Closed loop reuse in renovation projects

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Abstract

Renovating post-war social housing poses significant challenges and opportunities for sustainable construction. The reuse and recycling of building materials are essential to achieving a circular economy in the construction sector, which accounts for a significant share of materials consumption. In a case study of a gallery flat in Amsterdam, a materials analysis is made that shows the quality and potential ways of harvesting and reuse in renovation projects. This case is representative of a large number of social housing projects built in the 1960s. The concrete structure of these 1960s social housing buildings is of good quality and remains suitable for continued use. The facades mostly consists of bricks, windows, and panels, and have an insufficient thermal quality. In a renovation project, insulation will need to be improved. Brick masonry walls can be dismantled through off-site separation processes or by cutting the panels. Windows, doors, and panels are mostly secured by wooden frames and are relatively easy to remove without causing damage. Extra care should be taken when inspecting the sandwich panels for asbestos, as it was commonly used in building materials during the 1960s. The interior walls, made of lime-sand bricks and gypsum, should be carefully dismantled to avoid contamination, allowing for a higher recycling rate of the lime-sand bricks and gypsum. Besides the main materials, the repetitive design of the dwellings in these gallery flats results in a relatively large quantity of materials with similar properties. This consistency means that identical toilets, sinks, doors, and other fixtures have been used, making the design more efficient as the dimensions remain uniform. Overall it is important that reimplemented materials should be detachable to make sure that the material can be retrieved easily without damaging in the future. Renovating 1960s housing stock in the Netherlands, while integrating additional dwellings made from reclaimed materials, addresses housing shortages and environmental goals. This approach highlights the potential for circular building practices to reduce waste, promote resource efficiency, and transform renovation projects into models of sustainability.

Keywords: *Renovation, reuse, circular economy, 1960s social housing*

I. Introduction

By 2050, the circular economy must be fully integrated into society. The construction sector is responsible for a significant portion of material consumption, 50% of the raw material consumption and approximately 40% of the country's total waste is tied to the construction sector. (Ministerie van I&M & Ministerie van EZ, 2016). Achieving the goals of the circular economy requires a strong emphasis in the construction industry on reusing materials and, even more importantly, repurposing existing buildings.
Simultaneously, there is a pressing demand for housing, necessitating the creation of new dwellings within existing structures, utilizing reclaimed materials wherever possible. In the Netherlands, a substantial portion of the housing stock was constructed during the 1960s. These post-war social housings are now in urgent need of renovation (Havinga et al., 2020). A large share of construction waste comes from post-war housings between 1945 and 1970 (EIB and Metabolic, 2020). This shows both the urge as potential for controlling waste flows and reuse of building materials of renovation projects. Renovating post-war social housings with the focus on the reuse of the present materials while adding new housings offers a sustainable and innovative solution to address housing shortages and advance environmental objectives.

II. METHOD

In this research, a representative 1960s galleryflat *(Dutch: 'gallerijflat')* is selected as a case study for conducting a material analysis to determine the reusability of the typical materials of a galleryflat. The analysis starts with an inventory of present materials and its qualities. Hereafter the ways of demounting these materials and the quality after harvesting will be determined. Lastly, potential ways of reuse will be presented.

The inventory is conducted on archival drawings. Based on original drawings of the chosen building block the building is remodelled in 3D, whereafter the total volume and surface of every material can be retrieved out of the 3D model. The quality of these materials will be addressed to determine if the material needs to be removed or repaired or if they can be maintained. This will be done on existing literature and provided information by the contractor of the renovation project.

The possible ways of demounting the buildings materials will be addressed through existing examples and literature research. The quality of the materials after harvesting will be addressed to determine if the material can be maintained, directly reused, upgraded on site or transformed off site.

The last part of the material flow analysis will be the potential reuse of materials. Existing ways of reusing these materials will be discussed and compared based on literature and case examples.

III. RESULTS

3.1 Case introduction

The chosen case study is a stamp of gallery flats build in 1967 in the Klipperbuurt in Amsterdam. The Klipperbuurt includes the streets Tjalkstraat, Banne Buikslootlaan, Klipperstraat, Viermasterstraat, Lichterstraat, and Dekschuitstraat. Spread across 11 building blocks, the Klipperbuurt contains 577 dwellings. The buildings of the Klipperbuurt have similar floorplans, and consist of two, three or five repeated 'stamps'. The buildings have a closed plinth with storage space and garage boxes, interspersed with few dwellings. On top of this are four floors consisting out of dwellings, accessible through a gallery.

These buildings are in need of thorough renovation. In addition to renovation, there are plans of adding extra dwellings on top of the buildings, improving the plinths and building new apartment flats. Since 1967, the building only has been renovated once in 2009, this renovation only contained the replacement of the prefabricated concrete consoles underneath the gallery and balconies.

This case represents a typical example of the large number of apartment buildings constructed during the same period. For example, in the Amsterdam Western Garden Cities approximately 21.700 dwellings in the Western Garden Cities consist of this 'slab blocks' typology. 63% of these have a height a 5 layers, the same height as the case of the Klipperbuurt. (Havinga et al., 2020). Across the Netherlands, in 1,012 early post-war neighbourhoods, at least 650 homes were constructed between 1945 and 1970. Of these, 354 neighbourhoods had more than 50 percent of their housing stock built during this period (Argiolu et al., 2008). The spread and amount of post-war neighbourhoods and the share of the 'slab block' typology show the relevancy of both this research as the choice of the case study.

The representability and the need for renovation make the Klipperbuurt a relevant case for this research. With the analysis of the materials of this case and its potential reuse, a general overview of reusability in similar renovation projects can be obtained.

3.1 Concrete

Concrete is the most commonly used material in social housing of the 1960s, the material serves the purpose of main structure. The floors and structural walls of the case of the Klipperbuurt are constructed from cast-in-situ concrete, while the balconies and gallery consist of prefabricated concrete. In total, approximately 820 cubic meters of concrete have been used, comprising 67% of the building's total volume. Around 680 cubic meters is cast-in-situ concrete, the remaining 140 cubic meters is precast concrete.
The building's concrete structure remains in good condition. Furthermore, the extensive structural walls provide sufficient support for additional construction on top of the building. Current plans propose adding one level, though further research is ongoing. (Gemeente Amsterdam, 2024)
Considering the good condition of the concrete structure there is no need for demounting or demolishing. Moreover, it is hard to demount the static property of the cast is situ concrete without damaging them (Dolkemade, 2018). This makes it unfeasible to remove or demount the concrete structure.

Prefabricated concrete slabs and consoles demonstrate greater ease of disassembly than cast-in-situ concrete. In 2009, the prefabricated concrete consoles— the beams supporting galleries and balconies—were replaced due to material degradation over time. Without maintenance, these consoles had a lifespan of 42 years, indicating that the new consoles could be expected to last until 2050. An extension of the lifespan is feasible with proper maintenance, and it is likely that the longevity and performance of modern consoles have improved compared to those installed in 1967. Regardless, the quality of the concrete consoles remains sufficient for continued use within the structure.
The performance of the prefabricated concrete slabs supported by the consoles remains satisfactory, meaning there is limited need for replacement. The concrete slabs measuring 2800 and 3800 mm in length and 1500 mm in width could practically be repurposed as flooring or wall elements. However, if replacement is desired, it could potentially be carried out relatively easily and reused effectively. Careful attention is needed by examining these slabs, as literature and degradation models for concrete and steel corrosion stated that cracking and relative humidity have major influence for the degradation and service-life of concrete slabs. (Suchorzewskia, 2023)

Various ways of demounting and reusing concrete has been researched (*Küpfer, 2022)*. However, the actual reuse of concrete components is lacking compared to the identified and rich diversity of feasible applications. (*Küpfer, 2022).* In this research 77 existing cases where compared. Most of them reused the various types of precast components for equivalent reuse, meaning that the dismantled components where reused for the same function without resizing or major changes in the assembly system. In some cases, a different use was found for the demounted material, for example to stabilise the floor or to use in the foundation. (*Küpfer, 2022).*
The reuse of prefabricated slabs saves much energy compared to using new concrete slabs and it saves up to 55% of CO_2 emissions (Nunen, 1999). However, compared to maintaining the concrete in the original structure and compared to more sustainable materials, the reuse of prefabricated slabs releases more emissions.
Besides CO_2 emissions, the weight of the concrete limits their feasibility for use in new floors due to structural constraints of the existing structure. The choice of light materials such as wood in the new extension of the building is more practical than the reuse of concrete slabs.

Cast-in-situ concrete -compared to precast concrete- is more challenging to demount since it has cast joints. To demount these structures, a concrete saw is needed to cut the concrete. Drilling or demolishing concrete is also an option, but recycling the rubble results in lower-quality applications compared to reusing intact components that retain the similar performance as the original concrete. Reusing cast-in-situ floor slabs may have limited capacity regarding fire resistance, a limited load bearing capacity and a limited available span, depending on its quality. (Dolkemade, 2018). This makes the use of retrieved concrete only feasible to extend the lifespan when its building is being demounted or demolished.

Cutting concrete slabs with the intention to reuse the component of the renovated building is not very feasible, however it could be beneficial for spatial qualities of the building.
Choices to cut into the walls or floors to connect and diversify the dwelling types can be made but must be made very carefully. Connecting vertically requires drastic structural changes and at least an extra 6 square meters is used for circulation space (Battum, 2002). This makes vertically connecting the dwellings within the current structure impractical. It is more feasible to connect dwellings horizontally by cutting through the walls due to the minimal space required for creating a doorway in a structural wall and due to less drastic structural changes. In this particular case, the relatively high number of structural walls could help distribute the load, mitigating the impact of these minor interventions. However, if the aim is to add an extra layer on top of the existing structure, it is best to limit these interventions in the maintaining structure.

Another scale of cutting and demounting cast-in-situ concrete is by cutting large parts of apartments, while leaving the connections between the floors, walls and ceiling. In the project Superlocal in Kerkrade, parts of the concrete structure from an apartment flat were cut, split, and then extracted to make a new building to save the material from demolition (Superlocal, 2021). The cost of extracting 20 dwellings in this way is 186.000,- excl. VAT, with the cost decreasing when more dwellings are extracted. Moreover, the evaluation from this project states that the possibilities of cutting even bigger components is being researched, which could lead to more saved energy and costs (Bremen Bouwadviseurs).

The quality of the concrete in most gallery flats allows for extended use. Moreover, the relatively high number of structural walls enables the support of additional weight, meaning that extra layers could be added. Besides the good quality, demounting cast-in-situ poses great difficulties because of the cast joints which causes a decrease of the performance of the concrete when cut. This makes demounting a well-performing concrete structure in a renovation project very unfeasible.
There is also little need to dismantle prefabricated slabs, as they are in good condition, and dismantling could result in decreased performance. However, the replacement of the consoles in the Klipperbuurt show the importance of maintenance and quality checks. If replacement of the prefabricated concrete is necessary, it is impractical to reuse it in load-bearing walls or floors due to its reduced performance. Moreover, reusing on higher floors is insufficient because of its weight and inflexibility.
By cutting large sections of the upper layer, the additional weight on the remaining structure will be reduced, potentially allowing for lighter layers to be added on top of the existing structure. However, this approach is more radical and requires high costs and complex logistics. Additionally, the quality and load-bearing performance of the remaining structure will require further in-depth research.

3.2 Bricks

After concrete, bricks is the second most common material in the building. They are primarily utilized on the ground floor and in the main staircase, bonded with hard-cement mortar. In total, approximately 175 cubic meters of bricks have been used, accounting for approximately 14% of the building's total volume.
The quality of the bricks are likely insufficient for structural purposes as reclaimed bricks are used as facade elements rather than loadbearing structures (Icibaci, 2019). Moreover, the bricks are primarily used as facade material and have no structural function. In addition to the structural qualities of reclaimed brick, its thermal performance is suboptimal. Insulation will need to be added if the bricks are to be maintained or reused as facade material for the dwellings. If the bricks are not frost resistant, they are only suitable for internal use. Some

difficulties in assessing the frost resistance occur as the consistency of the whole consignment of retrieved bricks cannot be fully known. With testing a sample of bricks there is not a complete overview of the performance of all present bricks. The same goes for strength and water absorption, although these characteristics are unlikely to limit the use of reclaimed brick. (Brick Development Association, 2023)

The bricks from this time period are connected with concrete mortar. Unlike lime mortar, used before the implementation of concrete mortar, concrete mortar is difficult to remove from the bricks. Ways of demounting bricks are thermal separation, vibrational rasping and cutting planes. (Braam, 2020)
With both thermal separation as vibrational rasping the walls are scraped off the building by an excavator and collected from the ground (Gustafsson, 2019). Hereafter the bricks need to be separated from each other and the mortar. At the process of thermal separation the chunks of bricks are transported to a processing plant where they are heated in a gas kiln at 540º C for approximately 3 hours (Van Dijk, 2004). The different expansion coefficient of cement mortar and brick breaks their bond at this temperature. In this process 40% of the harvested bricks can be retrieved.
With the process of vibrational rasping, the brick chunks are transported to a processing plant where high-frequency vibrations are used to break the bond between the bricks and mortar. (Goodsite & Juhola, 2017). 50% of the bricks can be retrieved through vibrational rasping.
A way of demounting a brick wall where the bricks do not become individually separated is to cut the existing masonry into panels. Panels of 1 square meter where cut out of the facade and reused in a project of the Lendager group (Gorgolewski, 2018). With this technique brick walls can be harvested more efficient because the bricks don't have to be separated individually. With cutting panels the efficiency depends on the desired size of the panels and the quality of the brick wall, but can be up to 90%.

The bricks retrieved through thermal separation and vibrational rasping need a connecting element to transform into a masonry wall. Unlike cement mortar, lime mortar has a weaker bond and is easy to separate from bricks. However, the lower drying time and vulnerability during the building process is a downside (KNB, 2018).
New techniques of building masonry walls are dry connections systems. Various systems have been developed that can be completely demounted from the brick. Five systems described by Braam (2020) are *Facadeclick, Fixbrick, Clickbrick, Drystack* and *LeeBrick.* All of these bricks are customised. Therefore the reused bricks need to be adjusted to be applicated in the dry systems. In the *Facadeclick and Fixbrick* these adjustments are made before baking and are not suitable for reused bricks. Also the *Clickbrick* and *Drystack* do not allow for reused bricks because the surface of the brick for these systems are very smooth and even. The *Drystack* system uses bricks where 8 holes are drilled into. Because this system allows for a relatively large tolerance in vertical directions, making it compensate for irregularities, the system might be applicable for reused bricks (Braam, 2020).
The brick panels that are directly cut from the masonry wall can be applied in new buildings secured through a concrete caste or a steel frame. The connection of the panel with concrete makes it again an inflexible system that is hard to demount. Moreover, the use of new concrete to secure these panels only have a 8% smaller emission. The steel frames seem to be more easy to demount, although they are not yet used in practise (Braam, 2020).

If brick facades will be maintained in a renovation project, insulation will have to be added to improve thermal qualities in the dwellings. If the bricks are removed, they can either be separated off-site using thermal separation or vibrational rasping, or they can be removed intact by cutting panels. When reusing the bricks, it has to be implemented in an adaptable way, so that it can be demounted easily in the future. This is either by using lime mortar or the Drystack system as connection between the individual bricks or with the cut panels secured with steel frames.

3.3 Facade panels

The facades of the dwellings in 1960s housing often exists -apart from windows- of bricks or panels. Most facade panels are sandwich panels to improve insulation. The panels in the Klipperbuurt feature an insulating cork core of 20 mm thickness sandwiched between two layers of Glasal, creating a composite structure. Glasal panels were commonly used as exterior cladding and as material for doors and window frames and are often found in social housings of the 1960s. (Thijssen, 1999). These panels account for approximately 2% of the total building volume, comprising roughly 27 cubic meters. In this building, the panels are used on the facade of the gallery and balcony sides and are secured using wooden frames. Approximately 40% of these facades consist of Glasal sandwich panels.

Glasal is a brand name for a type of facade cladding characterized by their flat structure, smooth surface finish, and a range of colour variations. However, originally these panels were reinforced with asbestos. The use of asbestos was legally prohibited in 1993, making its reuse legally and practically impossible (Register, 2006). Because the high likeability of presence of asbestos, a professional should examine the sandwich panels.

Because the panels are secured with wooden frames it should not be difficult to demount them. This also goes for panels of a different material. In the case of presence of asbestos, demounting the panels is more safe than in other wet connections with asbestos.
If there is no asbestos found in the panels, the panels can be reused quite easily. The way of securing the panels with wooden frames means that the panels can be retrieved without degrading the material. The panels than can be recoated or painted to upgrade its aesthetical quality. If applied as facade cladding, insulation will have to be added. The material could also be used as interior walls as it is a relatively light and thin material. This allows for flexible reuse.

3.4 Interior walls

In the original drawings ‘Light building panels’ are being used as material for the interior walls. No further details were found regarding the materials these are made out of. These panels make up for 6 % of the total volume with a volume of 72 cubic meters. The hatching of the drawings - and the most likely used system in 19060s housing – seems to be of a wall build out of metal-stud or wooden frame with gypsum panels.

Gypsum boards are rarely reused. This is because the material often has holes for screws or other cuts that make the gypsum brittle. Moreover, gypsum is not a scarce and cheap material. That makes retrieving gypsum out of existing buildings relatively expensive (Duurzaam gebouwd, 2021).
Besides the quality and costs of retrieved gypsum panels, there are concerns about contamination from lead and asbestos due to the application of lead-based paint before 1978 and the use of asbestos in joint compounds (AWCI, 2022).
When demounting on a bigger scale the costs of retrieving gypsum can be similar to use of new gypsum boards. Knauf, market leader for gypsum in the building sector, states that around 10.000 square meters is viable, as they already reused panels from big projects (Duurzaam gebouwd, 2021). One building complex of the Klipperbuurt has too little gypsum boards, but all the buildings together might have enough to make a viable case. Practically this is challenging because of the phasing of renovation and (on site) storage.

The efficiency of recycling of gypsum is theoretically 100 percent. The Canadian company New West Gypsum Recycling already manages to achieve an 100% recycle efficiency (Gyproc, 2023). Companies in the Netherlands however, like Gyproc, are currently using 15% of recycled gypsum in the production of new gypsum. This is because the gypsum is often contaminated. When demounting gypsum it is important to sort the materials to prevent and limit contamination.

When reapplying (reused) gypsum, detachability is important. Without using screws or making other holes or cuts, the gypsum remains intact. In this way it can be demounted and reused easily in the future. Another point of improvement is the efficiency of using gypsum at new projects. According to the Association of Wall and Ceiling Industry 10% to 15% of gypsum board necessary for a new building ends up as scrap. This is because gypsum panels break up easily when not attached to framing or when they are not carefully stored and transported.
Damaged panels should be separated to prevent contamination and ensure they can be recycled. Retrieved panels must be stored carefully to avoid breakage. New and reused panels should be installed in a detachable manner to facilitate future disassembly and reuse.

3.5 Sand-lime brick

Sand-lime bricks (*Dutch: kalkzandsteen*) are mostly used on the ground floor in garages and storages. On the upper floors they are used as partition walls between the dwellings and in the stairwells. In total, 75 cubic meters of sand-lime bricks are used, making it 6 percent of the total building volume.
Sand-lime bricks have a long lifespan of 75 – 100 years (Vereniging Nederlands Kalkzandsteenplatform, 2022). The bricks of social housings build during the 1960s are often in good condition. On the upper floors and stairwells there is no need to replace the sand lime walls. On the ground floor however it might be beneficial to remove these walls to make space for dwellings, as now most buildings have a closed ground floor with garages and storages. This, however, is based on spatial quality rather than the quality of the material.

Reuse of sand-lime bricks is not common. Nonetheless, recycling of sand-lime bricks could in theory achieve a 100% efficiency. The actual efficiency is around 80 – 90 percent because of the contamination of the sand lime bricks during demolition. Producers of sand-lime bricks are looking for more optimal demolition techniques to achieve more clean granulate and a higher efficiency of recycling. (Milieudatabase, 2022)

3.6 Facade frames

The frames that secure the windows, doors and sandwich panels to the structure are made out of wood. In the drawing details '*hardhouten bevestigingslat'* and *'vuren glaslat'*. The frames that secure the facade fragments to the concrete structure are from hardwood, while the frames for the windows is made from spruce. The windows with aluminium frames can be opened, but are also secured with the wooden frames. The wooden frames amount to approximately 17 cubic meters, while the aluminium frames contribute 3 cubic meters. In the renovation plan the window frames will be replaced on the side of the gallery and upgraded on the side of the balcony.

The retrieved wooden frames can be reused easily. Wood is a light material that can be replaced and adjusted easily (Icibaci, 2019). This means that it could also be a good material to reuse in an added layer on top of the existing structure. The frames can be reused with the same function with upgrading it through sanding and painting. Because the quality of wood rarely decreases by adjustments, it can be sawed to adjust to other functions. If the wood will be used as façade material it should likely be treated to withstand weather conditions. The hardwood components have a better and more durable performance than the spruce components. External reuse of the spruce frames might be unfeasible if it requires too much maintenance.

Although wood is practically a material that is easy to demount and reuse, there is not yet an official way to certify used wood to be reused in the Netherlands (Icibaci,2019). There is also no official account regarding how much wood is reused in the Netherlands. Merl et al. (2007) conclude that there should be focused on standardizing classifications and definitions in Europe that support data collection and accurate comparison among cases.

Often, it is possible and efficient to harvest the frames altogether with the window or door. Examples of reused frames will be discussed at the chapters of windows and doors.

3.7 Windows

The glass windows of the building have an area of approximately 550 square meters. At the upper floors, 50% of the gallery and balconies facades are made out of glass. The thermal qualities of the windows that are originally installed during the 1960s do not match the required performance, so they will have to be removed.
Used glass is commercialized in limited amounts (Icibaci, 2019), mostly when already combined with window or doorframes. Single glass windows can not be reused as facade windows of dwellings because of its low thermal performance. However they can be reused for interior windows or at facades where there is no need for high isolation. Another possibility for the reuse of single glass windows is to use it as a second facade that makes up for the lack of thermal qualities.
Most gallery flats from the 1960s feature a large number of windows on the long sides of the building to provide enough natural light for the relatively small dwellings oriented with two opposing sides. The windows from a typical floor can be reused to create a second skin on one side of the building. Examples of single-glazed windows and frames being reused include: the BlueCity Offices, where they were reused internally; the Kamikatz Public House, which reused them externally with a double layer of window frames; and the Europe Building, which incorporated them as a second skin.

3.8 Doors

In total, there are 474 doors used in one building, an average of 14 doors per dwelling. In the current building economy, doors are abundant in the reuse market (Icibaci, 2018). This is partly because doors can be removed quickly and without damage. If retrieved doors have to be transported and reconditioned to desired sizes, it might be expensive compared to new low-cost doors in the market (Lazarus and Bioregional, 2002). However, in the 1960s social housings, the doors are predominantly the same size, and of course on the same location. This uniformity makes the design and implementation process possibly more efficient.
Upgrading by sanding and painting can be done on site if necessary. The most easy and straight forward reuse is to use them as doors again. Most efficient would be if the wooden frames and the doors are reused altogether. Apart from same-function reuse there are also examples of retrieved doors that were being applied as facade material.

3.9 Repetitive elements

The typical gallery flat from the 1960s consists of a repetitive dwelling floorplan. Moreover, there are often multiple identical or similar gallery flats in the same neighbourhood. The Klipperbuurt for example exists of 11 repeated blocks. This means that certain elements are used identically, with the same measurements. For example the kitchen, bathroom and toilet are identical -if they are still original or collectively replaced. This offers a more efficient design process for reuse as the dimensions of these products are uniform. Less time and effort might be needed to find -or make modifications to achieve- the same products with the same properties and measurements. The uniformity of these elements offer a more general solutions and implementations for reuse.

IV. CONCLUSION

The various materials used in a typical 1960s social housing project vary in quality, but most are suitable for reuse - or recycling. The good condition of the cast-in-situ concrete supports its continued use as the structural foundation of the renovated building. Demounting parts of this structure leads to lower performance for both retrieved as remaining concrete, making it unfeasible for reuse in a renovation project. The precast concrete slabs should be examined on cracks and damage but is highly likely to be in good condition as well. Demounting these slabs is easier than demounting cast-in-situ concrete but the weight and inflexibility of concrete makes it unviable for reuse.
More innovative solutions, such as cutting and reusing portions of the structure, are promising but incur high costs and complex logistics, and require further research.
Bricks present moderate reuse potential. The challenge of separating bricks bonded with cement mortar hinders their direct reuse. Individual reuse of bricks can be achieved through vibrational rasping or thermal separation, where cutting panels allow for reusing complete parts of the masonry wall.
Sand-limestones are generally in good conditions because of its high lifespan. Continued reuse thus is often possible. Direct reuse is rarely done, but efficient recycling is possible. Preventing contamination trough separation when demounting is essential to achieve a high recycle efficiency.
Gypsum too is rarely reused but is recycled with high efficiency. If carefully retrieved and stored, they could be reused. Otherwise it is essential to separate damaged panels to achieve a high recycle efficiency.
The reuse of the facade panels is prohibited if asbestos is present. Otherwise the light material allows for easy demounting and flexible reuse. The facade panels are secured by wooden frames which itself can be reused or adjusted. The wooden frames can also be reused while keeping the connection with the windows or doors intact. For windows, it is important that they can not be reused as single external layers for dwellings, as its insulation is lacking.
The repetitive design of the dwellings in these gallery flats not only result in a large amount of identical windows and doors but also result in a relatively large quantity of products or installations with similar properties. The consistency of the dwellings results in identical toilets, sinks, doors, and other fixtures, which allows for the development of general solutions and implementations for reuse rather than modifying each individual product.

Overall the detachability of every reused material is very important, in this way the material can be retrieved easily without damaging in the future. Designing and building for adaptability is an important step to achieve the circular building economy. Focusing on demountability, adaptability, and sustainable practices in the renovation of 1960s gallery flats can contribute to a more resource-efficient and environmentally responsible approach to construction.

V. DISCUSSION

This research is a global material analysis of an existing case. The quality assessment of every material can be conducted more precise, as now they are mostly assumptions. Apart from the assumed quality of the material the process of carefully demounting can be described and researched more in-depth. Also the possible ways of reusing the materials can be presented with more case studies. With a bigger variety of harvest methods and methods for reuse, these methods can be compared. With comparing every method, a valuation can be made to show the best way to reuse the materials and an general overview of gradations of possible reuses can be created.

Lastly, there are more materials in a building complex than addressed materials. The materials that were left unaddressed can be taken into account for new research, or a more inclusive categorisation of materials and applications can be applied.

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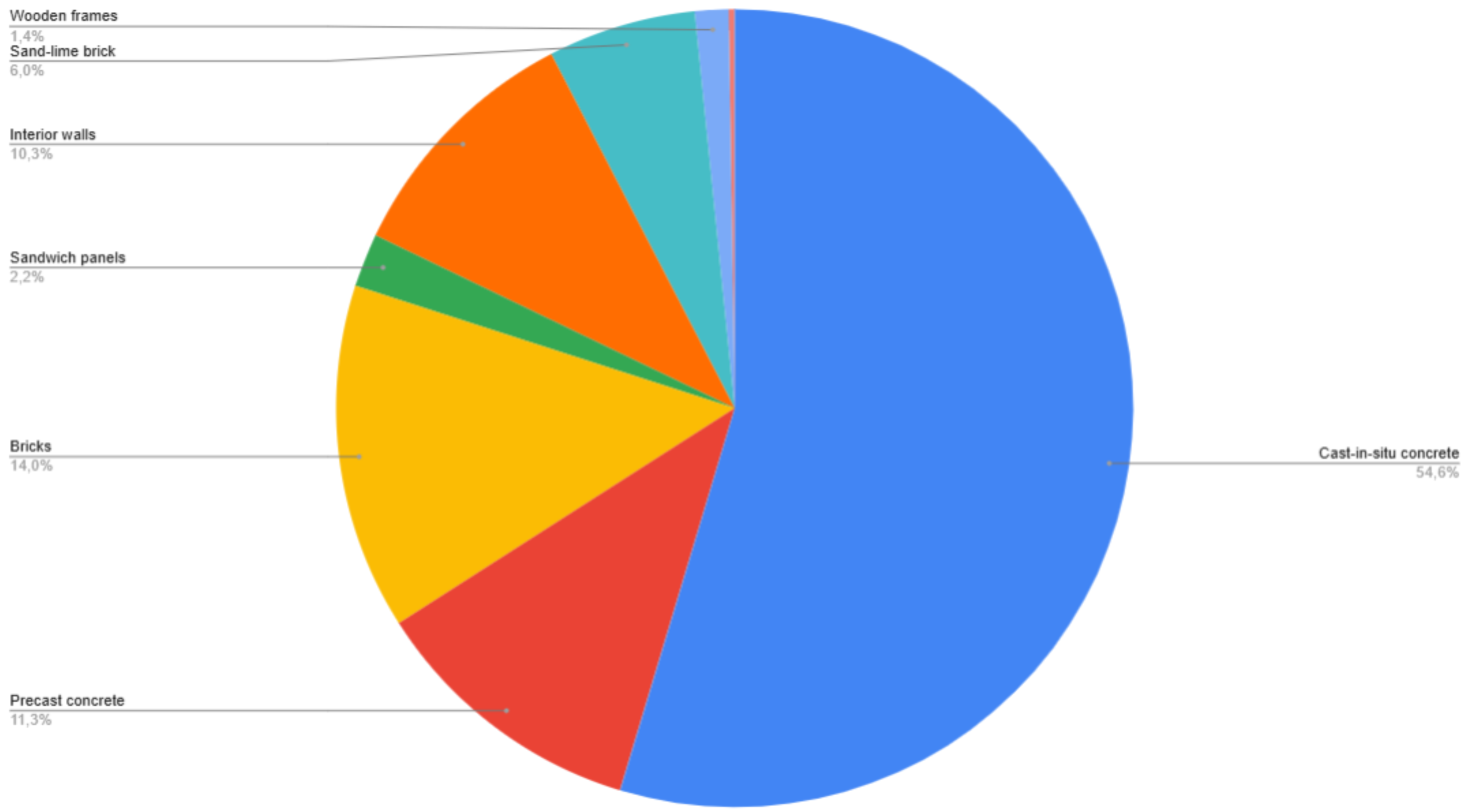
VII. Appendix

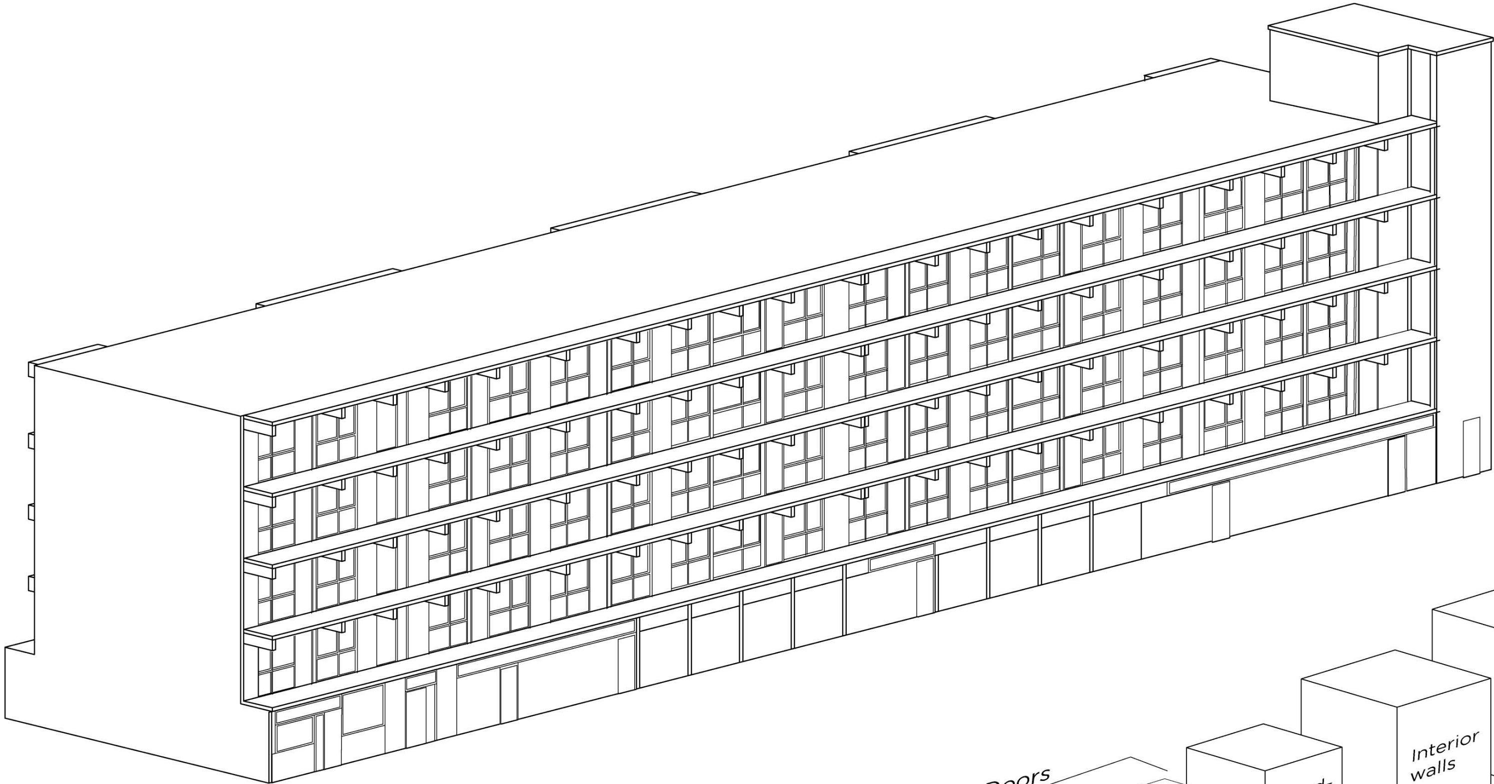
The table of materials consist of an overview of the volume, surface and amount of materials. This is retrieved from the 3D model based on archival drawing of one building. By dividing by 2 -the building consist of 2 repeated stamps- and multiplying by 33 -the total of these stamps- the total values are calculated. These values are global, as certain dimensions and materials are hard to retrieve out of the archival drawings. For example, the interior walls have a thickness of 7,5 cm but the material is unclear and the walls are likely hollow. This may result in distorted outcomes.

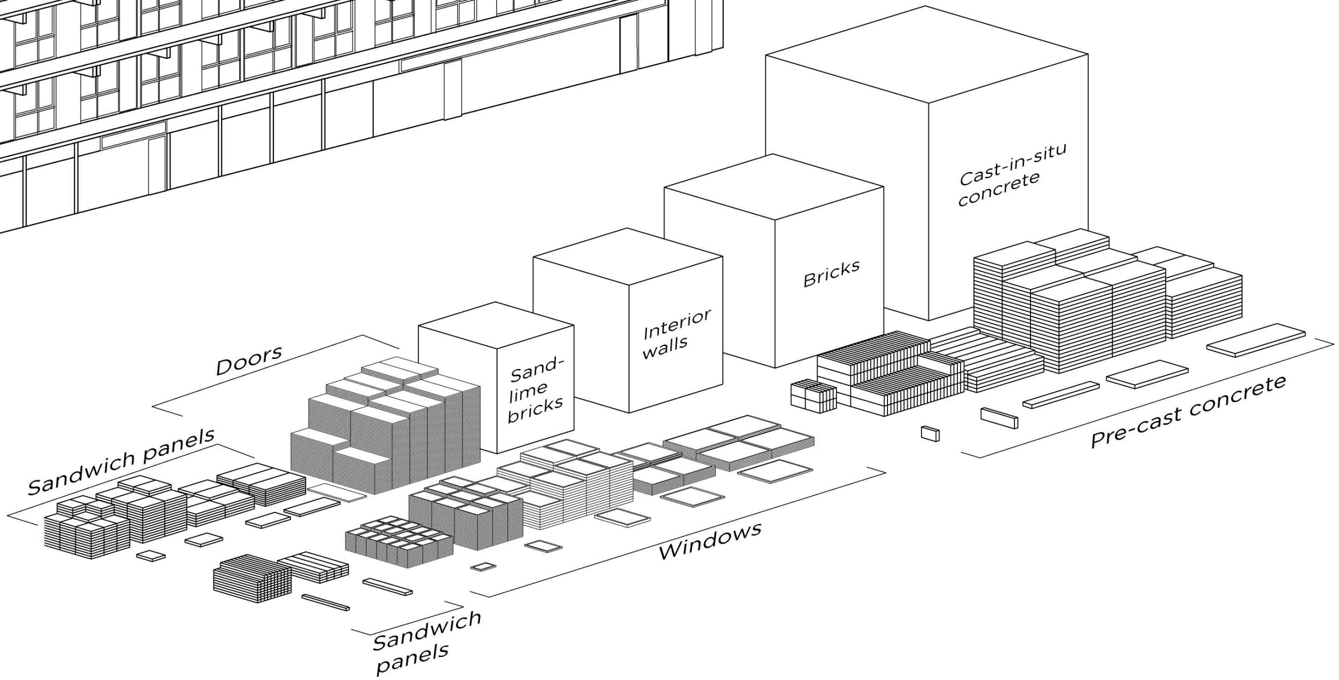
Materiaal	Volume 1 building (m^3)	Volume all buildings (m^3)	Facade surface 1 building (m^2)	# Facade Surface all buildings (m^2)	Amount 1 building	# Amount all buildings	Percentage total volume	Percentage total facade surface	Percentage surface typical facade
Cast-in-situ concrete	682	11248					54,59%		
Precast concrete	141	2334					11,33%		
Bricks	175	2881					13,98%		
Sandwich panels	27	446	502	8276			2,17%	22,62%	42,98%
Interior walls	128	2109					10,24%		
Sand-lime brick	75	1243					6,03%		
Wooden frames	17	288	175	2880			1,40%	7,87%	14,96%
Aluminium frames	3	56	68	1115			0,27%	3,05%	5,79%
Window			550	7425				24,81%	50,86%
Door					636	10494			
Total	1249	20606	2217	36584					

Table Building materials. Own work.



Piechart building materials



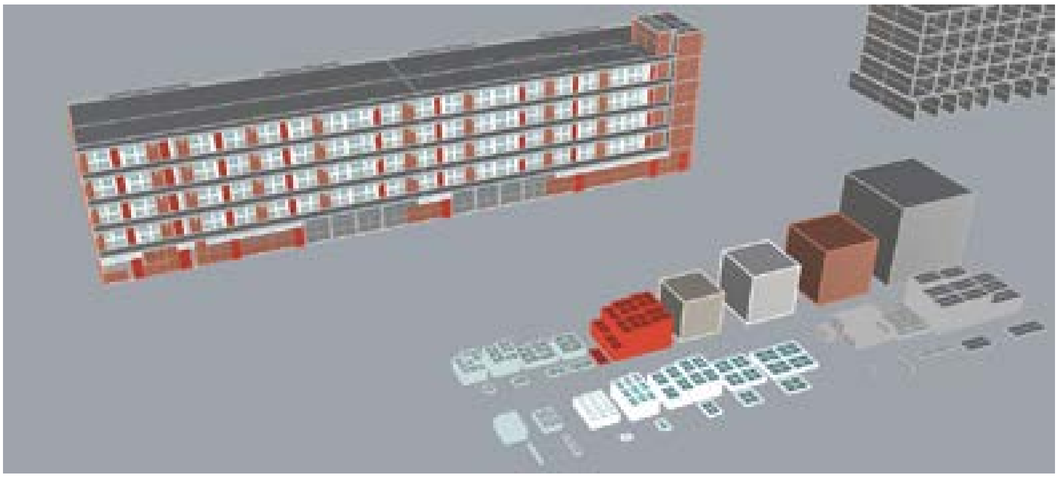


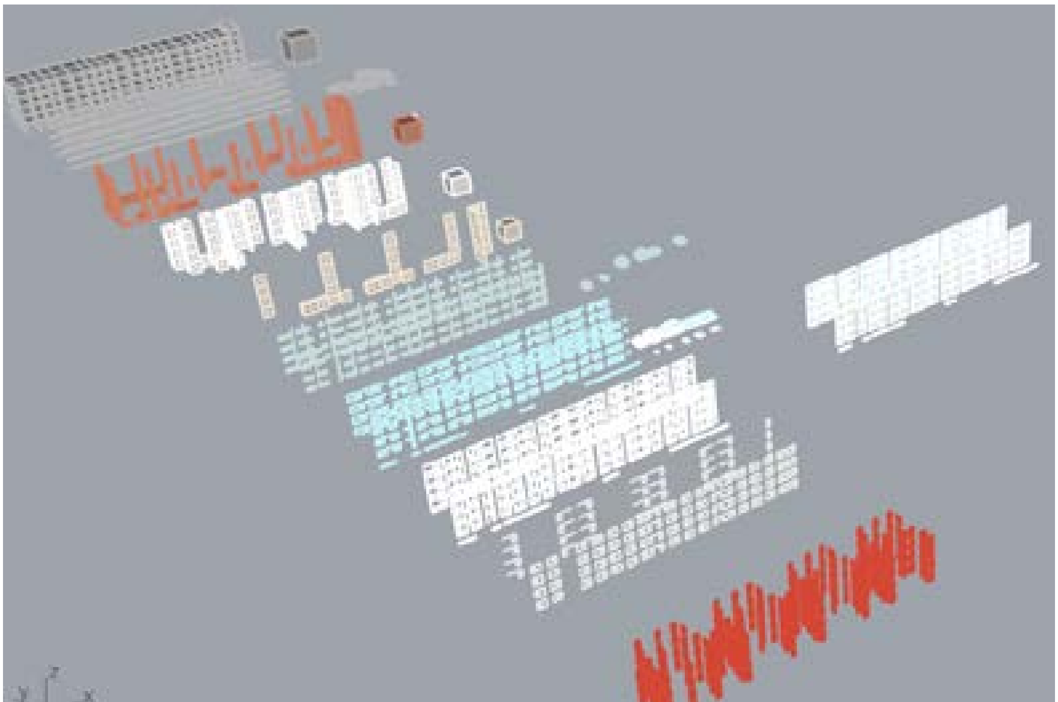
Material volume/surface

Cast-in-situ concrete	682 m^3	
Precast concrete	141 m^3	
Bricks	175 m^3	
Interior walls	128 m^3	
Sand-lime bricks	75 m^3	
Sandwich panels	27 m^3	502 m^2
Windows		725 m^2
Doors	636 pcs	

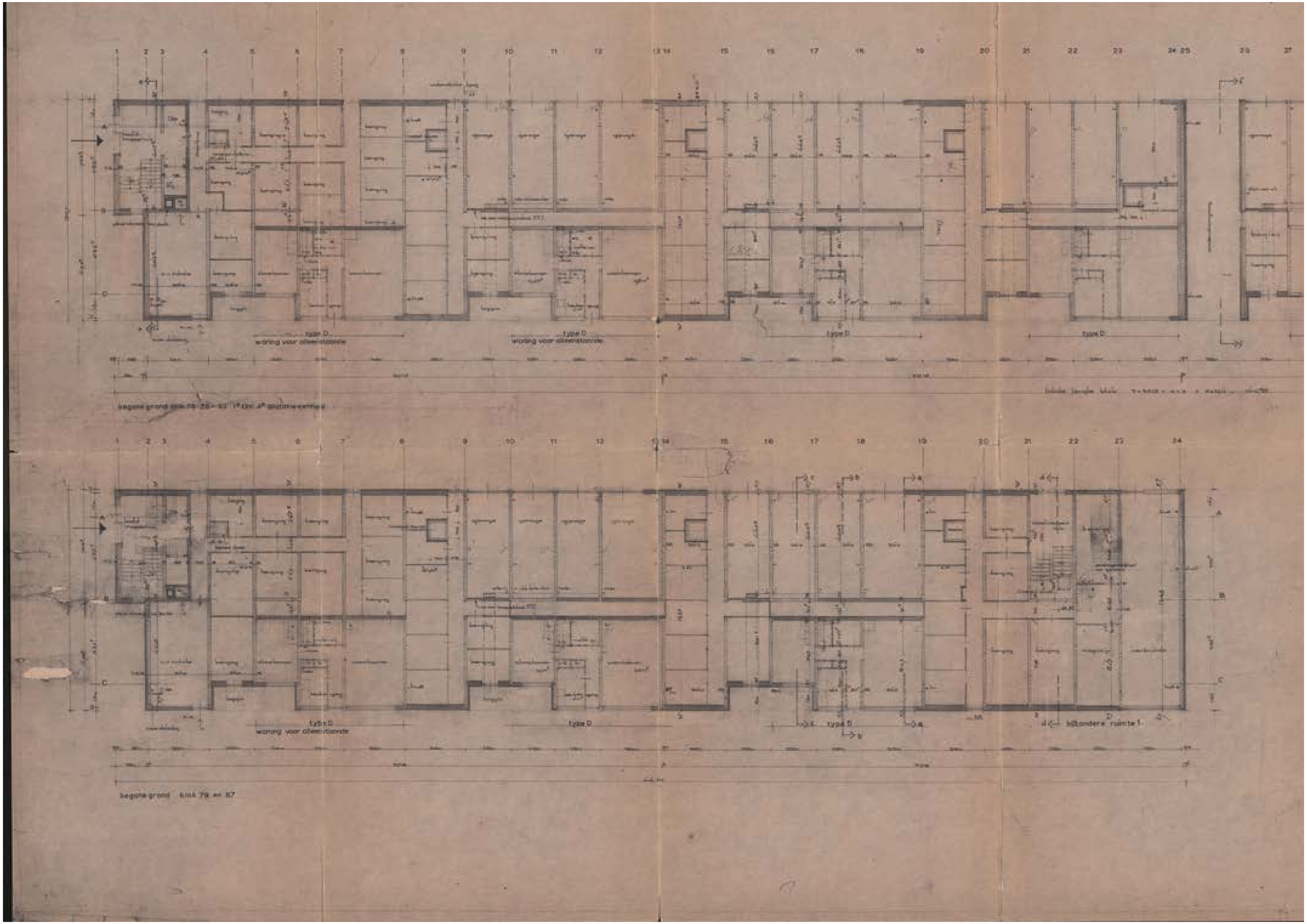
Building and building materials. Own work

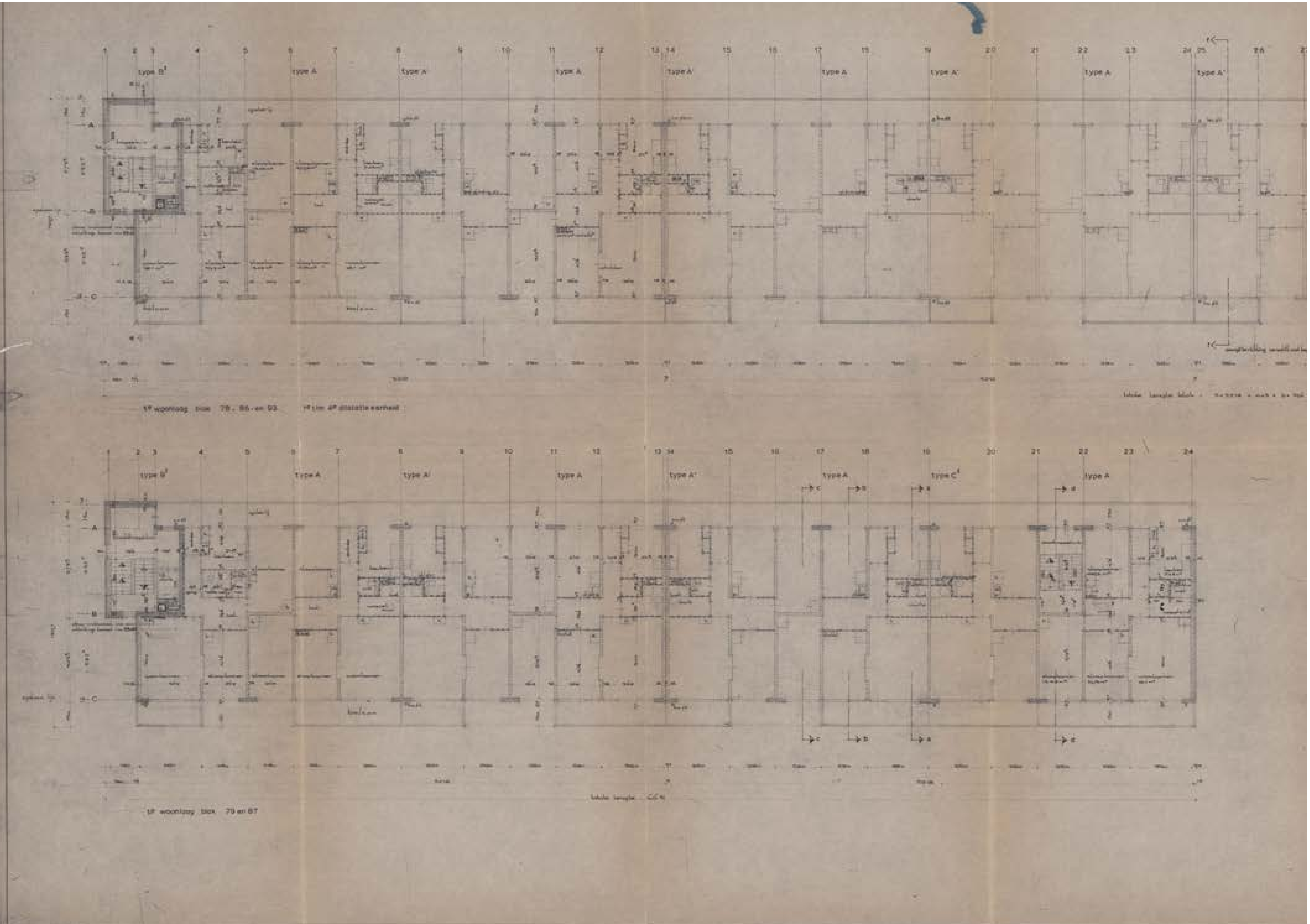
Own photo's site visit





Original drawings





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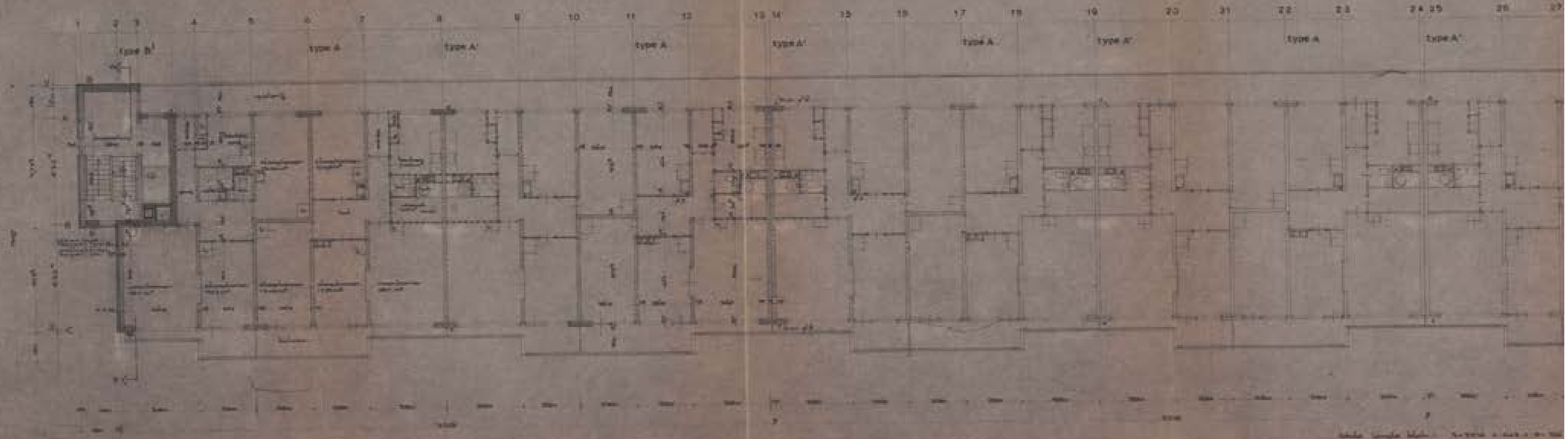
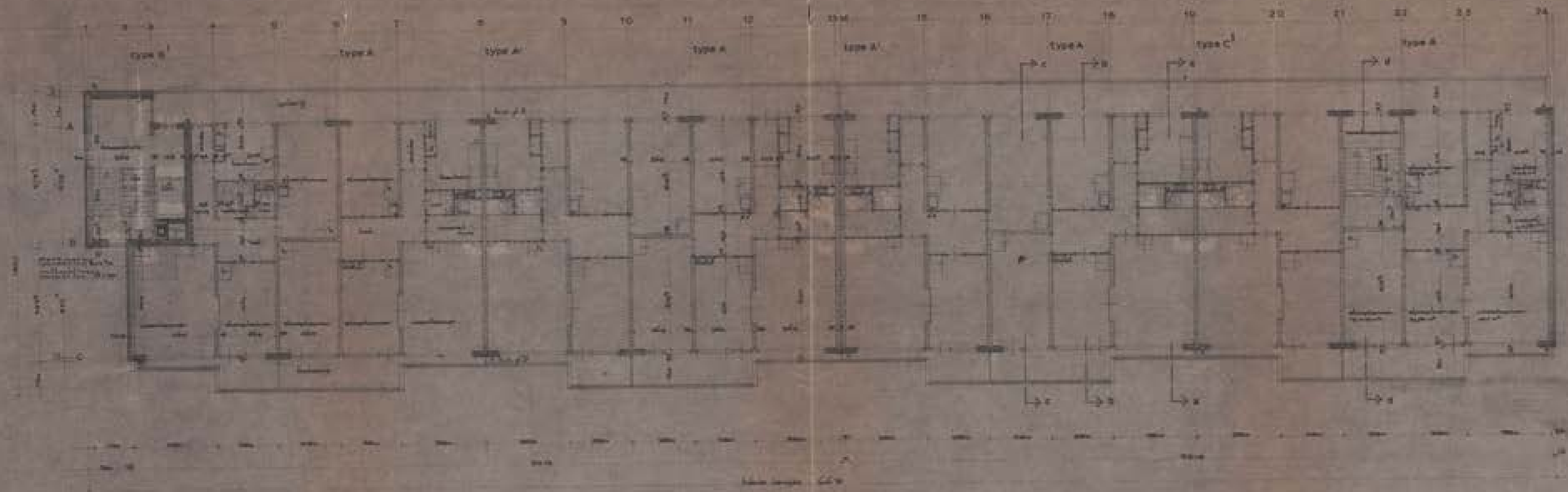
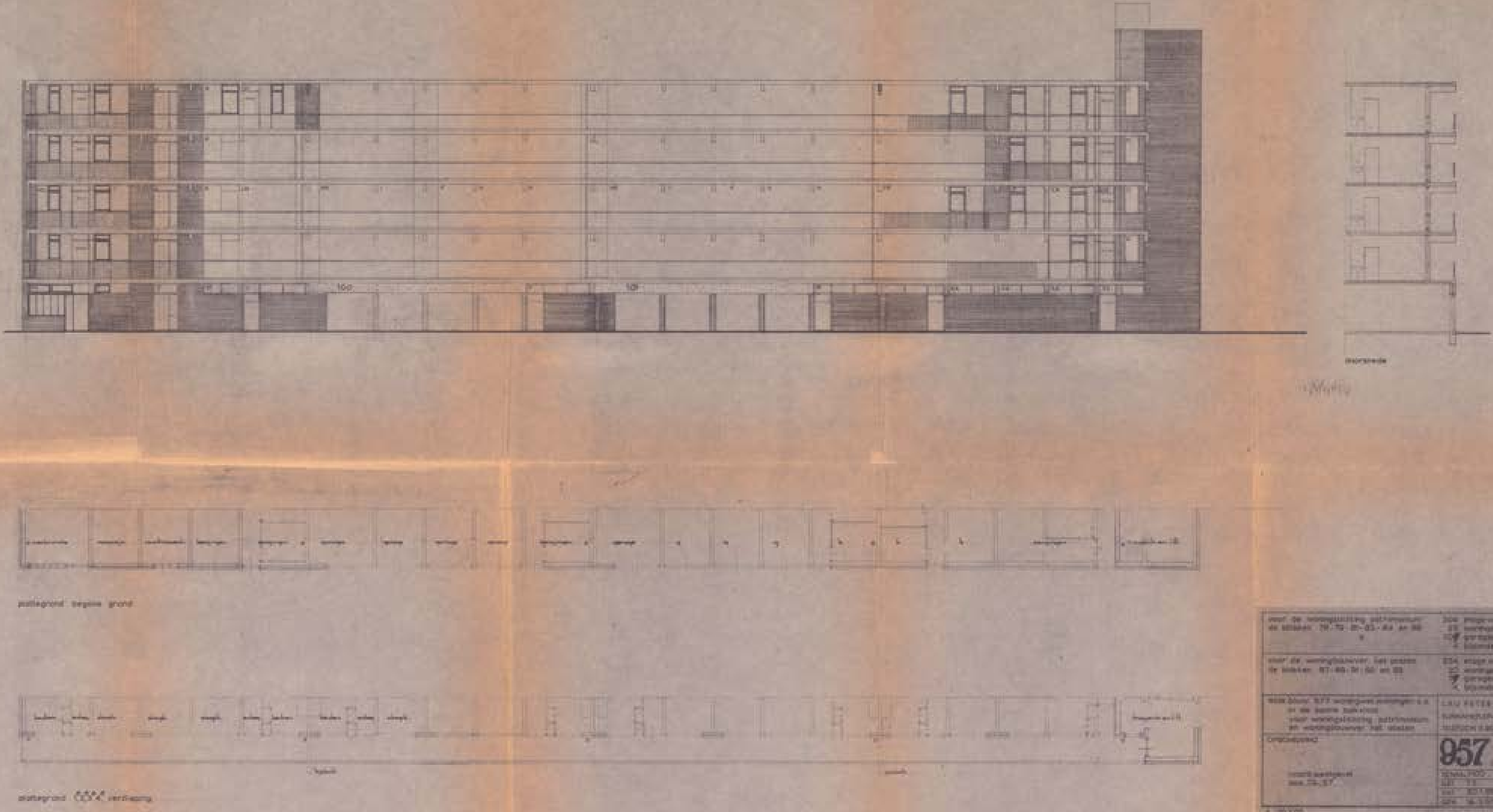


2e,3e en 4e woonlaag blok 76, 86 en 93 4e t/m 4e distictie eenheid



2e,3e en 4e woonlaag blok 79 en 87



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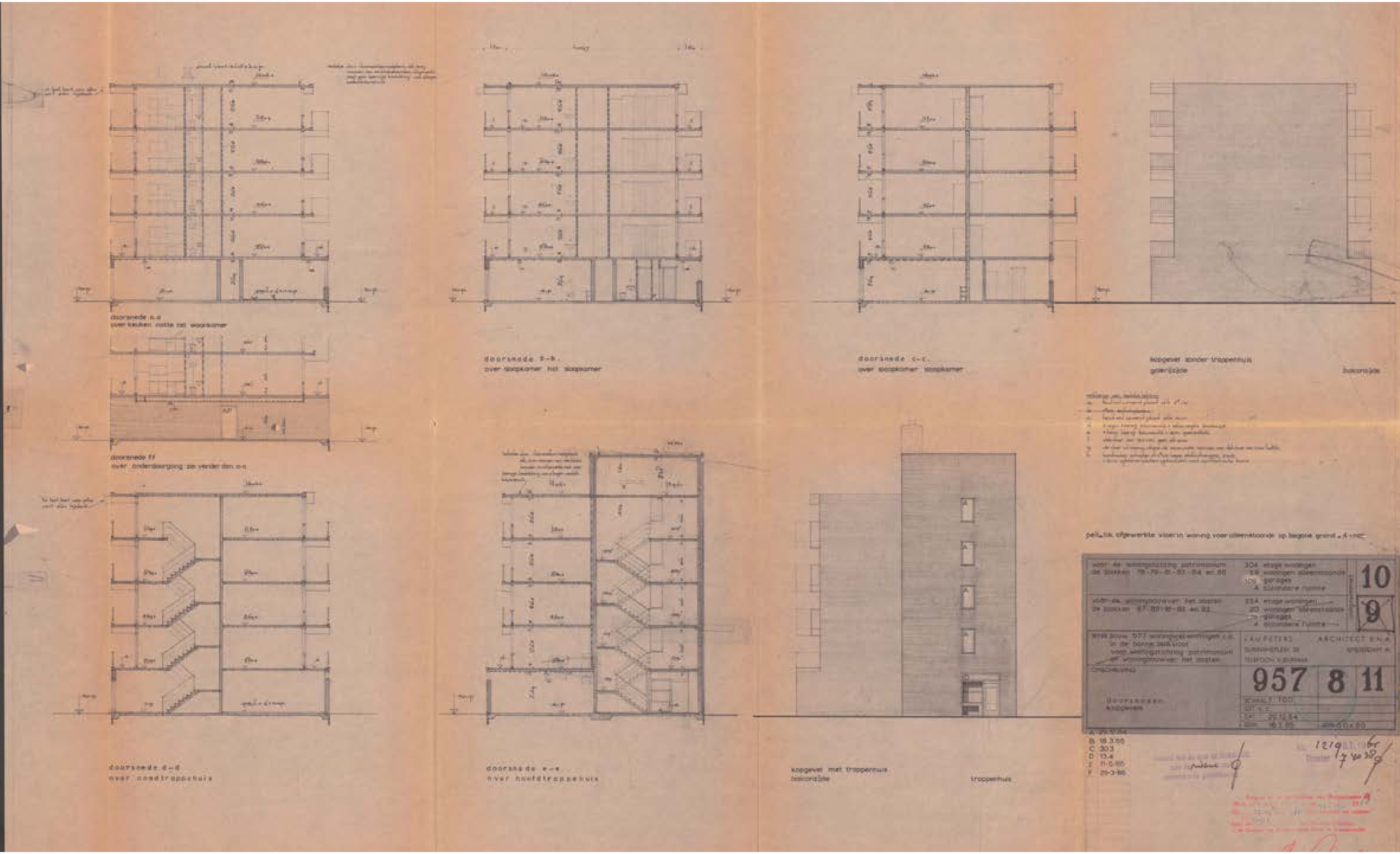

doorsnede a-a
over keuken naste het woonkamer
doorsnede b-b.
over slaapkamer het slaapkamer
doorsnede c-c.
over slaapkamer slaapkamer
kopgevel zonder trappenhuis
galerijzijde
balconzijde
doorsnede ff
over onderdoorgang zie verder dan a-a
peil 1.10 afgewerkte vloer in woning voor alleenstaande op begane grond
doorsnede d-d
over noodtrappehuis
doorsnede e-e
over hoofdtrappehuis
kopgevel met trappenhuis
balconzijde
trappenhuis
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architect
doorsneden
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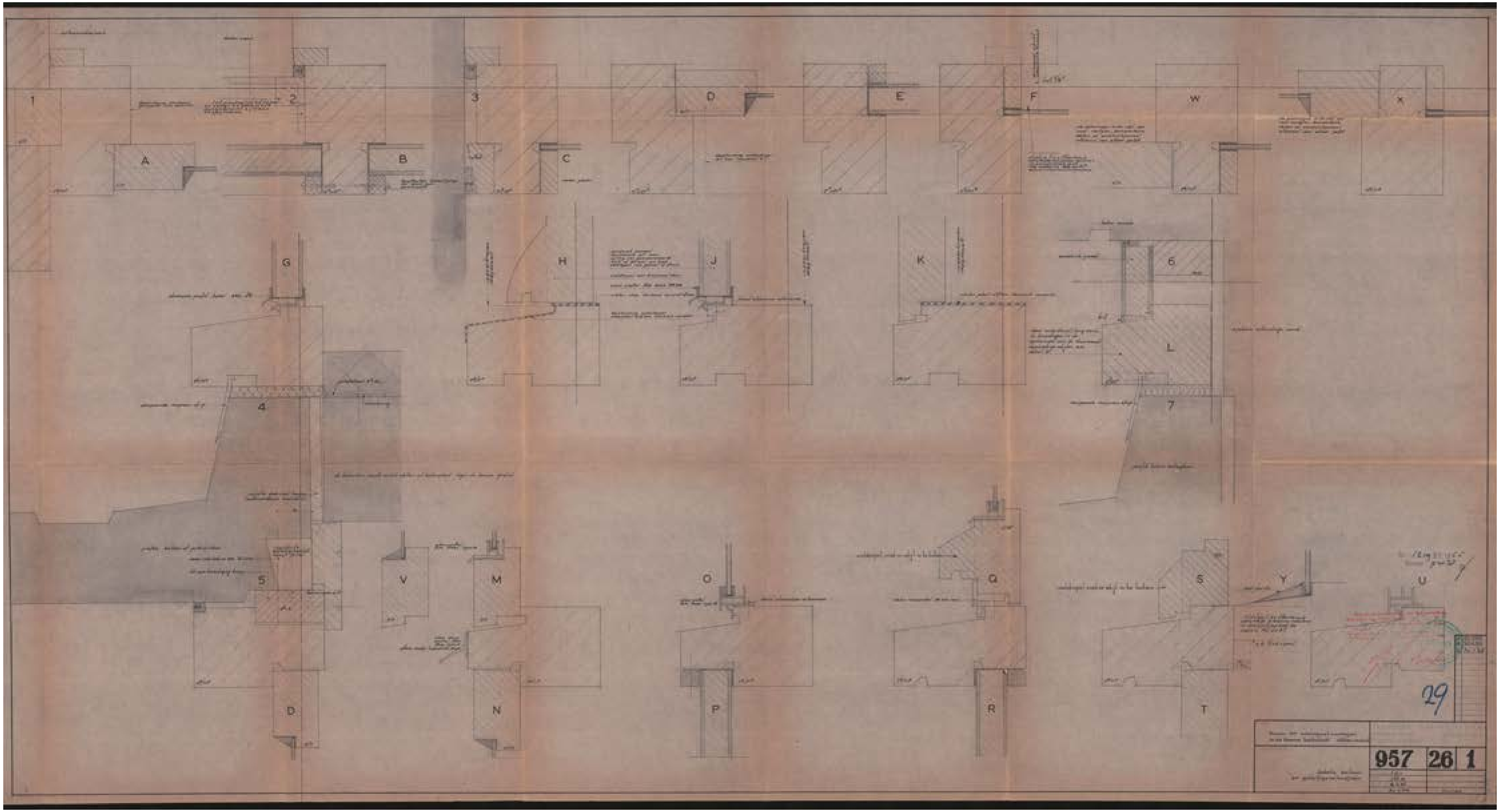
C 30.3
D 13.4
E 11-5-65
F 29-3-66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