process was divided into two parts. First the GIS was used as a tool to identify all the buildings in Gothenburg and filter out only residential buildings among them, after filtering out, a separate GIS polygon file with heights of the residential buildings were merged into the previous polygon and after compiling this information in QGIS, the data were extracted to Microsoft Excel where a detailed database for these residential buildings were prepared. The following explains the detail process conducted in the process.

GIS

Firstly, the shape polygon file was first uploaded to the QGIS. The file contained information about all the buildings in Gothenburg city. The spatial dataset used for the studies was collected from the Swedish national Land Survey "Landmäteriet". After uploading the shape file, the file was reprojected using reproject layer which assists in projecting the data in Coordinate Reference System (CRS). The currently used CRS is EPSG:3007 - SWEREF99 12 00. After uploading and reprojecting the shape file another layer was added in QGIS. The layer was point data in delimited text; comma-separated values (CSV) format which contained data on different buildings in Gothenburg. The CSV file with point data was uploaded to QGIS using the open data source manager in coordinate reference system EPSG:3007 - SWEREF99 12 00 and projected. The point data were then merged into the polygon layer using the join attribute by location from the processing toolbox.

The processing tool assists in transferring attributes from one layer to another based on their field value (object id). Finally, as the information about the height was missing in the previous data set nor was it available in the shape file, the height of the residential buildings was then extracted from a separate .shp file. The supplementary shape file contained polygon with height of all the buildings in Gothenburg. Once the layer was uploaded to create a points layer based on the centroids of input polygon layer, centroid tool was used in the shape file. All in all, three spatial datasets were used polygons with buildings in Gothenburg, heights of the buildings in Gothenburg and the pdf file to identify and filter out only the Single and Multi-Family residential building constructed between 1890-2010 based on the pool of data that was available. For this we referred to a supplementary literature, Fastighetsutdrag. In the literature, the section Byggnadsinformation 41-Byggtyp contained classification of different buildings including residential buildings in Gothenburg. The number 30-35 were labelled as single and multi-residential buildings. Then a new layer was generated, and the layer was then exported to excel, and a database was created with object id, built year, type of building (single or multifamily), height and so on. The below presented figure 10 represents the overall process conducted to merge the point data into polygon for the residential building in Gothenburg.

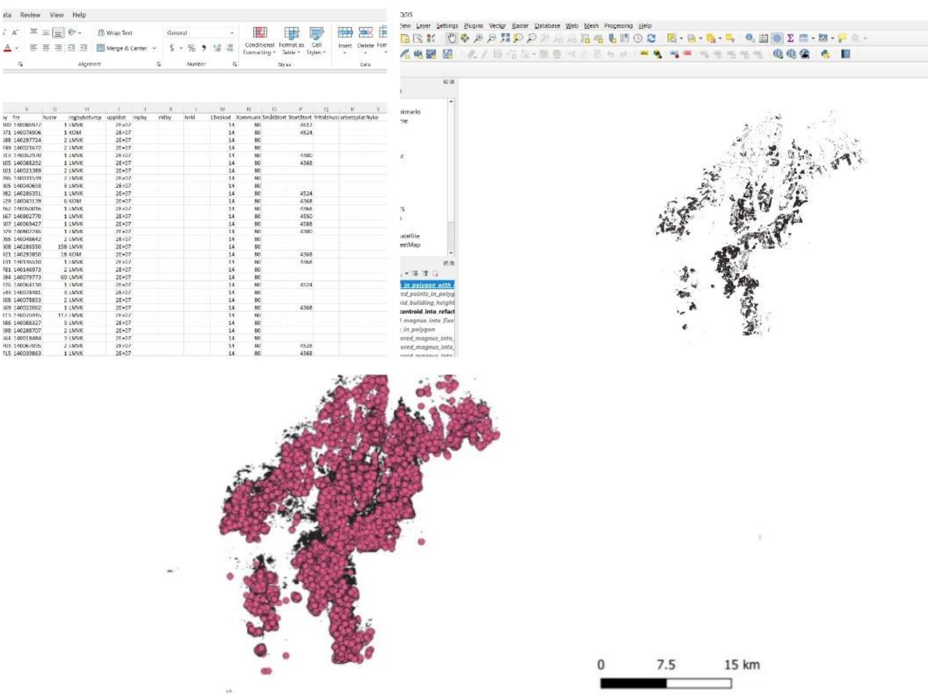

Figure 10. Merging of Points from Excel file to Polygon in QGIS.

Database in excel

After, the processing of the file in QGIS, the CSV file was exported to excel and a database with required information was built in excel. Firstly, the imported file from QGIS was thoroughly analysed with respect to Residential Building (Single and Multifamily). It was important to confirm the sort out data had only the residential buildings from the pool of information. The total number of sorted residential buildings numbered to 60724. Next, the construction year was rounded up to the closest decade in the excel database. Once that was done the buildings with no construction date were removed. It is construction date is important to classify the number of building floors as the height of the floors depend on year of construction for each of the buildings. As per the (Gontia et al, 2018), the heights of the floor ranges from 2.5-3.2 for both the Single as well as multi-Family Building. There were 3970 buildings that did not have construction year, so it was removed from the pool of information. The remaining data were further refined of any anomaly such as negative heights were changed to positive for 331 buildings, the buildings with height between 0-1 were rounded to 1 for 186 buildings and the highest height of the building is assumed to be 245 meters based on our interview with SBK. It was also informed that the tallest building in Gothenburg has a height of 245 meters. Once the heights were analysed, the number of floors were calculated by diving height of the building by height of floor for each of the buildings. The results were all rounded to upper values as we did not want the decimal values for this field. It is also important to note that the refurbished year was not used in the study as we did not know what was refurbished in the building as it could complicated the study. The final database has a total of 56755 residential building with single family residential housing numbering to 49979 whereas multifamily houses numbered to 6776. Once the residential buildings were sorted out the next step was to calculate the material of the building based on the different elements of each building which is elaborated in the following section.

Material and element

The following process was followed to calculate the material (concrete, wood, brick and metal) from the element as well as number of elements (window, bottom slab, roof and external wall) in the database.

Sorting of construction type

An investigation regarding the material composition of elements for residential buildings in between the years 1890-2010 for all single and multi-residential building in Gothenburg area was conducted. The construction type of the buildings was identified in relation to residential type, construction year and number of floors. Dividing the buildings into different construction type categories eases the understanding of how the material structure for the different elements distinguishes in relation to the years. The composition of materials for the building elements was identified. According to the paper (Gontia et al, 2018) the house structure for single family houses is dominantly a wooden construction type. While multifamily houses vary between wood, brick and concrete structure. The house structures for multifamily changed dependently on the year of construction, height of the floors and the number of floors and so did the elements.

Table 1 and 2 displays the construction type for single-family and multi-family residential buildings, these were sorted based on three main variables construction year, height of floor and number of floors based on the categorization of the construction type for the database about material intensity of residential buildings in Sweden. An assumption was made that the material composition for the buildings in 2010 are like the buildings in 2000 therefore the construction type for the buildings is similar.

Table 1. Sorting of construction type for single family-houses

Construction year	Height of floors [m]	Number of floors	Construction type
1890-2010	2,5-3,2	1-2	Wooden

Table 2. Sorting of construction type for multifamily houses

Construction year	Height of floors [m]	Number of floors	Construction type
1890-1930	2,7-3,2	1-3	Wooden
1890-1940	2,7-3,2	3-6	Brick
1950-2010	2,5-3,2	1-10	Concrete

Calculation of materials and elements of the building

The method to compile material from elements of existing building in the database for the residential buildings were conducted in 3 steps.

Compiling data

To understand the recycling and reuse in a more holistic way, the elements of the building needed to be broken down to the material composition. The materials for buildings changed depended on parameters such as building type, construction year and residential type and building height. The architectural material intensity coefficient was extracted from a previous study which analysed the material intensity database in Sweden in an international context. The data base of Sweden had information regarding the material intensity coefficients for different elements in residential households constructed between the years 1880-2000 in the city of Gothenburg. The residential building type varied between single-family with a wooden construction type and multi-family households which could varied between wooden, brick and concrete.

Creating the inventory of the construction materials

An inventory was created to understand in what quantity each material had for all the studied elements in a building. This was conducted through analysing the material coefficient file from (Gontia et al, 2018) and sorting out the elements that was essential for creating the database. Based on the building construction type and year of construction the inventory data was collected and sorted for the following building elements: bottoms slab, roof, external wall, and windows for materials concrete, metal, wood, and brick.

Calculations for external wall area

The area surrounding all building walls was calculated with the accumulated data. This was done for conducting the material weight for external walls. The shape area for the building slab and roof was taken from the building landmateriet.

$$O,i * NF,i * FH,i = EWA,i \text{ Equation (3)}$$

$$O,i = Circumference\ length\ of\ the\ building$$

$$NF,i = Number\ of\ floors$$

$$FH,i = Floor\ height$$

$$EWA,i = Externalwallarea$$

Material weight for each element of the building

Here equation 4 was used for calculating the specific material weight for each element. Similar area was used for calculating the bottom slab, intermediate floors, and roof material weight. Equation 4 has been used for both windows but the area changes in relation to material for the windows. Area for the wood of the windows is based on the outer dimensions of the window while the glass area is depended on the whole base of the window multiplied with the height. The material coefficient for each element was taken from (Gontia et al, 2018), the uncertainties regarding the material weight

$$Mi_{e,y} \cdot A_{e,y} = Mw \quad \text{Equation (4)}$$

$$Mw = Material\ weight\ [kg]$$

$$Mi = Materialintensitycoefficient\ \left[\frac{kg}{m2}\right]$$

$$A = Area\ [m2]$$

$$e = Specific\ element$$

$$y = Year\ of\ construction$$

Element weight

The sum of all materials is described as a specific element weight. The element weight was calculated for all houses with equation 5.

$$\sum MWX, i = TEW, i \quad \text{Equation (5)}$$

Assumptions

- Buildings was rounded to nearest tenth in construction year
- The material intensity and composition for 2000 and 2010 for all buildings are assumed to be similar. This assumption was made because of the lack of data for buildings constructed after 2010.
- Number of windows are assumed to be 8 per floor. No specific information regarding how many windows each building had was found hence the following assumption was made.

- The external wall has been calculated with the shape length and height of the building.
- The number of external walls, roof and bottom slab are assumed to be one because of the lack of data regarding building dimensions.

3.2.2 Demolition prediction for residential buildings in Gothenburg

After the database with material weights for four elements for all the residential building in Gothenburg was compiled, the next step was focused on finding which buildings would be demolished and when. A forecast of demolition was then carried out to gain an understanding of how the city might possibly alter over the course of time and which buildings might possibly be demolished and what material or element would be available over time. When buildings are predicted to be demolished, one can gain a deeper comprehension of the available material stock, which can then be evaluated to see whether it can fulfil the specifications of the new construction projects. In the study (Tanikawa, Hashimoto, 2009), a demolition rate was calculated for two cities in United Kingdom and in Japan. Based on the geographical proximity as well as usage of similar material in the development of residential building, the end of life of the residential buildings in United Kingdom was used as a reference to determine when the residential buildings in Gothenburg will be demolished. As per the study, the estimated average lifespan of a single-family home in the UK is 102 years, whereas the average lifespan of a multi-family home is approximately 96 years. Following the literature, the calculations for the demolition of residential building in Gothenburg were done by first extracting the life span from United Kingdom which was 102 or 96 years based on the type of building, then sorting it the different type of residential building (Single or Multi) in our database and finally adding the life in the constructed year to get the demolition year. The following equation also represents the process done to predict demolition which was done in the excel database. The calculation was for DY (demolition year) was conducted by adding the (LY) lifespan year on the (CY) construction year in the excel database as seen in equation 6.

$$DY = CY + LY \quad \text{Equation (6)}$$

Finally, once the information of the demolition was compiled in excel, the material that will be available from the prediction was illustrated for whole of Gothenburg as well as for both single and multi-family residential building individually. Further, this information was incorporated in QGIS and the spatial analysis for different materials as well as different residential building was conducted.

Assumptions

- As the geographical proximity of United Kingdom is close to Gothenburg and the material profile for residential buildings were similar, the demolition prediction of Gothenburg was assumed based on the demolition rate of United Kingdom.

3.2.3 Future construction and circularity through recycle or reuse

Once the demolition of the buildings was calculated the next step was to analyse the amount of material as well as elements requirement for future over the years and where the future residential construction would take place and what are the material or elements are required between 2035-2050.

For this process, the study started with analysing the plans for future construction of Gothenburg with reference to the planning document obtained from stadsbyggnadskontoret and with the documented information from an interview with Bjorn Sisjö, who works as the city head architect for Gothenburg. The plans are presented in figure 3. After receiving the document in image format, the study mapped the approximate construction zones in the GIS file as presented in figure 11. Further, to get details of type of building, the detail plans from Stadsbyggnadkontoret covering the new construction in the central regions along with the existing buildings were analysed. From these documents and current location profile the future construction taking place in different location were approximated. It was observed that between 2035 to 2050 most of the construction taking place were residential building construction and the five sections selected as presented in figure 12 were selected random based on the proposed development years.

The following figure 12 provides visual information of five different areas that were selected among different development areas. In these five areas residential building will be built between 2035-2050. Using this information as foundation stones the study proceeded to next step, ie: to analyse how many buildings will be built, what type of building will be built, when will it be built and when and where the materials for this possible construction could be found for recycle and reuse.

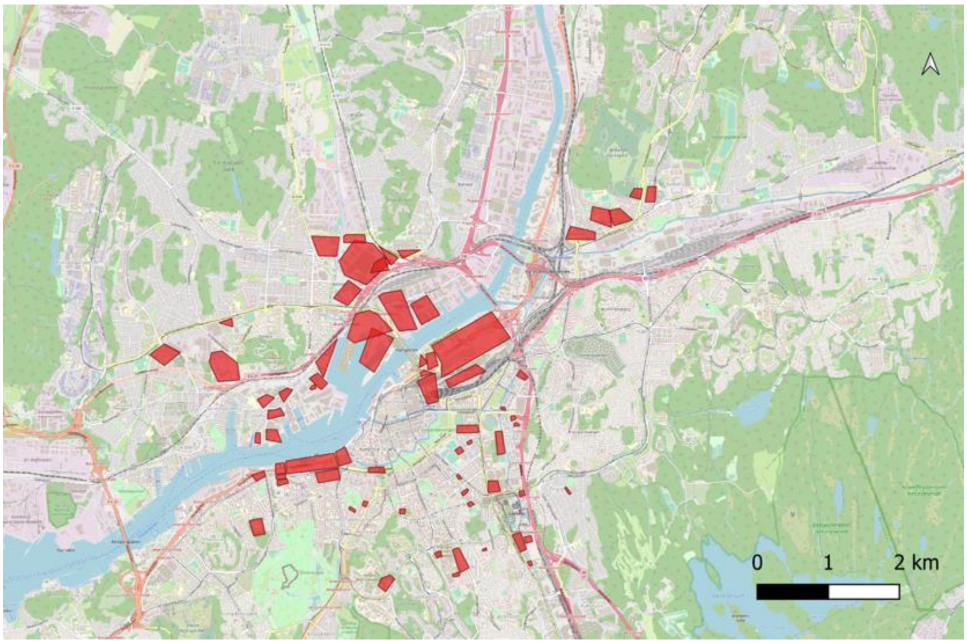

Figure 11. Mapping of future Contruction areas in GIS based on plan of Stadsbyggnadkontoret.

Figure 12. Five different zones selected for future construction based on plan of Stadsbyggnadkontoret which will be constructed between 2035-2050.

Table 3. Overview on sections 1-5.

Section number	Nearby Location	Section Size [m2]
1	Stampen	461043
2	Brämaregården, Lindholmen, Lundby vassa	156237
3	Backa	89872
4	Backa söder	22530
5	Biskopsgården	87669

As there was no direct data available that indicated how many buildings would be in the new locations while going through the detail plan from city planning council. Due to this limitation, to calculate the number of buildings that would be constructed in different sections, it was necessary to compute, the building factor, accurate estimate of the number of prospective residential structures that each section could have. The random sampling of existing areas provided an idea of the proportion of a total area to residential houses which will be used in future construction.

The first step was to calculate the area where future construction was planned in square meters considering the area of roads, nature and other amenities. The second step calculated the total area occupied by an existing residential building (both single family and multifamily) in that area. The third stage then divided the total area of all the residential buildings that were located at the area of interest with the amount of land area. This step provided a factor (in percentage) that indicated what proportion of the total area size the residential building area makes up. The following Equation 7 was used for the above-mentioned calculation of ratio of house to land, where RHAF stands for the residential area factor, RHA is the residential area and LA is the total location area. Everything was in the units [m2] expect the factor which was in percentage [%]. The factor was computed to be 8.2% which explains that in the total area of 100% only 8.2% of the land is occupied by the residential buildings.

$$RHAF = \sum \quad RHA/LA \quad \text{Equation (7)}$$

After finding out the factor, the next step was to calculate the amount of potential residential buildings that would be built in the selected areas. The procedure used for calculating the amount of area for the new residential buildings was done by multiplying the factor with the total project size area. Based on this information, the quantity of buildings for area was calculated which was done by dividing the amount of area used for new residential buildings with the residential type. The selection of building type was then done based on looking at surrounding building profile and assuming similar building will be constructed in that specific area.

*Table 4. Assumed construction in different selected section of Gothenburg along with i*nformation with different sections and archetype with year of construction and residential type and approximate quantity of house.

Section	Archetype ID from database	Year of construction	Building	Residential type	Quantity of potential buildings
1	118110	2004	Apartment	Multi-family	43
2	9303	1990	Apartment	Multi-family	70
3	53195	1949	Detached houses	Single-family	90
4	73132	1965	Detached houses	Single-family	27
5	104509	1940	Detached houses	Single-family	120

Finally, after computing the number of buildings and identifying the type of building the required quantity of materials for each section was computed. This was conducted by multiplying each architype building material stock with the quantity of potential buildings as followed in the earlier steps. Finally, creating a future material stock for the different section of the city allows quantifying of the material requirements. Once, all these information are quantified in Microsoft excel, the database was converted to CSV file and uploaded in QGIS for spatial analysis of different material availability based on areas. The spatial analysis will provide the knowledge for material location and assist with aiding material circularity.

Assumptions

- As the detail plans did not provide what type of buildings would be built in the selected area the assumption of future construction was made on basis of existing surrounding building types.
- The future construction will be analysed only for construction between 2035-2050.
- The 5 different sections are assumed to have all residential buildings construction in them.
- A factor of 8.2% residential area to land use has been calculated based on assumption (Land to House factor or building factor)
- To simplify the study, it is assumed that only one type of archetype (either SF or MF) will be constructed in each selected area.

4. Results

In the following section the result will be analysed for a total of 56755 residential building with single family residential housing numbering to 49979 whereas multifamily houses numbered to 6776. The database comprises of 88% of single-family residential housing whereas the multifamily houses numbers to 12% of total building in Gothenburg.

4.1 Building of material database for residential buildings in Gothenburg

The following section presents the result obtained from the database for all residential buildings in Gothenburg. It is important to note that the database has all together of 151 columns with detail analysis of different material as well as other binding materials for all the residential building in Gothenburg (multi and single-family). It is not possible to present all the result from each analysis hence the results will only present the analysis of four materials from four elements within a residential building ie: Brick, Wood, Concrete and Metals from elements such as roof, bottom slab, exterior walls, and window. The following section will present the results displaying the unique compositions of materials throughout the years for overall city, for single family and multifamily residential buildings. For further detail analysis the database can be found as a supplementary attachment with the report.

4.1.1 All residential housing

The total weight of materials such as wood, brick, concrete, and metals available in the constructed residential building, both single family and multifamily, from 1890-2010 has been presented in below Figure 13. The result only presents the sum weight for the materials and do not consist of binding materials like lime mix, sawdust, or insulation. The results provide understanding of the total quantity of pure materials namely (Wood, Brick, Concrete and Metal) that are available in Gothenburg and could be gained from the material stock of the city through urban mining. The result also provides understanding of how the material stock has changed over time. The result show that most of the buildings are built in 1970 and the highest amount of material used of construction in this duration is concrete as shown in figure 14.

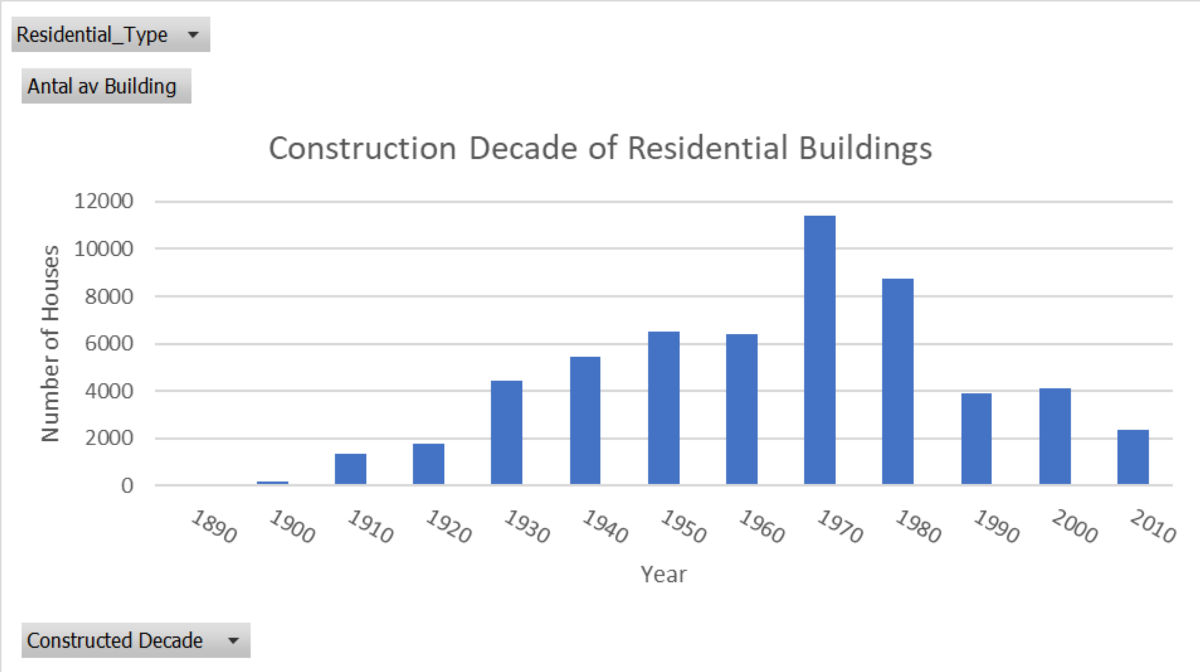

Figure 13. The average numbers of construction houses for both single and multi-residential buildings in relation to year.

It's evident from figure 14 that buildings with most materials in the city are constructed in 1970. The material that is most dominant in 1970 is concrete, followed by brick and wood. Concrete is the construction material that the city is most comprised of after 1960. Brick is still the second most used material. The material availability between 1890 and 1920 is below 200000000kg with wood being the material most buildings are comprised of.

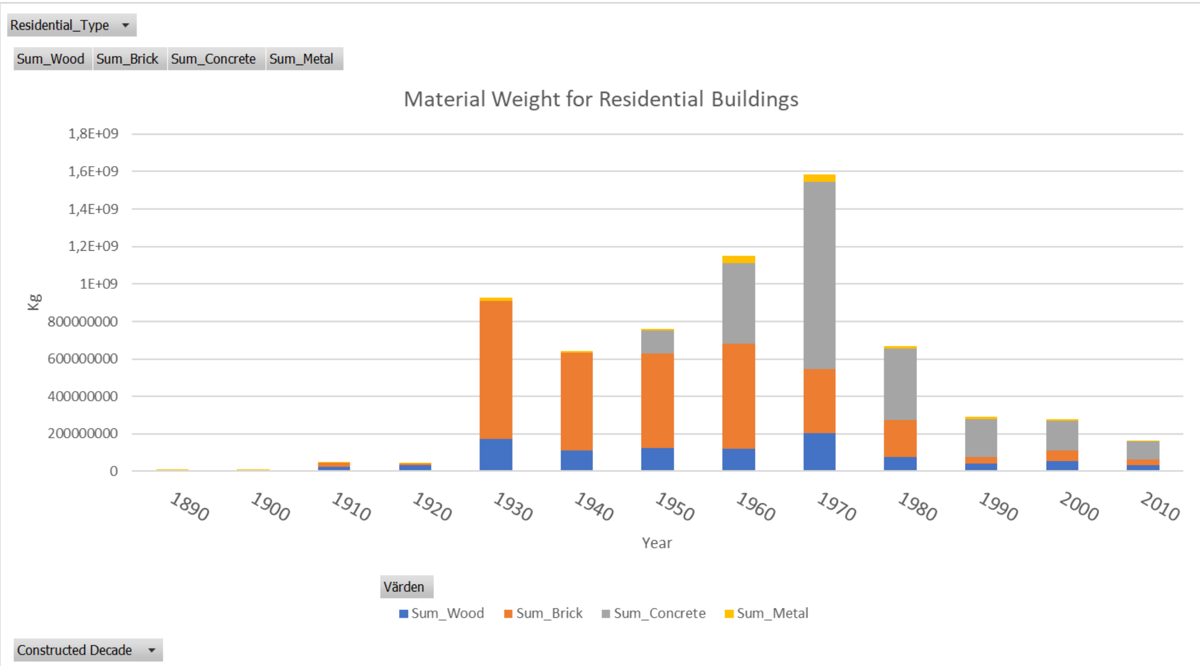

Figure 14. The sum of material available from residential buildings in Gothenburg for single-family and multi-family households.

The following figure 15 represents the general overview of area of central Gothenburg which has been investigated in the study to project the location and quantity of different materials and elements. All the results presented here are based on the quantity of material and elements available in and around Gothenburg from residential buildings. As shown in figure 16, it is visible that the quantity of wood is higher in the area such as Majorna, Valgraven and Landala. Similarly, figure 17 projects the quantity of brick which can be seen higher in the area near Gamlestaden, Majorna and Haga. Also, figure 18 and 19 projects the total quantity of metal and concrete. Concrete is more evenly distributed in the center part of Gothenburg but there is higher quantity of it in majorna. Highest concentration of metals is also found in Majorna but there is also in areas such as Brunnsparken.

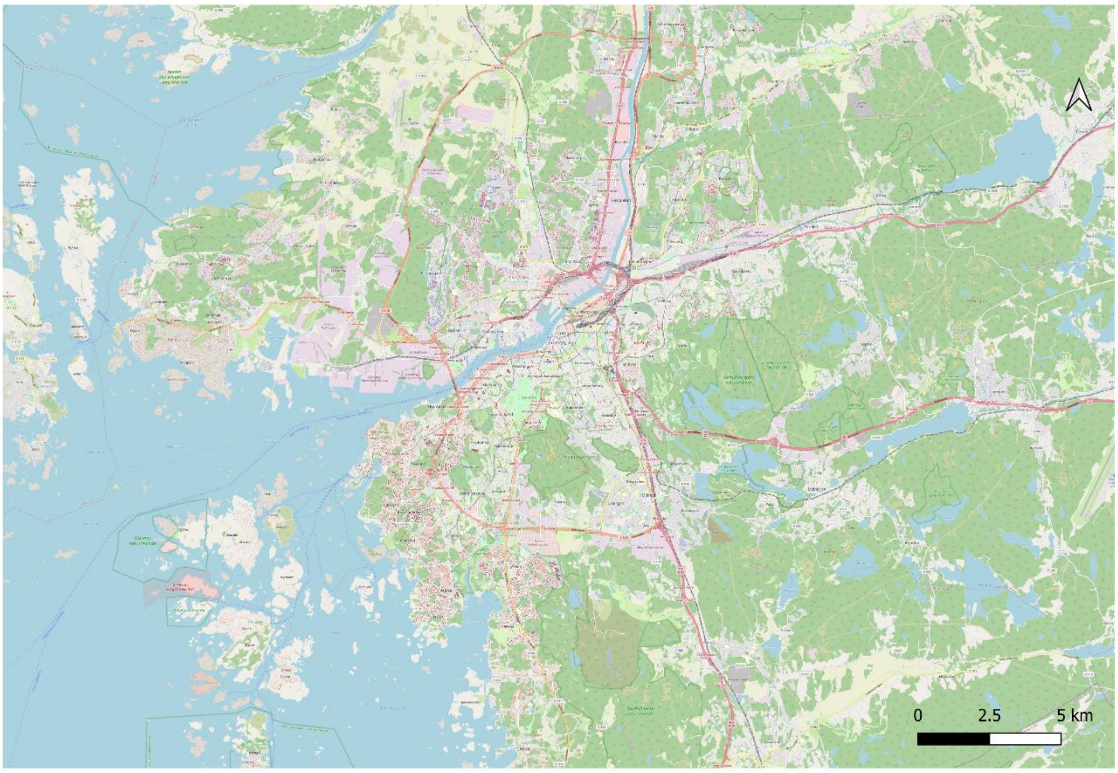

Figure 15. Central Gothenburg Area.

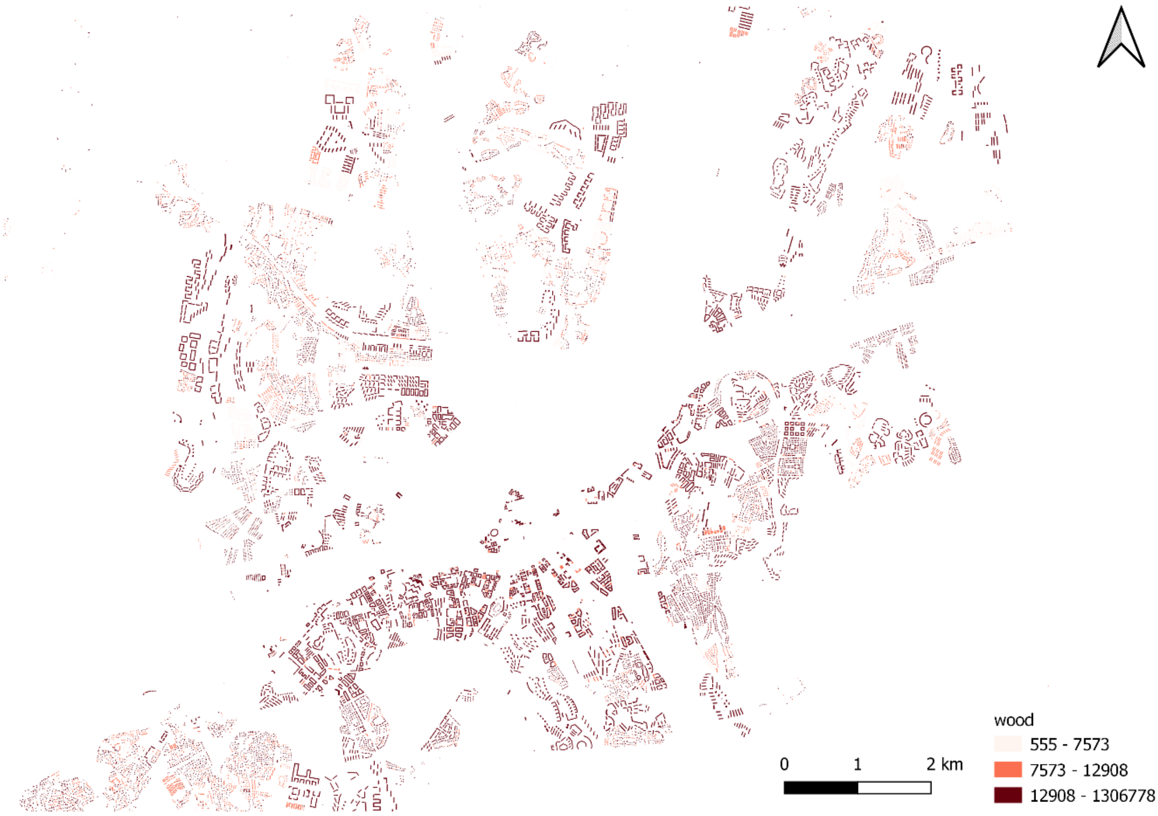

Figure 16. Distribution of wood around central Gothenburg.

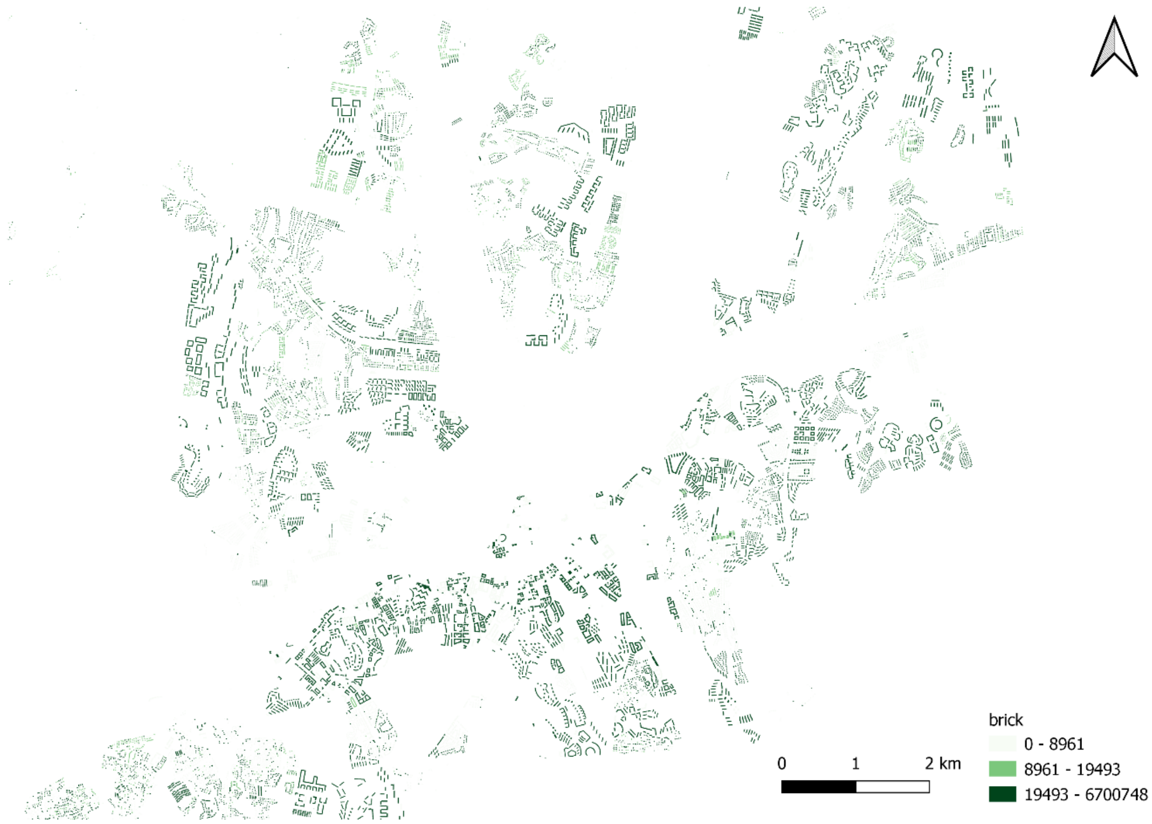

Figure 17. Distribution of brick around central Gothenburg.

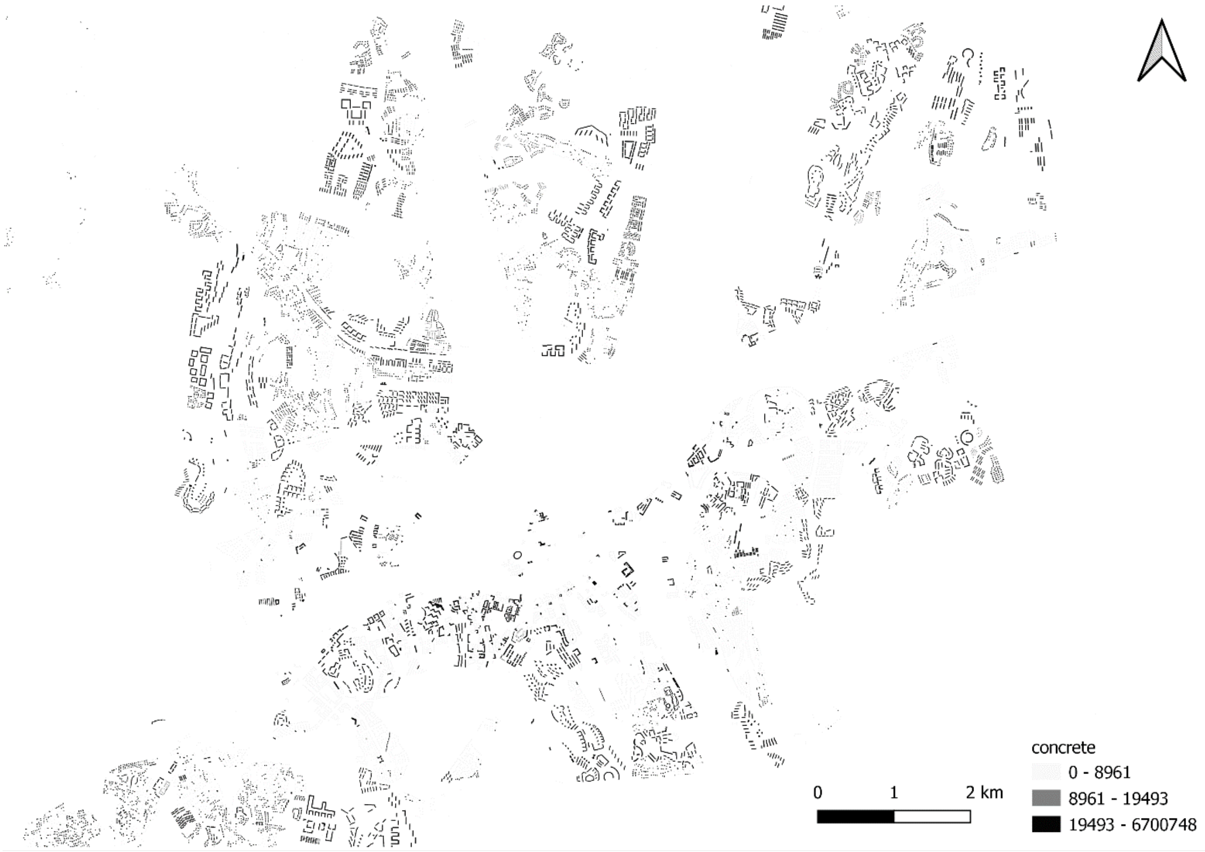

Figure 18. Distribution of concrete around central Gothenburg.

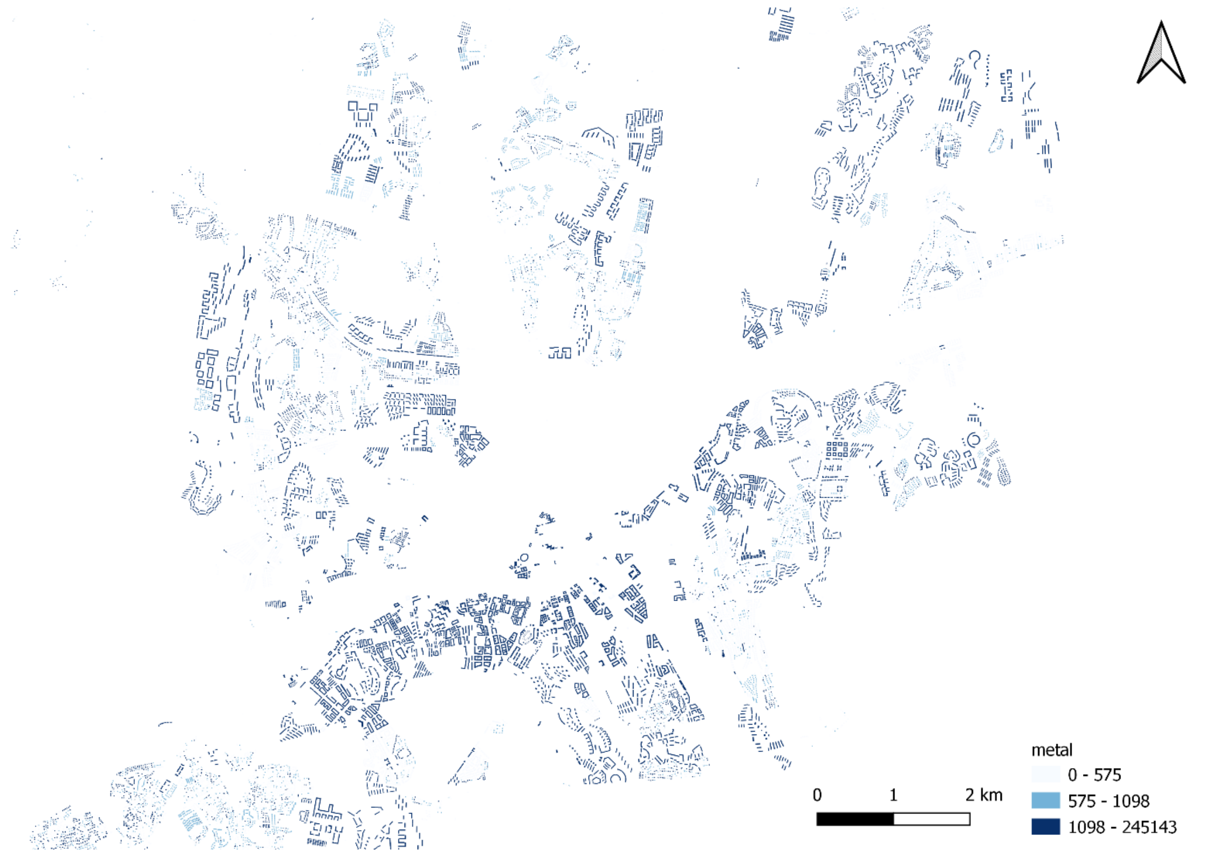

Figure 19. Distribution of metal around central Gothenburg.

4.1.2 Material weight and quantity of elements in a single-family residential housing

The following figure 20 represents the number of single-family residential housing which was built between 1890-2010 and material from four elements. The number of single-family housing accounts for 88% of the total houses in Gothenburg and most of them have been constructed in 1970 which account for more than 10,000 houses. Similarly, the figure 21 also analyses the composition of different material used over the time for construction of the single residential houses. There is a lot of construction that has been done in 1970 and there is decrease of number of buildings constructed since then.

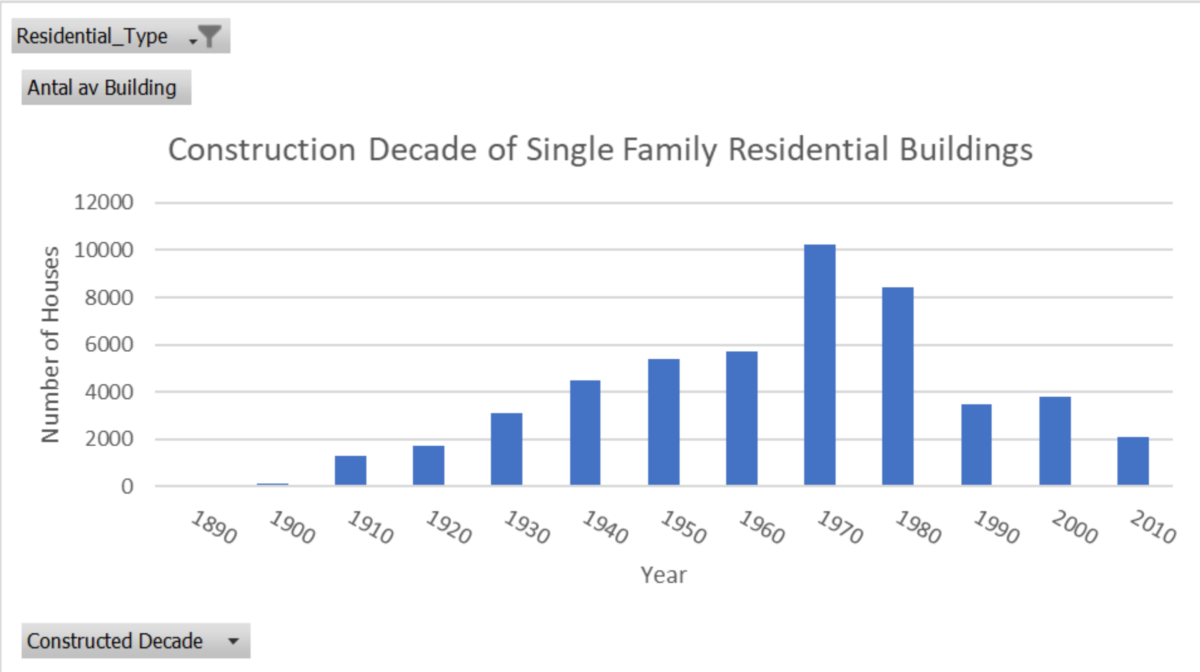

Figure 20. Illustration of the number of single-family houses over the respective years.

From the figure 21, it can be observed that windows are the dominating number of building elements, but this does not mean that most of the material weight comes from the windows. Bottom, roof, and external wall is seen as one element for each building. The reason for the external wall being classified as one for each building is because of the lack information regarding the quantity of walls surrounding the residential buildings. The external wall is therefore seen as on wall which surrounds the building length of the outside. Based on the information from the database brick and concrete are the most dominate material found through the construction years. Most windows consist of wood and glass, the mass of material created in relation to quantity of elements is therefore not valid. The construction year which produced most elements are 1970 and least are 1890.

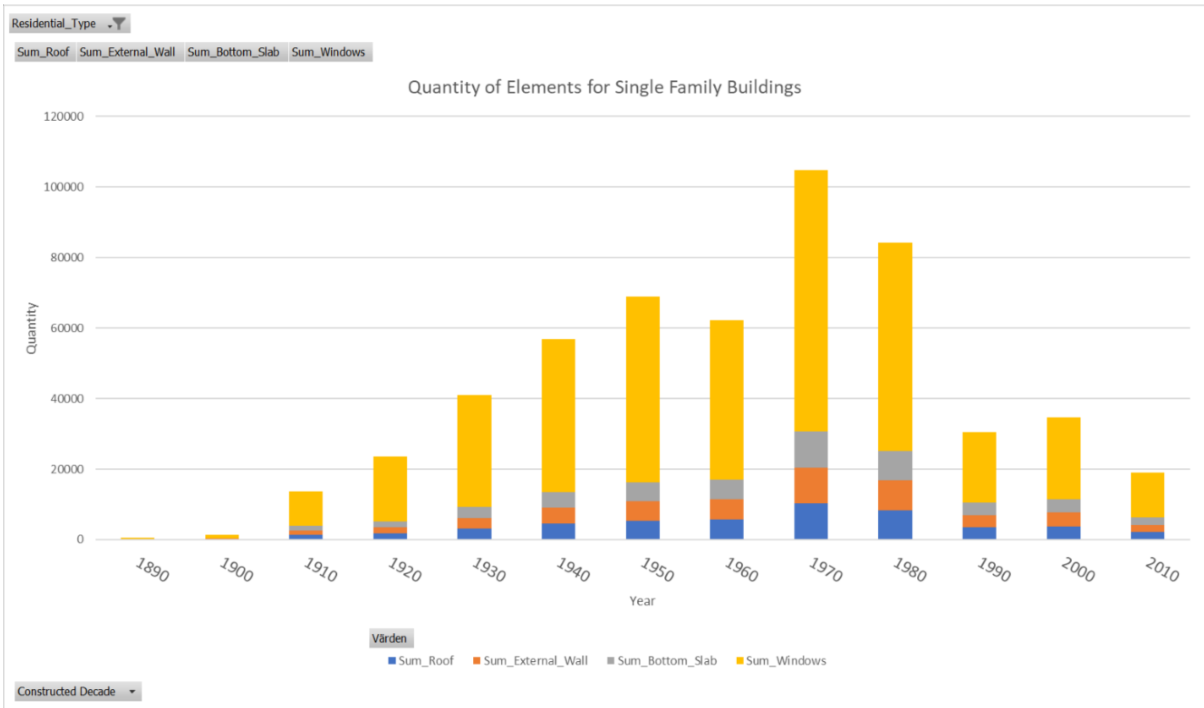

Figure 21. Quantity of elements in a single-family residential building.

From 1890 to 1940 in figure 22, wood is the most used construction material. The sum weight of the wood weight from 1890 are 1013699 Kg, 1900 had the sum weight wood of 2119766 Kg, 1920 wood weight are around 19066855 Kg, buildings from 1930 has a wood weight of 67878753 Kg and 1940 has a wood weight of 81980546 Kg. Single family houses from 1940 also have significant amount of brick which together has the sum weight of 4683623 Kg. Single family residentials from 1950-2010 consists mostly of concrete, followed by brick, wood and metal. The sum weight of concrete from 1970 are the highest compared to all the years with a weight of 432277659 Kg.

Figure 22. The sum of material available from single-family residential buildings in Gothenburg.

4.1.3 Material weight and quantity of elements in a multifamily residential housing

The following result presents the number of multi-family houses constructed for respective decade. The result helps to understand how the constructed number of multifamily residential building changed over the years. This also allows to understand the quantity of materials that is available in Gothenburg from multi residential building. From figure 23, it is evident that the multi-family residential buildings between the years 1890 and 1920 was in low production. During the year 1930, the number of constructions was in its highest peak of construction with over 1300 multi-family houses built during the decade. The number of houses built between 1930 and 1970 had high number constructions. The years 1980, 2000 and 2010 had the number of constructions below 400 for each respective decade. In 1990 a slightly higher number of constructions was done as compared 1980, 2000 and 2010.

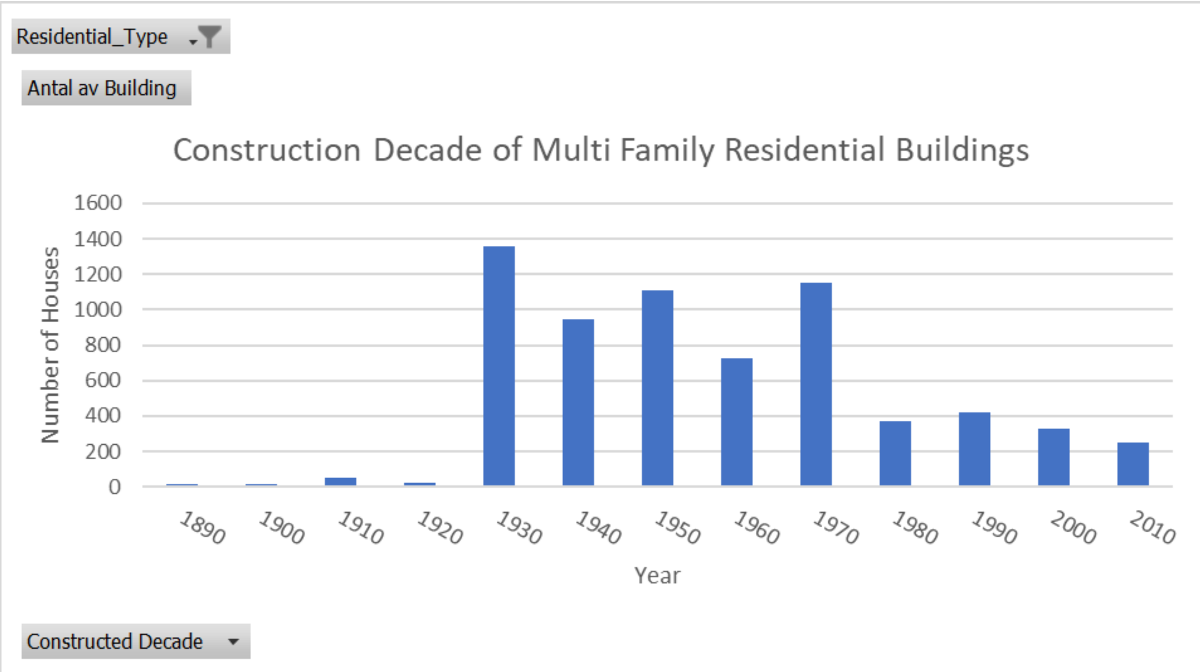

Figure 23. The number of constructed multi-family houses in Gothenburg over the decades.

Although it is clear from the figure 24 that windows make up most building elements, this does not imply that their weight accounts for most of the total material. Each structure's foundation, roof, and outside wall are a single component. Because there was a lack of information regarding the number of walls that surrounded the residential structures, the external wall was counted as just one for each structure even though there may be more than one wall in the area. The term "external wall" refers to the wall that is seen from the outside of the structure and runs the length of the outside perimeter. According to the findings of the research database, brick and concrete have been the most used materials throughout the history of the construction industry. Due to the fact that wood and glass make up the majority of windows, the mass of material formed in relation to the quantity of parts cannot be considered genuine for multifamily buildings just like in single family houses. The years 1930 and 1950 are the construction years that created most elements.

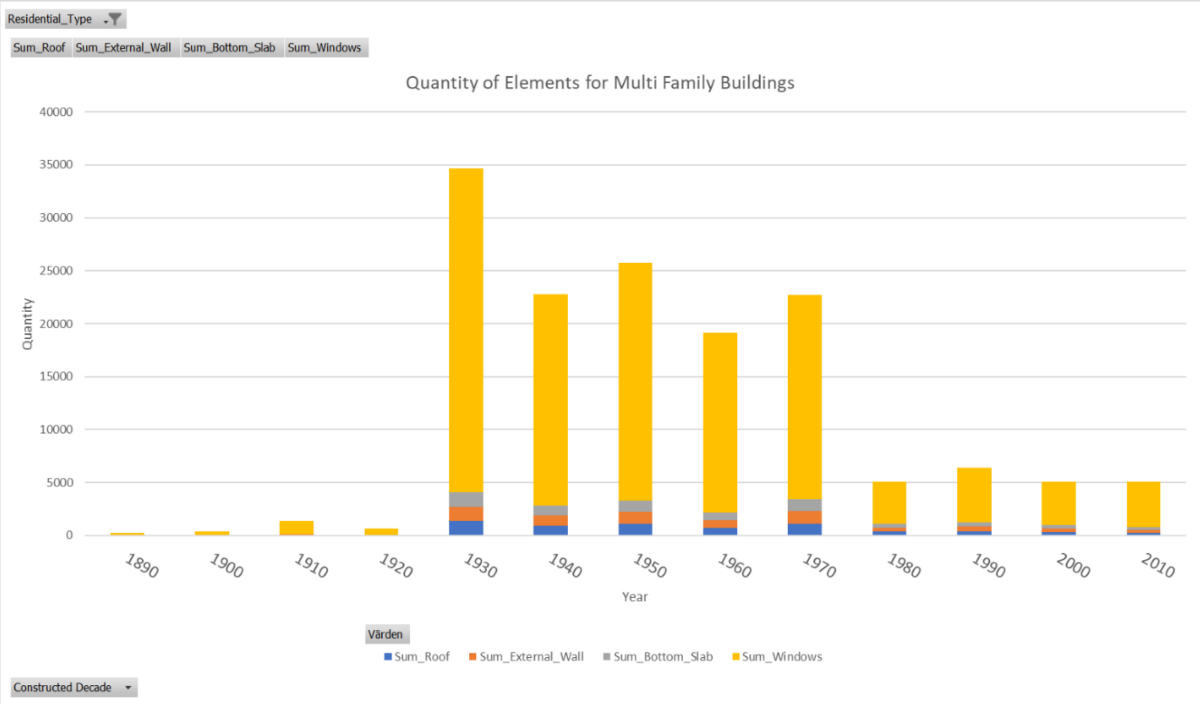

Figure 24. Quantity of elements in a multi-family residential building.

Multi residential buildings 1890-1950 consist mostly of brick-based structure followed by wood and metals. From 1950-2010 there is an increase of concrete weight in the buildings. The construction year with most concrete is 1970, followed by materials such as brick and wood. The construction year with second most concrete based structures is from 1960. Most of the buildings created after 1970 does have concrete composition but lacks brick, wood and metals in significant amount as seen in figure 25.

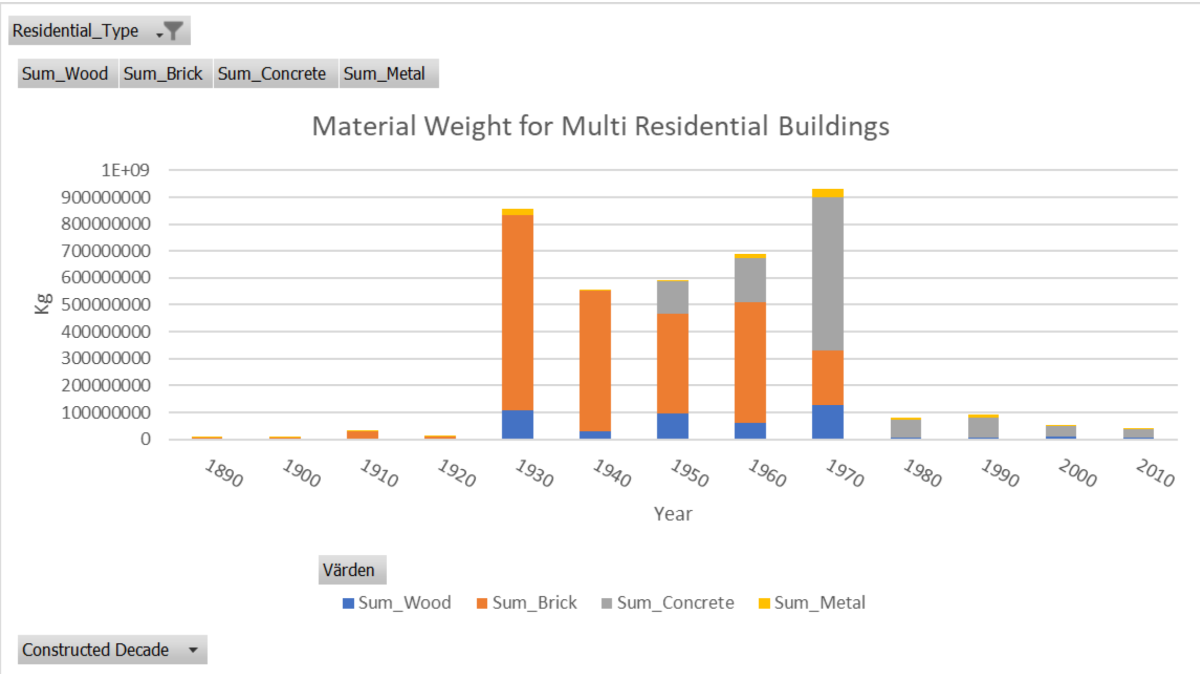

Figure 25. The sum of material available from multi-family residential buildings in Gothenburg

4.2 Demolition prediction for residential buildings in Gothenburg

The following section presents the result of predicted demolition from the database for all residential buildings in Gothenburg. It is important to note that the demolition of single residential building was assumed to be done in 102 years and 96 years for the multifamily residential building as described in the methodology section. The result in this section also presents the analysis of only four materials ie: Brick, Wood, Concrete and Metals from the following elements roof, bottom slab, exterior walls and window of the building. The following figures present the results displaying the unique compositions of materials throughout the possible years of demolition of residential buildings within the city.

The result show that 10245 number of the buildings both single and multi-family residential building will be demolished in 2072 as shown in figure 26.

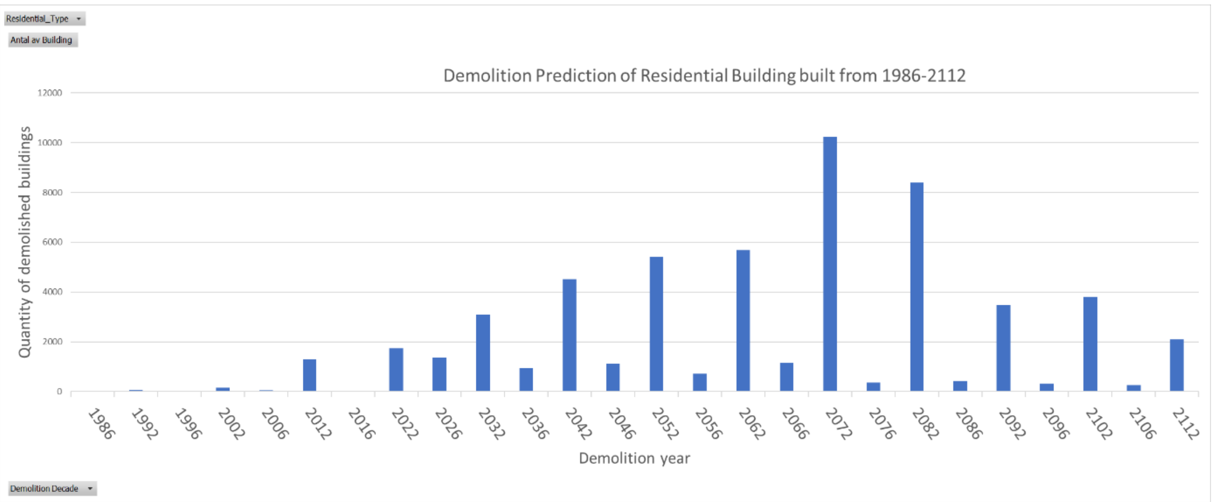

Figure 26. The number of houses in Gothenburg with predicted demolition over years.

To get a better understanding of the material distribution in the residential buildings that were under investigation, a potential demolition scenario was modelled and analysed to determine how much of the building's components will be accessible at various points in time over the course of the building's potential lifespan. As per figure 27, concrete will be the material that is most readily available following the destruction that will take place in 2066; the total weight of the concrete that will be available will be 568966435,4 kg. Bricks, which have a total weight of 206214411 kg, are the next largest material that is available, followed by wood, which has a total weight of 125358693 kg. Concrete will almost always be used in the construction of buildings that could be demolished between the years 2062 and 2112 because it is the material with the highest availability. Bricks will be the most readily available material following demolition from 2026 through 2056, with 2026 being the year that has the largest total brick weight, which is calculated to be 728764049 kg. For 2072, which has the highest possible demolition has 1030717.88 kg of metal, 432277659.9 kg of concrete, 136836086.1 kg of brick and 76433141.35 kg of wood that will be available after demolition. Similarly, as of elements, 10245 number of roofs, bottom slab and external wall and 74052 windows will be available.

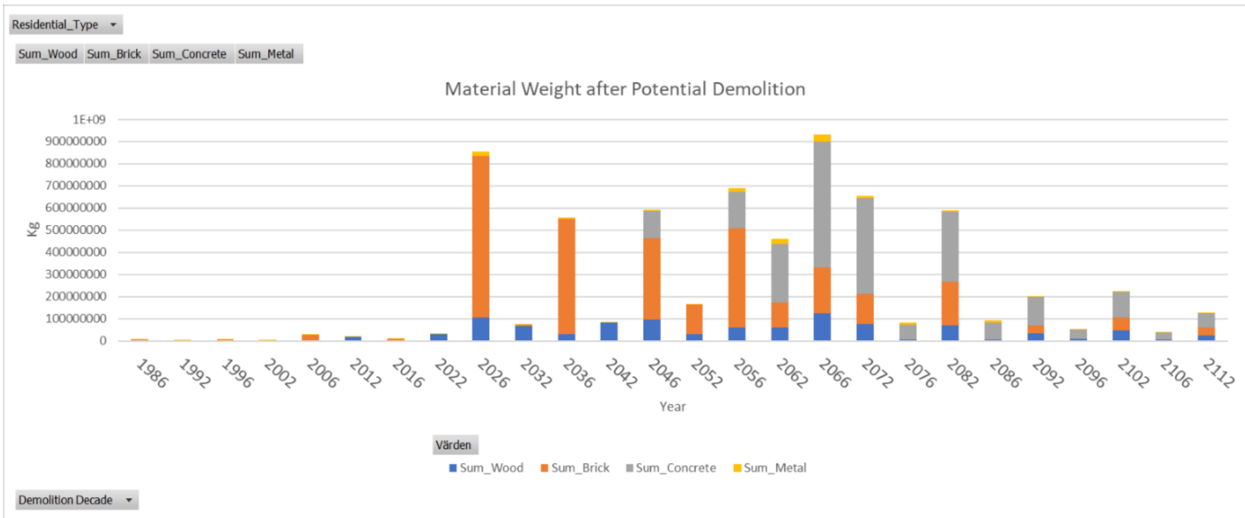

Figure 27. The amount of material that will be available after predicted demolition of residential houses.

After the building has been demolished, the number of windows that are still in good condition will be the aspect with the most potential for reuse. As per figure 28, the year 2072 will have a total of 74052 windows, making it the year with the most readily available windows. Each structure has the same quantity of bottom slab, external wall, and roof, but the total number of reusable pieces differs depending on the year it was constructed.

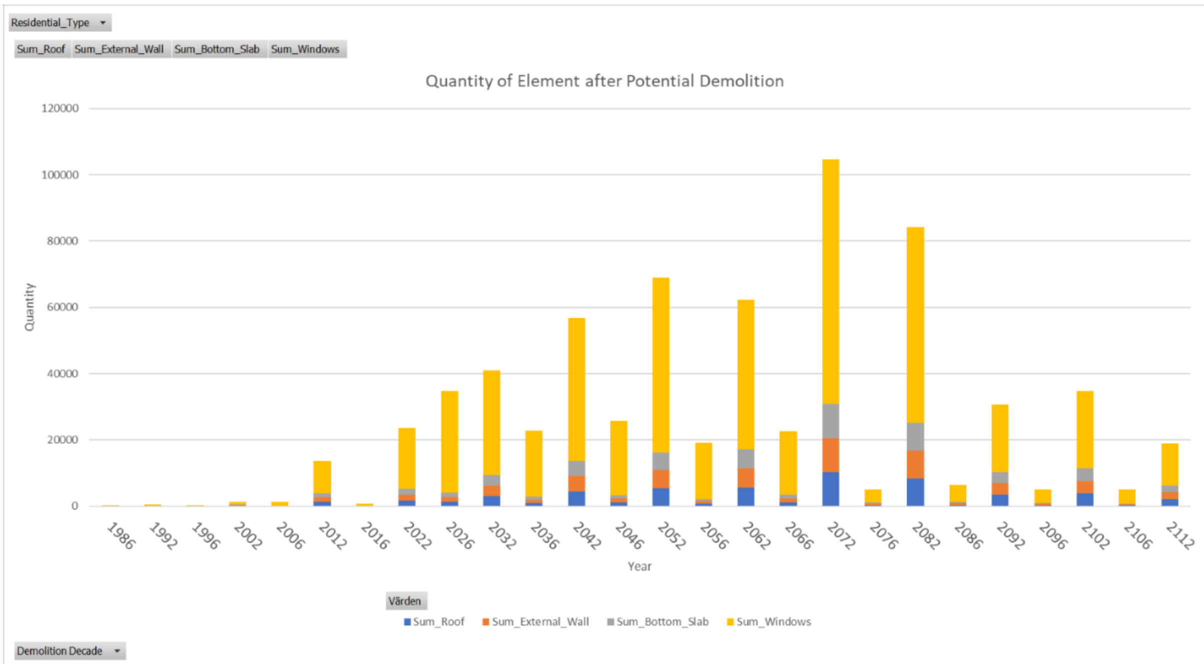

Figure 28. The quantity of element that will be available after predicted demolition of residential houses.

4.3 Future construction

The following section will present the result of required material and available material for possible future construction of residential building (single and multifamily residential building) in five sections based on the development plan of the city of Gothenburg as presented in figure 3. The result will also provide visual aid to identify the location from where material and element can be extracted for recycle and reuse during demolition. It has been assumed that section 1 will construct 43 and section 2 will construct 70 multifamily residential building between 2035 to 2050 whereas section 3 will construct 90, section 4 will construct 27 and section 5 will construct 120 single family residential building in the presumed time frame as presented in table 3 and 4. The result will be presented for necessary material in different sections for possible construction of residential building between the year 2035 to 2050. The goal of the section is present the required materials as well as elements.

4.3.1 Material and element requirement for future construction

The following table 5,7,9,11,13 presents the total amount materials (wood, metal, concrete and brick) whereas 6,8,10,12,14 presents the number of elements that will be required for construction of different residential building in five different sections for construction between 2035-2050. Also, the tables provide information on the quantity of different materials and elements available within different radius from the centre of the selected sections that could be used for mining material for the new buildings in the city. The range of radius that the study explores is 0-5km radius. The study doesn't exceed the furthest maximum radius of 5km while finding the source of material and element. If the available material is less than required material within 5km radius we have concluded that the deficit material for future construction should be covered by external source. In the result the number of elements for the house are satisfied within the observed distance from the centre however it is not the case in terms of material. With respect to that, the material available for single-family residential building is presented in section 3, 4 and 5 and multifamily residential building in section 1 and 2. The details of the buildings along with the calculations from which the material can be available are attached in annex 2.

Section 1

For section 1, in which it has been assumed multifamily housing will be developed, the most required material is brick, and as we see in table 5 the material is not meeting the requirement even while looking into all buildings that will be demolished between 2035-2050 within a radius of 5 km. Hence, it is suggested that the deficit amount should be compensated from external source. However, wood and metal demand are addressed by buildings that will be demolished within a radius of 2 and 5 km respectively. The requirements of wood could be obtained at a radius of 2 km with the available material stock at 5241753 kg wood. The figure 30 displays the buildings and location where the wood would be available. Whereas for the elements the distance of 5 km radius provides a lot more elements than requirement.

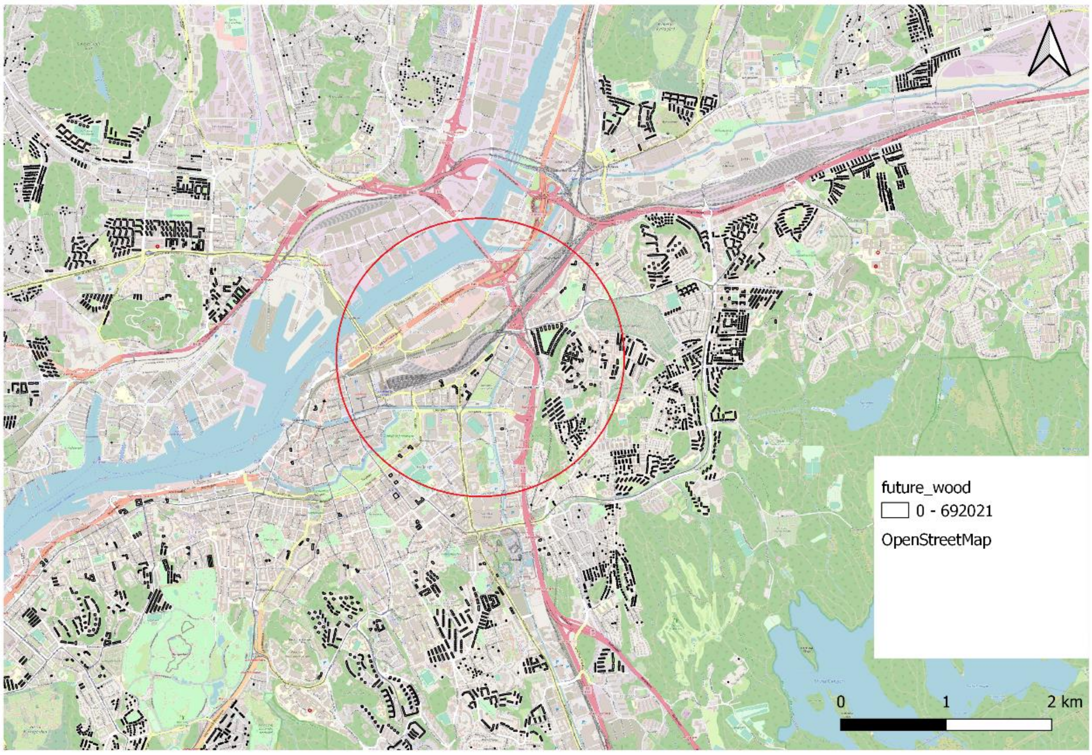

Figure 30. Location of wood within 2km radius of section 1.

Table 5: Requirement and availability of different materials in Section 1 with respect to radius.

Section-1			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	1557907	5241753	2
Brick	7801977	6880000	5
Metal	1132575	8217558	5
Concrete	7796683	8111039	5

Table 6: Requirement and availability of different elements in Section 1 with respect to radius.

Section-1			
Element	Requirement	Availability	Radius(km)
Roof	43	3956	5
Bottom slab	43	3956	5
Window	3784	4192	2
External Wall	43	3956	5

Section 2

In section 2 the requirements for material wood and metal are available within the radius of 5 and 2 km respectively as shown in table 7. The amount wood available within the radius of 5 km are 8648771 kg while the requirements for the section are 2189014 kg in terms of wood hence there is an excess of wood. Similarly, the weight of metals required is 241453 kg and the available weight of metals are 982176 kg. As for brick there is a deficit of material, and the demand needs to be met from external sources as the material is not available within the 5km radius. For the elements, it can be seen in table 8 that all the requirements are met by the availability within the observed distance.

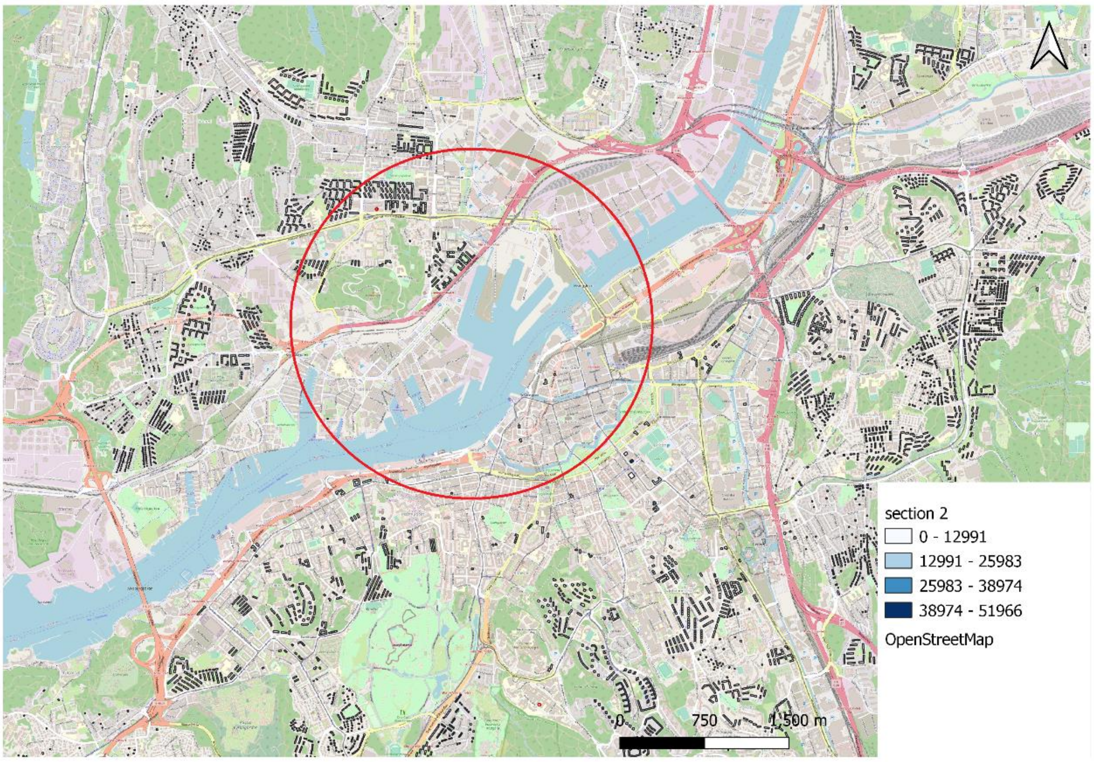

Figure 32. Metal availability within 2km radius of section 2

Table 7: Requirement and availability of different materials in Section 2 with respect to radius.

Section-2			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	2189014	8648771	5
Brick	24133463	7202352	5
Metal	241453	982176	2
Concrete	24133464	0	5

Table 8: Requirement and availability of different elements in Section 2 with respect to radius.

Section-2			
Elements	Numbers	Availability	Radius(km)
Roof	70	275	2
Bottom slab	70	3827	5
Window	1680	15308	5
External wall	70	3827	5

Section 3

For section 3, as presented in table 9 the brick and metals meet the requirement and demand from a radius of 2 and 1,5 km respectively. The brick availability was at 879806 kg in a radius of 2 km and had the requirement of 804343 kg. Similarly, metals had the availability at 271629 kg in a radius of 1,5 km with a requirement of 39103 kg. As for the elements, table 10 presents that the roof has a perfect match between requirement and availability whereas other elements also satisfy the requirements in excess.

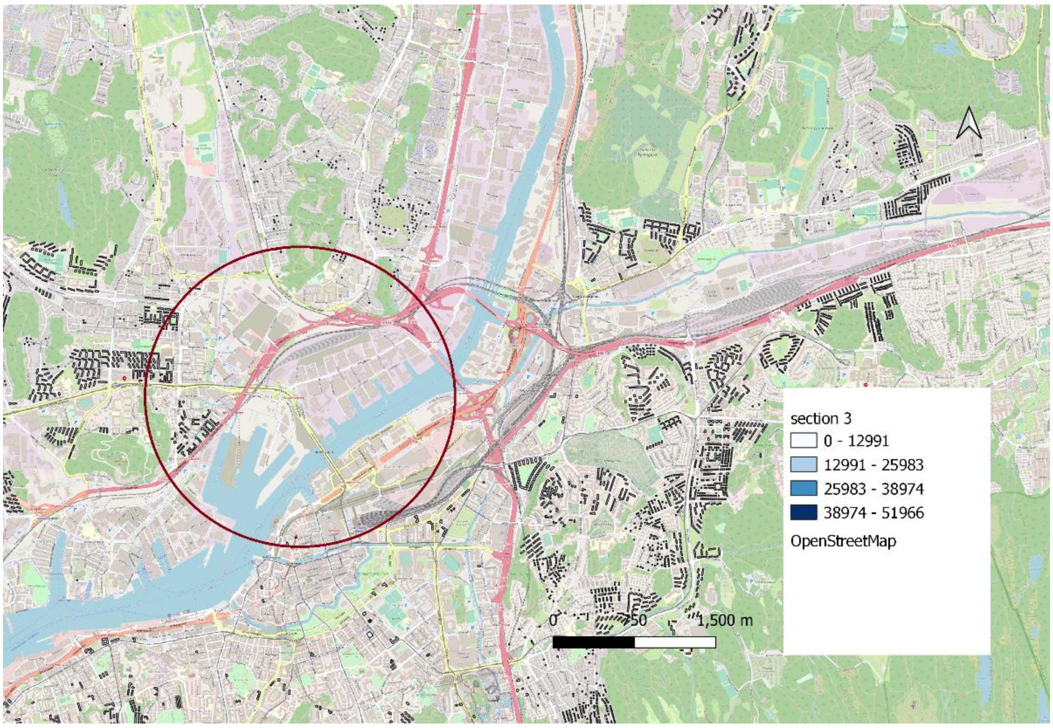

Figure 34. Metal availability within 1.5 km radius of section 3

Table 9: Requirement and availability of different materials in Section 3 with respect to radius.

Section-3			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	124288	123800	2
Brick	804343	879806	2
Metal	39103	271629	1.5
Concrete	7346596	0	0

Table 10: Requirement and availability of different elements in Section 3 with respect to radius.

Section-3			
Element	Requirement	Availability	Radius(km)
Roof	90	90	1.5
Bottom slab	90	320	2
Window	720	5120	2
External Wall	90	320	2

Section 4

It is clear from table 11 that in section 4 wood is the most required material followed by the metal. The required quantity of material is already available at a radius that is only 0.8 km away from the centre of the section 4. The quantity of metal required is 15176.9 kg, whereas the quantity of wood required is 41911.5 kg. The amount of available wood is 111749 kg, whereas the weight of available metal is 51670,50796 kg based on the radius of 0.8 km. Similarly, as seen in table 12, for elements all the requirements are fulfilled within 0.8 km radius as well and the number accounts to excess.

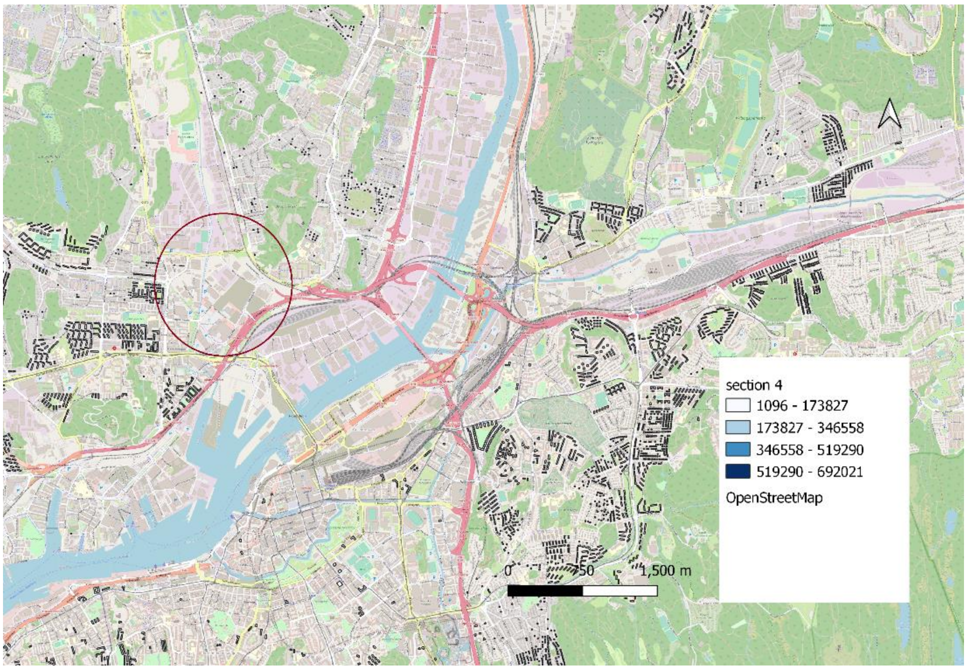

Figure 36. Metal and wood availability within 0.8 km radius of section 4

Table 11: Requirement and availability of different materials in Section 4 with respect to radius.

Section-4			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	41911	111749	0.8
Brick	296758	0	0
Metal	15176	51670	0.8
Concrete	636513	0	0

Table 12: Requirement and availability of different elements in Section 4 with respect to radius.

Section-4			
Element	Requirement	Availability	Radius(km)
Roof	27	40	0.8
Bottom slab	27	40	0.8
Window	432	640	0.8
External Wall	27	40	0.8

Section 5

In table 13, the material availability will not meet the demand for wood and brick therefore there will be a need of compensation it by buying more raw materials to balance the material requirement. The availability of wood is 9576 kg and for metal it is 28135 kg. The requirement for wood is 1388774 kg and for metal is 16124 kg. However, from table 15, it is visible that the number of elements all satisfy the requirement except for window hence to fulfil the required number of windows it is necessary to increase the radius of search from 0.4 km.

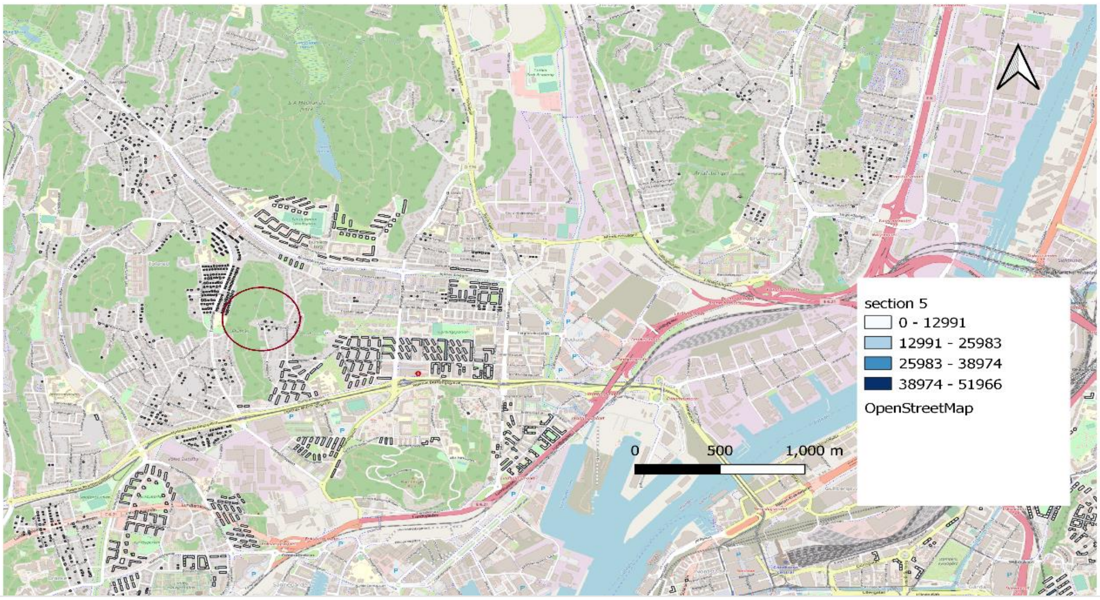

Figure 38. Metal availability within 0.35 km radius of section 5

Table 13: Requirement and availability of different materials in Section 5 with respect to radius.

Section-5			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	1388774	9576	0.4
Brick	1318925	867785	0.35
Metal	16124	28135	0.35
Concrete	2493101	0	0

Table 14: Requirement and availability of different materials in Section 5 with respect to radius.

Section-5			
Element	Requirement	Availability	Radius(km)
Roof	120	145	0.35
Bottom slab	120	145	0.4
Window	2880	512	0.4
External Wall	120	145	0.4

5. Discussion

According to Boverekt almost 20% of all residential buildings in Sweden were constructed between the years of 1965-1974 (”Bovereket, under miljonprogrammet byggdes en miljon bostäder” n.d). The residential building was in high demand in Sweden after 1950 because of population growth. As seen in the figure 39 it is clear that the highest construction year is in 1970. Based on the results from the study, the material weight and quantity of elements in figure 22 show similar trait. It is clearly visible that the buildings constructed between 1960-1970 carry's the most amount of material in the result. The results also indicates that in 1970 highest number of residential buildings were constructed. Similarly, figure 39 presents the number of houses constructed over the years in Gothenburg. This result displays the average number of residential (single and multi-family) constructions done for each year from 1980 to 2010. As seen in figure 23, the highest construction year was 1970 and the lowest was 1890. There is a slight increment in the curve of constructions from 1930 to 1950 but it dips down little in the year 1960. The construction of houses decreases between the years 1980 and 1990 but grows a little bit for 2000. The data from miljonprogrammet is on par with the result obtained while building the database and analysing the number of buildings along with the materials and elements.

In the database it could be observed that in certain years such as 1890, there is not adequate data regarding the construction date as well as amount of material and element. It could be argued that the issue might have resulted because of the poor documentation in archiving the data between late 1800 and early 1900 or lack of population. Therefore, it could be inferred that if the information is not properly documented the result might not represent the realistic weight of the materials or number of elements for that year of construction and this could in turn make the study faulty and not realistic. Hence, while documenting a database utmost care should be taken while processing the available data.

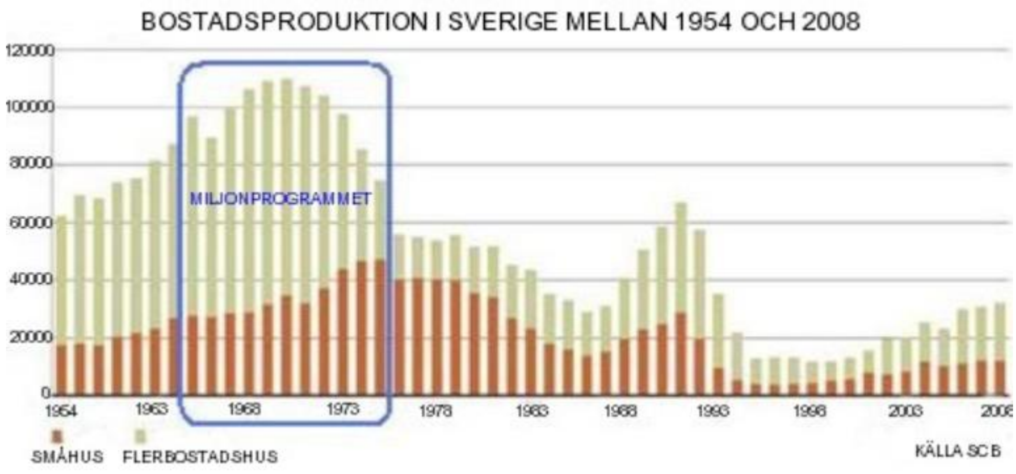

Figure 39. Graph x showcasing the amount of constructed single-family houses in (red), and the amount of multi-family houses constructed during the million programs in Sweden Source:(wikimedia)

For the current material weight as seen in figure 14, the result is parallel with number of buildings constructed as seen in figure 39. This indicates that the material weight increased with number of buildings constructed over the years. However, it is important to understand that this does not validate the real weight of the materials in the buildings. A potential future study to confirm the element material weight is needed to understand how close to reality the current database upholds. Also, the assumption regarding the material intensity coefficient for buildings in 2010 is the same as in 2000 and this may not be true and needs to be studied in the future. The same could be said about the number of elements where assumptions were made regarding the number of windows for each floor and the number of external walls. The quantity of external walls in the database is seen as a monolithic shape around the building, the reason for this is mainly because most buildings have 4 or several external walls which could not be found. All the assumptions made could be studied in future work and help to refine and expand the database.

In the study the demolition prediction of the residential building in Gothenburg was also done assuming end of life of 96 years for the multi residential building and 102 years for the single family. This allowed to map the period to analyse demolition between 1986-2112 as well as area or more precisely the location of house that will be demolished over the time. Being informed about the time and location would allow possibility to analyse the material flow, available material stock as well as assist in aspects such as symbiosis, waste management and so on during the projected time of demolition. The result project that 10245 number of the buildings both single and multi-family residential building will be demolished in 2072 and 432277659 kg of concrete will be available. Similarly, 2072 will have a total of 74052 windows available from this demolition. This documentation of information along with mapping can assist all the stakeholders such as policy makers, contractors, researchers, owner to manage the demolition properly while allowing to deal with unknown unknowns efficiently. One of the interesting aspects while analysing the demolition result was that though there were highest number of potential demolitions is projected in 2072, the amount of concrete that results from the demolition in 2072 is less than that of 2066 which amounts to 568966435 kg. This reflects that only having higher number of demolitions does not determine the quantity of material and the quantity depends on what and when the building was made from during start of life.

In the future construction scenario, the study presented the possible construction of residential building between 2035-2050 in and around central Gothenburg in five sections as per the city's development plan. The results presented the total amount materials (wood, metal, concrete and brick) as well as number of elements (roof, window, bottom slab and external wall) that will be required for construction of different residential building in these five different sections. The result tables provide information on the quantity of different materials and elements available within different radius (0-5km) from the centre of the selected sections that could be used for mining while constructing the new buildings in the city. The study doesn't exceed the furthest maximum radius of 5km while finding the source of material from nearby building. If the available material is less than required material within 5km radius we have concluded that the deficit material for future construction should be covered by procuring it from external source. From the above results the section 2 required most material followed by section 1, 5, 3 and 4. Similarly, element that was required the most during construction of new sections in the city were windows. Section 1 had most of the element requirements for windows, followed by 5, 2, 3 and 4. The number of external walls, bottom slab and roof were equally distributed among the buildings in respect to quantity of the buildings for each section.

The distance within which different material are available plays a key role in the circular strategy while also meeting the supply and demand over the years. The study investigates varied distance presented as radius from selected section for different elements and materials. It could be seen in section 1 that the demand of the wood or window could be addressed within the radius of 2km from the centre whereas other material and elements demand cannot be met within 2 km, so the search radius has been expanded to 5km. Similarly, for section 2 the amount of metal and roof required can be found within 2km radius in section 2 whereas other elements and materials are only found in 5km radius. Similar, variation in distance can be seen for section 3,4 and 5. It can be underscored that varied materials and elements will be available in various locations and are not concentrated in single area. This comprehensive knowledge of distance assists in planning and implementing circular economy strategies accordingly.

Finally, the overall process of transiting out of the linear process requires a strong collective input from various stakeholders without curtailing constant evolution. Currently, most of the cities over the globe has a conventional linear economy with focus on usage of product with single life and immediate usage. The cities also don't have an integrated process of data collection of the resources as well as overall system which is also the main hinderance when transiting to circular economy. Nevertheless, the current study provides an opportunity by exploring the avenue of quantifying the material in current urban system and pivots towards making residential development in days to come more sustainable. The study adopts to CE strategy of reuse and recycling of construction material from a residential housing ensuring readiness, autonomy, and resilience as well as long term sustainability both economically and environmentally. It also uses of technology as an important tool for creating circularity while paving the map for the way out of linearity by presenting the requirement and availability in different sections of future construction.

6. Limitations

It is important to note that the study only focuses on quantitative analysis of the material and elements but the whole scope of quality as well as regulation regarding the material recycle and reuse is an unexplored avenue of the study.

While making calculation of the materials available in the building, it is important to understand that the materials incorporated into the studies does not include all materials for each element and there are only four elements that accounts to be in a residential building. The reason for this is because of the lack of information provided regarding material composition for some construction years and material.

As the study could not find the end of life for the buildings in Sweden, the current result for demolition is based on demolition curve from previous study conducted in Manchester, UK due to the geographical proximity with Gothenburg. It has been assumed the demolition in Gothenburg will occur in 96 and 102 years for multi and single-family residential building. It is important to note that this might not be the precise number for end of life and the demolition curve must be analysed and studied further to get the precise number.

While analysing the future construction scenario one of the limitations was that there was no direct data available that indicated how many buildings will be in the new locations or the selected sections while going through the available documents. Neither the detail plan provided this information nor did the city planning council. Hence, to calculate the number of buildings that would be constructed in these 5 selected sections, it was necessary to take an approximate house to land area samples from different areas, in the study referred as the building factor. Hence, it was not possible to predict accurate estimate of the number of prospective residential structures that each section could have.

The study only analyses four elements within a residential building and four materials associated with it. It is important to note that a residential structure does not only have four elements but a lot more. Due to time constrain, the study had to limit the number of elements and material. Hence, for a more realistic analysis the study needs to be done thoroughly for all material and elements.

7. Conclusion

The study identified the current material stock for the single and multi-residential buildings are as follows; wood 997468813 kg, brick 3034773250 kg, concrete 2387907151 kg, metal 155819271 kg. For the quantity of elements for buildings in the construction year 1890-2010 are as followed; 56755 roofs, 56755 external walls, 56755 bottom slabs and 520572 windows.

The number of buildings being demolished in the future will change over time depending on construction year and residential type. As mentioned in the study, an assumption was made for the end of life of multi-residential households to be 96 years and single residential houses to be 102 years. The sum of demolished buildings in the future between the years 1986-2112 are 56755 number of buildings.

The result from material database and demolition prediction helped in analysing the future construction and available material for possible construction between 2035-2050. The year 2035-2050 is the duration in which the future development plan of city of Gothenburg aims to build residential houses. This information allowed to quantify the amount of material available as well as required in near future. The usage of tool such as GIS assisted in identifying the current location, area where the materials are present. It aids in identifying locations of building where the material will be available. The study has also presented the range of distance where the materials and elements will be available for different sections. The distance from the future development sector to the buildings that will be demolished was to analyse if the demand for future construction could be met or not within the range of 0-5km radius. The goal is also to use buildings as urban mine from which the material as well as element can be mined to recycle or reused during future construction.

One of the major hurdles within the CE strategy is lack of data, the comprehensive database developed for residential building of Gothenburg could be a steppingstone towards initiation of recycle and reuse of construction material during the future construction. The study shows that not having a proper data can produce an imprecise result. The result also allows to have a quantified number of materials as well as elements. This requirement and availability allow the possibility of symbiotic relation through sustainable consumption while reducing the waste by looping the required stock back into the system without compromising the growth effort.

In conclusion the result from the study clearly shows that there is material availability in city of Gothenburg and possibility of circular use through recycle and reuse is very pragmatic approach for future construction between 2035-2050. Hence, with proper involvement of all stakeholders reinforced with technical tools the transition into circular process in a residential building construction will be possible.

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9. Appendices

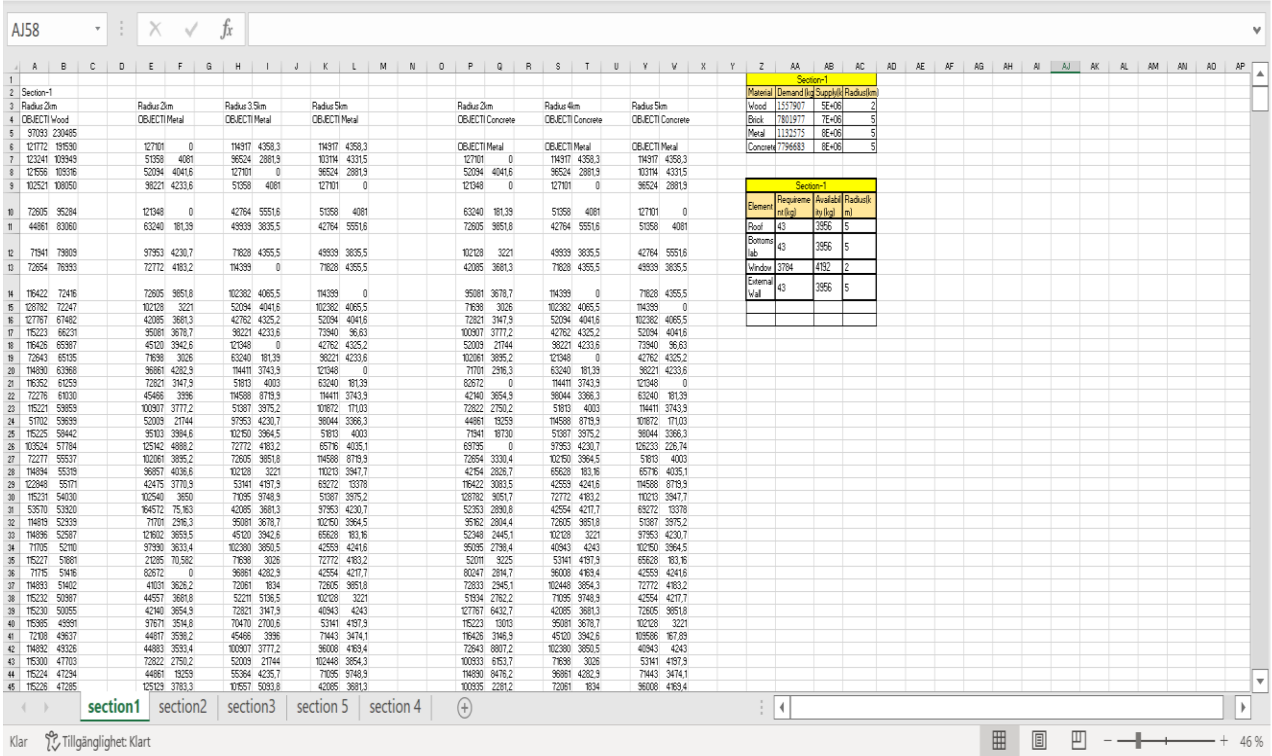
APPENDIX I

Table: Data Sources used in the study.

Data	Source	Description
Material Intensity Coefficeint	2018 Material-intensity database of residential buildings A case-study of Sweden in the international context (1).pdf	The excel database contained information of different Single family MIC ,multifamily MIC, construction age,
Building.shp	Landmäteriet	GIS,FILE
Fastighetskartan utdrag	Landmäteriet: Fastighetsuttag 50A (2).pdf	Different types of building from where we choose residential ones
GIS File with Heights	Landmäteriet	File with building Heights
Future Developments	City of Gothenburg (SBK)	Future construction of buildings between 2035-2050

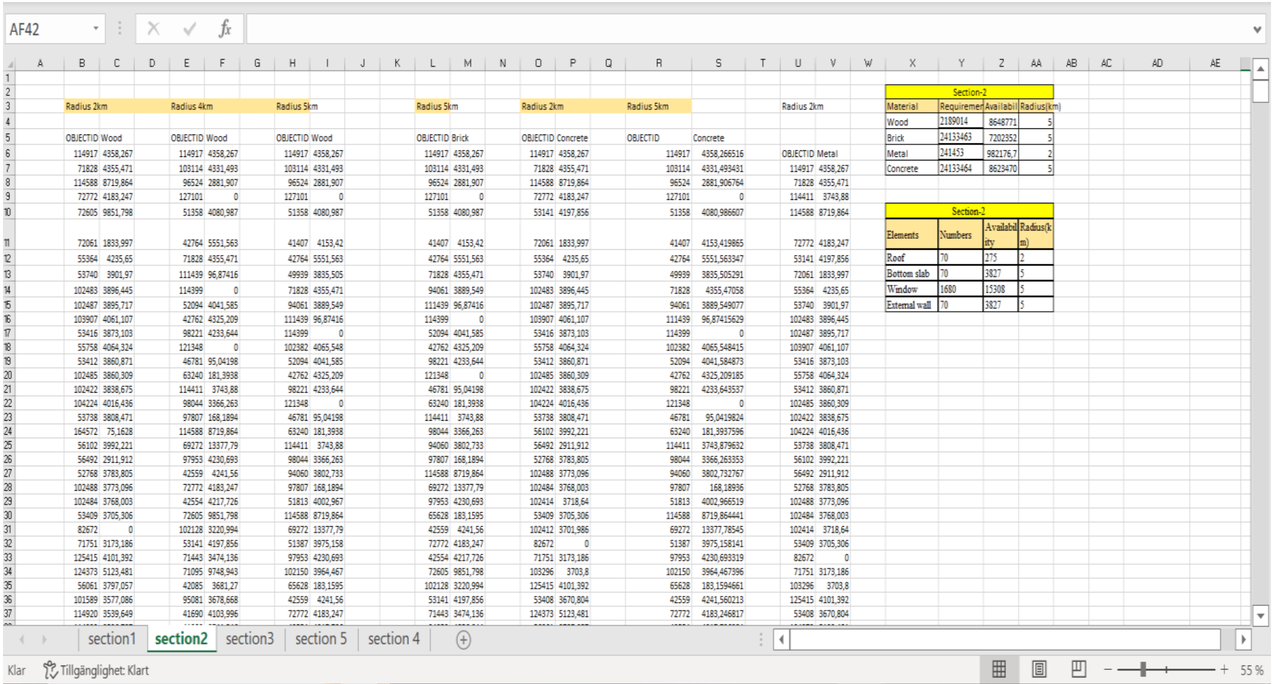
APPENDIX II

Calculation of materials and elements for different sections for future construction scenario.



Section-1			
Material	Demand (kg	Supply(k	Radius(km)
Wood	1557907	5E+06	2
Brick	7801977	7E+06	5
Metal	1132575	8E+06	5
Concrete	7796683	8E+06	5

Section-1			
Element	Requirement (kg)	Availability (kg)	Radius(km)
Roof	43	3956	5
Bottomslab	43	3956	5
Window	3784	4192	2
External Wall	43	3956	5



Section-2			
Material	Requiremen	Availabil	Radius(km)
Wood	2189014	8648771	5
Brick	24133463	7202352	5
Metal	241453	982176,7	2
Concrete	24133464	8623470	5

Section-2			
Elements	Numbers	Availability	Radius(km)
Roof	70	275	2
Bottom slab	70	3827	5
Window	1680	15308	5
External wall	70	3827	5

	A	B	D	E	H	I	K	L
1	Radius 2km		Radius 4km		Radius 2km		Radius 1.5km	
2	OBJECTID	Bricks	OBJECTID	Bricks	OBJECTID	Metal	OBJECTID	Metal
3	114917	4358,27	114917	4358,27	114917	4358,27	114588	8719,86
4	71828	4355,47	103114	4331,49	127101	0	72772	4183,25
5	63240	181,394	96524	2881,91	71828	4355,47	72061	1834
6	114588	8719,86	127101	0	63240	181,394	164572	75,1628
7	72772	4183,25	51358	4080,99	114588	8719,86	79945	3449,33
8	72605	9851,8	49939	3835,51	72772	4183,25	72449	3356,91
9	72061	1834	71828	4355,47	72605	9851,8	114270	13295,7
10	55364	4235,65	114399	0	72061	1834	125035	2871,41
11	103907	4061,11	52094	4041,58	55364	4235,65	125034	2772,22
12	55758	4064,32	98221	4233,64	103907	4061,11	114589	9364,93
13	104224	4016,44	121348	0	55758	4064,32	121896	2740,96
14	164572	75,1628	63240	181,394	104224	4016,44	114275	2721,01
15	56102	3992,22	114411	3743,88	164572	75,1628	114274	2690,98
16	56492	2911,91	98044	3366,26	56102	3992,22	122268	13796,6
17	52768	3783,81	114588	8719,86	56492	2911,91	72450	2478,3
18	21285	70,5824	69272	13377,8	52768	3783,81	114269	10424
19	71751	3173,19	97953	4230,69	21285	70,5824	6674	7601,38
20	125415	4101,39	65628	183,159	71751	3173,19	124890	0
21	124373	5123,48	72772	4183,25	125415	4101,39	122033	2097,16
22	56061	3797,06	72605	9851,8	124373	5123,48	72781	11706,9
23	101589	3577,09	102128	3220,99	56061	3797,06	114516	7373,3
24	101593	3573,12	53141	4197,86	101589	3577,09	72059	1911,9
25	52707	3563,16	71095	9748,94	101593	3573,12	72793	4434,92
26	52701	3539,34	42085	3681,27	52707	3563,16	72451	1798,69
27	52705	3547,63	95081	3678,67	52701	3539,34	114276	4640,39
28	52690	3518,82	41690	4104	52705	3547,63	48548	5787,13
29	101592	3496,23	45120	3942,55	52690	3518,82	114278	6778,57
30	79945	3449,33	71698	3026,03	101592	3496,23	72058	4101,46
31	102494	3479,63	96861	4282,93	79945	3449,33	72855	1588,15

Section-3			
Material	Requirement	Availability	Radius(km)
Wood	124288	123800	2
Brick	804343	879806	2
Metal	39103	271629	1.5
Concrete	7346596	0	0

Section-3			
Element	Requirement	Availability	Radius(km)
Roof	90	90	1.5
Bottom slab	90	320	2
Window	720	5120	2
External Wall	90	320	2

Section-4			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	41911	111749	0.8
Brick	296758	0	0
Metal	15176	51670	0.8
Concrete	636513	0	0

Section-4			
Element	Requirement	Availability	Radius(km)
Roof	27	40	0.8
Bottom slab	27	40	0.8
Window	432	640	0.8
External Wall	27	40	0.8

G	H	J	K	M	N
Radius 1km		radius 800mts			
OBJECTID	Metal	OBJECTID	Metal	OBJECTID	Wood
55364	4235,65	55364	4235,65	55364	4235,65
103907	4061,107	104224	4016,436	103907	4061,107
55758	4064,324	56102	3992,221	55758	4064,324
104224	4016,436	56174	3628,142	104224	4016,436
164572	75,1628	104219	3506,586	56102	3992,221
56102	3992,221	55729	111,1318	56492	2911,912
56492	2911,912	104220	2957,523	125415	4101,392
52768	3783,805	104222	2921,626	56061	3797,057
125415	4101,392	56176	2880,806	56174	3628,142
56061	3797,057	56175	2882,327	104219	3506,586
56174	3628,142	104208	2836,625	103913	3305,511
104219	3506,586	56514	2509,528	55729	111,1318
104895	3357,197	104223	2803,052	104220	2957,523
103913	3305,511	104602	2165,351	56405	2939,997
55729	111,1318	125855	371,1387	104222	2921,626
125034	2772,215	56513	250,7734	56176	2880,806
56064	2958,075	104599	241,8287	56175	2882,327
104220	2957,523	110872	223,5413	56080	2874,149
56405	2939,997	57658	213,9299	55442	2863,402
104222	2921,626	126442	218,22	103914	2860,579
56176	2880,806	125854	214,0107	104208	2836,625
56175	2882,327	56099	188,319	104896	2839,065
56080	2874,149	120915	188,4752	56065	2794,117
55442	2863,402	108887	180,157	103916	2698,976
103914	2860,579	64499	186,7389	56514	2509,528
104208	2836,625	57587	177,8882	104223	2803,052
104896	2839,065	104094	264,691	104602	2165,351
56065	2794,117	55534	144,3808	104091	16938,23
103916	2698,976	56434	144,149	125855	371,1387
56514	2509,528	103108	220,2779	104218	264,4885
104223	2803,052	55756	137,3839	81401	261,6233

Section-5			
Material	Requirement (kg)	Availability (kg)	Radius(km)
Wood	1388774	9576	0.4
Brick	1318925	867785	0.35
Metal	16124	28135	0.35
Concrete	2493101	0	0

Section-5			
Element	Requirement	Availability	Radius(km)
Roof	120	145	0.35
Bottom slab	120	145	0.4
Window	2880	512	0.4
External Wall	120	145	0.4

G	H	J	K	O	P	R	S
Radius 0.5 km		radius 0.4		radius 0.4		0,35	
OBJECTID	Wood	OBJECTID	wood	OBJECTID	Metal	OBJECTID	Metal
56369	3980,419	56005	162,2646	56369	3980,419	56369	3980,419
56005	162,2646	55468	284,2025	56005	162,2646	56005	162,2646
81991	3848,503	54245	298,7423	81991	3848,503	81991	3848,503
103931	160,9662	102708	195,8905	103931	160,9662	55201	3605,51
104640	160,3693	56022	287,9031	53738	3808,471	53407	3038,351
79756	3779,933	126938	182,8284	104640	160,3693	125859	2870,401
55201	3605,51	103265	177,2854	79756	3779,933	55195	2637,928
102412	3701,986	56083	244,9516	55201	3605,51	54399	2209,669
53408	3670,804	56006	239,6051	102414	3718,64	55468	284,2025
103330	3663,491	102810	233,82	102412	3701,986	54245	298,7423
104149	3384,907	78581	233,7951	53408	3670,804	102708	195,8905
56365	3460,978	56397	228,3498	103330	3663,491	56022	287,9031
103335	3448,678	56030	140,2548	56362	3575,52	126938	182,8284
103266	3445,966	56081	221,2123	103332	3463,386	103265	177,2854
56146	3286,507	54163	138,1569	56365	3460,978	56083	244,9516
54509	3425,988	56009	219,6604	103335	3448,678	56006	239,6051
55200	3312,04	56019	204,2523	103266	3445,966	102810	233,82
104443	3190,258	57581	184,9897	54509	3425,988	78581	233,7951
80064	3121,615	104310	163,9338	55200	3312,04	56397	228,3498
102413	3085,815	55683	163,4593	80064	3121,615	56030	140,2548
102420	3065,121	126710	163,2533	102413	3085,815	56081	221,2123
55190	3456,982	56672	163,0822	102420	3065,121	54163	138,1569
103023	2881,872	104308	162,8351	55190	3456,982	56009	219,6604
103327	2874,585	104013	162,5069	103023	2881,872	56019	204,2523
102114	2851,762	102807	161,9078	103327	2874,585	57581	184,9897
53407	3038,351	55688	161,2959	56371	2870,602	104310	163,9338
57143	3059,922	56003	160,5832	102114	2851,762	55683	163,4593
57496	3053,032	126711	160,4131	53407	3038,351	126710	163,2533
57216	3048,899	55678	159,4759	57143	3059,922	56672	163,0822

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
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