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Building structure relocation

Victor Verstichele

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ABSTRACT

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VICTOR VERSTICHELE:
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Building structure relocation is the process of physically moving a structure to a predefined location and has been practiced in many parts of the world for centuries. Presently building relocation can be considered as a last resort of preservation when buildings are threatened by demolition or destruction. Due to the growing awareness of building preservation and the improvement in techniques and reliability, the relocation of building structures is becoming an approved preservation method.
Next to being a method of preservation, buildings are presently being relocated for various reasons due to the specialization and democratization of the process.

A building and certainly a relocation project is never the same, therefore creativity, experience, and good engineering solutions are needed to make the move a success. The planning of the relocation and more specifically the determination of the method and the techniques is a key step in the relocation process.

This thesis tries to provide a general summary of the entire relocation process, based on recent case studies of relocation projects, relocation companies' experiences, and articles. All the steps to be taken to relocate a building are discussed in a chronological way, answering the big ‘how’ and ‘why’ questions. Eventually, the relocation of the tavara-asema building in Tampere is discussed as an example of the challenges that may occur in the process.

Key words: building relocation, structure translocation, moving buildings

CONTENTS

ABBREVIATIONS AND TERMS

TAMK	Tampere University of Applied Sciences
RC	Reinforced concrete
SPT	Self Propelled Trailer
SPMT	Self Propelled Modular Transporter
AEC	Architecture, engineering, and construction

1 INTRODUCTION

A building structure relocation is the process of moving a building from one place to another. Relocation is possible in a horizontal and vertical direction or a combination of both. Lifting a building can also be considered as relocation to another level. It is mostly viewed as a remarkable feat, possible only through the skillful application of the most modern technology available. (Curtis, 1979)

Relocating structures is the world's oldest and largest recycling industry. The tradition to relocate buildings already exists for centuries, but the original motivations may vary in different countries and cultures. The relocation of buildings was a very common occurrence in the United States since the late 18th century. The reasons were practical and financial. It was often simpler and cheaper to move a building than to build a new one from scratch. (Curtis, 1979)
Due to the fast increase of inhabitants in cities in China and the subsequent aggressive urbanization, numeral historic sites were lost. Therefore, from the years 1990, relocation in China became a preferable alternative to demolition. (Lo, 2017)
In Taiwan, buildings were relocated to adjust the orientation of the house when the family encountered a series of misfortunes for no apparent reason. Also, in the division of inherited properties, building parts were moved to properties of the sons. (Su & Wang, 2006)
Currently building relocations are conducted all over the world for various reasons as it has become a known method of building preservation.

Building relocations are conducted as a way to preserve a building when al other preservation options are excluded to save the building from its changing environment. It is considered as a last resort to save the building from demolition because the move of a (historic) building inevitably results in the loss of building integrity and damage to structure and decoration fabric, making it disputable as a preservation method.

In present times, the most common reasons for building relocations are adjusting to urban redevelopment, protecting it from destruction by instability or nature, or as an economic and sentimental alternative to building a new structure.

There are three main ways to relocate a building: (i) complete disassembly and reassembly at the new site, (ii) translocation as a whole on a moving device, and (iii) partial disassembly where the building is divided into different parts and transported to the new site. Selecting the right method and techniques depends on many factors. The new location site, the distance, and route between the sites being the most detrimental factors. However, with the specialization and democratization of the process, low-damage solutions for virtually every building become available.

2 REASONS FOR RELOCATION

Firstly, a distinction between historically significant buildings and normal buildings has to be made. Historically significant buildings will only be relocated as a mean of preservation. The relocation of non-historic buildings can have various reasons.

In most cases buildings are being moved as a preservation method to save it from demolition. The threat of demolition can have different causes; urban redevelopment, making place for economic activities, clearing parcels, etc. Destruction of the building is another major reason. With instability due to bad soil or foundations, destruction by nature like floods and earthquakes being some examples. The third major reason is purely economic and is rarely a decisive reason to relocate historically significant buildings. Buildings can gain more value on another site. Relocating a building to another parcel becomes more often a cheaper alternative to building something from scratch.
In this chapter several reasons for the relocation of buildings are being discussed with some specific examples.

2.1 Preserve historically significant buildings

Historic buildings are symbols of regional culture, art, and architecture. These buildings reflect the history of society, politics, economy, and culture at that time. Therefore, the buildings are an irreplaceable piece of history and need protection in times of modernization and continuous development in our modern society. (Xu et al., 2015) “One of the most complicated aspects of preservation is the incorporation of historic buildings into changing environments. “ (Peltola, 2008)

The first step in the relocation process is to determine if it is profitable in any way to preserve and relocate the building. Since a building relocation is not always economically advantageous, a qualification must be made to determine if the building is worthy of preservation.
The decision to preserve a building is easier or is obligated when it is historically significant. Determining the historical significance of a landmark is crucial for building awareness of the project, securing grants and funding, but implements

also stricter criteria. The relocation of historical structures mostly requires permission and supervision of a monument curator. (Drozd, 2019) The supervising commission is mostly part of the city, so regulations and criteria vary strongly between regions/countries. But in general, a plan must be developed and presented to a historic preservation commission that identifies the steps to be taken to secure the structure and minimize damage to historic features. The ideal preservation method should be a reinforcement method with minimum intervention. The relocation method can be considered when all other possible ways to save the structure from demolition have been investigated and when the result shows that the relocation method is the only proper method for the building's preservation. (Kozlu & Dördüncü, 2019)

2.1.1 Qualification of historical significance

Historic buildings can be registered to a heritage list. In America for example, there is the National Register of Historic Places (NRHP) (National Park Service (NPS), 2019), in Finland, there is a list that falls under the 'Act on the Protection of the Built Heritage' (Ympäristöministeriö, 2015). By this registration, the building's authenticity is protected and there are regulations about the way of preservation.

To conclude whether the building is worthy of preservation and thus worthy of being listed, an extensive study of the building and its history should be conducted. The nomination of historic buildings is conducted by a commission, this can be on local, national, or international level. The main criteria consist of age, integrity, and significance. Naturally, a building must have a certain age to qualify it as historic. The integrity means that it still must have its original character and look. Significance means that the building is connected to events, persons, activities, developments that were important in the past. (National Park Service (NPS), 2019)

Based on that study it can be determined what aspect of the structure contributes most toward qualifying it as worthy of preservation. Factors to be evaluated might include the uniqueness of the building type, its craftsmanship, the original function of the building, interior decorations, the uniqueness of the structural system, the nature of the building fabric itself, or the relationship of the building to its setting. The specific aspect(s) to preserve should be taken into account when the relocation method is determined, so the damage is minimal. (Curtis, 1979) For example, if a building known for its unique interior painting would be moved by complete disassembly, it would lose its significance and thus it is the main reason to preserve.

2.1.2 Loss of authenticity and integrity

The International Council of Monuments and Sites (ICOMOS) stated in its adaption to the Venice Charter (1964) in Chapter 7: "a monument is inseparable from the history to which it bears witness and from the setting in which it occurs. The moving of all or part of a monument cannot be allowed except where the safeguarding of that monument demands it or where it is justified by the national or international interest of paramount importance." In summary, the ICOMOS charters reject relocation except in situations of last resort where relocation is essential to safeguard, or to conserve, restore or preserve, or to comply with national or international interests. (Gregory, 2008)

By relocating structures, their new environment may change the original historic context or setting, which jeopardizes its significance. Often the original site and its relationship to the historic structure is as important as the building itself. A relocated building, even if placed on a terrain similar to where it stood previously, will seldom have the same aesthetic relationship to its new site. The move can cause the building to be removed from any heritage list, causing the loss of subsidies and protection to further preservation. To avoid this, some subjects must be documented before the move: (i) it must be shown that all other ways of preservation were not possible, (ii) the new site is chosen and the move itself is conducted in a way of minimal loss of integrity. (Curtis, 1979) "By studying examples of relocation, preservationists, as well as the public, can appreciate the practice as a valid act of preservation when it is the last resort." (Peltola, 2008)

2.1.3 Destruction by nature

The relocation of historic buildings to a more suitable environment to save it from destruction by nature has been frequently executed last decades as the importance of preservation grew. Many cases describe the relocation of old lighthouses due to the destructive force of the waves on the building and its foundations and/or the erosion of the coastline causing instability concerns. A known example is the relocation of the 4,830-ton Cape Hatteras lighthouse in 1999 (National Park Service (NPS), 2015)and more recently the Rubjerg Knude lighthouse in Denmark in 2019 (BBC, 2019).

Due to flood hazards, buildings can be relocated out of the floodplain or can be lifted to a safe height. (FEMA, 2007) The Village of Rhineland, Missouri, for example decided to move most of its buildings off the floodplain after being flooded 4 times in that year. (FEMA, 2011)

During earthquakes, historic buildings often suffer considerable damage, particularly those built before seismic codes were adopted. Seismic rehabilitation of a historic building can consist of various retrofitting techniques. A possible retrofitting technique is to move the building to a new foundation that can suppress most of the vibrations. Another option is to lift the building to install base insolation between the foundation and upper structure. (Lu & Wang, 2016)

2.1.4 Destruction by instability

Old historical buildings often have foundations made out of materials that lose their carrying capacity over time. Wooden foundations for example were widely used but can rot in time. The old foundations are mostly primitive and not properly adjusted to the soil proprieties the way new foundations are adjusted these days. Another problem can be the change of the soil properties in time because of adjacent structural developments or naturally evolving water movement in the soil causing erosion. In these situations, differential settlement of the building and thus damage is mostly inevitable.

The obvious solution is to insert new foundation structures or to enhance the carrying capacity of the existing structure or soil. An example of such a technique is the insertion of press piles as new foundations, which only require a small space so it can be used under buildings or in cellars. The pressure needed to push the piles in the ground is performed by using the self-weight of the building. (Franki Grundbau, 2020; Guo et al., 2013) Another technique is an underpinning of the structure to increase the stability and rigidity of the foundation. When the instability is just local or caused by a bad foundation, a solution is to just lift the building from its foundation and to replace or restore the old foundation. If, however these options are not applicable, a relocation to a site with new foundations and better soil properties can be considered.

Examples are structures on the coastline that became instable due to coastal erosion. The city of Kiruna, Sweden for example, is currently being relocated to a safer location because it began to sink into the caverns excavated by a neighboring iron mine (expected finalization in 2035). (Casey, 2019) In some cases the building is moved to a temporary location, the old foundation is restored or replaced, and the building is put back to its original position. (Xu et al., 2015)

2.1.5 Economic planning

Very often, whole areas are subjected to intensive economic planning. Because of the great economic importance of these projects, historically significant structures in those areas are subjected to high pressure. Moving these structures out of the planned area is mostly the only reasonable option to preserve it.

In the last decades, many large-scale relocations are caused by economic planning. An example is the relocation of the Church of The Virgin Mary, Most, Czechoslovakia in 1975 due to the discovery of brown coal under the city. (Curtis, 1979) Almost all other buildings in the town were demolished. A similar scenario took place in Tahawus, New York 1963 where the whole town was moved to make way to mine the underlying iron and titanium. A controversial example is the historic 12000-year-old town of Hasankeyf, Turkey. The old town is now completely submerged since April 2020 due to the completion of the Ilısu Dam. Despite being declared a conservation area in 1981, only a handful of ancient structures had been relocated to higher ground. (Şener, 2004; Taylor, 2019)

2.1.6 Urban (re)development

Big cities are constantly changing due to the increasing needs for transportation, housing, open space, etc. Therefore, intense urban redevelopment is needed to respond to these needs. Widening of streets, building underground space and transportation, elevating streets, improving sewerage systems are all examples of urban redevelopment that challenge the preservation of historic buildings.

The utilization of underground space is a trend in modern urban development, which might impose challenges to the protection of historic buildings. The Young Men's Christian Association building in Nanjing, China is an example of such a scenario. The building was temporarily moved on a stable support system and was moved back to its original position after completing the construction of a 4-story underground parking. (Xu et al., 2015)

2.2 Other reasons why buildings are being moved

The following reasons are implemented for buildings that not necessarily have a reason to be preserved out of historic significance. The move of these buildings is more out of interest of individuals and consists mostly of private buildings. The reasons are discussed separately, but naturally the relocation of a building often has multiple motives.

2.2.1 Sentimental value

In some cases, the owner of a house orders to move the building to avoid demolition for sentimental reasons. Hereby de relocation is rarely financially advantageous. A known example is the relocation of the Brown mansion, Pennysylvania in 1903. The house was moved along a hillside to an area 90 meters above the original site. The cost of moving the Brown mansion considerably exceeded that of its original construction, it is believed that the move was undertaken primarily out of a desire to preserve a family inheritance. (Curtis, 1979)

2.2.2 Cleaning the area for a new owner/building

With the current techniques, simple buildings like houses in wood and small frame buildings can easily be relocated. Therefore, the option to relocate buildings even becomes interesting for private projects. When parcels are bought by investors to start a building project on it, the existing structures on the parcel mostly will be demolished to make way for the new project. Since building relocation became a commonly used method, the structures on these parcels are sometimes sold for very low prices with the condition that the buyers pay for their relocation. This option can be lucrative for both the investor and the buyer of the structure. The investor saves the demolition cost of the building. The buyer has only the little cost of buying the building and the cost of moving it which together is mostly less than the construction cost of a new building.

2.2.3 Increasing the value of the structure

The increase in the value of a building can also be considered as an additional reason when moving historically significant structures with the intention of preserving it. The worth of a building can be measured in its actual worth, its grade of use, and its aesthetic value. Abandoned buildings, due to their unfavorable location, are sometimes relocated to more strategic places. Hereby the value increases and the building is actively used again which automatically leads to active care and preservation.

Examples are the relocation of historic structures in abandoned regions to higher populated regions, moving a building to a place that is more accessible or has a better view, and moving historic buildings to museum sites. To get back to the example of the Rubjerg Knude lighthouse in Denmark, the lighthouse had to be removed due to instability caused by eroding dunes. Because the stability of the tower was questionable, tourist visitations were restricted. After relocating, the tower became a part of the museum and was accessible again to tourism, resulting in an increased value to the historical site. (BBC, 2019)

2.2.4 Environmentally advantages over demolition

An additional consequence of the relocation of a building as an alternative to demolition is that the production of building waste during demolition is substantially diminished. The relocation and the resulting reuse of the building can be seen as the recycling of the whole building. This can be seen as an additional advantage to building relocation, but also as a main reason to opt for relocation when construction projects thrive to be environmentally friendly.

There is also a trend where buildings are designed for possible disassembly in the future. When the building has to make way, it can be disassembled and re-assembled at another location. (Wood, 2018)

2.2.5 Relocation from the workplace: prefabricated buildings

Prefabrication of elements has become a standard option in the construction sector because of the countless advantages and possibilities. Prefabrication reduces work hours on-site, assures high quality, and makes automatization possible. Some companies do not limit the prefabrication on element level but prefabricate whole structures or modular parts of big structures. Therefore, a structure can be designed and optimized for future transportation. The structures are of high quality because of their indoor construction under optimal conditions. Because of its modular possibilities, there is no limit to the size of the building and it can be relocated again in the future. Examples of optimization for transport are designing the sub-floor system with additional bracing to counter the stress of transport and optimize and standardize the lifting process. (Tejijo Talot, 2020)

2.2.6 Moving to the contractually specified setback space

The construction process of buildings is not always without mistakes. Sometimes the place can deviate from the planned location due to wrongly plotting the contour of the building. Because the building has to conform with the building permits the building can be relocated to the required and contractually specified setback space. (Telem et al., 2006)

3 RELOCATION PLANNING

Good planning is vital for the success of a relocation. Because of the complexity and uniqueness of every relocation, possible difficulties and problems during the relocation should be anticipated. The route planning is a major task when buildings are being moved on public roads. The relocation method and used techniques should also be determined with care and based on the advice of several external parties.

3.1 New location

To find a new location for buildings, detailed documentation of the original site is needed. In the case of historical buildings, the new site must be comparable to the original site to minimize the loss of historical significance.

3.1.1 Building's relation to the original setting

The documentation of the original setting should describe the orientation and position of the building, this includes the orientation to the sun, the position on the lot and to the street, the position of big vegetation, etc. The characteristics of the site itself: the topography, size, and landscape of the site. On a broader view the surroundings and neighborhood: the age, style, functions of the surrounding buildings. Since the relationship of a building to its surroundings sometimes is as important as the building itself, the documentation of the original state is essential.

3.1.2 Search for an appropriate new site

The selection of a new site plays an important role in the success of the relocation project and should be done with care. Starting from the knowledge acquired in the original setting, a comparable site should be found. Similar sites will make the building come into its own, meaning that proper selection enhances the integration of the transported building into its new surroundings and replicates the buildings' aesthetic value to its surrounding as much as possible. (Curtis, 1979)

An examination of the ground conditions at the new site is needed to determine the choice of foundation. If the ground conditions are very different from those on the original site, a different foundation design can be advised. This is an important factor when the old foundations are relocated too, some ground conditions could complicate or rule out the relocation of the old foundations. (Drozd, 2019)

3.2 Determination of the relocation method

Choosing the right relocation method is one of the most critical steps during a building relocation. The decisions in this process strongly affect the cost of the relocation and the grade damage to the building. Because of the uniqueness of most heavy moving operations, the method and equipment required for these undertakings are is mostly designed for the specific operation. (Telem et al., 2006) Generally relocation as a whole is considered the most preferable method in terms of cost and preservation. Moving the structure intact is less expensive than paying for the time and labor of disassembly and reassembly and it offers the least amount of negative impact to the (historic) fabric of the structure. (Goblet, 2006) Of course the intact move is not always possible, so (partial) disassembly can be seen as an alternative when an intact move isn't possible. The following factors can limit or rule out some moving methods and techniques and should be investigated when determining the right method.

3.2.1 Cost, time and quality

The cost-time-quality relationship in building relocation cannot be separated. Each aspect strongly influences the other two and vice-versa. Therefore, clear provisions have to be made in the planning process concerning these 3 aspects.

Quality

From the beginning of the process, a clear description of expectations should be made by the client on the quality of the move. The quality of the move includes the grade of preservation of the building and the amount of damage that can be tolerated. In some cases, an intact move of the building, including the foundation is requested. In other cases, only the exterior structure is considered to be preserved. (Lu & Wang, 2016)

Cost

In general, normal buildings are being moved when the relocation cost is lower than the cost to build a new structure on the new site. The relocation of historic buildings is very expensive because of the high demands concerning minimal damage and preservation. Therefore, the relocation of a historic building is mostly dependent on investments of governments and external organizations. When a building is considered historical, several forms of grants can be given.
The budget of the project influences possible methods and techniques to use, which determine the grade of preservation and damage.

Time

The relocation time can be divided into time for planning and preparation, and the time it takes to make the physical move.
The planning time highly varies and depends strongly on the time to obtain all the needed permits

The time of the physical moving process is generally dependent on the complexity of the building and the distance between the sites. Besides these two factors, the relocation method, the used techniques, and the coordination of the project influence the relocation time. The timespan wherein the relocation has to be executed can therefore sometimes rule out some methods and techniques. Intact relocation for example can be seen as the most complex method with extensive planning, but when the preparation is done, the physical move can be carried out relatively fast. Complete disassembly on the other hand does not require such an extensive preparation as intact move, but the physical move can take some time because of the documentation and the intensity of labor during disassembly and reassembly.

3.2.2 Building type

Timber buildings

In general timber buildings are lightweight and, compared to masonry buildings, capable to endure certain deflections. These two factors ensure that timber buildings can easily be transported as a whole and this is the preferred way since the fabric will be preserved too.

If the stability of the structure cannot be assured during relocation as a whole, reinforcement or other moving methods should be considered. Disassembly can be considered when the condition of the wood structure is questionable. In that case disassembly can be an opportunity to inspect the state of the wooden elements and to replace or strengthen elements when reassembling the building. (Curtis, 1979)

When disassembling timber buildings, the extent of loss depends on the condition of the structure and character of the connections, joists, etc. Some wooden joining systems can be disassembled without considerable damage, pinless connections for example. Others cannot be disassembled without sacrificing some material.

Log built timber buildings can easily be disassembled with minor damage or loss because of its simple connection technique and its absence of fragile fabric.
Heavy frame timber buildings can be moved as a whole when the condition is acceptable. Partial disassembly can be an alternative too when the external wood plating is vertical. If only the wooden structure is to be preserved, total disassembly is possible too.
Light frame buildings are seldom disassembled because of their fragility and high risk of damage during the disassembly process. Because of its lightweight these buildings are usually translocated on a truck trailer if the dimensions are acceptable. (Goblet, 2006)

Masonry buildings

Masonry structures are preferably moved as a whole so the original fabric and mortar will be preserved. In some cases, the chimneys of masonry structures are being dismantled or reinforced during the moving to prevent stability issues.
Masonry is a brittle material, which possesses very low tensile strength and shear resistance, but is quite strong in compression. During the lifting of a masonry building, tensile forces will occur and have to be compensated to avoid damage. Therefore, additional structural support and covering of the wall openings are advised to minimize damage. Placing radial and vertical prestressed cables externally like a cable net is a form of post-tensioning that offers a solution for the strengthening of masonry against tensile failure. (Şener, 2004)

Because of its design, brittleness, and high weight, masonry buildings need professional equipment with high bearing capacity to move and lift them.

Dismantling of masonry buildings is strongly discouraged because of the loss of integrity due to the sacrifice of the original mortar. The faithful reproduction of texture and coloration of the original masonry wall is also very difficult. Mortar containing Portland cement has high strength and bonding capacities that can cause the bricks to be severely damaged while removing the mortar in the dismantling process. (Curtis, 1979)

3.2.3 Size and weight of the structure

The size of the structure and consequently the weight of the structure can also be an important factor in determining the relocation method. The major drawback to large buildings is the spatial limitations on the route. Limited overhead clearance by power cables, traffic lights, tree branches but also steep slopes and other structures on or next to the route can complicate the intact move, making it more expensive or even impossible.
To move these buildings, (partial) disassembly can become a more favorable option. Cutting these buildings into manageable segments can be considered as a technique of minimal disassembly and ensuring intact segments. In case of buildings too tall for vertical clearances along the route, the removal of the roof or the chimney can sometimes suffice.

The weight of the building determines the choice and number of moving devices when being moved intact. Lightweight wooden buildings can easily be transported on truck trailers, but heavier buildings require special moving devices. Along the whole route, a study should be conducted if the underground and supporting structures can bear the weight of the building. Bridges and roads with underlying pipelines for example have strict load limitations.

3.2.4 Physical condition of the building

As discussed before, the physical condition determines if the building can withstand the forces during the relocation. An extensive study on the condition of the building can provide clarity over the measures that need to be taken in the preparation process and during the move. (FEMA, 2007) Wooden buildings in bad condition are sometimes disassembled to inspect the scope of damage and as an opportunity to restore or replace damaged elements. Masonry buildings in bad condition are generally not disassembled but rather reinforced with permanent or temporary measures for the move.

The specific items to assess the condition of the building are variable according to the construction type. When inspecting the building, the amount of visible damage should be assessed. A damaged roof or peeling wallpaper can indicate leaks and water in the building. In the case of wooden buildings, rotted or insect-infested wood can give clear indications. Deteriorating mortar or cracked masonry are the most visible indications of damage in the case of a masonry building. (Curtis, 1979)

A study of the used construction methods can give an insight into the strength of the joints and the bearing structure in general. The way the weight of the building is transferred to the foundations is dependent on the structure type and should be calculated to design the underpinning system if the building is moved as a whole. Even when a building is being disassembled, the structure should be investigated to foresee possible instability during the disassembly.

3.2.5 Distance between locations

The distance between locations is in the first place important in the field of the preservation of the integrity of a building. Short relocations on the same plot result in a minimal loss of connection to the building’s environment. When a building is moved out of its district, it is difficult to maintain the regional architectural identity of the building.

There is no actual maximum distance to transport a building as a whole, but in general it is limited by the cost and difficulty of coordination. (Drozd, 2019) Long routes on public roads require permits of all kinds and assistance from several services. (Goblet, 2006) There are permits needed to cross communities, to clear the road, and permits to temporarily remove obstacles and power utilities. Cost analysis and a technical options analysis should be considered to decide if the move is possible.

The choice of moving device also depends on the distance of the move. Short distances without rotation of the building can be conducted on a rail by gliding or rolling, in some cases curved translations on rails are possible too. Longer distances and curvilinear routes should be conducted on dollies or truck trailers.
In the case of disassembly, there are no limitations to the distance of relocation as long the pieces have a permissible size and weight to be transported.

3.3 Picking a suitable contractor and arranging permits

The choice of a mover depends on three primary factors: (i) the timeline, (ii) type of move, and (iii) type of structure. Timeline means the period in which the building needs to be moved. Short timelines require professional coordination and many workforces. The mover must have experience in the specific type of move since relocation as a whole and relocation by disassembly require different techniques, knowledge, documentation, and workflow. The type of building means the type of construction material of which the structure is comprised. As discussed in 3.2.2. there are building types that need more precaution and other ways of lifting etc. (Paravalos, 2006)

It is important to hire a structural mover that is familiar with the relocation of buildings of the type involved, especially within the area where the building will be moved. Local movers have the advantage of knowing the local permit requirements, as well as being familiar with town officials and other local ties to facilitate the move. (Peltola, 2008) There are associations of structural movers like the International Association of Structural Movers (IASM) that provide a database of companies performing relocation of the highest quality. (IASM, 2020)

The contract must outline contractor and owner responsibilities, it must precisely describe the duties and scope of liability for both the company and the owner. Some structural movers only move structures within the structure‘s lot because it does not require the contractor to implement the full extent of the permitting process. (Peltola, 2008) Other movers only conduct the move itself and not the preparation work or the construction of the new foundations.
When choosing a company to conduct relocation, the safety of the relocation is the most important factor, therefore the price should not be the decisive element. (Drozd, 2019)

3.4 Structural analysis and monitoring of the building

To evaluate the validity and effectiveness of the proposed method, analytical models can be used. Due to the complexity of old structures, it is almost impossible to evaluate and predict the behavior of the building during the move, a but simplified analytical model of the building can give certain insights. In the analysis of structures, strength, stiffness, and stability characteristics are considered as the three main criteria. The structure should be strong enough to carry the imposed loads, including its self-weight. Large deflections and differential displacements should not occur in the structure, either locally or overall. (Şener, 2004)

Dependent on the scope of the project, a Finite Element Model can be made from the building. The Finite Element Method models the structure by dividing it into small elements called finite elements. This method has been proven to give a realistic estimation of the stresses and deflections in a structure when correctly modeled. (Şener, 2004) Based on the result of these analyses, actions in the form of reinforcement to the structure or changes to the proposed method can be taken.

Next to estimating with analytical models, it is also interesting to monitor the effective stresses and deflections of the structure during the move. It helps to evaluate the effect of the translocation method on a building, but it can also achieve structural safety and protection during the move. (Zhang et al., 2019)

3.5 Route planning

The route planning for the transport of the building is the last crucial step before initiation of the physical relocation. Preferably the route should be as short and as wide as possible. The weight, size, and relocation method are most detrimental for the choice of the route and the measures to be taken on the route. The whole route must be wide enough for the transport vehicle to pass and take turns. Overhead clearance along the route and favorable ground conditions should be assured. Reparation and strengthening of the road, placement of temporary equipment (tracks, steel beds, platforms) should be considered along the whole route. The removal or reparations of elements such as heating, electricity, and water may be necessary to provide overhead clearance before carrying out the construction. (Kozlu & Dördüncü, 2019)
The choice of route will play a role in the necessary permitting allowing for such a move. All permits have to be obtained before the move can initiate. (Drozd, 2019)

4 RELOCATION PROCESS

Before the relocation process, the method of relocation was determined in the planning phase based on numerous factors. If the method is carefully selected, an optimal relation between cost, time, and quality can be obtained. The method by intact move of a building is very different from (partial) disassembly. The method by intact move is the most preferable as it will result in maximal preservation, minimal cost, and minimal damage. On the contrary, the method is the most challenging one in the field of technology, computations of loads, etc. Therefore, the method of intact move will be intensively discussed.

4.1 Relocation as a whole/ intact move

Moving a building intact is technically the most challenging, but also the most desirable method. The labor costs, possible wrongdoings, and damage in dismantling and reassembling are avoided. Hereby the original fabric will be preserved, which is mostly a decisive argument for preservationists to move the building intact. The move can also be done in a relatively short time span.
The intact moving method can be applied to all kinds of buildings as long as the economic and technological facilities allow. The choice of equipment depends on how its maximum capacity relates to the weight calculations of the planned building. (Kozlu & Dördüncü, 2019) The type of moving device depends on the distance between the old and new site and the condition of the route.

Although there are reliable and safe techniques available to move heavy structures, (Lu & Wang, 2016) stated there is a lack of specific and systematic construction management theories and technique design standards when it comes to moving (historic) building structures. They concluded that the used techniques and equipment are usually guided and influenced by other similar engineering standards and practices like Slide-in bridge construction or heavy equipment relocation. As a consequence, uncertainties and unsuitable use of these techniques may appear when it is applied to relocate building structures, which can result in poor quality control problems like cracking, direction deviation, and structural instability. The intact move of a building can be conducted by many construction companies who dispose of the techniques and materials to move structures, but in the case of building relocation, specific experience and knowledge are required.

The following steps are in chronological order for the traditional way to move buildings intact, as a consequence some of the discussed techniques do not always completely follow this traditional order.

4.1.1 Preparing building for relocation

During the relocation, the building will have to withstand forces and deformations the materials were not designed for. Therefore, an extensive feasibility study of the building is recommended. Out of this study conclusions can be made where damage is most likely to show up and measures can be taken to place reinforcement. Reinforcement can be carried out in two main ways: material and integrity reinforcement. Material reinforcement is the strengthening of the materials itself by repairs, grouting, filling cracks, replacing damaged parts, etc. Integrity reinforcement is to strengthen the whole building by adding reinforcement structures like steel frames, trusses, bearing walls, tension cables, etc. (Song et al., 2018)

First an assessment has to be made on what has to be repaired before the move and which parts should be removed. Dependent on the scope of the renovation after the move, unnecessary structures can be removed to lighten the structure and to make way for a temporary interior supporting structure. Weak floor systems, unsafe supporting walls, damaged roofs, etc. that threaten the structural safety of the building in normal conditions can be handled in two main ways: (i) they can be replaced by a reliable supporting structure. If these structures are beyond repair, they should be removed before the relocation. To save weight, a temporary light supporting structure can be put in their place and after the move new permanent structures can be constructed. The new structure can also be constructed before the move, with the consequence of extra weight but also an additional rigidity to the building. (ii) If these unsafe structures can or should be preserved, repairs and reinforcement are conducted before the move.

Chimneys, porches, and other cantilevered parts can experience high tensions during the move and should, out of precaution, be removed or reinforced. Adjacent structures that were added to the main building sometimes have separated floor slabs and walls which are not strongly connected to the main building's structural system. These structures need additional care to prevent them to be torn off the main structure.

Reinforcing the structural strength means to control the internal forces and deformation to guard the integrity of the structure. The overall stiffness and strength to external force are necessary to improve the building, including the ground disturbances and structural deformation due to unfavorable loads. (Ren-liang et al., 2017) The structural strengthening is mostly carried out in the form of steel profile frames and trusses on the inside and/or outside to create a rigid structure that preserves the current state of the building. These steel structures are preferred because of their relatively lightweight, high rigidity, and the ability to rapidly install and demount. Internal supporting frames can be installed not only to strengthen the building but also to partly relieve the supporting walls and frames from the weight of the upper structure. Another alternative is to add a permanent supporting structure, mostly in the form of an extra concrete layer, a lightweight carbon fiber fabric, or an epoxy sealant to the interior walls. (Fortner, 2009)

The exterior of masonry buildings is usually wrapped in a series of prestressed steel cables to maintain horizontal and vertical compression and to control the potential separation of mortar joints which can occur during the lifting. Another method with the same purpose is to wrap a polyolefin shrink film around the structure at the base and top of the exterior walls, as well as at the midpoint, to act as a tension ring. Bracing in the form of wooden shear panels or rigid frames can be used to seal off all the doorways, window spaces, arches, and other openings to suppress high stresses and deflections. Netting material can contain any rubble, masonry, or other debris that might become dislodged during the move. (Fortner, 2009)

The masonry material itself can be strengthened too. Although this step is sometimes skipped because damage to the masonry during the move is almost inevitable so anyway repairs have to be carried out after the move. Cracks in masonry walls can be filled with high strength mortar, the walls can be grouted or plastered with cement paste. (Song et al., 2018)

Simultaneously to or after the reinforcements, the ground around the building will be excavated, uncovering the foundations for the underpinning phase. Thereafter all utilities are to be disconnected from the building. The site will be cleared to allow access to necessary equipment and to provide a wide route. This includes removal and protection of trees and bushes, removal of fences, etc.

4.1.2 Underpinning of the structure

Underpinning is a widely used technique to strengthen the foundation of an existing building or other structure. There are several ways of underpinning, dependent on the ground conditions and structure of the building. In the case of building relocation, the beam underpinning system is used as a (temporary) lateral supporting structure for the superstructure during the move. The underpinning should have enough strength, stiffness, and reliable connections to bear the loads from the superstructure. It also has to bear the moving forces and friction during the move. (Lu & Wang, 2016) Therefore underpinning is a defining step in the technology of moving buildings intact. It is the critical technique that decides if the move will be a success. It has a direct impact on the stability and security of the moving process. (Daolin, 2018)

The way of underpinning is strongly dependent on the structure type and the scope of the building. The underpinning structure has to distribute the vertical loads of the superstructure as uniformly as possible through the moving device(s) to the soil. The design of the underpinning is therefore also dependent on the distribution and type of moving device. In general, there are two main types of underpinning; steel beam underpinning and cast concrete underpinning. Steel beam underpinning is used as a temporary lateral support during the move and is normally applied to simple lightweight structures in acceptable condition. Cast concrete underpinning is permanent lateral support that normally will be integrated into the foundation structure of the building at the new site. Concrete underpinning is used when structures become too heavy, big, or complex to use steel beams or when defections have to be as minimal as possible. Prestressed

underpinning beams are sometimes applied under very heavy frame buildings to distribute concentrated loads of the upper structure to the whole length of the underpinning beam.
The intact relocation of three prominent building types will be discussed because a different underpinning approach is required for each type.

Lightweight timber structures with a timber joist floor
Small lightweight timber structures most commonly consist of concrete foundations under the outer walls or piles along the perimeter of the building. On top of the foundation there is a horizontal timber floor frame that is separated from the soil in the form of a crawlspace or cellar. These structures can withstand a certain deflection, so a steel latticework temporarily takes the place of the foundation. It keeps the building on a flat plane during the move. This latticework is temporarily and will be removed when the building is placed on its new foundations at the new site.

Openings are made into the foundations to insert steel beams under the timber joist floor. These beams are called the main beams and are placed perpendicular to the timber joists of the floor frame. Because of the cellar or crawlspace under the floor, additional excavation under the building is mostly not necessary. In the case of very light, one-story buildings, these main beams suffice to lift the building. Heavier buildings sometimes acquire more local supporting points. Cross-beams on top of and perpendicular to the main beam can cover the function of the floor joists. Eventually needle beams can be placed on top of and perpendicular to the cross beams under the outer walls, under internal bearing walls, and also under places with heavy structures like fireplaces. Stiff-back beams can be added to connect the needle beams to form a grid. (Goblet, 2006) This leads to a network of steel beams where loads from the upper structure are transferred to an array of needle beams and eventually to the moving devices as seen in Figure 1.

To provide a tight connection and minimize deflections, narrow boards are placed between the upper structure and the beams where gaps occur. Some corporations even advocate to prestress or preload the steel beams to compensate for deflections before the weight of the building is placed on the beams. (Goblet, 2006)

Figure 1: Steel support frame on dollies (Wolfe House & Building Movers, 2016)

Legend: (A) Rocker beam; (B) Main beam; (C) Crossbeam; (D) Needle beam

Structural-grade-beam-and-slab foundations

Slab-on-grade floors also serve as a foundation and are typically designed to be continuously supported by the underlying soil. In the case of small slab-on-grade buildings the condition of the foundation slab and the ground conditions may determine if the building will be detached from the slab, or if the building will be moved with the slab attached.

The building can be detached when the condition of the slab is bad so the building can be placed on a new foundation at the end of the move. By detaching from the slab, the weight of the building will strongly decrease. It also implies that the underpinning system will have to compensate for the loss in lateral stability and rigidity, normally provided by the slab. In contrast with the steel beam underpinning for timber floor buildings, holes are made in the walls above the slab to insert the steel beams. Band board beams or angle irons are attached to the wall bottom and connected to the main beam. The building can be lifted from the slab if these steps are executed.

Moving the building with the slab attached is generally more difficult but has some important advantages. First of all, the ground floor does not need to be cleared. It also simplifies or even avoids internal shoring and bracing.
Since the slabs are continuously supported by the underlying soil, careful planning for the systematic removal of the soil and placement of support under the slab throughout the process is needed. In practice, tunnels are carefully dug, and steel beams are inserted. Eventually an array of steel crossbeams with close interval is formed. These beams take over the continuous support of the soil. Main beams are placed under these crossbeams so the structure can be lifted.

Grade beam floor buildings follow a similar workflow with the only difference that not necessarily the whole slab has to be supported, but only the grade beams. Figure 2 shows the workflow when the slab is strong enough to be directly lifted without steel beam support.
(Cushman, 2018; Goblet, 2006; US Army Corps of Engineers, 1990; Wolfe House & Building Movers, 2020)

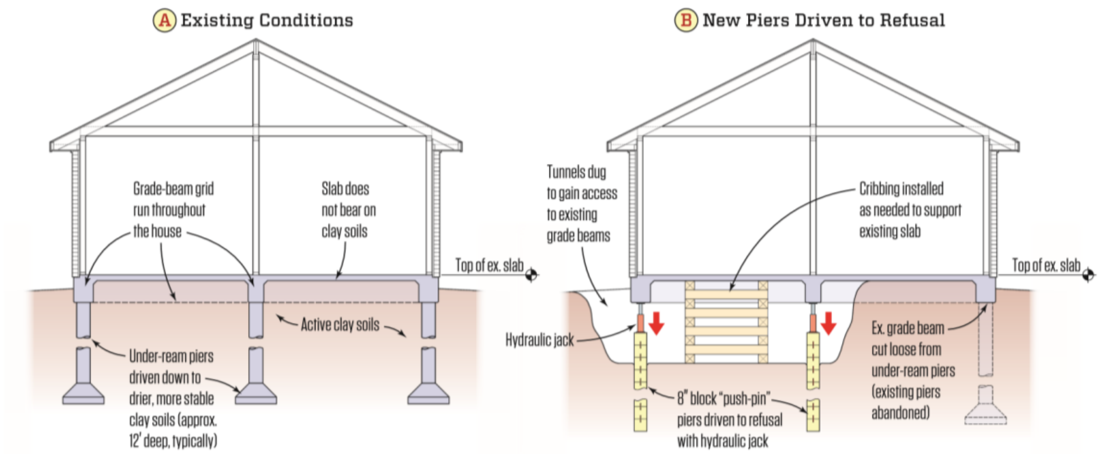

Figure 2: Elevating a Slab home (Cushman, 2018)

Heavy monolithic building structures

Heavyweight monolithic buildings are mostly underpinned with concrete, so a rigid concrete structure is formed. Heavy bearing wall masonry buildings are mostly underpinned with concrete beams.

There are two main concrete underpinning modes: the single-side beam mode (Figure 3) and the double-side beam mode. (**Fout! Verwijzingsbron niet gevonden.**)

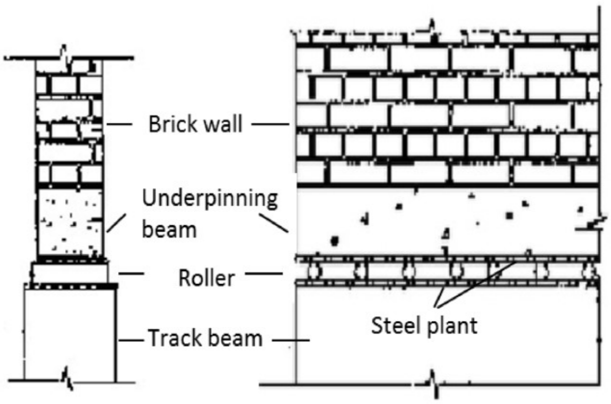

Figure 3: Single side beam underpinning (Lu & Wang, 2016)

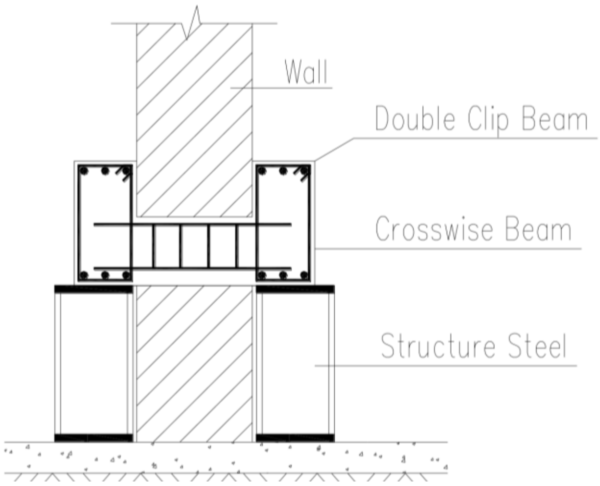

Figure 4: Double side beam underpinning (Xu et al., 2015)

In the single-side mode, underpinning is cast with the Pynford method. Several pockets are cut out of the bearing walls with saws, then steel or concrete so-called stools are placed in the pockets. These stools will support the upper structure during the cast of the underpinning beam. Once all the stools are in place, the remaining wall material between the pockets is removed to leave the wall supported on the pinned stools. The wall opening is then reinforced, covered with formwork, and filled with concrete. (Pryke, 1993) This technique is usually applied to masonry walls. This system has some large drawbacks compared to the double side beam underpinning. It requires a lot of labor and time to cut and fill the pockets in the walls. When buildings become very heavy the height of the beam will increase significantly since the single beam has to bear the loads, meaning a larger part of the walls has to be cut out.

In the double beam underpinning, cutting out the bearing wall is sometimes even not necessary. Since the strength of the underpinning comes from the side beams, the cutting height in the bearing wall is limited. In the case of masonry walls, small pockets are cut out and filled with reinforcement steel connecting the side beams as illustrated in Figure 4. Another way is to grout the part of the masonry wall that will connect the side beams. After that, holes are drilled and steel rods are inserted.
In the case of concrete walls, holes are drilled at a constant interval and steel rods are inserted. The surface of the concrete walls at the height of the underpinning is sometimes roughened to ensure a good connection between the new and old concrete. Because of the 2 side beams, a high rigidity and bearing capacity can be reached at a relatively small beam height.

To underpin a bearing column, a 4-sided wrapped underpinning joint around the columns with 2 underpinning beams and 2 coupling beams for the frame structure are preferred. The available surface to transfer the loads is very limited, compared to bearing wall underpinning. Therefore, high expertise is required to underpin bearing columns. The load transfer is provided by steel rods going trough the column, connecting the opposite underpinning beams. A good connection of the new concrete with the column is vital so roughing is recommended. Shear slots can also be made to provide an optimal connection as shown in Figure 6.

The underpinning beams are used as upper beams on the moving devices. Therefore, steel plates are placed at the bottom of the underpinning to bear the local compressive forces at the place of the connection with the moving device. (Guo et al., 2013; Lu & Wang, 2016; Song et al., 2018; Yue et al., 2017)

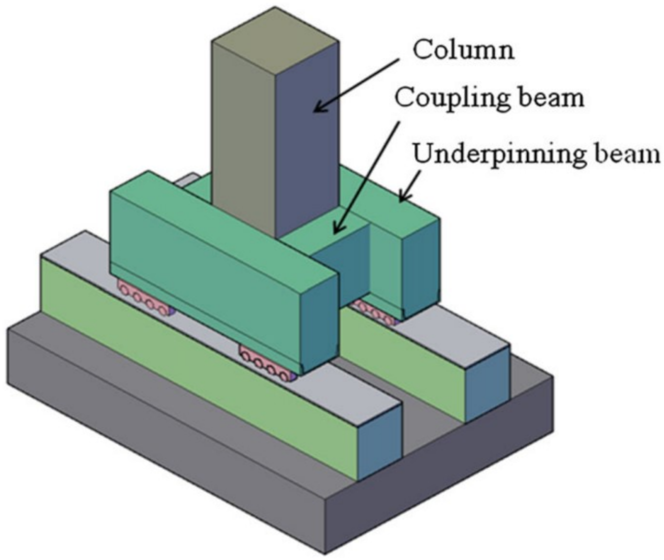

Figure 5: Isometric view of the our-sided wrapped underpinning joints (Yue et al., 2017)

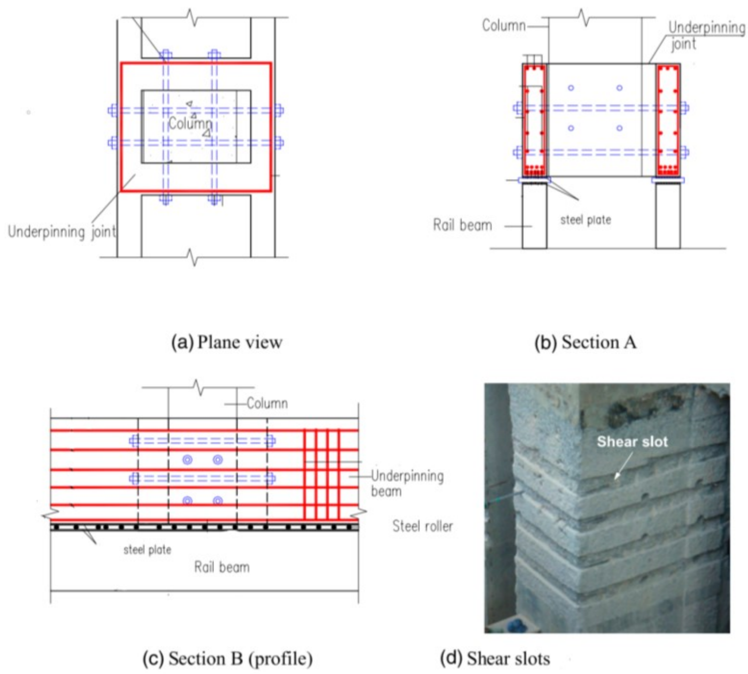

Figure 6: Column underpinning in plane and side view + shear slots (Guo et al., 2013)

4.1.3 Separation from the foundation

In the separation step the upper structure is separated from its foundation by cutting structure below the underpinning. The separation is an essential step to make the superstructure movable and in this step the bearing capacity of the underpinning system will be tested. The most commonly used techniques can be manual cutting, semi-mechanical cutting, and mechanical cutting methods. (Lu & Wang, 2016)

Wooden buildings are mostly connected to the foundation by bolts tightened with nuts, so the separation implies the removal of the nuts.

4.1.4 Lifting the structure

In the lifting step the upper structure is lifted from its old foundations. In most cases this step is necessary to create a workspace to install moving devices and tracks, and to remove foundation parts that may obstruct the move. In some cases, there is originally enough free space to install the moving devices so lifting is not needed. The used methods are similar to those used for shoring and seismic retrofitting of buildings.

The most commonly used and most recommended system is the Unified Jacking System (Emmert Structural Elevation, 2018) (Figure 7). The system is capable of safely and effectively making large irregular lifts. The unified hydraulic jacking system allows each jack to receive an equal volume of oil, no matter the weight or pressure, to raise the structure evenly leveled during the whole lifting process which ensures minimal cracking or distortion of the structure in the process.

The first step in the lifting process is to define the place, the amount and type of jacks used. The jacks have to be strategically placed under the underpinning structure to minimize the tensions in the underpinning. The number of jacks should be as many as possible because of the more supporting points, the lower the tensions in the upper structure. In practice the type and number of jacks are calculated on the full weight of the whole building.

Out of the study of the ground conditions, the bearing capacity of the soil can be derived. Based on these soil characteristics and the force each jack will receive, a proper foundation under the jacks can be designed. This foundation can go from simple wooden bed blocks under the jack to even foundation poles under a steel-plated reinforced concrete slab.

When all these preparations are done, the building can be lifted. It is preferred to firstly slowly approach the force on the jacks equal to the pre-calculated lift-load derived from the estimated weight of the building. With the help of moving sensors, the actual force to lift the building can be captured. From these results, the jacks can eventually be readjusted to the actual loads. This first lift is also an opportunity to test the strength and rigidity of the underpinning structure. (Brand & Werner, 1997) After that first test, the actual lift can be carried out.

When the building is to be lifted to a level higher than the jacks can perform, the lift is carried out in several cycles. Once the jacks reach their maximum level, cribbing is installed under the structure. Cribbing is a temporary supporting structure and mostly consists traditionally of hardwood timbers stacked in an interlinking network. Nowadays interlocking polymer beams are preferred over wooden beams because of the higher stability and because they do not splinter or absorb fluids. It should be noted that cribbing also needs a proper foundation. After installing the cribbing, the jacks can be retracted and raised to start the second lift, and so on.

Eventually when the building is on its proper level, the jacks can be removed and the work under the structure can be carried out. When the moving devices are installed, the building can be lowered by the jack until the moving devices fully support the loads. Several modern moving devices are provided with built-in hydraulic jacks like the newest dollies and skids for example. That means the devices can lift the building on their own. (Peltola, 2008)

When dealing with lightweight structures like wood frame buildings the lift is sometimes even carried out by a crane at four points and directly placed on a trailer. (Moir, 2006)

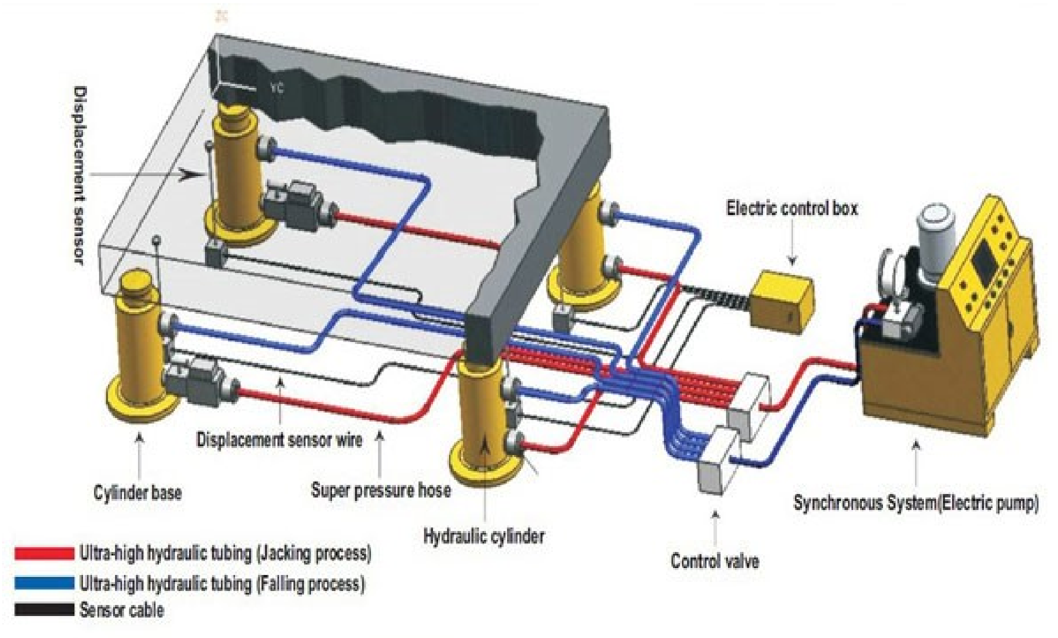

Figure 7: Unified Jacking system (Emmert Structural Elevation, 2018)

4.1.5 Translocation on a moving device

The moving device will make the shift of the upper structure possible. It must carry the whole weight of the building during the move. The selection of the moving device is dependent on the distance, underground, and weight of the building. The place of the moving device(s) should be determined with great care. A horizontal force is needed to physically move the building, which can be applied in several ways.

wheel plug-fuse

These devices consist of a specialized trailer that is put under the lifted structure. In order to transfer the weight of the building to the device, the structure can either be lowered until it is fully supported by the device or an integrated hydraulic system in the moving device is lifted until it fully carries the building. The wheel plug-fuse method is suitable for building relocation projects with small to medium weight and long moving distance. Heavy buildings normally cannot be moved on these devices, not because of the limited carrying capacity of the devices, but because of the carrying capacity of the soil. When these devices operate on bare soil, it is preferred to flatten and compact the soil to ensure a smooth move. When the characteristics of the soil still are not good enough, steel plates can be put along the route to distribute the loads coming from the moving devices to a bigger area. This is the only type that can be used to move a building on public roads. Several types exist, each with their range of use.

Flat-bed trailers are suitable for building relocation project with a small load and long moving distances. When the load is too big for a trailer, self-propelled trailers (SPT) are used. These trailers are similar to a conventional trailer, but with a motorized module on the front.

When the dimensions of the structure are too big to be transported on the two previous types, heavy load trailers can be used. These trailers are a frame with a large number of axle lines and can be connected with beams or coupled as modules to create larger trailers. Because of its simple concept and high price-effectiveness, these trailers are preferred to transport large structures over long public roads.

On-site transportation with limited distances and high movability is generally carried out by Self-Propelled Modular Transporters (SPMT). The SPMT is also used when previous transporters cannot cover the whole building. Each module consists of 4 to 8 axle lines and can be fitted with an own engine and control system. Due to the high variety of combinations, each module can be placed precisely under a bearing point, so the modules can be added until every part of the building is properly supported. The modules can be connected to form large platforms on wheels with a possibility of 360-degree steering. The newest SPMT's are provided with a hydraulic system that can adjust unbalanced deflections between multiple supports automatically when it works in unison with the other modules. This is feature is very important to provide a constant horizontal position of the structure when the unavoidable irregular settlement of the soil takes place. (Mammoet, 2020)

Sliding

The sliding method is used to relocate very heavy buildings that will be moved horizontally over a short distance in a straight line or even in a constant arc over a track beam. In the sliding method, the superstructure moves through the relative slip between the moving device and the lower track beam. The track normally consists of a metal track fitted with PTFE (Teflon) blocks. The load is directly transmitted from the device to the track, so the supporting beam under the track should be strong enough and/or have strong foundations to bear and spread the load.

There are two main types of sliding devices: traditional type, hydraulic controllable type. In traditional type, a stainless-steel block is applied to the bottom of the upper-structure and serves as a slider. The traditional type needs an external horizontal force to initiate and retain the shift. Different from it, the hydraulic controllable type, also called a skid-shoe, utilizes an internal force controllable jack as sliding bearing, which can be locked into a pair of slots fitted on sides of the skidding track. This type is computer-controlled and can effectively avoid the influence of orbital roughness and slider failure. Several skid-shoes can be connected to perform a simultaneous move. (Lu & Wang, 2016; Mammoet, 2020)

The advantages of the sliding shift are that the move is smooth and shock resistant as well. The combination of the Teflon on the stainless steel with lubricant results in very limited friction (μ appr. 10% of the vertical load) (Huaying & Ruisong, 2015), allowing to move very large loads with a relatively small horizontal force. On the traditional devices of sliding shift there is the problem of a big horizontal force applied to the underpinning structure to move the building. This causes an additional traction force (when the structure is pulled) or compression force (when the structure is pushed) to the upper structure. To solve the problem, an internal force controllable sliding bearing (skid shoe) was developed, dividing the horizontal force to the multiple skid-shoes and not on the upper structure. Due to its high cost and the requirement of a computer control system, it is suitable for large load and high-rise buildings translations. (Huaying & Ruisong, 2015)

The shape of a skid strongly depends on the weight it has to bear. Mostly, the bigger the load, the higher the skid, and thus the higher the building must be lifted to install the skid between the track and the upper structure. Modular low height skids also exist. These skids have a large surface and can be coupled to cover the whole length of the upper structure beam. This has the advantage that there are practically no deflections of the upper beam and the tensions in the upper structure underpinning beam are more uniformly transferred to the track beam.

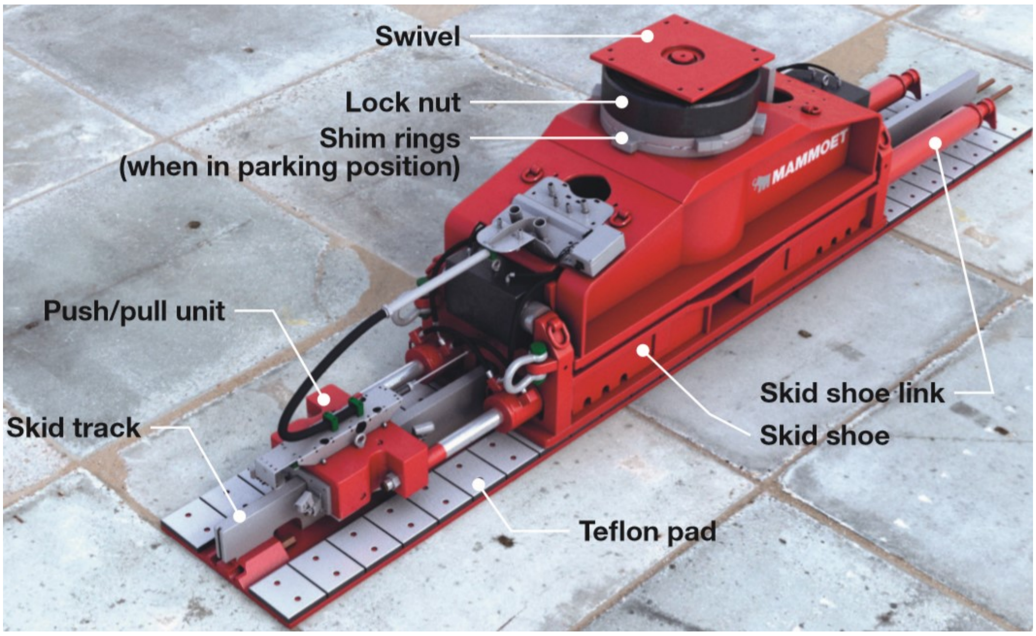

Figure 8: Hydraulic skidding system (Mammoet, 2015)

Rolling

The rolling method is generally applied in cases similar to those of the shift method; to horizontally relocate heavy buildings over a short distance in a straight line. In the rolling method, rolling cylinders are placed between the upper structure and the beam track. The roller consists generally of steel cylinder moving skates. The track beam can be a steel roll beam or a concrete beam with a steel plate on top.

The main advantage of rollers as a moving device is the very low friction coefficient (μ is appr. 5% of the vertical load), fast movement, and the low height of the device. In some cases, rollers can be installed on the track beam without lifting the structure. (Huaying & Ruisong, 2015)
Alike the sliding system, the horizontal force can either be directly applied to the rolling device by hydraulic jacks locked on the rail or else by an external pushing or pulling force on the underpinning system.

The distribution of the rollers can be divided into two classes: uniform distribution and local distribution as shown in Figure 9. In the uniform distribution the rollers are evenly distributed under the underpinning system. This system is normally applied under structures where loads are uniformly distributed along the whole length of the underpinning system. This causes limited internal forces and deflections in the underpinning beams and the loads are more equally transferred to the track beam. This system is therefore mostly applied on bearing wall structures but in some cases the uniform distribution can be applied under-frame structures. When the underpinning system under a frame structure is prestressed in a way like Figure 10, the tendons provide upward forces to the underpinning joints, so part of the column load is transferred to the midspan.

In the local distribution, the rollers are installed under the corresponding position of support components. This is mostly applied under structures where loads are not uniformly distributed to the underpinning, like frame structures. The local distribution leads to a more concentrated load transaction to the track beams. Therefore, the dimensions of the track beams are normally bigger when the local distribution is used to bear these more concentrated loads. (Huaying & Ruisong, 2015; Lu & Wang, 2016)

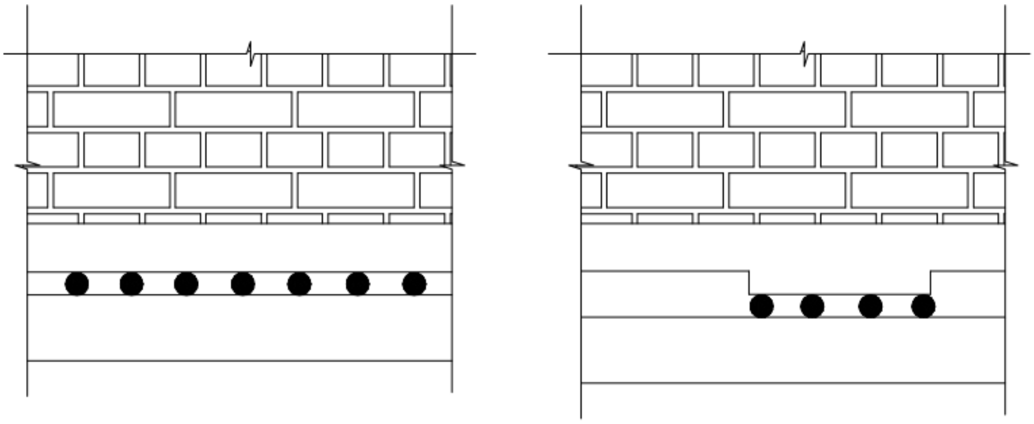

Figure 9: Uniform and local distribution of rollers (Huaing, 2015)

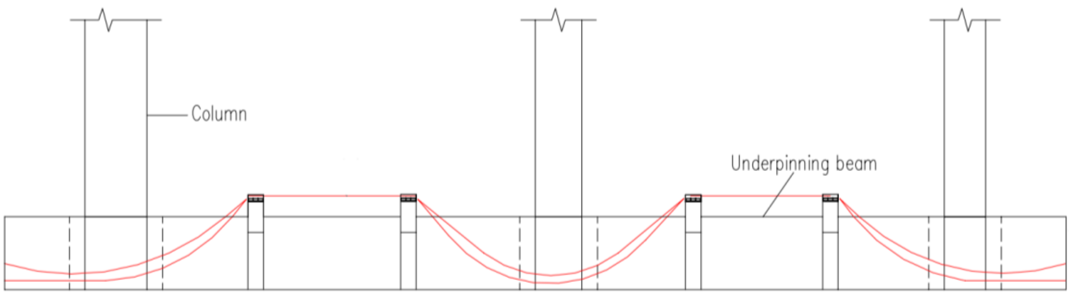

Figure 10: Prestressed underpinning beam (Guo et al., 2013)

Horizontal thrust mechanism

Once the superstructure is placed on a moving device, a force is needed to overcome the static friction force to move the building. As previously discussed, modern moving devices can be applied with an internal power unit to make the horizontal shift possible. Next to applying an internal force, there are two other options: pushing the structure or pulling the structure. In some cases, a simultaneous combination of the two is applied. To push the building forward, hydraulic or mechanical jacks can be used to apply force to the back of the structure. The other option is to pull the building with tendons or a jack from the front. (Lu & Wang, 2016) Normally a reaction frame is installed to distribute the horizontal forces to the structures as shown in Figure 11.

The pull system with steel tendons usually has higher efficiency and better stability than the push system, because the tendon pull system can provide a continuous pulling force along the track. The push system is discontinuous because the pushing jacks have to retract and relock to the track after each push, resulting in instability and low efficiency on long tracks.

The pulling system however produces tensile stresses in the horizontal underpinning frame which is generally disadvantageous to RC structures. Therefore, the push system is more favorable for structures with RC underpinning. To avoid tensile forces to RC structures by pulling, the pulling tendons can be installed to the back of the structure, running under of even through the underpinning structure to the reaction system, resulting in compression forces to the underpinning structure. (Guo et al., 2013) (Figure 11)

Pushing or pulling heavy structures creates a reaction force, which has to be taken on by a reaction structure. A steel interlocking track in the track beam where the hydraulic jacks can interlock for every push can be provided to several moving systems (Figure 8). In the case of rollers on steel beam tracks or the use of pulling tendons, a separate reaction structure will be built to take on the reaction forces as illustrated in Figure 11.

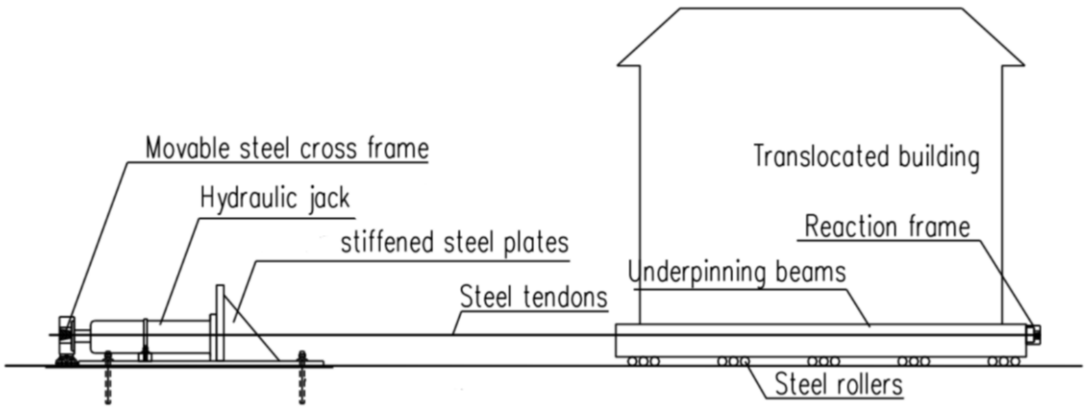

Figure 11: Pulling system with steel tendons fixed from the back of the structure to the reaction structure (Song et al., 2018)

4.1.6 Placement on the new location

Foundation

All preparations should be conducted on the new site to ease the process of putting the building in the right place. If the new foundations are already constructed, they have to be constructed in a way they do not obstruct the placement of the building to its final place. The problem with finishing the foundation construction before the full building relocation is that houses are not perfectly squared so the foundation sometimes does not fit the building. Therefore, when old or complex buildings are being moved, constructing the foundations after putting the building on its final place is preferred. (US Army Corps of Engineers, 1990)

Connecting the building to its new foundation

The connection method between the upper structure and the new foundation has a significant influence on the future use of the building. The new connection should provide structural safety to the upper structure and have a seismic capacity.

A common connection method is the secondary pouring connection which involves pouring concrete in situ between the foundation and the underpinning, columns, and shear walls. Before the concrete is poured, a rebar overlap between the upper structure and foundation has to be executed to ensure the reliability of the connection.

To improve seismic performance, a base isolation method can be carried out. In this method, an isolation layer is installed between the upper structure and foundation. The isolation layer can consist of rubber bearings, sliding bearing, or rolling bearing. This connection method is naturally more difficult and more costly than the common method. (Lu & Wang, 2016; Song et al., 2018)

In the case of buildings moved with a steel latticework, the placement on the new location can be considered as the reverse of the underpinning, lifting and separation process. First the building is translocated to its new location, then cribbing is placed under the structure. Thereafter the moving apparatus is removed, and the building is eventually being lowered or lifted to its final level. Finally, the new foundations can be built under the structure and the steel beams can be systematically removed.

In the case of buildings moved on an RC underpinning and an RC track, the underpinning and track are preferably integrated into the foundation of the building.

4.2 Complete disassembly

Complete disassembly relocation is the method where the building components are systematically dismantled, stocked, transported in/on trucks, and reassembled at the new location. This method is mostly considered as a last-resort alternative when an intact move is not possible. In most cases it is however the only method to transport a building over a very long distance along a route with spatial- and load limitations. In the case of moving small-size, ashlar or log buildings, or even rock-carved structure, disassembly is generally preferred. Due to the growing interest in circular construction presently, more and more new buildings are designed to be disassembled over time. The method is not suitable to move buildings made of rubble stone since it is almost impossible to associate the stones that are dispersed during the dismantling process with the same stones. (Kozlu & Dördüncü, 2019) Buildings in bad conditions are sometimes disassembled to inspect the scope of damage and it is also an opportunity to restore or replace damaged elements.

The biggest drawback to disassembly is the unavoidable loss of original plaster, fabric, mortar, and the high labor intensity. Next to that, damage to materials during the dismantling and wrong applications during the reassembly always occurs. Even if materials close to the original are used and applied with the original technique, the original appearance might never be fully reproduced. (Curtis, 1979; Goblet, 2006) The extend of loss depends on the condition and material type. Some buildings are therefore discouraged, and others encouraged to disassemble. Brick walls with strong Portland cement for example will have high damage when one attempts to separate the bricks from the mortar, but log buildings on the contrary have a simple structure allowing easy dis- and reassembly.
Because of the high grade of loss and damage, building relocation by disassembly results in the biggest loss to the building's authenticity. Since this method is mostly selected when the relocation distance is long, all the relations to the original setting will be lost too.

4.2.1 Building documentation

The first and most important preparation step is extensive documentation of the building. To avoid mistakes or wrong applications, one should always be able to check the documentation of the original state. Therefore the documentation should be as detailed as possible. A traditionally used tool is to apply a unique mark to adjacent components that will be separated during the disassembly. When all markers are applied, the building can be imaged and documented in detail. Last decade, a few emerging technologies and techniques revolutionized the accuracy and amount of documented information. Traditional methodologies of detailed documentation of structures required an on-site, labor-intensive, physical survey using electronic distance measurement devices with hand-held tools. (ResErections, 2020)

Laser Measurement and Imagery

Laser scanning provides a new approach to disassembly and reconstruction of buildings. Laser scanners have very high accuracy and detail because of the high density of measured points. Scanning is particularly suited to recording highly irregular surfaces such as timber frames and stonework. Individual components can be identified from the scan. When scans are combined with photogrammetry, brick, terracotta, or stonework can also be identified as individual components. The laser scanner captures a lot of information in a very short time. It provides the 3D location, orientation, measurement, texture, and color of the objects scanned. Based on the scan data, a model of the building can be rendered using specialized AEC software. (ResErections, 2020) This provides the possibility to rotate, enlarge, and interrogate the model on-site with an electronic device.
Although the price of a device and the software is quite expensive, the cost of a building survey is approximately 1/3 of the cost of manual methods. (ResErections, 2020)

4.2.2 Preparing the building

As the building will be dismantled, the structure does not need the level of reinforcements necessary in the intact move. However other types of reinforcements are applied to secure the stability of the building during the disassembly. Removing components can create instabilities that need to be compensated with structural bracing. A disassembly plan should be designed with guidelines concerning the chronological order of dismantling and safety on the site.

4.2.3 Disassembly

Building relocation by disassembly is intrinsically different from intact moving. The process has low technical complexity, but careful documentation and skilled execution are key factors to move the building successfully. The dis- and reassembly requires a lot of time and workforce, so the budget of the relocation has an impact on the care and time of the relocation.

Generally, the disassembly starts at the top of the building. Proper knowledge of the construction method and care is needed to successfully detach components from the building. Ignorance and fast workflow can cause a significant augmentation of damage to the building components. (Curtis, 1979)
During the dismantling, an efficiënt documentation system of the individual components should be worked out. Some companies provide each component with a tag containing various information and sometimes even a link with the 3D model. After granting information to the component, it should be stocked in the order needed for reassembly. Frequent photographic coverage is preferred to document techniques and materials that are only visible during the disassembly. Damaged elements should also be documented so repairs or replacements of these components can be carried out before the reassembly starts. This to properly facilitate the reassembly.

4.2.4 Transport

Logical stocking of the components is key to a successful reassembly. Several components of the same building part can be stocked together on a pallet. The components should be protected from damage during the transport. Damaged elements can be taken out of the pallets to find proper replacements. When all pallets are prepared and tagged, the pallets can be loaded on a trailer in a logical order.

4.2.5 Reassembly

A big advantage of relocation by disassembly is the possibility to improve the building easily without changing the external appearances. Modern construction techniques can be applied during the reassembly to improve and adjust the building to the modern requirement in terms of seismic resistance, thermal insulation, acoustic performance, etc. Therefore, a clear determination of the preservation grade should be made. In the case of historic buildings, it is mostly preferred to reassemble with the original technique and without any augmentations. Other buildings only require having the same appearance as the original which implies large freedom and during reassembly.

The reassembly happens the same way buildings are constructed, with the only difference of careful selection of the building components. The damaged and lost materials during the move should be recreated in a way it resembles the original.

4.3 Partial disassembly

Partial disassembly can be considered as a method of building relocation that is a hybrid between an intact move and complete disassembly. It is generally applied to simplify the relocation or when there are spatial and weight limitations along the route. The structure is divided into large workable pieces, combining the favorable aspects of the previous two techniques. (Curtis, 1979) Besides, relocation time, labor costs, and fabric loss are minimized. The disassembly grade can strongly vary. The disassembly can go from dividing the building vertically into several intact sections to dividing the building by their elements like entire walls, roof parts, etc. The way of partial disassembly strongly depends on the type of structure. Therefore, two main methods of partial disassembly are discussed.

Vertical separation into intact segments
Raising and moving very large structures is sometimes not possible or very complex. To simplify the move, the building can be vertically divided into manageable segments. As discussed in the preparation phase of the intact relocation, adjacent structures to the main building that are not structurally unified are advised to separate during the move. Logically, reinforcements and bracing must be applied to compensate for the structural loss caused by the separation. Balloon frame buildings are the easiest to vertically separate since only cuts between studs must be made. In the case of masonry buildings, whole sections of stones need to be removed. Rafter roofs are easily divided by cutting between rafters or joists. Purlin roofs are cut closely alongside the rafter. Platform frame and historical timber frame are discouraged to separate vertically (US Army Corps of Engineers, 1990)

Separation into workable elements
Another way of partial disassembly is to divide the structure into workable elements with dimensions and weight suitable for transport on normal trailers. Platform frame buildings for example are relatively easy to divide into big pieces.
Another reason to horizontally divide the building is because of limited overhead clearance on the route. Removing the roof, chimneys, or even a whole floor level my be needed. (Curtis, 1979)

4.3.1 Disassembly

When cutting is needed, a careful determination of the cutting line must be made. The cut must minimize the damage to the supporting structure. Therefore, cuts through hallways are preferred if possible because these places have a minimum of intersection floors and internal walls. Bracing should be placed at locations where structural elements are cut to provide rigidity to the section. In the case of dividing into intact sections, the openings made by the cut should be covered to protect the interior from weather damage.

4.3.2 Reassembly

The design of the foundations needs extra attention when structural floor planes or floor beams are cut into sections. It may sometimes be difficult or impossible to reunite these structural sections into one rigid whole. Therefore the foundation sometimes has to be designed to support every section separately.

Wooden sections are easily reassembled by adding connecting timber between the sections or just connecting the sections with screws. The complexity of the reassembly strongly depends on the location of the cutting line. Masonry building sections can be reassembled by rebuilding the bricks that were removed during the disassembly, resulting in an intact wall without cutting line. In this case the faithful reproduction of the original mortar is necessary to give the wall its original look.

5 CASE STUDY: TAVARA-ASEMA BUILDING IN TAMPERE

5.1 Introduction

The Tavara-Asema building is an old cargo station next to the railway in the Tammela district of Tampere. The construction of the warehouse building was a response to the increasing transport and storage needs of the city. The function of the cargo station was to act as a space for the reception, dispatch, and temporary storage of goods. It was designed by Bruno Granholm, Chief Architect of the Finnish Rail Administration, and was completed in 1907. The green painted brick office, which will be relocated, is designed in Art Noveau style. Attached to the brick office building were several steel and wood warehouses and canopies, these structures have already been dismantled. The cargo station's layout is protected.

History of the building

During the Civil War, red prisoners were held at the goods station and one of the corrugated tin sheds still has bullet holes. The prisoners were also reportedly executed, both at the cargo station and in the nearby dismantled magazines.

Some of the wooden structures were destroyed during the Winter War bombings.

In the 2000s, the building has housed the office, storage and training facilities of the Tampere Opera.

Only the brick office part has been preserved in its original form. Adjacent structures were demolished.

Currently (12/05/2020), the preparations for the move of the cargo station are being carried out and the demolition of the Morku building has started.

5.1.1 Reason for relocation

The old cargo station is one of the last buildings that is directly adjacent to the East side of the railways (Figure 12). That causes the Ratapihankatu road, which runs next to the East side of the railway, to make an arc around the cargo station. Ratapihankatu connects the eastern junction of the Rantaväylä tunnel and the Viinika roundabout. The flow of traffic on the street is central to the functionality and attractiveness of the downtown transport system. The area of the station is currently developing very strongly, which will result in a lot of new residents moving into the area, creating new jobs, and significantly increased activity and traffic in the area. The current situation will cause disruption or, at worst, slow down and hinder the development, growth, and job creation of the area.

The transfer of the cargo station to the location of the Morku building site enables direct alignment resulting in better traffic transit and safety to cyclists and pedestrians. (Nikkilä, 2018)

Figure 12: Ratapihankatu street (current situation) (Högmander & Saarikoski, 2018)

Figure 13: Old position (shaded) and new position (pink) of the cargo station and the straightening of the Ratapihankatu (Pesonen, 2020)

5.1.2 Qualification of the building as worthy of preservation

The situation of the tavara-asema building is quite delicate because there are two historical buildings threatened at the site: the Morku building and the tavara-asema. The Morku building is a wooden building, constructed at the same time as the tavara-asema and served as a union building of the railway company. Relocating the tavara-asema building is only possible if the Morku building is demolished. Another option was to preserve the Morku building and to demolish the tavara-asema building. Either way, to straighten the 'Ratapihankatu', one of these two historic buildings had to be demolished. (Airo, 2017) To decide which of the two buildings must be preserved, a qualification has been made.

In 2015, the city council marked the tavara-asema building as protected, partly because of a petition with 8500 signatures opposing demolition in 2013.

The protection was granted because the freight station is part of Tampere's history. Among other things, red prisoners have been kept in the warehouse connected to the cargo station. These factors made the tavara-asema more worthy of preservation than the Morku building. Because of the bad condition and presence of asbestos, an extensive renovation is needed, which includes a complete replacement of the roof and internal structures. Therefore, only the exterior brick walls are to be fully preserved. (Tolonen, 2019)

Figure 14: Renovated cargo station after the move, respecting the old look and building methods (Nikupaavo-Oksanen, 2020)

5.1.3 Development of the planning process

Since the late 2000s, the building was under threat of demolition. This led to the creation of the Pro tavara-asema movement, who plead to preserve the building. The preservation of the station was also advocated by Pirkanmaa Provincial Museum and The Center for Economic Development, Transport, and Environment. (Torkkola, 2013)

In November 2013, a petition with 8500 signatures opposing the demolition, was handed over to the city council. This led to the protection of the building in 2015.

In October 2016, the Tampere City Government decided that the transfer of the cargo station would be too expensive, and instead of the transfer, the future of the area would be decided by changing the town plan.

Tampereen Tammelalaiset ry submitted a proposal for the protection of Morku to the Pirkanmaa Center for Economic Development, Transport, and the Environment (ely) in January 2017. The association proposed the protection of the building under the Building Heritage Act.

The Ely Center rejected the protection proposal in April 2018. The Tammelans of Tampere appealed the decision to the Ministry of the Environment.

In the summer of 2018, the Tampere City Government decided that changing the town plan with its probable appeal processes would take too long, so returned to the previous relocation plan and the plan preparation was suspended.

To cover the relocation costs, it was decided to organize a competition in which an operator who undertakes to renovate and develop operations in the old buildings will be able to build adjoining business premises.

In the 2019 budget, 3.2 million euros was set aside for the transfer of the cargo station. After the financing was confirmed, the procurement procedure was restarted, and Kreate Oy was selected as the contractor with a bid price of 2.68 million euros. (Tolonen, 2019)

Ely forbade the demolition of Morku until the fate of the defense proposal was legally resolved.

The Ministry of the Environment rejected the association's appeal in March 2019. The Tampere residents of Tammela continued to appeal the decision of the Ministry to the Hämeenlinna Administrative Court.

Currently (12/05/2020), the preparations for the move of the cargo station are being carried out and the demolition of the Morku building has started.

5.2 The physical condition of the building

The 4,000 to 5,000 tons cargo station is in poor condition, especially the roof and the internal structures. The wooden floor structures have collapsed in time and were reinforced several times but contain asbestos.

5.3 Relocation process

5.3.1 Preparing the building for relocation

Due to the poor condition of the structure and the presence of asbestos, the roof and internal structures of the building will be demolished to provide safety during the move. The roof of the building will later be rebuilt at the new location to resemble the look and construction methods of the old building. (Pesonen, 2020) There are three other reasons to demolish the roof and the internal structures. (i) The building will be much lighter and a lot of free space will be created. This provides an easier execution of the process, especially the piling for the track beams. (ii) There is not much space on the site so all free space can be used.
(iii) Without the inner structures, there is a big space, providing opportunities for later development.

Figure 15: Building before and after preparation works (Nikupaavo-Oksanen, 2020)

Structural reinforcement is provided in the form of wooden frames in the wall openings. The building will be moved by individual skid-shoes working together to provide an equal move over the whole structure. Because of the absence of any internal horizontal supporting structure and small chances of unequal movement of the skid-shoes, a network of horizontal steel trusses is placed between the opposing walls to form a rigid horizontal frame. (Figure 16) (Hakanen, 2020)

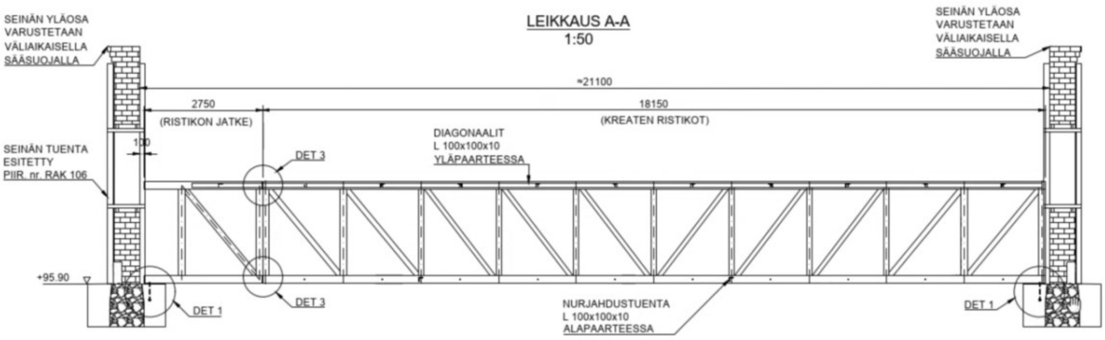

Figure 16: Steel truss reinforcement: side view

5.3.2 Underpinning of the walls

The double-sided concrete underpinning will be used in this project.
When the foundations became visible during the excavations, 2 different foundation types were distinguished (Figure 17). The southern foundations are big stones without any mortar or concrete. The northern foundations are RC beams. The underpinning of the foundations is carried out in following order: first the loose stones of the southern foundations are grouted to form a strong entity, then the two RC side beams are cast in situ to the foundation. When these beams are at strength, holes are drilled through the beams and foundations. DYWIDAG or GEWI steel bars are inserted in the holes. These bars are prestressed before the rest of the holes are filled with grouting, resulting in a horizontal compression force of the to side beams to the foundation. (Hakanen, 2020)

Figure 17: Loose stone foundation (left) and RC beam foundation

5.3.3 Lifting of the structure

Because of the high weight of the structure, the lifting jacks have to be placed on a supported platform. This platform consists of a 500mm thick RC slab supported by 4 140x8mm steel piles. A total of 13 hydraulic jacks will be installed next to the place where the 13 skid-shoes will come. This position of the jacks is chosen so the supporting points during the lift and the move are not so different, resulting in a simpler design of the underpinning beams. The supporting points are logically corner points and midspan points with a maximal distance of 10m in-between. The cargo station will be raised by 1400mm to make way for the cast of the track beams and to place the skid-shoes. (Hakanen, 2020)

5.3.4 Translocation on a moving device

In this project, the sliding method has been chosen. 9 RC beams (500mm thick and 1000mm high) will serve as track beams. The track is diagonally compared to the wall orientations. The 9 track beams were carefully designed so that the 13 skid-shoes could be placed on it. Soil research showed that some silt layers can cause deformations. To prevent these deformations, 10m long piles were drilled in the ground at a close interval to support the track beams. (Hakanen, 2020)

5.3.5 Placement on the new location

After being moved 28 meters to the east and then 2.5 meters to the south, the building will reach its new location. The new RC foundations will be cast before the move. The track beams intersect the new foundations, so cutouts are provided. Once the building is in place, the vertical hydraulic jacks in the skid-shoes will lower the building until there is a gab of 50mm left between the new foundation and the underpinning beam. This gab will be grouted to ensure a good connection between the two concrete elements. (Hakanen, 2020)

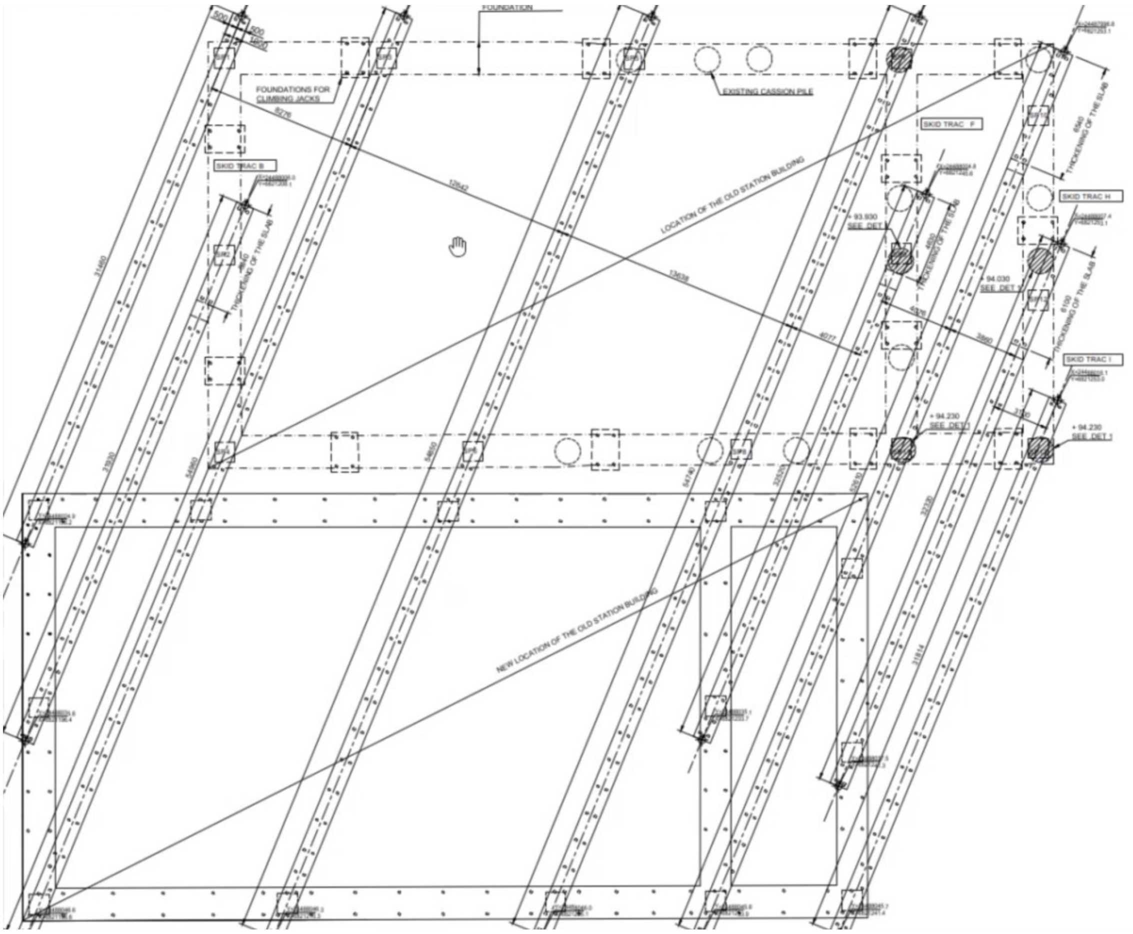

Figure 18: Plan view of the original location (dashed lines), the new location (full lines) and the track beams

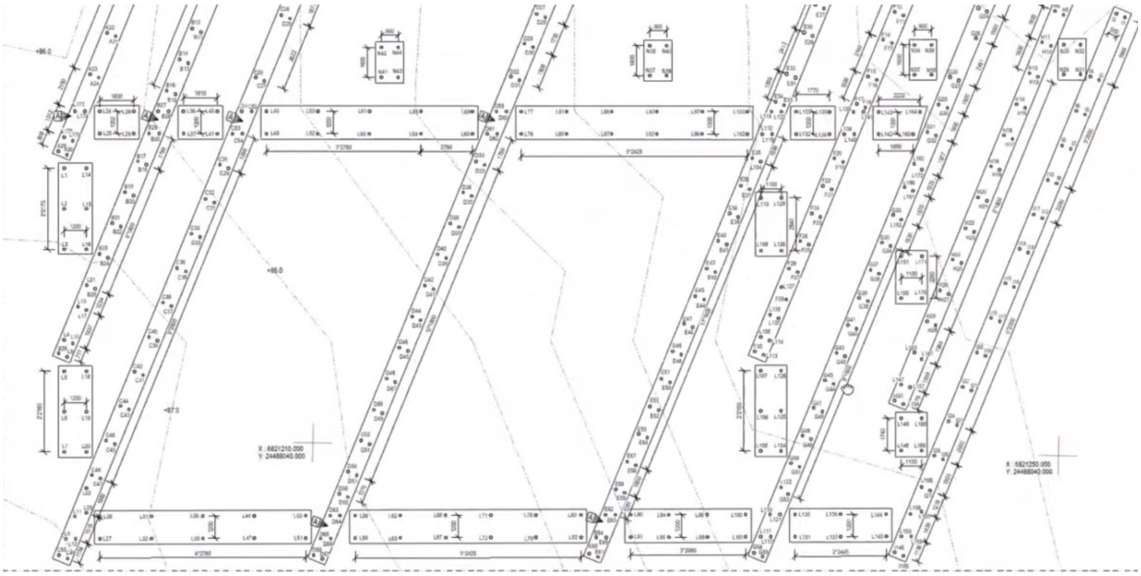

Figure 19: Plan view of the new foundations and intersecting tack beams at the time of relocation

6 DISCUSSION

1. Building relocation has become a valid preservation method to historically significant buildings, but should only be used as a last resort when all other preservation options are excluded.
2. Due to the growing awareness of the government and the public about building preservation, a budget is more easily acquired for the mostly very expensive option of relocation.
3. New techniques and specialized companies can make building relocation of all types and sizes of buildings an economic alternative to demolition and construction of a new building.
4. Building relocation is a valid method to solve modern problems and there is a potential to apply it in other cases.
5. The practice of building relocation varies strongly in different continents. In North America there is a long tradition of moving buildings, mostly because of the lightweight building types. Therefore, there are a lot of small enterprises specialized in the relocation of simple buildings. The steel beam underpinning technique is frequently used in North America.
   Building relocation in Asia and more specifically in China was in the past only reserved for small historic buildings. Due to fast urban developments in the 1990s, the structural moving evolved fast due to the tight participation between Government, universities, and businesses. Therefore, these days very large buildings are being moved with new techniques. (Moir, 2006)
6. The methods for building relocation are mostly adapted from similar engineering standards and practices like slide-in bridge construction or heavy equipment relocation. Consequently, the use of these techniques is not always suitable for fragile (historic) building relocation. Therefore, the selection of a proper contractor and the right application of these techniques to (historic) buildings is vital for the success of the relocation.
7. Building relocation fits in well with the circular construction model. As being an alternative to demolishing, the building is being recycled. The growing interest in modular building and the construction for eventually later disassembly will allow simple moves and disassembly to repurpose materials.

8. Structural monitoring during building relocation is presently barely performed but is increasingly emerging as an efficient approach toward verifying support for the preservation of historic buildings. It helps to evaluate the effect of the translation on a building and can serve as a model to determine the best plan for future translocations of historic buildings needing more stability and protection. (Zhang et al., 2019)
9. The tavara-asema project proves that the demolition of historic buildings because of economic planning is not without public and political resistance. Therefore, the preservation and relocation of the tavara-asema became a priority, despite being the most expensive alternative.

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APPENDICES

Appendix 1. Figures