Delivery estimation for building projects

Development of a program to estimate delivery schedules

Helena Billing Clason & Nils Resvik

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Lund University, Faculty of Engineering, LTH
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Lunds Tekniska Högskola
Institutionen för byggvetenskaper
Box 118
221 00 Lund

Phone: 046-222 74 21
Fax: 046-222 44 20
Homepage: www.bekon.lth.se

Preface

This thesis constitutes the final part of the Master of Science program in Civil Engineering at the Faculty of Engineering, Lund University. The thesis scope has been adapted to the time limit of 20 weeks full time studies which equals 30 ECTS credits. The work process started September 12 and was finished March 7. The research has been performed at the consulting company Prolog Bygglogistik and the thesis has the purpose of helping Prolog Bygglogistik AB in their future projects.

We would like to thank our tutors Anne Landin at the Division of Construction Management, Lund University and Joakim Reslow at Prolog for their commitment and important opinions about our project.

Helena Billing Clason   Nils Resvik

Lund, 7th of March 2012

Abstract

Title: Delivery estimation for building projects
- Development of a program to estimate delivery schedules

Authors: Helena Billing Clason
Nils Resvik

Supervisors: Anne Landin, the Division of Construction Management, Faculty of Engineering, Lund University.
Joakim Reslow, Prolog Bygglogistik AB.

Background: There are usually many contractors involved in a construction project creating a large number of deliveries with varying character which makes delivery planning difficult. The building project Bo01 in Malmö is one example of a project where major delivery problems occurred from congested roads due to inadequate planning. Problems could probably have been avoided if a delivery schedule would have been developed at an early stage of the planning process.

Problem: Currently there is a lack of standardization when it comes to estimating deliveries to future construction projects which lead to difficulties in planning delivery schedules in a beneficial manner.

- How can delivery schedules be estimated early in a construction project?

Purpose: The purpose of this thesis is to enable for a qualified estimation of delivery schedules for future construction projects by developing a computer program.

Result: A program was developed to estimate delivery schedules for construction projects. For a building project described by size, basic design and time schedule a delivery schedule can be estimated including number of deliveries, type of delivery vehicle and construction phase for the delivery occurrence.

Keywords: Building material supply, Construction site deliveries, Excel program, Building project

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List of abbreviations

Vehicle abbreviations

CT –	Concrete truck
DT –	Dump truck
LT –	Light truck
NT –	Normal truck
TwT –	Truck with trailer

Building abbreviations

Apt –	Apartment
BA –	Building area. *Area of the foundation.*
GFA –	Gross floor area. *Total area of all floors.*
SA –	Slab area. *Equals (GFA – BA).*
Exc –	Excavation
Fl –	Floor
Bd –	Building

1 Introduction

In this first chapter the reader is introduced to the research scope. The background results in a problem, which form the basis for the research purpose. Further are the delimitations of the study presented together with an example of how the program is intended to be used and finally the disposition of the thesis is presented.

1.1 Background

Construction deliveries represent one third of the total transported weight in Sweden and is thus the largest transportation sector in the country[1]. It has been shown that the efficiency of transports in Sweden is slightly lower than in other industrialized countries[2] and facts indicate that the construction transportation costs are high and it is possible to reduce them[3].

A key feature for a competitive construction company is the use of material administration strategies, which includes planning, management and control of logistics[4]. The basis for cost savings and improved efficiency are created during logistical planning of a project[5]. Deliveries are an important part of logistics, since it is the final step in the supplier's supply chain and the first in the construction site supply chain. If there has been any previous interference at the supplier or at the construction site, the deliveries are often used as a buffer to adjust the errors. Therefore, deliveries require close attention and planning to function optimally[6]. However, there are shortcomings and among those who works at construction sites two-fifths believe that more than one of four production disruptions is caused by problems with deliveries[7].

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[1] Åkerier.se, 2012. *Typer av transporter.* [Online] Available at: http://www.åkerier.se/typer-av-transport.html [Accessed 19 02 2012].
[2] Hansson, F., 1999. Materialadministration med datorstöd i byggprocessen. Lund: KFS i Lund AB.
[3] Jarnbring, J., 1994. *Byggarbetsplatsens materialflödeskostnader*. Lund: Institutionen för teknisk logistik, LTH.
[4] Hansson, 1999
[5] Jonsson, P. & Mattsson, S., 2010. *Logistik*. Lund: Studentlitteratur.
[6] Hansson, 1999
[7] Nicander, O., 2009. *Logistik i byggprojekt*, Lund: Lund University.

A complication with the construction industry is that project sites are temporary work places[8] and each project face new premises and in many cases unique conditions. The specific conditions must be handled[9] which requires unique logistical planning at each new project[10]. Also, buildings are complex structures with several components which imply a large number of contractors involved. As various contractors work on the site at the same time, there is often a large number of deliveries with varying character taking place. Hence, deliveries to construction sites are difficult to plan[11].

Despite the knowledge of problems with deliveries and the complexity of building projects, delivery planning is in the current situation inadequate[12]. At the building project Bo01 in Malmö major problems occurred with deliveries due to congested roads. The awareness that these problems could arise were low and problems could probably have been avoided if a delivery schedule would have been developed at an early stage of the planning process. Based on a delivery schedule, the project time schedules could have been adjusted in order to reduce the highest traffic loads and adapt delivery routes for the increased traffic[13].

1.2 Problem Formulation

Currently there is a lack of standardization when it comes to estimating deliveries to future construction projects which lead to difficulties in planning delivery schedules in a beneficial manner.

- How can delivery schedules be estimated early in a construction project?

1.3 Research Purpose and Objectives

The purpose of this thesis is to enable for a qualified estimation of delivery schedules for future construction projects by developing a computer program.

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[8] Jarnbring, 1994
[9] Hansson, 1999
[10] Jarnbring, 1994
[11] Hansson, 1999
[12] Reslow, J. *Supervisor meeting at Prolog Bygglogistik AB* (10 10 2011).
[13] Brisvall, J. & Persson, J., 2000. *Bygglogistik i samband med Bo01 i Malmö*, Lund: Lunds Tekniska Högskola.

The specific objectives for the features of the program are:

- To estimate the number of deliveries to a construction site, in what phase the deliveries will occur as well as define the types of delivery vehicles.
- To be usable early in the construction planning stage.
- To be user-friendly and easy to develop.

1.4 Scope and Limitations

The computer software used for development of the delivery estimation program is Excel. Excel is chosen since it is a user-friendly and wide-spread program and thus accessible for many users. The research will focus on developing an Excel program that produces a quantitative result. The report will present and explain the data and the process used to develop the Excel program.

The research will be limited to new construction of apartment buildings with a concrete frame, since it represents a common type of construction projects in Sweden. Other building types and reconstruction projects are left out of this study since they would largely increase the scope. The research will also exclude logistics and delivery handling *inside* construction sites, to benefit the focus on estimating deliveries *into* the sites.

1.5 Example – usage of the program

The purpose of the study as presented above is in the following described through an example in order to explain the practical use of the delivery estimation program:

A company or a municipality is planning a new area in a city, which will consist of six different apartment buildings. The basic specifications are known for each building project and a schematic time schedule has been developed. Given what is known for each building project, the Excel program will estimate how many deliveries and what kind of deliveries will occur as well as presenting when in the projects they will occur. Based on the results for the individual projects it is then possible to estimate the total deliveries to the entire area.

The start date and general time schedules of the different projects can also be changed with respect to each other. This can be done in order to investigate how planning of the construction project affect the delivery schedule. The time-plan can be optimized to avoid numerous deliveries at the same time period, which may imply logistical problems at the construction site or high traffic loads at adjacent roads.

The estimated delivery schedule can then be used when planning the construction site logistics. The required number of unloading places, the routes at the site upon unloading and unloading methods can be planned at an early stage. Also, the increased traffic to the construction site can be compares to capacity of the adjacent roads. If the capacity is not enough, the delivery routes can be re-planned before traffic problems arise.

1.6 Thesis outline

- Chapter 1, *Introduction,* the reader is introduced to the research scope. The background results in a problem, which form the basis for the research purpose. Further are the delimitations of the study presented together with an example of how the program is intended to be used and finally the disposition of the thesis is presented.

- Chapter 2, *Methodology,* presents the research structure for the development of the program. The next sections describe and motivate the research approach and methods as well as aspects of credibility and dependability are addressed.

- Chapter 3, *Theory,* provides a fundamental review of the research topic, divided into the sections construction process, construction logistics and building construction. The basics of the planning process and the phases during construction are described, as well as deliveries and construction supply chain. In order for the reader to understand coming statements later on in the report, parts of building construction theory are described.

- Chapter 4, *Theoretical framework,* describes the conceptual design of the program and its basic assumptions. The other sections describes simplifications and assumptions of the construction process and construction logistics used in the program.

- Chapter 5, *Case study,* presents the case study that was conducted in order to determine material types and components included in a building as well as material quantities.

- Chapter 6, *Quantitative data,* presents data analysis for two various areas of interest. In the first sections material quantities for site-cast concrete frames and prefabricated concrete frames are analyzed. The second section presents data regarding deliveries to a construction site.

- Chapter 7, *Qualitative data,* presents the qualitative data used to complement and verify the information from the case study and quantitative data analysis. The major part of the chapter describes various loading ratios and delivery ratios for subcontractors.

- Chapter 8, *Compilation of data,* information from the quantitative data, case study, interviews and secondary data are compiled and evaluated and then presented in a table for inserting in the program.

- Chapter 9, *Result,* describes the layout and features of the program as well as a general description of the calculations performed in the program. The chapter can be used as a manual of how to use the program.

- Chapter 10, *Discussion,* concludes the master thesis by discussing the research approach and result. Criticism are directed to the research as well as considerations for the user are presented. Finally, suggestions for further research to improve and develop the program are addressed.

- Chapter 11, *References,* lists references used in the study.

- Appendix

2 Methodology

The first section of this chapter presents the research structure for the development of the program. The next sections describe and motivate the research approach and methods as well as aspects of credibility and dependability are addressed.

2.1 Research structure

The development of the delivery estimation program was done in several steps listed below.

1. Theory within the field was mapped out in order to create a better understanding of construction process, construction logistics and delivery planning methods.

2. The conceptual design and features of the program was developed and tested in order to meet the objectives.

3. Assumptions the prototype was confirmed and unknown data needed for developing the program was determined through empirical studies.

4. The gathered data was compiled and evaluated to provide the basis for the program.

5. The final version of the program was developed based on the conceptual design and compiled data.

2.2 Research Method

2.2.1 Research approach

The systems research approach was chosen for this master thesis. It means that the reality is understood in terms of mutually dependent components[14]. The research aims to investigate fragments, identify parts and how they are linked. The researcher bases the study on theory consisting of models, normative aspects and practical systems. Research methods consist of case studies with quantitative and qualitative approaches. The analysis involves creating models of the reality positioned outside the research area.

A system approach was chosen since a case study suited the research problem and purpose. The case study forms the basis for the research. In order to collect additional data and to provide various aspects of the study, quantitative and qualitative methods were used. For some aspects of the study, both strategies were applied in order to use triangulation to confirm the results.

2.2.2 Case study

A document case study was conducted which means that secondary data from one specific case were studied and analyzed[15]. The case study method was chosen since it provides a good overview of a building project. The method of studying documents was chosen since it is time-saving when a large amount data of data is required.

The case was selected based on the accuracy for the research scope and the selection method is described in section 5.1. Only one case was studied since a multiple case study would increase the scope and less attention could have been paid to details.

2.2.3 Quantitative method

A quantitative method was chosen for the parts of the study where quantified results were requested. The method is based on analyzing data and was used for the parts in which usable and reliable statistics was available. The quantitative method was preferred since it provides

[14] Gammelgaard, B., 2004. *Schools in logistic research? A methodological framework for analysis of the discipline,* Copenhagen: Emerald Group Publishing Limited.
[15] Bryman, A. & Bell, E., 2003. *Business Research Methods.* New York: Oxford University Press.

generalizable basis for conclusions[16]. The statistical data was collected through secondary sources since it would be too extensive to collect primary data.

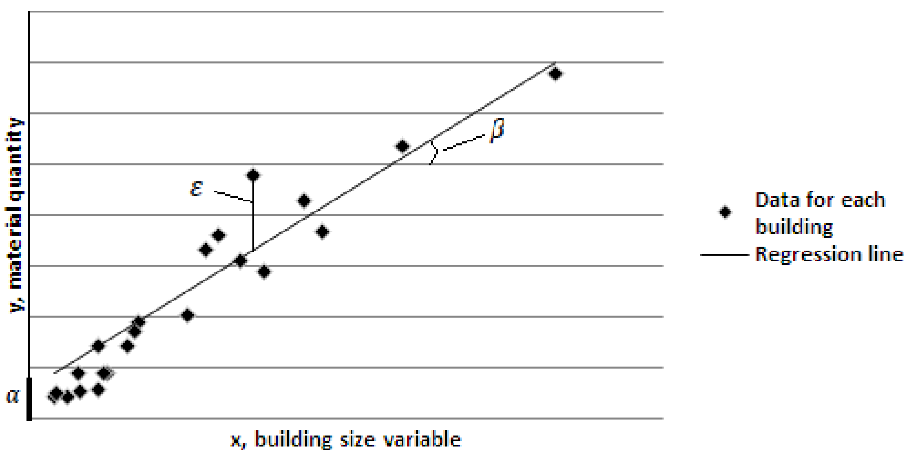
Statistical data about quantities of material and components for building projects were obtained to analyze material quantities in buildings.

Statistical data of deliveries to construction sites was analyzed to get an overview of common delivery types and the distribution of various vehicle types.

2.2.3.1 Linear regression analyses

In order to analyze the correlations between quantitative variables describing the size of the building and the amount of material used during construction, a linear regression analysis was used. The method was chosen since it analyzes a linear correlation which was a basic assumption when the program was developed, described in section 4.1.1. The method for performing the analysis was based on the compendium Correlation Analysis by the Centre for Mathematical Science at Lund University[17]. The analysis was performed in Excel with the Analysis Toolpak add-in program.

The variables were plotted on a scatter diagram and a regression line was adapted to the data in order to describe a linear correlation.



[16] Ibid

[17] Matematikcentrum, 2010. *Sambandsanalys, LTH.* [Online] Available at: http://www.maths.lth.se/matstat/kurser/fms032/sambandVL_10.pdf [Accessed 19 02 2012].

Figure 1: Example - regression analysis of material quantity vs. building size.

$$y = \alpha + \beta \cdot x + \varepsilon$$

$y = (building\ size\ variable)$
$x = (material\ quantity)$
$\alpha = (regression\ lines\ intercept)$
$\beta = (regression\ line's\ incline, e.g. material\ ratio)$
$\varepsilon = (residual, error\ in\ calculation)$

- y was assumed to be normally distributed.
- x was assumed to be measured with negligible error.
- ε was assumed to be random and normally distributed with an expected mean value of zero.

Analysis approach:

1. Individual observations that significantly differed from the other observations (e.g. outliers) were delimited from the analysis. Most likely they contained inaccurate data which would provide an inaccurate result.

2. Data was plotted on a scatter diagram together with the regression line to indicate a linear relationship between the variables. If the residual plot indicated quadratic or an increasing dispersion trend, the linear regression model was rejected.

3. The estimation of α was checked. It should (within its confidence interval) be eqeal to zero, which implies a proportional relationship between the variables. A proportional correlation was requested as it is a key assumption for the mathematical model used by the program.

4. The estimation of β was checked. It should (within its confidence interval) not be equal to zero, which implies a correlation between the variables. β is the value requested from the analysis, called quantity ratio, which describes the quantity of material variable according to a design variable of the building

5. In order to study which variable describing the size of the building (e.g. GFA, BA, no. floors) that correlated most with material quantities, the scattered graphs were compared visually.

In order to study how different building designs influenced the quantity ratio β, various quantity ratios β were compared (i.e. column frame vs. wall frame). In order to determine if the ratios significantly differed, the scattered graphs and regression lines were compared visually.

2.2.4 Qualitative method

A qualitative method focuses on words and context rather than statistics[18]. The method was chosen for the parts of the study where reliable or usable statistical data were not available or that a non-quantifiable result was requested for a specific aspect of the study.

Non-quantifiable data were requested when the basic design of the program was developed. It consisted of gathering complementary data to the theory and was done through interviews.

Quantifiable data were requested when determine the ratios and then the quantitative method was preferred. But, the statistics that were obtained through secondary data covered far from the information that was requested. Conduct own statistical studies was too extensive, and therefore interviews was used to conduct quantified data.

2.2.4.1 Interviews

The study used open interviews, which means that only the area of interest and purpose of the interview is predefined[19]. The reason for the choice was to allow for various questions based on the respondents' answers and to utilize their expertise in adjacent areas in addition to the predefined area of interest.

Quasi-quantification is the method of translating words, such as often, rarely or some, into numbers[20]. This was used to some extent when quantifiable data were requested.

The respondents were selected from their professional position and their adequacy to provide accurate data. A total of 29 interviews were carried out with professionals within building material supply and construction

[18] Bryman & Bell, 2003
[19] Ibid
[20] Ibid

management. The majority of the interviews were executed by telephone and in some cases with personal contact or by e-mail exchange.

2.3 Method Criticism

2.3.1 Reliability

Reliability concerns the question of whether the results of research will be the same if it is implemented again[21]. In order to increase the reliability, the work has been carefully documented. A criticism is that a large part of the data was collected by qualitative interviews and estimates. Based on documents it is likely that the data is affected by temporary conditions, which affect the reliability

2.3.2 Validity

Validity describes how well the result corresponds with the research objective and how well a conclusion that contains a causal relationship between two or more variables are sustainable or not[22]. In order to ensure validity data has been crosschecked through interviews and critically examined by the authors.

A criticism of the validity is that an accurate delivery schedule or complete data over deliveries to a project was not obtained. Thus, the result of the program has not been checked as well as the fundamental assumption that a building's size is proportional to the number of deliveries.

2.3.3 Generalizability

Generalizability is whether or not the findings of a study can be generalized beyond the specific research context[23]. A criticism of the generalizability is that a major part of the study was based on a case. As only one case is studied it can be criticized whether the program can be used for a variety of building projects.

In order to ensure the generalizability of the program quantitative data was used as a complement, which is more generalizable data. Also interviews were used in which the respondents were selected to provide a general perspective.

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[21] Ibid
[22] Ibid
[23] Ibid

3 Theory

This chapter provides a fundamental review of the research topic, divided into the sections construction process, construction logistics and building construction. The basics of the planning process and the phases during construction are described, as well as deliveries and construction supply chain. In order for the reader to understand coming statements later on in the report, parts of building construction theory are described.

3.1 The construction process

The construction process is a complex process and varies for each specific project. This section describes a general view of the construction process of new buildings described by Nordstrand in the book *Byggprocessen*[24].

3.1.1 Planning a new building

The building project starts once the client has decided to invest in a building and clarified its needs. The first phase is the Product determination phase during which the basis for the construction phase is formed. The product determination phase is usually a long process and can be planned in several different ways. Normally, a preliminary study is done in which the overall need is described. It is usually followed by a program phase and then a projection phase.

[24] Nordstrand, U., 2003. *Byggprocessen.* Stockholm: Liber.

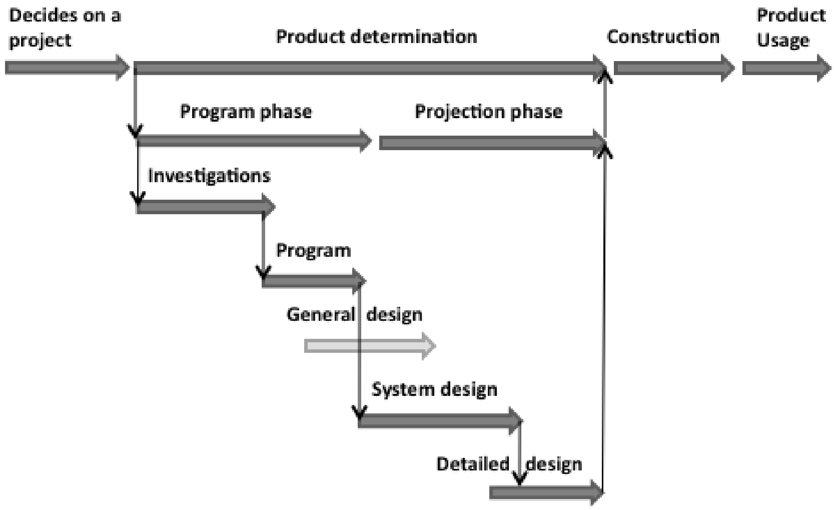

Figure 2: Phases of a building project (Nordstrand, 2003)

3.1.1.1 Program phase

The program phase usually consists of investigations that are compiled in a building program. The aim is to specify the client's requirements and specifications and clarify the conditions for the project, knowledge that secure the completion and economics for the project. The various types of investigations are building investigation, placement, economics and time schedule.

Building investigation

The building investigation describes what the building will be used for, the general building design such as size and floor plans and technical, environmental or architectural requirements.

Placement

The location of the building is investigated with respect to the current housing situation, environmental impacts and municipal development plan. The site is investigated based on foundation conditions, cost and availability of water and electricity.

Economics

General financial calculations are developed based on the building and placement investigation and constitute an important base for the client's decision-making. Usually calculations are based on previous experience of cost per area unit. Area units most used are gross floor area and building area.

Time schedule
A general time schedule is set based on the conditions for the project.

3.1.1.2 Projection phase

The projection phase involves the creation of drawings, descriptions and construction documents that meet the requirements of the building program. The projection phase is usually divided into three phases; general design, system design and detailed design.

General design
The aim of the general design is to determine a main option for the final design from functional and aesthetic aspects. The general design phase usually starts in the program phase. The results of the general design are summarized in the draft documents that form the basis for further work.

System design
System design involves designing building structures and building systems so that the building program is met. The goal is to determine the product so that only details remain. The results are compiled in the system acts as a basis for the building permits application.

Detailed design
The dimensions of all parts of the structure and installation components are determined. The final design is compiled by drawings and descriptions that the building is being built based on.

3.1.2 Constructing a new building

Basically, construction is carried out based on the drawings and construction documents from the first sod until the building is complete. The construction process consists of a number of activities that are carried out in order to create the result. The activities are using resources such as workers, material and machinery, which are delivered to the construction site. Thus, activities can be linked with the delivery flow to the site.

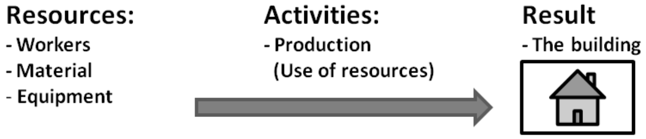

Figure 3: The principle of a construction project (Nordstrand, 2003)

The activities on a construction site are divided into different phases, performed during the different periods of construction. The figure below is describing the main phases that create demand of material or machinery that are delivered to the site.

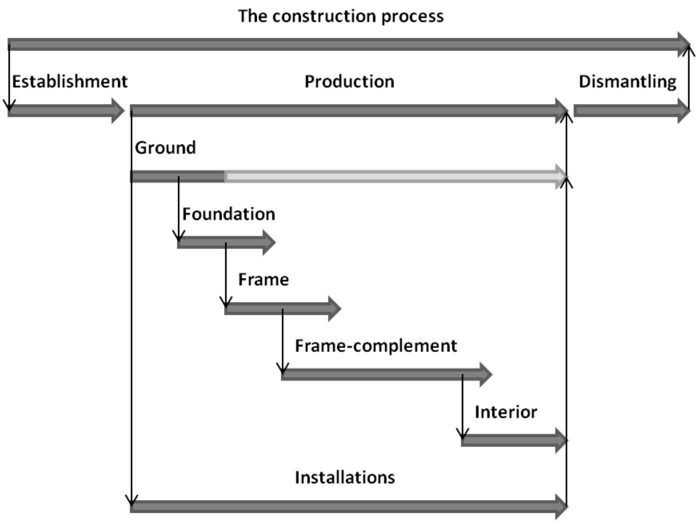

Figure 4: The construction process (Nordstrand, 2003)

The first phase is establishment. The building contractor acquires various production facilities, e.g. sheds, storage, temporary supply systems, machines, temporary roads, fence etc., which are delivered to the site.

The second phase is the production phase. Throughout the production phase, the temporary factory is managed and maintained and provided with materials and equipment. The production phase is divided into another six phases, which partially overlap.

- The ground phase includes excavation for the foundation and underground pipes as well as piling if needed. Also some landscaping and filling work occur.
- The foundation phase includes construction of the foundation structure and basement.
- The frame phase includes construction of the vertical frame and slabs.
- The frame complement phase includes; facade, roof, and interior walls being built as well as installation of doors, windows and painting.

- The interior phase is the final phase and consists of mounting of kitchens, appliances, closets etc.
- The installation phase is carried out throughout the production phase and includes all installation work e.g. water pipes, electrical power, ventilation, heating and computer systems.

The third phase, when production is finished, is dismantling the construction site. The establishment is transported from the site.

3.2 Deliveries

Definitions and approaches used in the report, regarding delivery planning will be described in this section in order for the reader to understand statements later on in the report.

3.2.1 Delivery planning

The main planning tool for the implementation of the construction is the project time schedule, which forms the basis for delivery planning. In addition to the time schedule the following parts are also important to consider[25]:

- The material needs at the site and the total amount of material that will be handled.
- The type of material, its volume and weight.
- The number of deliveries and their frequency
- The delivery vehicle type and size.
- Legislation, i.e. vehicle length, axle load restrictions.
- Delivery service, terms and conditions.

A delivery schedule should include[26]:

- Timing of the delivery
- Quantity per delivery
- Type of delivered cargo

3.2.2 Loading rate

In the present situation, there is no standardized definition of the loading rate[27]. Generalization is problematic since it regards area (usually referred to as platform meters or number of pallets), volume and weight limitations on a vehicle. Depending on what type of material is transported, different units of the loading are used, as well as the loading rate varies for various vehicle types.

In general, loading rate refers to the proportion between the actual load and total loading capacity of the specific vehicle[28].

[25] Hansson, 1999

[26] Bengtsson, B., 1973. *Metod för planering av byggarbetsplatsens interna transporter.* : Statens råd för byggforskning.

[27] Trafikanalys, 2011. *Statistikunderlag rörande tomtransporter och fyllnadsgrader,* Stockholm: Trafikanalys.

[28] Ibid

3.2.3 Classification of deliveries

Deliveries can be categorized by size, frequency, speed or reliability. The following categories are categorized by weight and volume[29]:

- Full goods; goods of similar kind that fill the entire capacity of a truck.
- Partial goods; goods of similar kind that do not fill the entire capacity of the truck (1 to 5 tons for a normal truck).
- General goods; goods of various sizes and types that only fills the truck's capacity to a minor extent (100 to 1000 kg for a normal truck). Can be considered for transfer between short and long-range transportation.
- Parcel goods; goods of smaller type and size (1 to 100 kg)
- Light goods; the smallest goods type (less than1 kg)

3.2.4 Joint loading

The logistical term joint loading means that two or more delivery dispatchers share transportation vehicles[30]. Joint loading is not relevant for full goods deliveries, but all smaller goods categories can be joint loaded. Joint loading allows for higher efficiency for carriers, implies that larger delivery vehicles can be used and creates a steadier demand of transportation services. Thus, most carriers use joint loading, except for express delivery carriers where there is direct transport between sender and receiver.

Joint loading occurs for some deliveries to construction sites. This implies a lower filling degree of goods and material delivered for each specific construction site[31].

3.2.5 Supply Chain

There are various ways of supplying material to construction sites. The most common ones can be summarized as in figure 5 below.

[29] Tarkowski, J., Irestål, B. & Lumsden, K., 1995. *Transportlogistik.* Lund: Studentlitteratur.
[30] Ibid
[31] Nicander, 2009

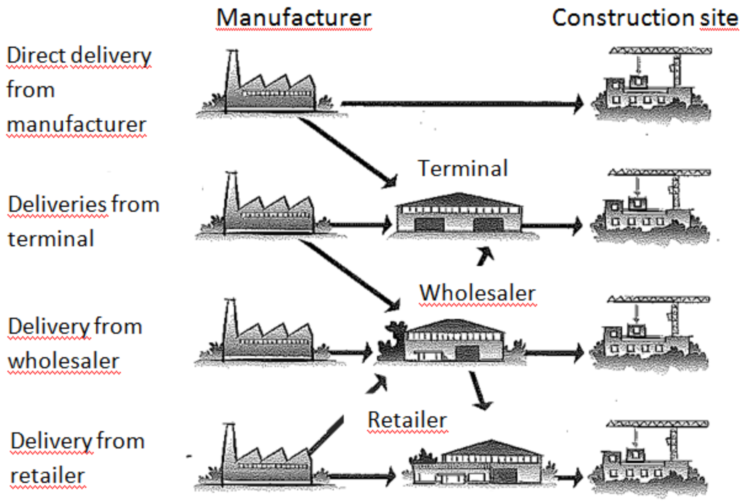

Figure 5: Supply chain for building material (Nordstrand, 2003)

Some material is delivered straight from the material manufacturer to the construction site as in the first image[32]. In order to decrease the number of deliveries the contractor can set up a terminal adjacent to the construction site together with a transportation company or a wholesaler. This way various material types can be loaded and delivered from the terminal to the construction site on the same vehicle. Building material can also be sent from the manufacturer to the construction site via a wholesaler or a building material retailer. Electricity, heating and plumbing installations are for example mostly delivered from a wholesaler directly to the construction site[33]. The majority of building materials are distributed via retailers. The advantages this means for a construction company is that the retailers supply various material types from advantageous locations.

[32] Nordstrand, 2003
[33] Näringsdepartementet, 2000. *Från byggsekt till byggsektor; byggkostnadsdeligationens betänkande,* Stockholm: Statens Offentliga Utredningar.

3.3 Building construction

This section will present the parts of building construction theory that has been used in order to develop the delivery estimation program. The reader might find this section useful for understanding assumptions and arguments later on in the report.

3.3.1 Groundwork

The amount and type of groundwork required depend on soil and nature conditions as well as the building design[34]. The groundwork that is taken into account in the delivery estimation program includes excavation, drainage and deep foundation work.

3.3.1.1 Excavation

Excavation material includes all material that is excavated from the ground and transported away from the construction site, e.g. soil, stone and crushed rock. The amount of excavation material depends on soil conditions at the site and the building design, and thus it is highly individual for each project.

In general all building projects need excavation of some extent. Typically, the topsoil is not suitable for supporting a building since it shrinks and swells when the moisture content in the ground changes[35]. Therefore, the topsoil is normally removed. Where the soil in the upper layers of the ground does not have sufficient bearing capacity to carry the load from the superstructure, the foundation has to be placed deeper where there are stronger soil layers. This requires more groundwork, and if there is rock in the ground that has to be broken up or blasted, the excavation time will increase.

The soil around an excavation needs to be retained to keep it from falling back into the excavated hole[36]. If the site is large the soil around the whole can be sloped back to avoid this from happening. If there is no room to create a slope around the excavation an excavation support that withstands the earth pressure, and hence, retains the soil is constructed.

3.3.1.2 Drainage system

For all structures it is important to ensure that the building will not be damaged from water in the ground or from water on the ground surface

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[34] KTH, 1992. *Byggnadsteknikens grunder.* Stockholm: KTH.

[35] Allen, E. & Iano, J., 2009. *Fundamentals of building construction.* 5th red. New Jersey: John Wiley & Sons Inc, Hoboken.

[36] Allen & Iano, 2009

there must be a sufficient drainage system. This system normally consists of drainage layers of single or macadam permeable to water, drainage pipes leading water away and non-woven fabric to avoid mixing of the drainage layers with the ground layer[37].

3.3.1.3 Filling

If a basement has been constructed, any extra space between the basement and ground is filled with macadam closest to the basement wall and additional soil[38].

3.3.2 Foundation

The foundations transfer loads from the substructure to the ground. There are two types; shallow foundations and deep foundations[39].

3.3.2.1 Shallow foundations

Shallow foundations transfer loads from the substructure directly to the soil at the bottom of the substructure. A type of shallow foundation is the slab on grade that consists of a reinforced concrete slab[40]. The slab is thicker underneath bearing walls to withstand the loads from the substructure. In many cases slab on grade is the most economical choice of slab foundation and it is also the most commonly used in Sweden.

3.3.2.2 Deep foundation

Deep foundations are used when the soil layer at the bottom of a substructure is inadequate as bearing soil. The deep foundation then transfer the load from the structure through these layers down to qualified bearing soil or rock[41]. Deep foundations can be either piles or caissons.

3.3.3 Concrete frame

Concrete framing systems are the most common systems used for apartment buildings today and there are a few varieties of them, which will all be regarded in the delivery estimation program[42].

3.3.3.1 Site-cast concrete frame and slab

Constructing a site-cast concrete framing system means casting the concrete elements at the construction site. By using site-casting it is

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[37] KTH, 1992
[38] Ibid
[39] Allen & Iano, 2009
[40] KTH, 1992
[41] Allen & Iano, 2009
[42] Ibid

possible to cast uncommon shapes and hence this method allows for flexibility in design[43].

Exterior concrete bearing walls are reinforced to ensure bearing capacity and to connect the walls to adjacent slab. Site-cast interior walls are in general also reinforced to provide stability during construction[44].

3.3.3.2 Precast concrete frame and slab

For a framing system of precast concrete, building elements are produced at a factory and thereafter transported to the construction site to be assembled[45]. The precast elements can vary in size and form from panels to boxes shaped as rooms. In general the concrete elements are supplemented with thermal insulation on site, but in some cases sandwich panels are used[46]. Precast concrete slabs can be of different types. Solid flat slabs were the first concrete slabs used. Hollow-core slabs and double tee slabs are common today since installations can be placed and hidden inside the slabs.

3.3.3.3 Filigree slab

As an alternative to site-cast and precast concrete framing systems, a combination of them, *filigree wideslab method*, can be used. The method consists of a precast slab which is covered by an additional layer of concrete cast on site[47].

3.3.3.4 Combined system

Instead of having a pure concrete framing system it is also common to combine a concrete system with other bearing systems. An example that often occurs is the combination of steel columns and concrete slabs[48].

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[43] Ibid
[44] KTH, 1992
[45] Ibid
[46] Sandin, K., 2004. *Praktisk husbyggnadsteknik.* Lund: KFS Förlag.
[47] Ibid
[48] Ibid

4 Theoretical frame of reference

This chapter's first section describes the conceptual design of the program and its basic assumptions. The other sections describes simplifications and assumptions of the construction process and construction logistics used in the program.

4.1 Conceptual program design

The concept of the program is to transform input data into output data using a model.

Input data -> Model -> Output data

The input data consist of information about the construction project including:

- Building's design.
- Project's time schedule.
- Construction management.

The output data consist of the delivery schedule including:

- Type of delivery vehicles.
- When the deliveries arrive.
- Number of deliveries.

For this program to be useful, it is necessary to reduce the input data to the information that is accessible at an early stage of the project planning and significantly affecting the delivery schedule. The building's design is described by a number of quantified variables and pre-defined selections. The project's time schedule is simplified by defining phases of the construction process, and the construction management impact on the delivery schedule is adjusted by a key ratio.

The output data is also simplified to be usable and accurate. The delivery vehicles are categorized and the timing for the delivery is based on the phases of the construction process.

4.1.1 The model's assumption

The model is using a basic simplification to convert the input data to output data. It assumes a proportional relationship between the quantified variables describing the building's size (input variable) and the number of deliveries (output variable).

The quantitative variable that describes the building's size can be the gross floor area, the number of floors, the number of apartments or other appropriate variables that have a proportional relationship to the number of deliveries. Since there is a proportional relationship between the input and output variable, the input variable can be multiplied by a ratio in order to create the output variable:

Input variable (Size) * Ratio (Deliveries/Size) =
Output variable (Deliveries)

The output data from the program should also describe the delivery vehicle class that arrives to the construction site and during which construction phase it arrives. Therefore, a number of ratios are used, which are linked to specific components that are included in the building. Each component is assumed to be delivered during a construction phase and is delivered by a vehicle type with a specified loading. Thus, the program calculates a number of output variables, where each output variable describes the delivery for each component and material type in the construction project.

The output variable is then divided with the specified amount of time required for the construction phase, which is defined in the input data. Thus, the number of deliveries per day for a specific component is obtained, what type of delivery vehicles that are used and in which construction phase it is delivered.

Output variable (Deliveries) / Time for construction (Days) = Deliveries per day

This calculation is done for every component that needs to be transported to the site during construction and then added together to compile the result.

Example of how the model works

One component of a building is the foundation. The input data may include the type of foundation and the building area (BA). The example building has a BA of 1000 [m^2], which is the quantified input variable. And a site-cast slab foundation, which is one of the pre-defined selections for describing the building design. The construction of the foundation is assumed to occur during the foundation phase and according to the time schedule for the building the foundation will take 10 days to build.

The program chooses a ratio based on the specific foundation type, which in this case is site-cast slab foundation. The ratio is already programmed in the program and may be:

- 0.10 concrete trucks per BA (transporting fresh concrete)
- 0.05 normal trucks per BA (transporting reinforcement and formwork)

According to the input data there will be 0.10*1000 = 100 concrete trucks and 0.05*1000 = 50 normal trucks. That implies a traffic of 100/10 = 10 concrete trucks per day and 50/10 = 5 normal truck per day during the foundation phase due to deliveries for the foundation.

4.2 Project information

The program is intended for use in the program phase or early in the projection phase to impact the planning of the project at an early stage. At that stage there should be program investigations and a conceptual design available. We assume that these contain sufficient information about the project in order to find out:

- Size:
    - Building area
    - Gross floor area
    - Number of apartments
    - Number of floors
- Ground
    - Amount of excavated material for foundation
    - If piling needed
- Frame
    - Vertical frame type
    - Slab type
- Construction management
    - If the loading rate will be high, medium or low
- Time schedule based on construction phases

4.3 Phases of the construction process

In order to simplify the construction process and the time schedule for the building we have chosen to divide it into phases according to section 3.1.2. For simplification, the establishment and dismantling phases are not considered in the program. These phases normally do not cause large amounts of deliveries to the site[49]. Deliveries of the building materials for each phase are assumed to occur during the same phase.

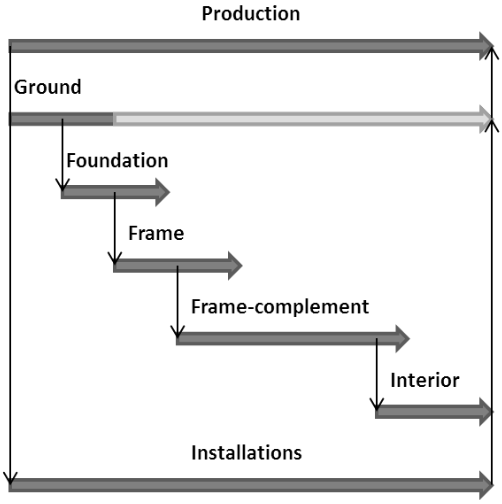

Figure 6: Construction phases used in the program (revised from Nordstrand, 2003).

When the phases occur and time scale of the phases can be defined independently of each other in the program. It allows overlapping the phases and testing how various planning affect the delivery schedule.

[49] Reslow, J. *Supervisor meeting at Prolog Bygglogistik AB* (16 01 2012).

4.4 Classification of delivery vehicles

Various types of delivery vehicles have different size, maneuverability and require different unloading methods and unloading times. Therefor it affects the planning of the construction site's unloading equipment, unloading areas and routes as well as adjacent roads. Thus it is important that the delivery schedule contain information about the type of delivery vehicle that will arrive to the site.

There are a wide variety of vehicle types and in order to simplify the program a classification was developed. The classification focused on being simple and to include aspects that influence planning. The classification is based on information from interviews that were performed during the study.

There are some vehicles that have not been included, for example mobile cranes, forklift trucks and other construction vehicles that are driven to the construction site. This type of construction vehicles is not delivering material and do not generate major traffic, and was therefore not included.

Truck type	Description
Dump truck [DT]	Dump trucks are transporting loose material such as dirt, gravel or sand. Therefore the vehicle type is mainly used in the ground-phase.
Concrete truck [CT]	Concrete mixer includes the type of trucks used for transporting fresh concrete. Unloading is done by a concrete pump or near the casting site as soon as possible upon arrival.
Normal truck [NT]	Normal truck includes all other trucks that do not belong to any other category. The category includes open and covered trucks as well as trucks with crane and garbage trucks.
Truck w/ trailer [TwT]	Truck with trailer includes normal trucks with trailers and semi-trailer trucks. The characteristic of the vehicle type is a high load capacity and it requires large unloading sites.
Light truck [LT]	Light trucks include cars that weight less than 3.5 tons.

Table 1; Definition of vehicle types

5 Case study

This chapter presents the case study that was conducted in order to determine material types and components included in a building as well as material quantities.

5.1 Selection of case and data source

The choice of case was based on a number of requirements. Firstly, the case should be an apartment building with a concrete frame according to the delimitations. Secondly, the building should have a design common for apartment buildings in Sweden in order to allow data to be generalized for other projects. Thirdly, the case shall provide accurate and exact data regarding the building design and material quantities.

In order to get a complete list of materials from the case, the authors chose to use tender documents where all estimated materials for a project are summarized. Thus, tender and supporting documents were collected from various building projects. Based on the requirements stated above the authors chose to proceed with the project Fågelsten BRF. Tender documents were provided by the tender engineer Erik Mårtensson at NCC Construction Sweden[50]. The documents included a cost analysis with specified estimated material quantities, drawings and a project description. The data was analyzed with the purpose of obtaining general quantity ratios for all materials in a building.

5.2 About the case

Fågelsten BRF is a housing cooperative constructed by NCC in Mölndal, Sweden. The project consists of three identical 4-storey buildings containing 12 apartments each[51]. The framing system is made up of bearing concrete walls and steel columns in the exterior walls. In between the steel columns there are curtain walls of wooden joists. Filigree elements constitute slabs and the interior bearing walls plus walls between kitchens and bedrooms are made out of concrete. Interior non-bearing walls consist of wood joists and plasterboard. The first floor and the balconies are covered with a facade of glulam panels. Fiber cement panels are used for the remaining walls.

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[50] NCC Fågelsten, *Tender documents*. Accessed from: Mårtensson, E. *Tender Engineer at NCC Construction, Sweden* (Accesed 10 01 2012)

[51] Ibid

Facts, Fågelsten BRF	
Gross floor area	3692 [m²]
No. apartments	36
No. floors	4
Description	Apartment building with filigree concrete slabs and site-cast concrete bearing walls.

Table 2: Project description for Fågelsten BRF

5.3 Quantity ratios

The building materials were categorized into the construction phases, where the materials are assumed to be used. Some materials belonged to more than one phase; these are stated in the first section 5.3.1. These will be divided into phases later on in the report. All materials are summarized in tables for each phase and for particular items there are explanations of certain assumptions.

Quantity ratios were calculated for the materials possible. The rest will be given ratios later on in the report. The ratios were based on the amount of material in the project divided by any variable describing the size of the building. The variable was chosen based on how well it was considered to generalize the amount of material.

5.3.1 Quantity ratios for materials belonging to multiple phases

Material	Quantity ratio	Unit	Variable
Concrete	0,393	[m³/GFA]	GFA
Reinforcement[i]	14.819	[kg/m²]	GFA
Reinforcement accessories[i]	4.229	[kg/m²]	GFA

Table 3: Quantity ratios for material belonging to multiple phases

i. The total amount of concrete was not defined specifically for building components. Thus, the quantity ratio calculated describes the total amount of concrete in the building including concrete for foundation, filigree slabs and all interior bearing walls plus walls between kitchens and bedrooms.

ii. As for concrete, the amounts of reinforcement and reinforcement accessories were not specified by building components either. The total amount of reinforcement was determined per GFA since it is distributed throughout the building.

5.3.2 Ground phase

Material	Quantity ratio	Unit	Variable
Ground construction	Unspecified	-	-

Table 4: Quantity ratios for material belonging to the ground phase

5.3.3 Foundation phase

Material	Quantity ratio	Unit	Variable
Concrete[i]	0,25	[m3/m2]	BA
Edge forms, steel[ii]	1,066	[m/m^2]	BA
Foundation insulation[iii]	-	-	-
Reinforcement[iv]	8,06	[kg/m2]	BA
Filling			
Foundation columns[v]	17,4	[kg/m2]	GFA

Table 5: Quantity ratios for material belonging to the foundation phase

i. The amount of concrete ordered for Fågelsten was not separated for walls, foundations and slabs in the information received. Thus instead, thicknesses for various designs of concrete foundations were found in Wikells (2010). Based on those an average concrete consumption of 250 mm/m^2 BA was estimated including the concrete for both foundation and edge beams.

ii. Edge form for the foundation was determined per building area assuming the perimeter of the building is somewhat proportional to the building area.

iii. The types of insulation were specified in the project data but it was difficult to generalize the amounts used which are why they were not presented here. Foundation insulation will be considered later on in the report.

iv. The amount of reinforcement used specifically for the foundation was not pointed out in the project documents. To determine the amount of foundation reinforcement, the foundation example *4.018* from Wikells[52] was used as a reference. The consumption of reinforcing nets here was 1,2 m^2/m^2 building area and the nets were of type 6200 placed in two layers. For a reinforcing net, type 6200 and size 4,85 * 2,25 meters the weight is 25,4 kg[53]. Calculation gave the total weight of reinforcement net above.

v. The foundation columns regarded were in Fågelsten used for the foundation of storages and carports. It was assumed that extra buildings for storages etc are normal for apartment buildings and the deliveries of material for these should be taken into account. Since the sizes of the extra buildings depend on the number of apartments/size of the main building the ratios were determined in terms of GFA.

5.3.4 Frame phase

Material	Quantity ratio	Unit	Variable
Concrete for filigree slabs[i]	Unspecified	-	-
Concrete for walls[i]	Unspecified	-	-
Pre-cast filigree slab[ii]	1,114	[m^2/m^2]	Slab area
Pre-cast concrete stairs	Unspecified	-	-
Wall forms	Unspecified	-	-
Form for slabs (props)	Unspecified	-	-
Form wood[iii]	1,314	[kg/m^2]	GFA
Form plywood[iii]	0,989	[kg/m^2]	GFA
Reinforcement	Unspecified	-	-
Form oil[iv]	0,013	[kg/m^2]	GFA
Steel	Unspecified	-	-
Mounting hardware	Unspecified	-	-
Balconies	Unspecified	-	-

Table 6: Quantity ratios for the frame phase

[52] Wikells, 2010. *Sektionsfakta - NYB 10/11.* Växjö: Wikells Byggberäkningar AB.

[53] BE Group, n.d. *Armeringsnät.* [Online] Available at: http://www.begroup.com/sv/BE-Group-sverige/Produkter/Armering/Produktinformation/Armeringsnat/ [Accessed 31 01 2012].

i. The amount of concrete used in Fågelsten was not divided on building elements and could not be specified for foundation, walls and slabs individually.

ii. Pre-cast filigree slabs were calculated for the total slab area as opposed to GFA since no filigree slabs will be used for the foundation.

iii. The quantity ratios for plywood and wood used as form when casting the frame were based on the volumes used in Fågelsten and a wood weight of 500 kg/m^3 [54].

iv. Quantity ratio was based on the amount used in Fågelsten and an assumption for the weight of 1kg/l oil. It was not possible to determine how much form oil was used for walls and slab casting individually, but this was estimated not to affect the amount of deliveries and the ratio was hence determined per gross floor area.

v. Mounting hardware such as fittings and distance pieces were assumed used for construction of the frame and was hence placed under this phase.

5.4 Frame complement phase

Material	Quantity ratio	Unit	Variable
Facade panels[i]	8,034	[kg/m^2]	GFA
Façade panels: drip plates[i]	-	-	-
Façade panels: balconies[ii]	3,414	[kg/m^2]	GFA
Wood: sawn timber[iii]	14,769	[kg/m^2]	GFA
Wood: panel boards[iii]	1,962	[kg/m^2]	GFA
Wood trims[iii]	0,818	[kg/m^2]	GFA
Wood: plywood[iii]	0,312	[kg/m^2]	GFA
Roof hatches[iv]	2,642	[m/m^2]	BA
Roof trusses[iv]	0,062	[m^2/m^2]	BA
Sheet metal: Joists[v]	1,209	[kg/m^2]	GFA
Sheet metal: Rails[v]	0,365	[kg/m^2]	GFA
Sheet metal: Rails for exterior walls[v]	0,588	[kg/m^2]	GFA

[54] Allen & Iano, 2009

Sheet metal: Roof profiles[v]	1,065	[kg/m²]	BA
Plasterboard roofs[vi]	5,230	[kg/m²]	BA
Plasterboards wet areas[vi]	186,095	[kg/apt]	APT
Fireboard[vi]	0,998	[kg/m²]	GFA
Plasterboard regular[vi]	15,955	[kg/m²]	GFA
Mineral wool (all types)[vii]	1,213	[m²/m²]	GFA
Insulation, joints[vii]	0,437	[m/m²]	GFA
Insulation, sill [vii]	0,048	[m/m²]	GFA
Insulation: Spacer pipes [vii]	0,009	[pack/m²]	GFA
Insulation: Caulking [vii]	0,060	[m/m²]	GFA
Plastic foil[viii]	0,152	[kg/m²]	GFA
Windbreak[viii]	0,043	[kg/m²]	GFA
Sealing tape[viii]	-	-	-
Bitumen felt[ix]	2,517	[kg/m²]	BA
Glulam beams[x]	0,564	[kg/m²]	GFA
Glulam columns[x]	0,162	[kg/m²]	GFA
Regular windows[xi]	0,048	[pcs/m²]	GFA
Small windows[xi]	0,013	[pcs/m²]	GFA
Casement doors for balconies[xi]	0,011	[pcs/m²]	GFA
Interior entrance doors[xi]	1	[pcs/apt]	APT
Interior wooden doors[xi]	0,036	[pcs/m²]	GFA
Storage doors steel[xii]	0,005	[pcs/m²]	GFA
Wooden front doors[xii]	0,003	[pcs/m²]	GFA
Mounting hardware[xiii]	Unspecified	-	-
Leveling underlayment (mortar)[xiv]	26,25	[kg/m²]	GFA
Suspended ceiling	Unspecified	-	-
Sheet metal	Unspecified	-	-

Table 7: Quantity ratios for the frame complement phase

i. The type of façade panels used in Fågelsten weigh approximately 3 kg/m[55]. Combined with data of the amounts used the quantity ratio above was calculated. The facade area of the building compared to the floor area is not necessarily linear but depends on the geometry of the building. An

[55] Respondent Y: Sales at a façade panel wholesaler.

approximation was made that the facade area can be considered linearly proportional to the total GFA of the building; hence the amount of facade materials was determined per GFA. No volume data was specified for the drip plates.

ii. The facade for the balconies was in Fågelsten BRF different from the facade for the rest of the building. For other projects the balcony facade might as well be the same as the facade for the rest of the building which was the reason why no consideration was taken for the amount of balconies in the project. Hence, estimation was made that approximately the same amount of facade deliveries would be generated for a project without balconies. The two different facade types were still separated in the calculations though. This separation was chosen based on the assumption that other building projects are likely to have two different types of facade material as well. Hence, separating the materials was considered to generate an estimation of deliveries closer to reality. For calculations, the same approach was adopted as for other façade material.

iii. The quantity ratios for plywood, sawn timber and panel board were based on the assumed weight of 500 kg/m^3. Using average thicknesses/cross section areas from the various types used in Fågelsten combined with the amounts of material used, the final quantity ratios were calculated. For wood trims the calculation was based on a weight of 0,6 kg/m for the type of wood trims used in Fågelsten[56]. The ratios were all determined per gross floor area since it was difficult to determine where in the building the material had been used.

iv. Roof hatches and roof trusses are related to the area of the roof and were therefore in the program linked to the building area.

v. Quantity ratios were based on the volume of sheet metals from Fågelsten and calculated average weights of the types of sheet metal used in the case; 0,67 kg/m for joists, 0,60 kg/m for rails, 1,2 kg/m for rails exterior walls and 0,51 kg/m for roof profiles[57]. Amount of sheet metal used for walls was determined per gross floor area. The amount of roof profiles was determined per building area.

vi. Quantity ratios were based on the volume of plasterboards in Fågelsten and calculated average weights of the types of plasterboard used in the case; 9,26 kg/m^2 for regular plasterboard/plasterboard for roof, 10,79 kg/m^2 for plasterboard wet rooms and 14,25 kg/m^2 for fireboard[58]. The ratio of plasterboard used for the roof was determined per building area.

[56] Byggmax, 2012. *Byggvaror.* [Online] Available at: www.byggmax.com/se-sv [Accessed 07 02 2012].
[57] Ibid
[58] Ibid

The amount of plasterboard used specifically for wet areas were determined per number of apartments since this was estimated to give the most general ratio. The amount of fireboard was calculated per gross floor area which was based on the estimation that this ratio would be similar for most buildings. The remaining plasterboard that was used in the project was not specified and was assumed mostly used for non-bearing interior walls and curtain walls. Hence, a decision was taken to calculate the amount of material per gross floor area.

vii. Most of the mineral wool used in Fågelsten BRF was presumably used for interior and exterior walls. Hence, the ratios for the various types of mineral wool and accessories such as spacer pipes were all determined per gross floor area.

viii. Quantity ratios were based on the amount of plastic materials used in Fågelsten combined with corresponding weight data; 180 g/m^2 for plastic foil, 60 g/m^2 for sealing tape[59] and 60 g/m^2 for windbreak[60]. The quantity ratio calculated for sealing tape was very small and was ignored. Plastic materials discussed here were assumed mainly used for the exterior walls and determined per gross floor area.

ix. Quantity ratio was based on the area of bitumen felt used in Fågelsten and the weight which was 1,99 kg/m^2 for the type of felt used[61]. The amount of bitumen felt was calculated per building area based on the same discussion as for roof material in note iv.

x. The average weights of the glulam beams and glulam columns used in Fågelsten were calculated based on an assumed weight of 500 kg/m^3 and were determined to approximately 282 kg/beam and 13,5 kg/column. Combined with the amounts of columns and beams used the quantity ratios were obtained. Both glulam beams and columns were in this project used for storages and carports. The assumption was made that the construction of these started later than the frame of the main buildings and is therefore placed during the frame-complement phase. The number of apartments is assumed to follow the gross floor area for the building and hence, the number of carports and storages as well. Therefore the ratio for the amount of glulam materials used for carports and storages were calculated per gross floor area.

xi. The amount of windows and doors for the project was not specified in the material from NCC and hence, the amount was determined from the

[59] Ibid

[60] Icopal, 2012. *www.icopal.se.* [Online] Available at: http://www.icopal.se/Produktsortiment/vagg_golv_grund/lufttatt%20hus/vindskydd.aspx [Accessed 07 02 2012].

[61] Byggmax, 2012

building drawings. For the three main buildings the total amounts were 177 windows, 48 small windows 36 balcony glass doors, 36 interior entrance doors and 18 steel storage doors, which gave the quantity ratios above.

xii. The number of wooden front doors for storage rooms was given in the project description. The ratio for them was determined per gross floor area of the main buildings similar to the other materials for the storage rooms.

xiii. Nails, screws and other mounting material were put together in the group mounting hardware since an assumption was made that they are delivered together during the frame-complement phase.

xiv. A normal thickness of leveling underlayment for apartment buildings is 15 mm[62]. A mortar weight of 1,75 kg/mm, m^2 floor is required which resulted in a total required amount of mortar of 26,25 kg/m^2 floor with leveling underlayment. Subcontractors for leveling underlayment were for Fågelsten procured for the total amount of 0,735 m^2/m^2 GFA which gave the weight quantity ratio for mortar above.

5.5 Interior phase

Material	Quantity ratio	Unit	Variable
Floor covering	0,645	[m^2/m^2]	GFA
Kitchen lighting	Unspecified	-	-
Kitchen appliances[i]	1	[set/apt]	APT
Laundry	Unspecified	-	-
Water and heating equipment[ii]	1	[set/apt]	APT
Interior fittings[iii]	1	[set/apt]	APT
Steel banisters	0,013	[m/m^2]	GFA
Wood banisters	0,015	[m/m^2]	GFA
Kitchen cabinets	1	[set/apt]	APT
Cabinets	Unspecified	-	-
Painting	Unspecified	-	-

Table 8: Quantity ratios for the interior phase

62 Respondent W: *Specialist leveling underlayment.*

i. For the project there is one kitchen per apartment, hence kitchen appliances were determined per apartment assumed one kitchen per apartment is a normal case. The kitchen appliances in this case were included: dishwasher, freezer, fridge, fridge/freezer, microwave oven, stovetop, stovetop protection, cooker hood fan, filter, dryer, washing machine and oven.

ii. All apartments in Fågelsten BRF include one bathroom and one kitchen. Considering this a normal case, water and heating equipment were determined per apartment. Water and heating equipment in Fågelsten BRF were: shower, bathroom cabinets, washstand, kitchen tap, washstand tap, thermostatic mixer, shower set and toilet seat.

iii. Even interior fittings were linked to the number of apartments in the program since they were all ordered in one set per apartment. All the various interior fittings will not be presented here; a complete list of all items is shown in attachment xxx.

5.6 Installation phase

Material	Quantity ratio	Unit	Variable
Ventilation[i]	Unspecified	-	-
Heating[i]	Unspecified	-	-
Plumbing[i]	Unspecified	-	-
Electrical installations[i]	Unspecified	-	-
Security systems[i]	Unspecified	-	-
Elevators[i]	Unspecified	-	-

Table 9: Quantity ratios for the installation phase

i. Data for the exact amounts of installations used in Fågelsten was not specified since it was outsourced to subcontractors.

6 Quantitative Data

This chapter presents data analysis for two various areas of interest. In the first sections material quantities for site-cast concrete frames and prefabricated concrete frames are analyzed. The second section presents data regarding deliveries to a construction site.

6.1 Material quantities

In order to determine the material quantities required for construction, data from previous building projects were analyzed. The construction of the frame assume to represents a large proportion of deliveries and was considered important to study closely. Site- and pre-cast concrete frames were therefore chosen for analysis since there were gaps in the data from case study.

The data was compiled and a correlation analysis between the building size and quantities of materials was examined.

6.1.1 Site-cast concrete frames and slabs

6.1.1.1 Data source and general description

The data regarding site-cast concrete frames and slabs was received from the Swedish association for concrete suppliers and consisted of already constructed projects using site-cast concrete for the frame[63]. The information included basic data about the buildings and more specific data about the frame, i.e. drawings and material quantities.

A total of 32 building projects were considered in the analysis with areas of 2.000-40.000 m^2 GFA and four to eleven floors[64]. The data excluded buildings with uncommon designs and projects where information was inadequate. The projects are presented in Appendix 1.

[63] Betongbanken, u.d. *Platsgjutna stommar; Referensobjekt; Bok 1 & 2.* Bromma: Svenska Fabriksbetongföreningen.

[64] Ibid

6.1.1.2 Compilation of the data

The buildings were first described based on the data that was obtained for:
- Gross floor area, GFA [m^2].
- Number of floors.

In order to determine how various frame designs affects the amount of material, the frames were divided into six categories. The categories were based on how the frame was designed and which components were used:
- Site-cast structural interior walls?
- Site-cast structural exterior walls?
- Site-cast structural columns?
- Prefabricated structural exterior columns or walls?
- Prefabricated structural interior columns?
- Filigree floor slab or site-cast floor slab?

The material quantities included concrete and reinforcement for vertical supporting parts, i.e. walls, columns and floor slabs:
- Reinforcement in walls and columns [kg].
- Concrete in walls and columns [m^3].
- Reinforcement in floor slabs [kg].
- Concrete in floor slabs [m^3].

6.1.1.3 Correlation analysis

The material quantities were analyzed by performing a regression analysis, described in section 2.2.3.1 . The correlations between material quantities and GFA/number of floors were analyzed. Differences in material quantities due to various frame designs were also studied.

The analysis showed that GFA was the variable that best described the material quantities for both slabs and frame components. The correlations were shown to be both proportional and have a relatively strong linear relationship.

Generally, the correlation between concrete and GFA was stronger than the correlation between reinforcement steel and GFA, where the residuals became greater with larger GFA. Thus, the amount of reinforcement varied more for each project.

Significant differences for various frame and slab designs were identified if the slab was site-cast or of filigree type and if the structural system was of wall frame or column frame. Other design issues did not significantly affect the quantity ratios. Below are the results from the analysis and the scattered regression charts are presented in Appendix 1.

Site-cast slab

A total of 27 projects were designed with site-cast slabs, which in the context of this study is a large base and thus provides an accurate result.

- 0,2131 concrete [m^3] per gross floor area [m^2].
- 8,88 reinforcement [kg] per gross floor area [m^2].

Filigree slab

A total of five projects used filigree slabs. A smaller population results in somewhat less accurate result.

- 0,1671 concrete [m^3] per gross floor area [m^2].
- 3,33 reinforcement [kg] per gross floor area [m^2].

Wall frames

A total of 23 projects used wall frames as the vertical structure. The material quantities varied more for the vertical frame than for the slabs, especially for the reinforcement quantities. Thus, the material quantities can differ more for various projects.

- 0,1149 concrete [m3] per gross floor area [m2].
- 3,73 reinforcement [kg] per gross floor area [m2].

Column frames

A total of nine projects used column frames as the vertical structure. The data showed a similar correlation as for the wall frame. Only office buildings were designed with a column frame.

- 0,0729 concrete [m3] per gross floor area [m2].
- 7,16 reinforcement [kg] per gross floor area [m2].

6.1.2 Pre-cast concrete frames, slabs and stairs

6.1.2.1 Data source and general description

The data was received from the pre-cast concrete manufacture Strängbetong[65]. The data summarized the types of precast elements used for specific projects and its weight, as well as basic information about the projects.

A total of six apartment building projects were considered in the analysis, giving a span of 4.000-25.000 m2 GFA and 4-25 floors[66]. The data were also limited to not include uncommon designed buildings and projects where the information was inadequate.

6.1.2.2 Compilation of data

The data was compiled in order to enable for the analysis. The buildings were described upon the general data that was contained, including:

- Outside gross floor area, GFA [m^2].
- The number of floors.

All buildings were apartment buildings designed with a wall frame. What specific types of elements used, i.e. sandwich-panels or normal concrete panels, solid or hollow core slabs, was not considered in the compilation then it is too much in detail for the purpose.

The material quantities included pre-cast concrete elements for slabs, wall frames and stairs as well as steel parts for wall frames.

- Concrete elements for pre-cast slabs [kg].
- Concrete elements for pre-cast wall frames [kg].
- Steel parts for concrete frames [kg].
- Concrete elements for pre-cast stairs[kg].

[65] Strängbetong; Pre-cast frames, *Tender documents*. Accessed from: Edlund, S. O. *Marknadschef Bostad Mellansverige at Strängbetong* (Accesed 25 01 2012).
[66] Ibid

6.1.2.3 Correlation analysis

The data was analyzed by performing a regression analysis, described in section 2.2.3.1. The correlations between material quantities and GFA and number of floors were tested for each component.

The analysis identified that the GFA was the variable that best described the concrete quantities for slab, wall frame and staircase components as well as additional steel parts for the wall frame. The correlations were shown to be both proportional and have a relatively strong linear relationship. Regression scatters are presented in Appendix 2.

Pre-cast slab

All six projects were designed with pre-cast slabs. The correlation was relatively high.

- 357,26 concrete elements [kg] per gross floor area [m^2].

Pre-cast wall frame

All six projects were designed with pre-cast slabs. The correlation was relatively high for the concrete elements. The correlation for the amount of steel parts and GFA is low, hence there is more uncertainty.

- 671,14 concrete elements [kg] per gross floor area [m2].
- 1,61 steel parts [kg] per gross floor area [m^2].

Pre-cast stairs

All six projects were designed with pre-cast stairs. The correlation between concrete elements and GFA was relatively low, the same case for correlation between concrete elements and number of floors. Therefor there are some uncertienty in the result.

- 8,84 concrete elements [kg] per gross floor area [m2].

6.2 Deliveries

Data of deliveries to the construction project MKB Svante was obtained in order to analyze the distribution of various types of deliveries. The number of deliveries could not be analyzed since the data did not include all deliveries. The data were sorted and simplified to carry out the analysis.

6.2.1 About the project MKB Svante

MKB Svante is an apartment building project in Malmö, including one larger and one smaller building[67]. The apartments are modernly designed equipped with balconies and laundry equipment.

Facts, MKB Svante	
Gross floor area	23400 [m^2]
No. apartments	213 + 15 (large and small building)
No. floors	6-8
Construction period	Apr 2006 – Dec 2008

Table 10: Project description for MKB Svante (MKB Fastighet AB, 2009)

In order to reduce the time for construction a highly industrialized construction method was used, i.e. pre-cast concrete elements and pre-cast bathroom modules were used[68]. In the workplace, there was storage for both smaller and larger types of material[69].

Through collaboration between the developer, contractors and the Swedish national board of housing, building and planning (Boverket), a project was implemented to give an inspiring example of efficient logistical solutions[70]. The aim was to create profitable logistics, reduce waste, increase customer value and document the procedure. The workplace was fenced to improve safety and monitor the deliveries. A guard verified that the correct delivery was admitted. If it was not on time or incorrect it was rejected. A delivery monitoring systems was used to administer the deliveries and reservations of deliveries were made via the Internet.

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[67] MKB Fastighet AB, 2009. *Projektbeskrivning MKB Svante.* Malmö: MKB Fastighet AB.
[68] Ibid
[69] Boverket, 2008. *Effektiv Logistik i innerstadsprojekt,* Malmö: Boverket.
[70] Ibid

6.2.2 Deliveries to the project

6.2.2.1 Scope and credibility of the data

Through Reslow at Prolog[71], we obtained data from the delivery monitoring system. The data covered 925 deliveries and including;

- Type of material delivered
- Contractor who ordered the material
- Delivery vehicle
- If crane unloading was used
- Arrival and departure time

The data do not cover all deliveries to the site. Only two of four unloading sites were registered in the system during a part of the total construction time, e.g. deliveries of the frame and pre-cast modules were not registered. And information of some deliveries was not complete. Despite the shortcomings, the data provides an estimate of the distribution of delivery vehicle types. What type of vehicle commonly used for certain types of materials and contractors.

By studying the type of material delivered it can be concluded that the deliveries that have been registered are mainly included in the complement, interior and installation phase. It is in compliance with the time when deliveries were registered (April 2007 to September 2008) as well as the contractors that the deliveries were aimed for.

6.2.2.2 Overall distribution of various delivery vehicles

There were gaps in the data regarding the delivery vehicle types. If the type was not specified the delivery was ignored. The deliveries were grouped into the following vehicle types:

- Normal truck
- Garbage truck
- Concrete truck
- Truck with trailer
- Light truck and Car
- Dump truck (not detected)

[71] MKB Svante, *Data over deliveries*. Accessed from: Supervisor; Reslow, J. *Prolog Bygglogistik AB* (Accessed 10 10 2011).

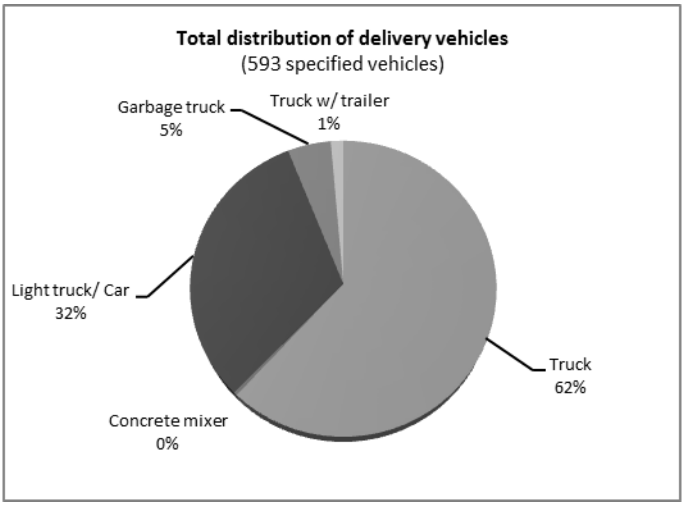

Figure 7: Total distribution of delivery vehicles

According to the figure 7 normal trucks represent the majority of delivery vehicles, followed by light trucks and cars. Other vehicle types are in minority. This governs deliveries in the complement, interior and installation phase.

6.2.2.3 Distribution of delivery vehicles for various contractors

The data included which contractor the deliveries were aimed for. Unknown and not often contractors were ignored. The following contractors were considered:

- Installations:
  - Electrical (Com Tech Solution AB)
  - Water and sewerage (NVS Installation AB)
  - Ventilation (VEAB AB)
- Construction (Peab Sverige AB)
- Floor (Golv & Kakel Bernt Lövkvist)
- Painting (Schööns Måleri AB)

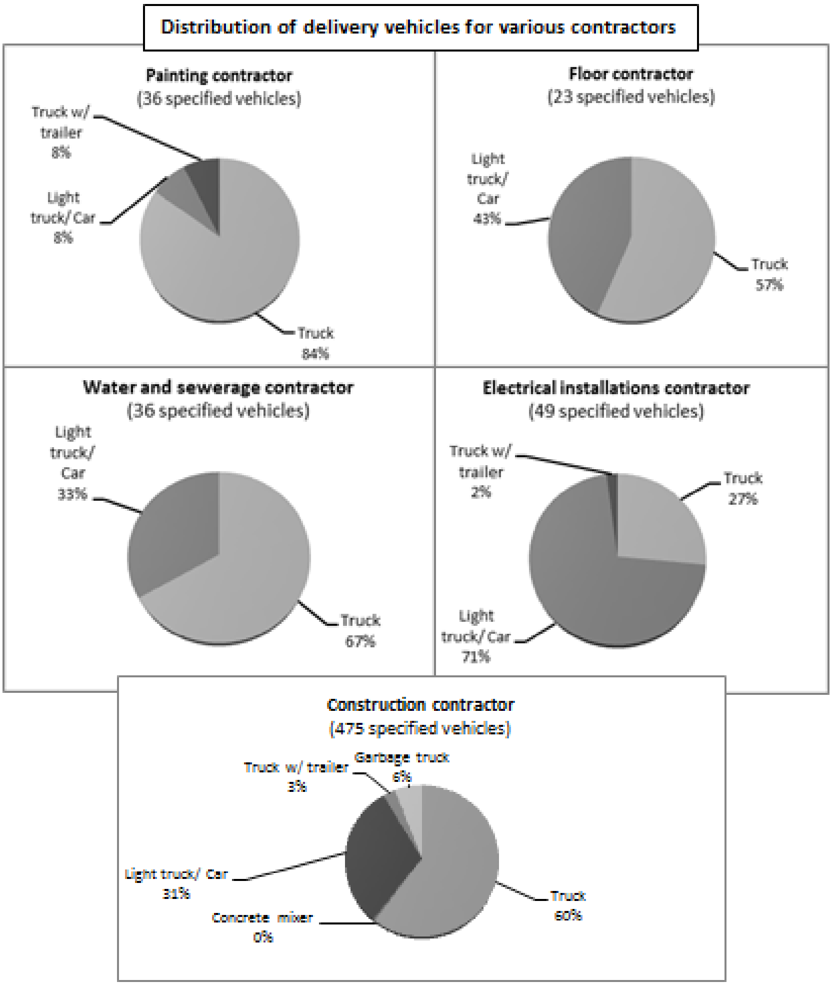

Figure 8: Distribution of delivery vehicles for various contractors

According to figure 8 it can be concluded that the distribution differs, i.e. the painting contractor uses a larger proportion of trucks, and the electrical installations contractor uses a large proportion of light trucks and cars for deliveries.

6.2.2.4 Distribution of delivery vehicles for various contractors

There were gaps in the data about material types and components delivered to the site. Inadequate and unsure deliveries were ignored. The data had to be categorized into different material groups and components in order to be analyzed.

Material type	Delivery vehicle distribution	Population
Construction tools	Normal truck: 100%	14
Doors	Normal truck: 100%	5
Garbage	Normal truck: 56% Light truck: 2% Garbage truck: 42%	64
Insulation	Normal truck: 75% Light truck: 25%	20
Kitchen parts	Normal truck: 100%	5
Leveling underlayment	Normal truck: 56% Light truck: 44%	16
Locks	Light truck: 100%	8
Plasterboards	Normal truck: 95% Light truck: 5%	20
Radiators	Normal truck: 75% Light truck: 25%	8
Reinforcement	Normal truck: 100%	3
Roofing material	Normal truck: 100%	13
Windows	Normal truck: 89% Light truck: 11%	18

Table 11: Distribution of delivery vehicles for various material types

7 Qualitative data

This chapter presents the qualitative data used to complement and verify the information from the case study and quantitative data analysis. The major part of the chapter describes various loading ratios and delivery ratios for subcontractors.

7.1 General considerations

7.1.1 Research area to examine

The qualitative data analysis was conducted to complement and verify information that was not obtained through the case study or the quantitative data analysis. The major scope regards loading ratios and delivery ratios for subcontractors.

The methods used are interviews combined with literature studies.

7.1.2 Selection of respondents

In order to study delivery methods for construction sites basically two interview respondent groups can be identified. The ones that receive the material and the ones that supply the material. Since material suppliers are managing the deliveries it is reasonable to assume that they are more familiar with the delivery methods. Suppliers also deliver to a wide variety of construction sites; hence they can provide a more general picture. Therefore suppliers were chosen as the main respondents

According the theory section building materials are supplied from manufacturers, wholesaler or retailers. For some of the components there are several suppliers and to get an opinion on which supplier that is most common a construction management team at a major housing project was contacted[72]. Based on their information appropriate respondents were contacted.

7.2 Ground

Excavation material

The vehicle type usually used for transporting excavation material is dump truck. From larger construction sites the major parts of the transports are

[72] Respondent AA: *Site manegement at a contractor.*

made with big dump trucks for which the loading rate is normally about 30-33 tons regardless of whether trailer is used or not. The volume transported depends mainly on the density of the excavation material. Per Asmundsson at Akka Frakt estimated that excavation material has an average density of 2 tons/m^3, which implies a load of 15-17 m^3/delivery[73].

Macadam

The bearing layer for the foundation varies depending on the ground condition. A normal macadam layer thickness is 300 millimeter[74].

Filter Fabrics

Most building projects use one layer of filter fabric and for large construction projects deliveries are usually made directly to the construction site[75]. Normally only one delivery is required, since a semi-trailer truck can load filter fabrics for a building area up to 50.000 m^2.

Drainage pipes

Drainage pipes are placed along the outer edges of a building and dimensioned according to building area[76]. Assuming normal-sized drainage pipes with diameters of 300 millimeter, a semi-trailer truck can be loaded with 300 meters of pipes.

Piling foundations

Piling is required when the carrying capacity of the ground is less than the weight of the building and is custom designed for each project. A sample building project of 25.000 m^2 GFA constructed on ground with relatively poor bearing capacity used 2242 tons of concrete piles[77]. Piles are normally delivered with semi-trailer trucks loaded with 30 tons.

7.3 Foundation

Concrete

Fresh concrete is delivered to the construction site by concrete trucks at the time of casting. The loading capacity of a concrete truck is normally between 5-7.5 m^3 concrete[78].

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[73] Respondent A: *Transportation coordinator at a Carrier.*

[74] Respondent C: *Sales manager at a wholesaler for Geo products*

[75] Ibid

[76] Ibid

[77] Respondent Y: *Work manager at a piling entreprenuer.*

[78] Heidelberg Cement Group, 2012. *Betongindustri.* [Online] Available at: www.betongindustri.se [Accessed 05 01 2012].

Foundation insulation systems

Foundation insulation from the company Sundolitt is packaged on trucks with trailers that have packing lengths of 19,2 meters which equals 138 m^3 [79]. Richard Yngve at Sundolitt estimates that the amount of foundation insulation in the project Fågelsten would all be packed on europallets and would require a total packing length of 37,2 truck loading meters, which would result in a number of two deliveries.

Edge form

Edge form is used when casting the foundation slab. An amount of 720 m fits onto 10 pallets, which implies one delivery with a normal truck[80].

7.4 Frame

Precast concrete elements

Pre-cast concrete elements are transported by semi-trailer trucks and the deliveries are carefully planned in order to minimize the number of deliveries[81]. Different types of elements can be joint loaded. The loading rate often depends on the weight limit for the road, but an average can be estimated to 30 tons per delivery. For filigree slabs specifically, a fully loaded 24 meter truck with trailer can deliver approximately 280 – 340 m^2 of filigree slabs[82].

Forms for slab

Props for carrying slabs during casting are delivered for each floor slab that is cast[83]. All material for one floor fit on one truck with trailer assuming the floor has an area of around 500 m^2 or less. In case of site-cast slab, which is less common than pre-cast or filigree, approximately 25 % more props will be needed.

[79] Respondent CC: *Transport coordinator at a insulation wholesaler.*
[80] Haucon Sverige, 2010. *Kantbalk-för enkel formsättning vid platta på mark.* [Online] Available at: http://www.haucon.se/product_pdf/katform.pdf [Accessed 21 02 2012].
[81] Respondent F: *Sales at a Pre-cast concrete frame manufacture.*
[82] Abetong, 2012. *Filigranbjälklag.* [Online] Available at: http://www.heidelbergcement.com/se/sv/abetong/home.htm [Accessed 10 01 2012].
[83] Respondent V: *Sales manager at concrete form entreprenuer.*

Wall forms

Only one set of form for wall is required per building since the form is moved when one part of the wall is cast[84]. One set fits on an open trailer truck.

Reinforcement

According to Oskar Emilsson at Armeringdirekt, around 30 tons of reinforcement can be delivered to the construction site on a semi-trailer truck[85]. However, Emilsson estimates that around 20 tons is the average filling level.

Steel

Steel deliveries during the frame phase generate in general one delivery per floor on a light truck[86].

Balconies

Balconies are delivered in complete sets including slab element, handrail and mounting hardware[87]. Usually, the sets are delivered on normal-sized trucks loaded with up to 20 balconies.

7.5 Frame-complement

Façade panels

Generally façade panels are delivered on normal-sized trucks loaded with ten tons of material on average[88]. Drip plates and other accessories for the panels always come on the same delivery.

Roof trusses

A normal loading ratio for semitrailer trucks is around 48 trusses per delivery[89]. Generally, roof trusses are mounted with a center-to-center distance of 1.2 meters which means one semitrailer truck is sufficient for a 57 meter long building.

Material from building material retailer

In general, a large part of deliveries to big construction sites are supplied directly from the manufacturer. For large building projects the building

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[84] Ibid

[85] Respondent G: *Sales at a steel reinforcement wholesaler.*

[86] Respondent J: *Project leader at a steel entreprenuer.*

[87] Respondent X: *Project leader at a bolcony enteprenuer.*

[88] Respondent Z: *Sales at a façade panel wholesaler.*

[89] Respondent H: *Sales at a roof truss manufacture*

material retailer Optimera mainly supply standardized types of building materials and products such as gypsum, joists, wood products and fittings[90].

In some cases, the site management prefers smaller and more frequent deliveries, particularly if they have less space for storage or work according to just-in-time principle. In these cases, Optimera supply materials and components that would otherwise be delivered directly from the manufacturer, i.e. doors, kitchen parts, sockets and other interior components[91].

Large construction projects usually order large quantities of material. For scheduled deliveries the loading rate is normally relatively high and joint loading of various materials are unusual. However, extra deliveries in addition to the scheduled deliveries are common. There are approximately twice as many extra deliveries than scheduled deliveries and they occur at least every day[92]. These deliveries contain smaller quantities and joint loading is more common.

For scheduled deliveries of building material such as wood and plasterboards the loading is usually 10-12 tons per delivery on a normal truck. The loading weight varies if the site management prefers smaller and more frequent deliveries and for various types of materials[93]. E.g. light materials such as insulation[94] are loaded with less weight and building components of small quantities are delivered with light trucks.

Windows and doors

Normally, 40 to 60 doors or windows are delivered with a semi-trailer truck or truck with trailer[95]. The delivery includes the accessories required for installation.

Leveling underlayment

Assuming water will be supplied at the construction site, only mortar will be delivered for leveling underlayment. The most common delivery vehicle is a truck with a trailer that takes an average load of 12-13 tons[96].

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[90] Respondent B: *Stock and transport maneger at a building material retailer.*
[91] Ibid
[92] Ibid
[93]Ibid
[94] Knauf, 2011. *KnaufInsulation.* [Online] Available at: http://www.knaufinsulation.se/ [Accessed 06 02 2012].
[95] Respondent L: *Logistics at a window and door wholesaler.*
[96] Respondent W: *Specialist leveling underlayment.*

Suspended ceiling

Deliveries of the suspended ceiling are usually done for one floor at a time[97]. A normal truck fits up to 1550 m^2 of ceiling but generally only 300-400 m^2 is delivered at the same time.

Sheet metal

For buildings up to a GFA of 1000 [m^2] one delivery of sheet metal is enough, including metal roof, drainpipes and windowsills[98].

Mounting hardware and office equipment/daily deliveries

For the supply of mounting hardware such as nails, screws etc as well as for office furniture and accessories, a trading company in tools and machinery for construction projects is usually procured. According to the site manager Sture Gustafsson at JM, most of this material is ordered with short notice[99]. During the most intense time periods of projects there is a car from a trading company (such as Ahlsell) arriving almost daily.

7.6 Interior

Parquet flooring

For larger building projects deliveries are usually scheduled once a week with 200-300 m^2 of floor per delivery on a normal truck[100].

Kitchen lighting

Normally, lighting armature for the kitchen is delivered with light trucks[101]. The load on one truck varies, but normal is around eight apartments per delivery.

Kitchens

According to the site manager Sture Gustafsson at JM, the most common method is to procure the supply of kitchen cabinets and kitchen appliances separately. Kitchen cabinets are usually delivered on trucks with all furniture for five-six kitchens (e.g. five-six apartments, assuming one kitchen per apartment) per delivery[102].

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[97] Respondent M: *Technical information at a suspended ceiling wholesaler.*
[98] Respondent U: *Order processor at a metal sheet wholesaler.*
[99] Respondent I: *Site manager at a contractor.*
[100] Respondent Q: *Sales at a floor manufacture.*
[101] Respondent S: *Delivery manager at a lightning entreprenuer.*
[102] Respondent I: *Site manager at a contractor.*

Arpad Kardos at Electrolux estimates that all appliances for one kitchen take up a space of approximately three cubic meters[103]. He also states that a normal-sized truck with which they deliver appliances to construction sites contains ten-twelve m^3. Kitchen appliances are very attractive to thieves and hence, the strive is usually to deliver these appliances just in time for the installation. The deliveries are sometimes made on trucks with trailers which can take a greater volume.

Laundry Systems

According to Tonny Madsen at Electrolux Laundry systems, most new apartment buildings are provided with laundry facilities in each apartment as well as a laundry room in the basement[104]. For a basement laundry room all facilities can be delivered on one truck with a trailer at one specific time. One laundry room can service up to approximately 30 apartments, and even more if each apartment also houses its own washing machine.

Water and heating equipment

The interior parts of the bathroom, i.e. toilet, sink, taps, shower, mirror, locker, are loaded onto one pallet per apartment[105]. In some cases two pallets per apartment is required. On average, bathroom interiors for 6 apartments are delivered at a time with a truck with trailer.

Interior fittings

All interior fittings such as keys, door signs, mail boxes, towel hangers etc are delivered in packages including all appliances for one apartment[106]. The packages are delivered on small trucks and normally the packages for all apartments in one building entrance is delivered on the same truck and time.

Cabinets

Cabinets are usually supplied with light trucks loaded with approximately 8 cabinets per delivery[107].

Painting

The number of deliveries for a painting subcontractor mainly depends on how well the deliveries are planned. A normal delivery ratio is one delivery per apartment with a normal truck[108].

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[103] Respondent O: *Manager at a kitchen appliances manufacture.*
[104] Respondent T: *Sales at a laundry manufacture.*
[105] Respondent N: *Logistic manager at bathroom interiour wholesaler.*
[106] Respondent I: *Site manager at a contractor.*
[107] Respondent B: *Stock and transport maneger at a building material retailer.*

7.7 Installation

Ventilation installations

According to Björn Broberg at Sydtotal, ventilation for apartment buildings is usually ordered per shaft[109]. Most often, only the exhaust air is designed for, i.e. the vent pipes going from kitchens and bathrooms, up to a heat exchanger at the top of the house. For a standard apartment building one ventilation duct leads to two apartments per floor. Typically, an apartment building in Sweden is not higher than seven-eight floors with two-three apartments per floor. To make an estimation of the deliveries a standard building of five floors and four apartments per floor to base the calculations on was agreed on. Ventilation pipes are delivered in lengths of three meters. Björn Broberg estimates that a building as above would require 90 meters of ventilation pipes, i.e 30 pieces.

Besides ventilation pipes, ventilation units also need to be taken into account. There is usually one unit per shaft but a couple of shafts can also be connected to the same unit, so that the number becomes one unit per two-three shafts[110]. Assuming an apartment building similar to Fågelsten BRF, the construction would require one ventilation unit per shaft.

A normal delivering truck is three meters high and about three meters wide and they are ordered per loading meter. The diameter of ventilation pipes for apartment buildings is usually in the range of 125-160 mm[111]. 30 pieces of such pipes fit easily on one truck according to Björn Broberg. Hence, one truck is sufficient for delivery of all the ventilation pipes in the above example.

Regarding ventilation units, the fact that they are bulky makes it most common to deliver them separately[112]. Referring to the above example, it is usually sufficient to deliver all material for one ventilation shaft on one truck.

Heating

Heating installations generate major deliveries and are delivered by regular-sized trucks without trailers[113]. The two most common heating

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108 Respondent J: *Project economics at a painting contractor.*
109 Respondent E: *System developer at a ventilation contractor.*
110 Ibid
111 Ibid
112 Ibid
113 Respondent P: *Manager at a heating and plumbing entreprenuer.*

systems are radiators with district heating or boilers/heat pumps. Boilers/heat pumps are bulky and delivered by truck. For an apartment building of five floors with four apartments per floor Lennart Karlsson, department manager for Heating and Plumbing at Bravida, estimates that about fifteen full-sized trucks are required for delivery of the full heating system. A notation to make is that under floor heating is common in apartment buildings as an alternative to radiators. Under floor heating is bulky and if it is used, a much higher number of deliveries will be generated.

Plumbing

For an apartment building, the amount of plumbing deliveries will be large compared to other building types due to a higher amount of kitchens and bathrooms[114]. Estimation is that about fifteen deliveries will be generated also for plumbing for the example apartment building above.

Both heating and plumbing material is usually delivered per floor or per apartment and occurs frequently as the installation at the construction site progresses.

Electrical installations

The electrical installations that are needed for a standard building consist of cable drums, cable trays, distribution boards, window sills, fixtures etc. Henrik Lewerentz working within electrical installations at Bravida estimates that around 30-50 cable drums are needed per floor for the example building above which corresponds to approximately three-four deliveries per floor[115]. Cable trays are bulky and it takes approximately one truck per floor for the delivery of them. Distribution boards are usually delivered on a separate truck and also generate one delivery per floor. Window sills take up a lot of space and approximately one truck per floor is required even for them. Fixtures are delivered on pallets, in ordinary-sized trucks. About three-four pallets per floor are usually needed, which fits on one truck.

Security Systems

According to Peter Williams[116] at Bravida Security Systems, the security system installations that Bravida typically performs are fire and burglar alarms, and sometimes access systems. The deliveries of such installations are small and usually come in one package or on one pallet. The number of

[114] Respondent P: *Manager at a heating and plumbing entreprenuer.*
[115] Respondent R: *Manager at an electrical installations entreprenuer.*
[116] Respondent BB: *Manager at a building safety entreprenuer.*

deliveries mainly depends on the possibility of storing material at the construction site. For a building of approximately five floors height, Williams estimates that the number of deliveries varies between 4 and 25 for the whole project. The material is delivered in a small car and the deliveries are spread over the entire construction period.

Elevator installations

According to Patrik Berndtsson working at the elevator company Kone, all elevator material comes on trucks with trailers[117]. The number of elevators delivered per truck varies a lot and usually depends on the order from the contractor as opposed to the truck size. Patrik Berndtsson estimates that a number of two elevators per truck represents an average order from construction sites.

[117] Respondent D: *Sales manager at a elevator manufacture*

8 Compilation of data

In this chapter information from the quantitative data, case study, interviews and secondary data are compiled and delivery ratios are calculated for inserting in the program.

8.1 General approach

The compilation was carried out to generate the basic delivery data for the program. The information needed to develop the program was:

- List of all materials delivered to a building project along with corresponding construction phases.
- A delivery ratio for each material and the variable affecting the delivery ratio (e.g. variable describing the size of the building).
- The type of vehicle used for the delivery.

In order to obtain delivery ratios two approaches has been used. In most cases a quantity ratio was obtained from the case study or quantitative data analysis and was combined with a loading ratio obtained from the qualitative data analysis. Dividing the quantity ratio with the loading ratio gave the delivery ratio:

$$Delivery\ ratio = \frac{quantity\ ratio}{loading\ ratio}$$

In some cases this approach could not be performed and the delivery ratio was then obtained directly from the qualitative data analysis. Information about the type of vehicle used for the delivery was obtained from the qualitative data analysis.

8.2 Data sources and assumptions

Table 12 presents all material and deliveries from the study along with their corresponding calculated delivery ratio. Also the source used to determine the ratio for each material as well as underlying assumptions are presented here. A full list of the quantity ratios and loading ratios used for calculations are found in Appendix 4. Also the types of delivery vehicles are found here.

Phase/ Material	Data source	Assumption	Delivery ratio	
1. Ground				
1.1 **Excavation**	Material – input Loading - sect. 7.2	The volume of excavation material will be specified by the program user, since the amount of excavation varies for each construction project (section 3.3.1.1.). The amount will be specified in the unit cubic meters. For simplification, the program will not require to specify the type of excavation material. Loading ratio was assumed 16 m^3/delivery (section 7.2)	6,25E-02	del/m^3 Exc
1.2 **Drainage pipes**	Material - sect. 7.2 Loading - sect. 7.2	In order to determine the perimeter (i.e. the length of the drainage pipes, see section 7.2) related to the building area, a rectangular building with a base length twice as long as the width was assumed. The geometry was chosen after having studied several apartment building drawings and was considered a normal design. A relationship between the perimeter of the building i.e. length of drainage pipes (L) and the building area (BA) was determined: $$L = 6 \cdot \sqrt{BA/2}$$	0,02*√(BA /2)	del
1.3 **Macadam**	Material – sect. 7.2 Loading - sect. 7.2	From section 7.2 a thickness of the macadam layer was chosen to 300 mm which was assumed spread underneath the whole building area. Hence, a volume of 0,3 m^3 macadam/m^2 BA was calculated. Loading ratio was assumed the same as for excavation material.	1,88E-02	del/m^2 BA
1.4 **Filter fabrics**	Material – assumed Loading - sect. 7.2	Required area of filter fabrics was assumed the same as the building area. Loading ratio was assumed 50000 m^2/delivery based on the estimation done by Berggren	2,00E-05	del/m^2 BA

			in section 7.2		
1.5	**Piles**	Material – sect. 7.2 Loading - sect. 7.2	Loading and quantity ratios were based on the sample project described in section 7.2. According to respondent X. piles are only used for projects with poor ground conditions, and hence the user of the program will specify if piles are used or not. It was assumed that no other quantity ratios are affected by the choice of building or not building with piles.	3,00E-03	del/m^2 GFA
2.	**Foundation**				
2.1	**Concrete**	Material – sect. 5.3.3 Loading - sect. 7.3	An average loading ratio of 6.0 m^3 on a concrete mixer truck was estimated based on section 7.3.	4,17E-02	del/m^2 BA
2.2	**Edge form, steel**	Material – sect. 5.3.3 Loading - sect.7.3	Based on section 7.3 the edge forms used in Fågelsten were assumed to fill half a truck which gave the loading ratio.	7,40E-04	del/m^2 BA
2.3	**Insulation**	Material – sect. 7.3 Loading - sect. 7.3	In order to determine a ratio for the amount of insulation deliveries, the calculations were based on the estimations in section 7.3. Yngve appreciated that two deliveries would be required for all the various types of material for foundation insulation used in Fågelsten BRF, section 6.4. The amount of foundation insulation in general was assumed to be proportional to the foundation area and hence determined in terms of deliveries per building area. The foundation area of storages was not taken into account.	2,96E-03	del/m^2 BA
2.4	**Reinforcement**	Material – sect.5.3.3 Loading - sect.7.4	The data from section 5.3.3 was used for estimating amount and type of reinforcement net in a foundation.	2,79E-04	del/m^2 BA
2.5	**Filling**	Material – sect. input Loading - sect. 7.2	In order to estimate the quantity of filling material, various kinds of excavation methods were studied. The	8,69E-03	del/m^3 Exc

			methods studied are described by Wikells in the book Sektionsdata, including quantities of excavation and filling material. By compiling the quantities for the various methods it was concluded that the average amount of filling material was approximately 13,9 % of the excavation material.		
2.6	**Foundation columns**	Material – sect. 5.3.3 Loading - sect. 7.5	Foundation columns were assumed delivered from building material retailer and loading ratio was chosen from section 7.5.	1,58E-03	del/m^2 GFA
2.7	**Garbage Truck**	Material & Loading - sect. 6.2.2.2	Based on section 6.2.2.2, it was assumed that garbage trucks constitute 5 % of the total amount of deliveries. Thus, the delivery ratio for garbage trucks was expressed in terms of percentage of other deliveries. The data in 6.2.2.2 does not include deliveries during the foundation phase but garbage trucks were assumed to occur even during this phase and were therefore taken into account here.	5,00E-02	del/del
3.	**Frame**				
3.1	**Concrete**	Material – sect.6.1.1.3 Loading - sect. 7.3	The concrete quantity ratios are based on the quantitative data in section 6.1.1.3 for slabs (site-cast and filigree) and vertical bearing elements (walls and columns). The quantity ratio from Fågelsten was not taken into account since the amounts used were not specifically divided on building elements. A concrete truck loading ratio for use in the program was decided to 6.0 m^3 based on section 7.3	3,55E-02 (site-cast slabs) 2,79E-02 (filigree slabs) 1,92E-02 (site-cast walls) 1,22E-02 (site-cast columns)	del/m^2 SA del/m^2 SA del/m^2 GFA del/m^2 SA
3.2	**Concrete elements**	Material – sect. 6.1.2.3 & 5.3.4 Loading - sect. 7.4	The quantity ratio for precast slabs was based on the quantitative data analysis in section 6.1.2.3. For filigree slabs no data corresponding to the one for precast slabs	1,19E-02 (precast slabs) 3,59E-03 (filigree slabs)	del/m^2 SA del/m^2 SA

			was obtained from Betongbanken. Instead, data from Fågelsten section 5.3.4 was used since filigree slabs were used in the project. The loading ratio and vehicle type for the delivery of precast slabs was based on section 7.4. The loading ratio for filigree slabs was assumed 310 m^3/del based on section 7,4 as well.	2,24E-02 (precast walls)	del/m^2 GFA
3.3	**Concrete staircases**	Material – sect. 6.1.2.3 Loading - sect. 7.4	The amount of prefabricated stairs was taken from the quantitative data analysis in section 6.1.2.3. The loading ratio was assumed the same as for prefabricated slabs based on section 7.4.	2,95E-04	del/m^2 GFA
3.4	**Forms**	Material – sect. 5.3.4 Loading - sect.7.4 &7.5	Delivery ratios for wall and slab forms were taken directly from the interview with Petersson in section 7.4. Quantity ratios for wooden forms were taken from section 5.3.4 and the material was assumed delivered from a building material retailer (section 7.5).	1,00 (wall forms) 1,00 (props) 1,31E-04 (wood) 9,89E-05 (plywood)	del/Bd del/Fl del/m^2 GFA del/m^2 GFA
3.5	**Reinforceme nt**	Material – sect. 6.1.1.3 Loading - sect. 7.4	Reinforcement quantity ratios were based on section 6.1.1.3 for both slabs (filigree and site-cast) and vertical bearing elements (walls and columns). The ratio includes both rebars and reinforcing net for walls. Loading ratios were based on section 7.4. Reinforcement accessories were assumed delivered together with the bars and not generate any extra deliveries.	1,67E-04 (filigree slabs) 4,44E-04 (site-cast slabs) 3,58E-04 (column frame) 1,86E-04 (wall frame)	del/m^2 GFA del/m^2 GFA del/m^2 GFA del/m^2 GFA
3.6	**Form oil**	Material – sect.5.3.4 Loading - sect. 7.5	Form oil was assumed delivered from a building material retailer. The delivery ratio calculated was really small and was therefore disregarded in the program.	-	
3.7	**Steel**	Material – Loading - sect. 7.4	Delivery ratio was taken directly from the interview with Hansson in section 7.4.	1,00	del/fl
3.8	**Mounting**	Material –	Extra deliveries assumed	1,00	del/day

	hardware	Loading – sect. 7.5	from section 7.5		
3.9	**Balconies**	Material – Loading - sect. 7.4	For the quantity ratio one balcony was assumed per apartment. Loading ratio from section 7.4	5,00	del/apt
3.10	**Garbage Truck**	Material & Loading - sect. 6.2.2.2	Based on section 6.2.2.2, it was assumed that garbage trucks constitute 5 % of the total amount of deliveries. Thus, the delivery ratio for garbage trucks was expressed in terms of percentage of other deliveries.	0,05	del/del
4.	**Frame-complement**				
4.1	**Façade**	Material – sect.5.4 Loading - sect. 7.5	The quantity ratios for façade were based on the project Fågelsten in section 5.4 which hence implied an assumption of façade consisting of two different kinds of panel board. Loading ratios were based on the Ivarsson interview in section 7.5.	8,03E-04 (façade panel) 3,41E-04 (façade panel, balconies)	del/m^2 GFA del/m^2 GFA
4.2	**Wood**	Material – sect. 5.4 Loading - sect. 7.5	All wood materials were assumed delivered together from a building material retailer. Hence, a loading ratio of 11000 kg/del was assumed from section 7.5.	1,34E-03 (sawn timber) 1,78E-04 (panel board) 7,43E-05 (wood trims) 2,84E-05 (plywood)	del/m^2 GFA del/m^2 GFA del/m^2 GFA del/m^2 GFA
4.3	**Roof**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratios were obtained from Fågelsten. Roof hatches were assumed supplied from a building material retailer and was given a loading ratio according to 7.5. Loading ratio for roof trusses were based on the interview with respondent G in 7.5	2,52E-03 (roof hatches) 1,29E-03 (roof trusses)	del/m^2 BA del/m^2 BA
4.4	**Sheet metal**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratios were obtained from project Fågelsten (section 5.4). Sheet metal was assumed delivered together with other types of material from a building material retailer and hence, the loading	1,10E-04 (joists) 3,32E-05 (rails) 5,35E-05 (rails, ext walls)	del/m^2 GFA del/m^2 GFA del/m^2 GFA

		ratio from section 7.5 was used.	9,68E-05 (roof profiles)	del/m² BA
4.5 **Plasterboard**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratios were based on the material data from Fågelsten (section 5.4). Loading ratios were based on deliveries from a retailer, section 7.5.	4,75E-04 (roof) 1,69E-02 (wet areas) 9,07E-05 (fireboard) 1,45E-03 (regular)	del/m² BA del/apt del/m² GFA del/m² GFA
4.6 **Mineral wool**	Material – sect.5.4 Loading - sect. 7.5	Loading ratios for the types of mineral wool used in Fågelsten were all found at the webpage for the insulation supplier Knauf Insulations, referenced in section 7.5.	6,61E-04 (all) 2,14E-05 (caulking) 3,90E-04 (joints) 1,71E-05 (sill)	del/m² GFA del/m² GFA del/m² GFA del/m² GFA
4.7 **Plastic material**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratios were taken from section 5.4. Sealing tape was not taken into account due to the very low weight. Plastic material was based on the loading ratio for materials for a building material retailer in section 7.5	1,38E-05 (plastic foil) 3,91E-06 (windbreak)	del/m² GFA del/m² GFA
4.8 **Bitumen felt**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratio from Fågelsten section 5.4. Bitumen felt was given a loading ratio from a building material retailer, section 7.5.	2,29E-04	del/m² BA
4.9 **Glulam**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratios were taken from Fågelsten and loading ratios for glulam products were assumed from building material retailer.	5,13E-05 (beams) 1,47E-05 (columns)	del/m² GFA del/m² GFA
4.10 **Windows and doors**	Material – sect. 5.4 Loading - sect. 7.5	The quantity ratios for various kinds of windows and doors were based on the case Fågelsten, section 5.4. A loading ratio of 50 doors or windows per truck was assumed based on section 7.5.	9,60E-04 (windows) 2,60E-04 (small w.) 2,20E-04 (casement doors) 2,00E-02 (entrance) 7,20E-04 (interior)	del/m² GFA del/m² GFA del/m² GFA del/apt del/m² GFA

				1,00E-04 (steel) 6,00E-05 (storage)	del/m^2 GFA del/m^2 GFA
4.11	**Mounting hardware**	Material & Loading – sect. 7.5	Delivery ratio taken directly from section 7.5 for mounting hardware.	1,00	del/day
4.12	**Leveling underlayment**	Material – sect. 5.4 Loading - sect. 7.5	Quantity ratio was based on section 5.4. Loading ratio was taken to 12000 kg/del from section 7.5	1,61E-03	del/m^2 GFA
4.13	**Suspended ceiling**	Material & Loading - sect. 7.12	Based on the interview in section 7.5 a delivery ratio of one truck per floor was assumed.	1,00	del/Fl
4.14	**Sheet metal**		Delivery ratio was calculated directly based on section 7.5	1,00E-03	del/m^2 GFA
4.15	**Extra material from trading company**	Material & Loading - sect. 7.5	Based on the interview with respondent H; site manager at a contractor in section 7.5 one delivery a day with extra material from a trading company was estimated for the program.	1,00	del/day
4.16	**Garbage Truck**	Material & Loading - sect. 6.2.2.2	Same as for 3.10.	0,05	del/del
5.	**Interior**				
5.1	**Floor covering**	Material – sect. 5.5 Loading - sect. 7.6	Quantity ratio was based on the amount used in the project Fågelsten. Based on section 7.6 a loading ratio of 250 m^2 floor covering/ delivery was decided on.	2,58E-03	del/m^2 GFA
5.2	**Kitchen lighting**	Material & Loading - sect. 7.6	Delivery ratio was decided directly from section 7.6	1,25E-01	del/apt
5.3	**Kitchen appliances**	Material – sect. 7.6 Loading - sect. 7.6	A quantity ratio for kitchen appliances was given from the interview in section 7.6 and a loading ratio of 11 m^3/delivery was chosen based on this interview as well. An assumption was made that all kitchen appliances stored on one truck can be installed the same day and hence no storage on the construction site is needed even when the trucks come fully loaded.	2,73E-01	del/apt
5.4	**Laundry**	Material –	A number of one laundry	1,00	del/Bd

		assumed Loading - sect. 7.6	room per building was chosen assuming that this will be sufficient for most apartment buildings (based on interview, section 7.6). From section 7.6 a loading ratio of a set of appliances for 1 laundry room per delivery was chosen.		
5.5	**Water and heating equipment**	Material – sect. 7.6 Loading - sect. 7.6	An average quantity ratio of 1,5 pallets per apartment was chosen based on section 7.6. Loading ratio was taken from here as well.	1,67E-01	del/apt
5.6	**Interior fittings**	Material & Loading - sect. 7.10	Delivery ratio was given from section 7.10.	1,00	del/Bd
5.7	**Banisters**	Material – sect. xxx, xxx and assumption Loading - sect. 7.3	Assuming a banister diameter of 45 mm (2 mm thick for steel banisters) and using the weight of wood and steel from sections xxx and xxx (7800 kg/m3??) (0,795 and 2,205 kg/m) respectively gave quantity ratios for wood and steel banisters. Loading ratios are based on delivery from a building material retailer, section 7.3	2,61E-06 (steel) 1,08E-06 (wood)	del/m^2 GFA del/m^2 GFA
5.8	**Kitchen cabinets**	Material – assumed Loading - sect. 7.10	A quantity ratio of one set of kitchen cabinets (i.e. one kitchen) per apartment was decided on. Using the information from the interview with Gustafsson in section 7.10, deliveries of kitchen cabinets were given a loading ratio of five apartments at a time.	2,00E-01	del/apt
5.9	**Cabinets**	Material – sect. Loading - sect.	For the quantity ratio four cabinets per apartment was assumed.	5,00E-01	del/apt
5.10	**Painter**	Material & Loading - sect. 7.6	Delivery ratio was given directly from section 7.6	1,00	del/apt
5.11	**Garbage Truck**	Material & Loading - sect. 6.2.2.2	Same as for 3.10.	0,05	del/del
6.	**Installation**				
6.1	**Ventilation**	Material & Loading - sect. 7.7	Since the interview with Björn Broberg in section 7.7 was based on an example building	2,00E-01 (pipes) 1,00	del/fl del/bd

			of five floors it was appreciated that the most suitable calculation was to determine the ratio for number of pipe deliveries per number of floors. This determination meant that no consideration was taken into the fact that one truck might be sufficient for deliveries to more than five floors. It was assumed that this would measure up for an assumption that it is hard to store installation material for more than five floors at the construction site. For ventilation units, one shaft is assumed per building.	(shaft)	
6.2	**Heating**	Material & Loading - sect. 7.7	Based on the interview with Lennart Karlsson in section 7.7 heating system installations are usually delivered per floor or per apartment. Since the number of apartments per floor is likely to vary between projects, it was assumed advantageous to determine the number of deliveries per apartment. Hence, fifteen trucks of heating material are assumed required for deliveries to twenty apartments.	7,50E-01	del/apt
6.3	**Plumbing**	Material & Loading - sect. 7.7	Same approach was made as for heating deliveries.	7,50E-01	del/apt
6.4	**Electrical installations**	Material & Loading - sect. 7.7	Delivery ratios for all electrical installation materials were based on the interview with Lewerentz in section 7.7. A number of three deliveries was chosen for cable drums.	1,00 3,00 1,00 1,00 1,00	del/fl del/fl del/fl del/fl del/fl
6.5	**Security systems**	Material & Loading - sect. 7.7	Based on the interview in section 7.7 with Peter Williams a number of ten deliveries was assumed for security systems. The number was chosen from the lower part of the range Williams	2,00	del/fl

			mentioned since access systems and burglar alarms are less common for apartment buildings than offices. The assumption led to a delivery frequency of two cars per floor.		
6.6	**Elevators**	Material – sect. assumed Loading - sect. 7.7	The number of elevators in a building was assumed to depend on the project and to be likely to increase with floor size. However, an average number of elevators per floor area was difficult to determine and a possible investigation was assumed to give an unreliable result. In the program, an average number of one elevator per building was assumed. Loading ratio was given from section 7.7.	5,00E-01	del/fl
6.7	**Garbage Truck**	Material & Loading - sect. 6.2.2.2	Same as for 3.10.	0,05	del/del

Table 12: Data source and assumptions for compiled data

9 Result

This chapter describes the layout and features of the program as well as a general description of the calculations performed in the program. The chapter can be used as a manual of how to use the program.

9.1 Program layout and features

The delivery estimation program is opened through Excel. In the various sheets in the workbook it is possible to enter information about various buildings that is going to be constructed in the project. All features and results for each building are available in each sheet. The layout was designed to make it easy to overview and use the program. It is possible to directly monitor the changes of the delivery schedule when the project description and time schedule are adjusted. The delivery schedules for the various buildings are compiled in a compilation sheet.

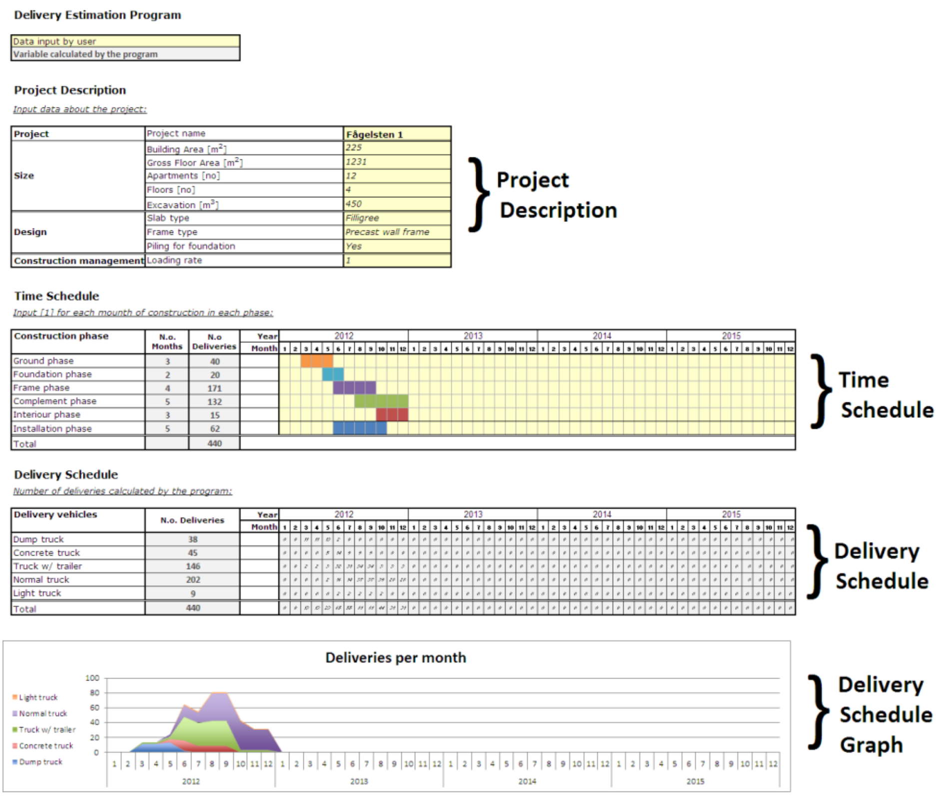

Figure 9: Layout of a sheet in the delivery estimation program

9.1.1 Project Description

The first part of the program regards the information about the building analyzed. The input data shall be based on available information or adequate estimations.

The size of the building is described by input values for; *building area, gross floor area, number of apartments, floors* and *excavation volume*. The design is described by choosing slab type and frame type from predefined selections. By clicking on the slab type box, the following three choices will appear: *Pre-cast slab, Filigree slab* and *Site-cast slab.* The frame type also includes three choices: *Pre-cast wall frame, Site-cast wall frame* and *Site-cast column frame.* Whether or not piling is used in the project is indicated by choosing *Yes* or *No* in the piling for foundation box.

Various construction management approaches can imply different loading ratios. If the approach is to strive towards just-in-time deliveries it can be assumed that the loading rate decreases. On the other hand, if the management intends to stock a lot of material on site the loading rate may increase. By adjusting the loading rate the filling degrees are adjusted for the deliveries affected by the construction management approach.

Figure 10 shows the layout of the program. To illustrate the feature of the program data from the case BRF Fågelsten has been inputted. As the project consists of three separate buildings, data of each building is inputted in three separate sheets. Figure 10 shows information regarding building 1.

Project Description

Input data about the project:

Project	Project name	**Fågelsten 1**
Size	Building Area [m^2]	*225*
	Gross Floor Area [m^2]	*1231*
	Apartments [no]	*12*
	Floors [no]	*4*
	Excavation [m^3]	*450*
Design	Slab type	*Filligree*
	Frame type	*Precast wall frame*
	Piling for foundation	*Yes*
Construction management	Loading rate	*1*

Figure 10: Layout of the project description section in the program

9.1.2 Time Schedule

The time schedule is in the program described by the construction phases: *Ground, Foundation, Frame, Complement, Interior* and *Installation.* When the timetable is put into the program, the numbers of months for each phase are calculated as well as the total number of deliveries for each phase.

Figure 11 shows the layout and the time schedule that has been assumed for building 1 in BRF Fågelsten. A total of 440 deliveries is calculated and distributed over the various phases as shown in the figure.

Time Schedule

Input [1] for each mounth of construction in each phase:

Construction phase	N.o. Months	N.o Deliveries	Year	2012											
			Month	1	2	3	4	5	6	7	8	9	10	11	12
Ground phase	3	40													
Foundation phase	2	20													
Frame phase	4	171													
Complement phase	5	132													
Interiour phase	3	15													
Installation phase	5	62													
Total		440													

Figure 11: Layout of the time schedule part

9.1.3 Delivery Schedule

Based on the input data, the program calculates a delivery schedule. The column *No. Deliveries* in the table presents the total number of deliveries for each vehicle type. The numbers to the right shows the number of deliveries for each month. If the material that the deliveries contain is of interest it can be checked in the calculation rows described in section 9.2.

Figure 12 shows the delivery schedule for building 1 in BRF Fågelsten and the distribution over the various vehicle types.

Delivery Schedule

Number of deliveries calculated by the program:

Delivery vehicles	N.o. Deliveries	Year	2012											
		Month	1	2	3	4	5	6	7	8	9	10	11	12
Dump truck	38		0	0	11	11	13	2	0	0	0	0	0	0
Concrete truck	45		0	0	0	0	5	14	9	9	9	0	0	0
Truck w/ trailer	146		0	0	2	2	3	32	31	34	34	3	3	3
Normal truck	202		0	0	0	0	2	16	14	37	37	39	28	28
Light truck	9		0	0	0	0	0	2	2	2	2	2	0	0
Total	440		0	0	13	13	23	65	55	81	81	44	31	31

Figure 12: Layout of the delivery schedule table

9.1.4 Delivery Schedule Graph

The program draws a graph of the delivery schedule. By studying the graph the user gets an overview of the estimated delivery schedules. Figure 13 illustrates the delivery schedule for building 1 in case Fågelsten.

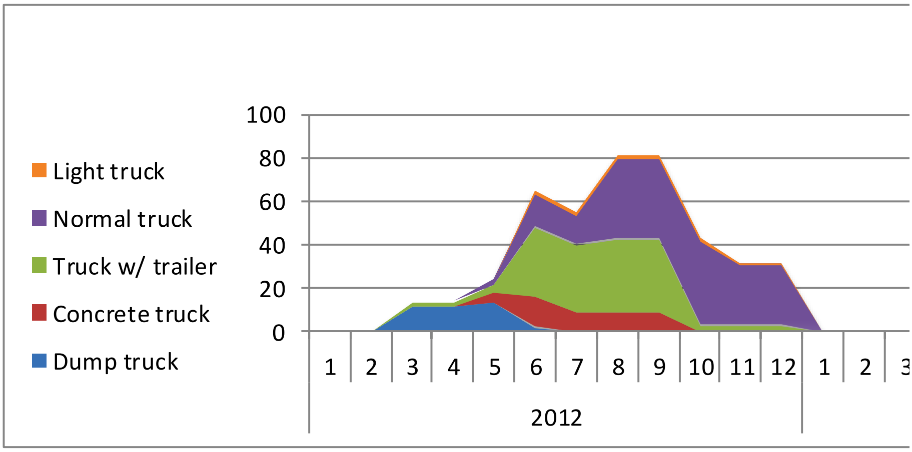

Figure 13: Layout of the delivery schedule graph

9.1.5 Compilation of various building projects

The compilation sheet summarizes the delivery schedules for each building. Figure 14 illustrates the total delivery schedule graph for all three buildings in BRF Fågelsten. Each building is assumed to have the same project information but individual time schedules that overlap. It can be concluded that peaks of more than 150 deliveries per month will occur in September and December 2012.

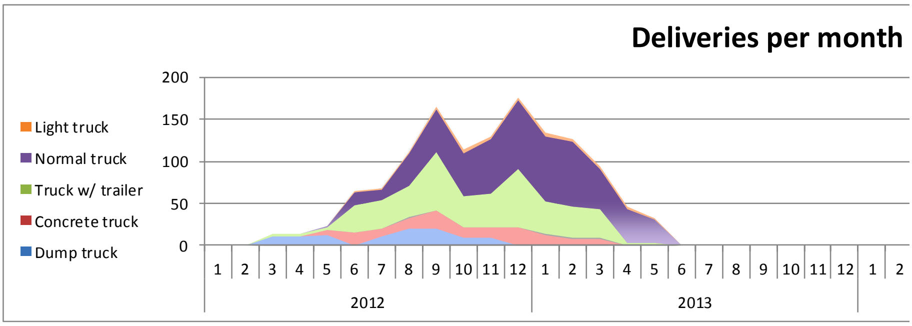

Figure 14: Compiled delivery schedule for the whole project

9.2 Calculations of the program

The calculations that the software executes are hidden in the Excel chart, but can be unhidden if requested. All calculations are performed according to the fundamental model described in section 4.1. They were programmed to be easy to understand and change.

The calculation part consists of a number of *calculation rows* for each material and component in the building. The *calculation rows* are named and a color code describes the construction phase when the delivery occurs. Furthermore, the delivery vehicle, delivery ratio and size variable are defined here according to Appendix 3. The user may want to change these which can be done easily.

Based on the input data, the *calculation row* calculates the estimated number of deliveries; in total and per month as well as when they occur for each material. The program summarizes all calculated data and compiles it into the delivery schedule.

10 Discussion

This chapter concludes the thesis by discussing the research approach and result. Criticism is directed to the research and considerations for the user are presented. Finally, suggestions for further research to improve and develop the program are discussed.

10.1 General about the research result

This master thesis has resulted in a program that meets the specific objectives stated in the introduction. Hopefully, the program will have a good impact on construction planning and facilitate the planning of deliveries. Further, the authors hope that the program will increase the attention paid to deliveries and their importance for a successful project.

10.2 Criticism of the research approach

During the study, the authors have not been able to find data of how many deliveries that actually occur at a building project. Secondary data has not been available and to test the program on an actual project was too extensive for the scope of the research. This implies an uncertainty around the program's reliability.

The large amount and variety of deliveries along with the complexity of a building project causes a large scope of the research. The research topic contains different aspects and the authors had to prioritize which parts were important to investigate. This was done by constant consideration of which factors affect the number of deliveries most. A combination of quantitative and qualitative data analysis and a case study has enabled many aspects to be covered. However, the scope processing these methods was large and made it difficult to deepen into details. It may have led to certain factors that affect the number of deliveries being overlooked.

The uniqueness of each building and construction project also implied difficulties in generalizing the program for various building projects. A major part of the quantity ratios have been based on one case study and the delivery ratios on individual interviews. Both methods included estimations, which may have been sources of error. If the sources contained unusual delivery ratios it has made the program less reliable. Such errors have not been possible to detect since for a major part of the data it has not been possible to do crosschecks with other sources.

Despite the criticism of the program's reliability it should be stressed that the program probably gives a good *estimate* of an early stage delivery schedule, which was the purpose stated in the introduction.

10.3 Considerations when using the program

When using the program it is important to consider how the analyzed project relates to the assumptions made while developing the program. For an optimal use it is hence essential for the user to be familiar with the program premises described in the report. If the premises or assumptions differ from the ones for the project that will be analyzed, it should be taken into account and the program may be adjusted.

By reviewing the result it has been identified that the proportion of light trucks calculated by the program was significantly smaller than the proportion from the quantitative data analysis where the distribution of different delivery vehicles were analyzed. One reason for this is that the study was limited to taking into account only *the most common* type of vehicle for each material supply. For example, most insulation material was delivered on normal trucks according to the qualitative and quantitative data analysis, and thus the program assumes that *all* deliveries come on normal trucks. But, according to table 11 in the quantitative analysis chapter, 25% of the deliveries of insulation actually come on light trucks, which was not included in the program. For a lot of materials the deliveries were delivered by both normal and light trucks, where normal trucks was most common and thus the proportion of light trucks was underestimated which should be borne in mind.

10.4 Future research

In order to create more reliable results the master thesis could be complemented with a deeper analysis of the case study and interviews as well as complement the data with additional cases and surveys. The program could also be evaluated by comparing results with an actual delivery schedule or by tests on a real project.

To further develop the program it can be extended to include more building types, e.g. office and public buildings. Also, various framing systems, building designs and degrees of prefabrication can be implemented as well as degrees of just in time deliveries.

It is also possible to introduce new features to make the program more useful. It is relatively simple to include the number of unloading locations required on the construction site. There are studies of average unloading times for different types of vehicles. By combining unloading times with the delivery schedules, the number of required unloading locations can be estimated.

Furthermore, internal logistics at the construction site can be planned by studying the equipment that specific deliveries require, i.e. the number of hoists, cranes or forklifts needed to unload the trucks. By combining this data with the delivery schedule, required amount of internal logistic equipment can be estimated for each construction phase.

Another possible application is to estimate carbon emissions from construction deliveries by compiling average mileage and emissions for different transportation types and combining with the delivery schedule. The analysis could be interesting for studies of a building's overall emissions and carbon dioxide footprint.

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A. Transportation coordinator at a Carrier:
   Asmundsson, P. *Transportation coordinator at Akka Frakt* (19 01 2012).

B. Stock and transport maneger at a building material retailer:
   Backeus, K. *Lager & Transportchef at Optimera* (06 01 2012).

C. Sales manager at a wholesaler for Geo products:
   Berggren, T. *Sales manager at FLA Geoprodukter* (30 01 2012).

D. Sales at a elevator manufacture:
   Berndtsson, P. *Kone* (02 02 2012).

E. System developer at a ventilation contractor
   Broberg, B. *System and Business Developer at Sydtotal* (30 01 2012).

F. Sales at a Pre-cast concrete frame manufacture:
    Edlund, S. O. *Marknadschef Bostad Mellansverige at Strängbetong* (25 01 2012).

G. Sales at a steel reinforcement wholesaler:
    Emilsson, O. *Ordermottagare at Armeringdirekt* (11 01 2012).

H. Sales at a roof truss manufacture:
    Granberg, C. *Säljare at Carlenskogs Takstolar* (06 02 2012).

I. Site manager at a contractor:
    Gustafsson, S. *Platschef at JM* (02 2012).

J. Project leader at a steel entreprenuer:
    Hansson, D. *Projektledare at Svensk Stålentreprenad AB, Partille* (20 02 2012).

K. Project economics at a painting contractor:
    Hedström, S. *Kalkyl at Alviksmåleri* (21 02 2012).

L. Logistics at a window and door wholesaler:
    Holmström, A. *Leveransbevakare at Elitfönster* (07 02 2012).

M. Technical information at a suspended ceiling wholesaler.
    Jakobsson, P. *Teknisk informatör at Gyproc* (06 02 2012).

N. Logistic manager at bathroom interiour wholesaler:
    Josephson, L. E. *Logisitcs manager at Svedbergs* (21 02 2012).

O. Manager at a kitchen appliances manufacture:
    Kardos, A. *Distriktchef at Electrolux Centrala Bygg* (14 02 2012).

P. Manager at a heating and plumbing entreprenuer:
    Karlsson, L. *Department Manager Heating and Plumbing at Bravida* (04 01 2012).

Q. Sales at a floor manufacture:
    Kindblad, M. *Kundservice at Tarkett* (06 01 2012).

R. Manager at an electrical installations entreprenuer:
    Lewerentz, H. *Department Manager at Bravida* (04 01 2012).

S. Delivery manager at a lightning entreprenuer:
Lönn, J. *Order and delivery at Flux* (21 02 2012).

T. Sales at a laundry manufacture:
Madsen, T. *Säljare at Electrolux Laundry Systems* (14 02 2012).

U. Order processor at a metal sheet wholesaler.
Norling, M. *Order processer at Plåtgrossisten.se* (21 02 2012).

V. Sales manager at concrete form entreprenuer:
Petersson, S. *Marketing manager at Peri* (06 02 2012).

W. Specialist leveling underlayment:
Roth, K. *Specialist golvavjämning at Finja* (07 02 2012).

X. Project leader at a bolcony entepренuer:
Rönnberg, L. *Project leader at Alcon Balkongentreprenad* (21 02 2012).

Y. Work manager at a piling entreprenuer:
Stark, R. *Arbetschef at BESAB* (30 01 2012).

Z. Sales at a façade panel wholesaler:
Thorén, M. *Marknadschef at Ivarsson* (06 02 2012).

AA. Site manegement at a contractor:
Wetterberg, E. *Foreman at the project Kanien, NCC Construction Malmö* (05 01 2012).

BB. Manager at a building safety entreprenuer:
Williams, P. *Construction manager at Bravida Säkerhet* (14 01 2012).

CC. Transport coordinator at a insulation wholesaler:
Yngve, R. *Transportkoordinator at Sundolitt* (30 01 2012).

12 Appendix

Appendix1 *Concrete and reinforcement for site-cast concrete frames and slabs*

Appendix 2 *Concrete elements for pre-cast concrete frames and slabs*

Appendix 3 *Layout of a calculation row*

Appendix 4 *Material-, loading- and delivery ratios for all materials and components*

Appendix 1 – Concrete and reinforcement for site-cast concrete frames and slabs

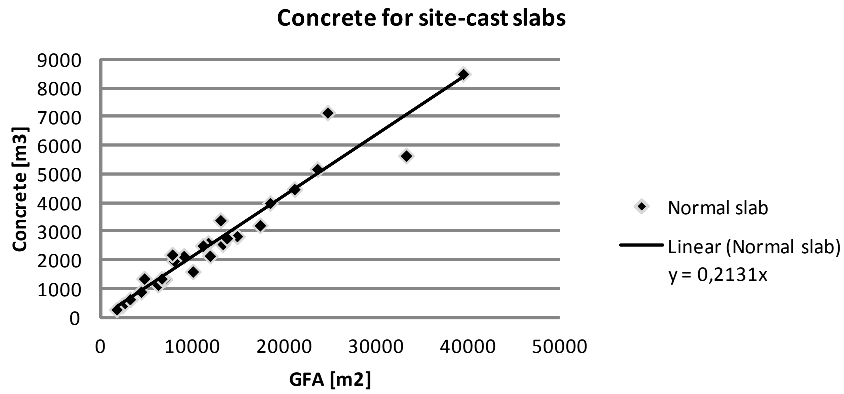
Data

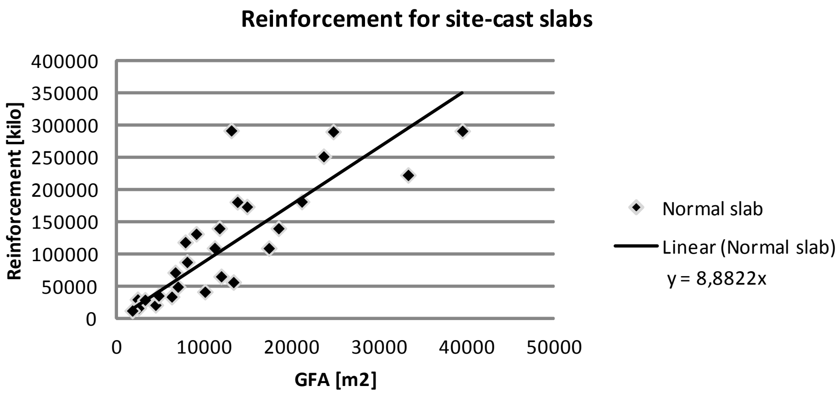
Data of site-cast concrete frames and slabs

Project	Type	GFA [m2]	Floors	Structural interiour walls	Structural conc. exteriour walls	Deck supported by columns	Filligree slab	Prefab. exteriour columns or walls	Prefab. interiour columns	Reinf. walls [kg]	Reinf. columns [kg]	Reinf. slabs [kg]	Concr. walls [m3]	Concr. columns [m3]	Concr. slabs [m3]
Ankaret, Göteborg	Apartment	13250	8	Yes				Yes		62200		56500	1552		2569
Badhuset, Sundsvall	Office	11650	8		Yes	Yes				43600	11400	140000	915	66	2610
Berget, Lycksele	Apartment	6900	8	Yes						37550		49450	950		1345
Bollen, Lund	Apartment	3000	4	Yes			Yes			13200		10500	440		700
Braxen, Karlstad	Apartment	4300	6	Yes			Yes			18000	8900	17000	711	6	697
Brinckan, Stockholm	Apartment	21050	8	Yes	Yes					296900		181400	3993		4484
Cykelstyret, Motala	Apartment	4350	6	Yes				Yes		7520		21182	285		907
Davida, Malmö	Office	13000	11			Yes				31600	40000	291800	325	165	3400
Ejnar, Uppsala	Apartment	17300	7	Yes						106880		109200	2150		3220
Fisken, Malmö	Office	7950	6		Yes	Yes				44740	3100	87730	600	23	1980
Gasklockan, Malmö	Office	24650	7			Yes		Yes		85000	8800	290000	900	140	7150
Gesunden, Stockholm	Apartment	6200	6	Yes						23000	3750	34000	685	25	1150
Herrevadsbro, Göteborg	Apartment	14800	11	Yes				Yes		72300		173600	1447		2840
Hästhagen, Göteborg	Apartment	10000	6	Yes						38320		41610	1015		1610
Karlsberg, Trollhättan	Apartment	6600	3	Yes	Yes					31100		71400	855		1365
Keflavik, Stockholm	Office	39400	7		Yes	Yes				327000	36800	291100	3250	300	8500
Kommunhus, Storfors	Office	2300	3		Yes	Yes			Yes	10000		29800	127		421
Långtäppan, Karlstad	Apartment	33200	3	Yes						66530		222720	3400		5650
Mjölner, Göteborg	Office	9000	9			Yes		Yes	Yes	10000		131400	440		2150
Måran, Örebro	Apartment	11850	6	Yes						99470		65440	1800		2160
Präntaren, Borås	Apartment	4900	6	Yes			Yes	Yes		13000		23000	450		1180
Regementet, Skövde	Apartment	11100	6	Yes	Yes					72890		109410	1665		2515
Regnvalla, Helsingborg	Apartment	4700	3	Yes				Yes		16408	2800	35640	424	28	1365
Rönnen, Östersund	Apartment	1600	5	Yes	Yes		Yes			8850	300	3380	207	3	217
Siktet, Stockholm	Office	7750	9		Yes	Yes				69700	5800	118500	875	43	2200
Spegeln, Täby	Apartment	18400	6	Yes						55500		139990	1850		4000
Syrenen, Haninge	Apartment	23550	7	Yes						61600		251700	2680		5180
Tornugglan, Täby	Apartment	2400	4	Yes				Yes		9500	100	16400	206	1	450
Vattenklövern, Nyköping	Apartment	14100	7	Yes	Yes		Yes			84000		44000	2400		2200
Vindflöjeln, Örebro	Apartment	3150	3	Yes				Yes		8403		29102	261		642
Öna, Mora	Office	1700	2	Yes	Yes					7420	950	12400	233	10	288
Öskaret, Sundsvall	Office	13700	6		Yes	Yes				70700	16300	181000	607	55	2770

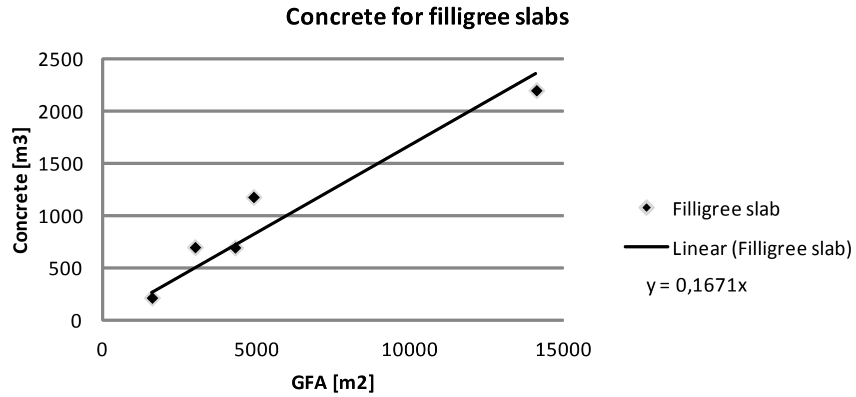
Correlation analysis

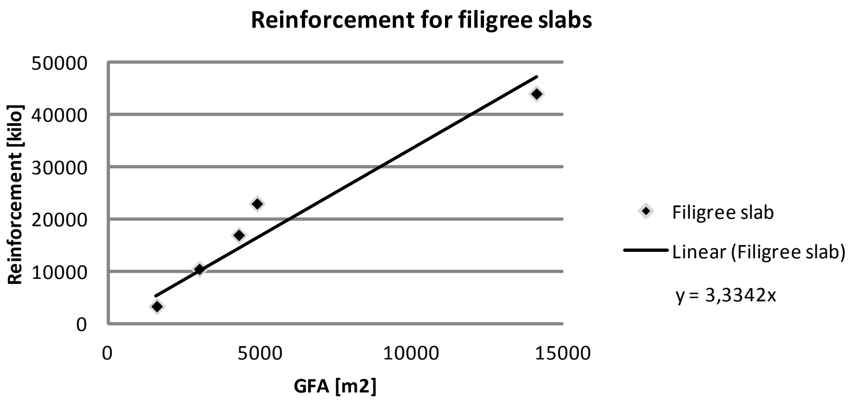
Site-cast slabs



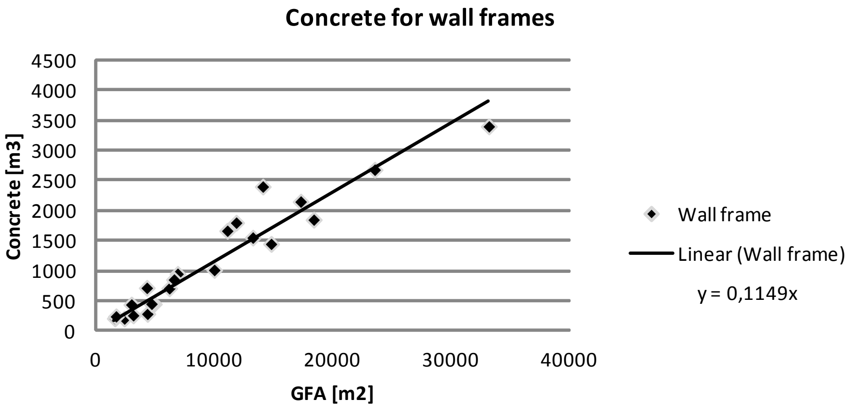


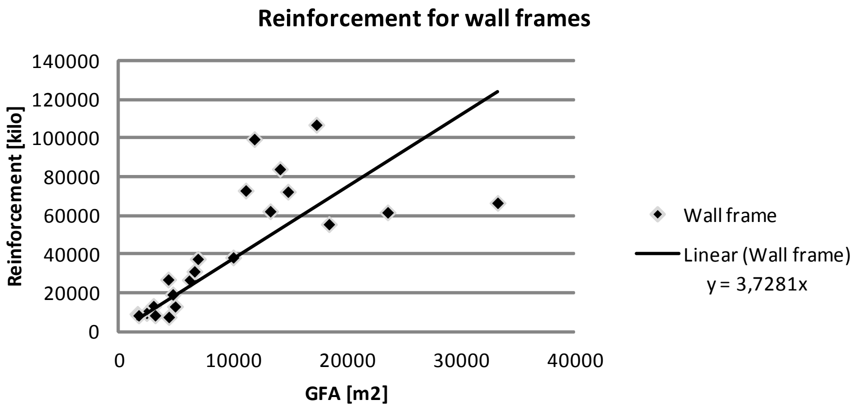
Filigree slabs



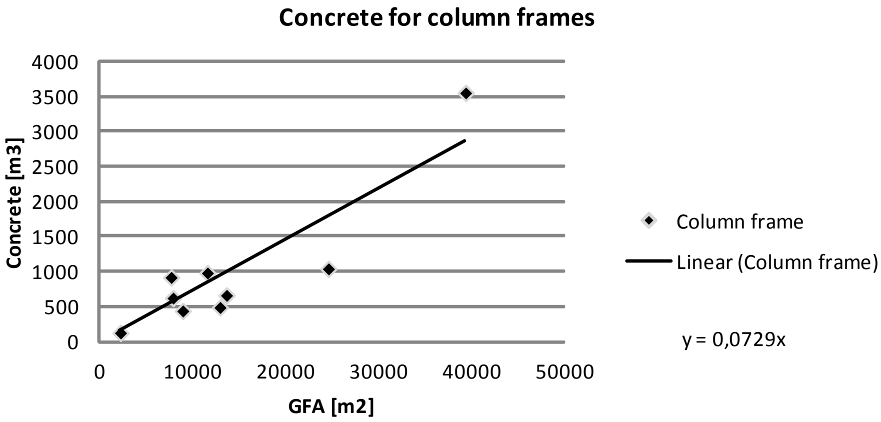


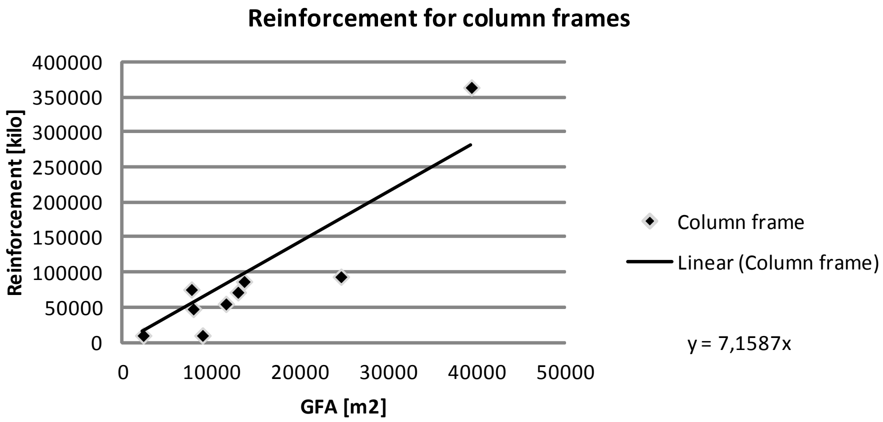
Wall frames


Concrete for wall frames
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Concrete [m3]
0
10000
20000
30000
40000
GFA [m2]
Wall frame
Linear (Wall frame)
y = 0,1149x


Reinforcement for wall frames
140000
120000
100000
80000
60000
40000
20000
0
Reinforcement [kilo]
0
10000
20000
30000
40000
GFA [m2]
Wall frame
Linear (Wall frame)
y = 3,7281x

Column frames





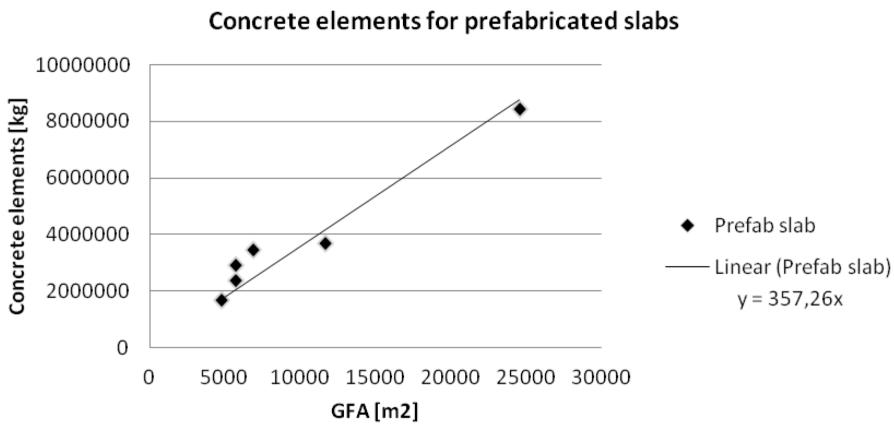
Appendix 2 – Concrete elements for pre-cast concrete frames and slabs

Data

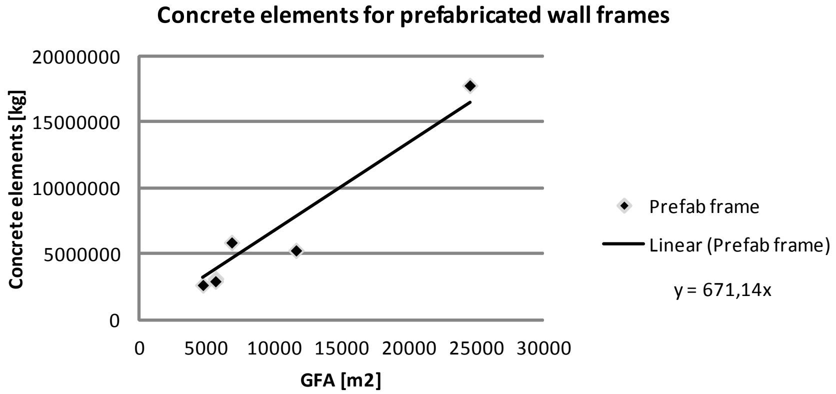
Project	Type	GFA [m2]	Floors	Slab concr. [kg]	Wall concr. [kg]	Stair concr. [kg]
Kusin Vitamin Annedal	Apt	11637	4	62200	5263000	56500
Äppelblomman Beckomberga	Apt	4725	5	43600	2635000	140000
Tallhöjden Södertälje	Apt	5674	5	37550	3115000	49450
Ängby Park Blackeberg	Apt	24528	5	13200	17783000	10500
Båtsman Annedal	Apt	5660	6	18000	2925000	17000
Lusten Hög	Apt	6861	25	296900	5864000	181400

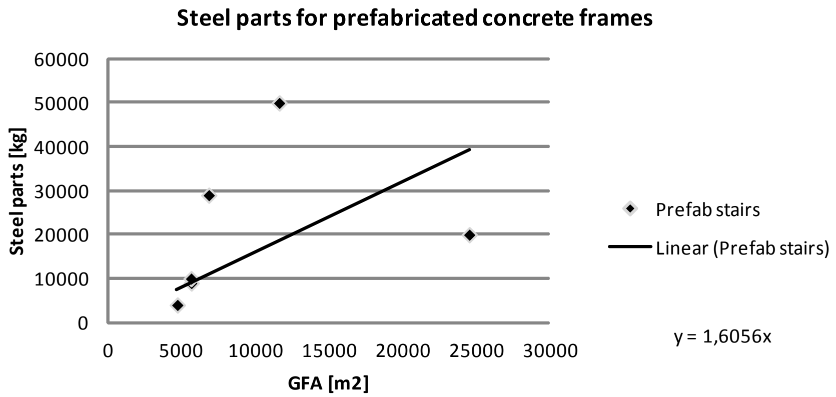
Correlation analysis

Pre-cast slabs

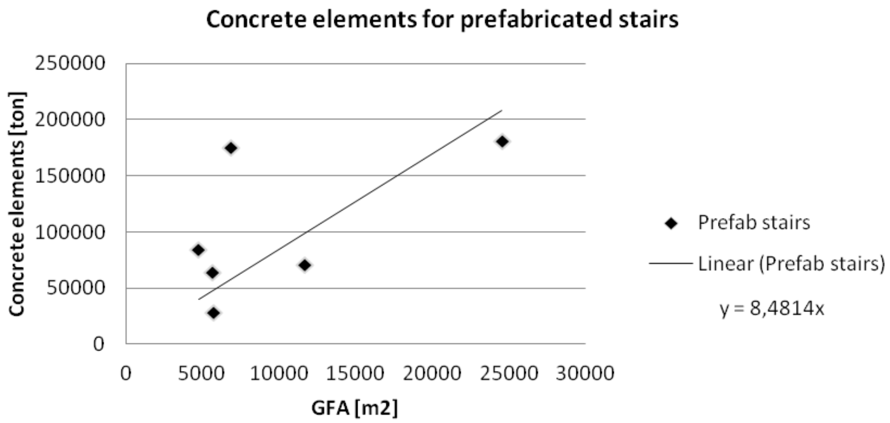


Pre-cast wall frames





Pre-cast stairs



Appendix 3 – Layout of a calculation row

Material or Component and construction phase	Vehicle type	Delivery Ratio	Variable	Loading rate	Total deliveies	Deliveris/month	Other	Year/Month 2012: 1	2	3	4	5	6	7	8	9	10	11	12
Floor covering	Dump truck			0,95	0	0		0	0	0	0	0	0	0	0	0	0	0	0
	Concrete truck			0,95	0	0		0	0	0	0	0	0	0	0	0	0	0	0
	Truck w/ trailer			0,95	0	0		0	0	0	0	0	0	0	0	0	0	0	0
	Normal truck	0,0026	GFA	0,95	9	3	(Round Up)	0	0	3	3	3	0	0	0	0	0	0	0
	Light truck			0,95	0	0		0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4 – Material-, loading- and delivery ratios for all materials and components

	Material	Variabl e	Quantit y ratio	Unit	Vehicle type	Loadin g ratio	Unit	Delivery ratio	Unit
1.	**Ground**								
1.1	Excavation	Exc	1	m^3/m^3	DT	16	m^3/del	6,25E-02	del/m^3
1.2	Drainage pipes	BA	6*√(BA/2)	-	TwT	300	m/del	0,02*√(BA/2)	-
1.3	Macadam	BA	0,3	m^3/m^2	DT	16	m^3/del	1,88E-02	del/m^2
1.4	Filter fabrics	BA	1	m^2/m^2	TwT	50000	m^2/del	2,00E-05	del/m^2
1.5	Piles	GFA	90	kg/m^2	TwT	30000	kg/del	3,00E-03	del/m^2
2.	**Foundation**								
2.1	Concrete	BA	0,25	m^3/m^2	CT	6	m^3/del	4,17E-02	del/m^2
2.2	Edge form, steel	BA	1,066	m/m^2	NT	1440	m/del	7,40E-04	del/m^2
2.3	Insulation	BA	-		TwT	-		2,96E-03	del/m^2
2.4	Reinforcement	BA	5,586	kg/m^2	TwT	20000	kg/del	2,79E-04	del/m^2
2.5	Filling	Exc	0,139	m^3/m^3	DT	16	m^3/del	8,69E-03	del/m^3
2.6	Foundation columns	GFA	17,4	kg/m^2	NT	11000	kg/del	1,58E-03	del/m^2
2.7	Garbage Truck	-	-		NT	-		5,00E-02	del/del
3.	**Frame**								

3.1	Concrete								
3.1.1	Slabs								
3.1.1 (a)	Site-cast	SA	0,2131	m^3/m^2	CT	6	m^3/del	3,55E-02	del/m^2
3.1.1 (b)	Filigree	SA	0,1671	m^3/m^3	CT	6	m^3/del	2,79E-02	del/m^2
3.1.2	Vertical bearing elements								
3.1.2 (a)	Site-cast walls	GFA	0,1149	m^3/m^3	CT	6	m^3/del	1,92E-02	del/m^2
3.1.2 (b)	Site-cast columns	SA	0,0729		CT	6	m^3/del	1,22E-02	del/m^2
3.2	Concrete elements								
3.2.1	Slabs								
3.2.1 (a)	Precast slabs	SA	357,26	kg/m^2	TwT	30000	kg/del	1,19E-02	del/m^2
3.2.1 (b)	Filigree slabs	SA	1,114	m^2/m^2	TwT	310	kg/del	3,59E-03	del/m^2
3.2.2	Precast walls	GFA	671,1	kg/m^2	TwT	30000	kg/del	2,24E-02	del/m^2
3.3	Concrete staircases	GFA	8,84	kg/m^2	TwT	30000	kg/del	2,95E-04	del/m^2
3.4	Forms								
3.4.1	Wall forms	Bd	-		NT	-		1,00E+00	del/Bd
3.4.2	Forms for slab (props)	Fl	-		TwT	-		1,00E+00	del/Fl
3.4.3	Wood	GFA	1,314	kg/m^2	NT	10000	kg/del	1,31E-04	del/m^2
3.4.4	Plywood	GFA	0,989	kg/m^2	NT	10000	kg/del	9,89E-05	del/m^2
3.5	Reinforcement								

3.5.1	Slabs (rebars and net)								
3.5.1 (a)	Filigree slabs	GFA	3,3342	kg/m^2	TwT	20000	kg/del	1,67E-04	del/m^2
3.5.1 (b)	Site-cast slabs	GFA	8,8822	kg/m^2	TwT	20000	kg/del	4,44E-04	del/m^2
3.5.2	Walls								
3.5.2 (a)	Column frame	GFA	7,1587	kg/m^2	TwT	20000	kg/del	3,58E-04	del/m^2
3.5.2 (b)	Wall frame	GFA	3,7281	kg/m^2	TwT	20000	kg/del	1,86E-04	del/m^2
3.5.3	Accessories		-		TwT	-		-	
3.6	Form oil	GFA	0,013	kg/m^2	NT	11000	kg/del	-	
3.7	Steel		-		TwT	-		1,00E+00	del/fl
3.8	Mounting hardware		-		NT	-		1,00E+00	del/da y
3.9	Balconies	Apt	1	set/apt	NT	20	sets/del	5,00E-02	del/ap t
3.10	Garbage Truck	-	-		NT	-		0,05	del/del
4.	**Frame-complement**								
4.1	Facade								
4.1.1	Facade panels	GFA	8,034	kg/m^2	NT	10000	kg/del	8,03E-04	del/m^2
4.1.2	Facade panels, balconies	GFA	3,414	m/m^2	NT	10000	kg/del	3,41E-04	del/m^2
4.2	Wood								

4.2.1	Sawn timber	GFA	14,769	kg/m^2	NT	11000	kg/del	1,34E-03	del/m^2
4.2.2	Panel board	GFA	1,962	kg/m^2	NT	11000	kg/del	1,78E-04	del/m^2
4.2.3	Wood trims	GFA	0,818	kg/m^2	NT	11000	kg/del	7,43E-05	del/m^2
4.2.4	Plywood	GFA	0,312	kg/m^2	NT	11000	kg/del	2,84E-05	del/m^2
4.3	Roof								
4.3.1	Roof hatches	BA	27,741	kg/m^2	NT	11000	kg/del	2,52E-03	del/m^2
4.3.2	Roof trusses	BA	0,062	pcs/m^2	TwT	48	pcs/del	1,29E-03	del/m^2
4.4	Sheet metal								
4.4.1	Joists	GFA	1,209	kg/m^2	NT	11000	kg/del	1,10E-04	del/m^2
4.4.2	Rails	GFA	0,365	kg/m^2	NT	11000	kg/del	3,32E-05	del/m^2
4.4.3	Rails exterior walls	GFA	0,588	kg/m^2	NT	11000	kg/del	5,35E-05	del/m^2
4.4.4	Roof profiles	BA	1,065	kg/m^2	NT	11000	kg/del	9,68E-05	del/m^2
4.5	Plasterboard								
4.5.1	Plasterboard, roof	BA	5,230	kg/m^2	NT	11000	kg/del	4,75E-04	del/m^2
4.5.2	Plasterboard, wet areas	Apt	186,095	kg/apt	NT	11000	kg/del	1,69E-02	del/apt
4.5.3	Fireboard	GFA	0,998	kg/m^2	NT	11000	kg/del	9,07E-05	del/m^2
4.5.4	Regular	GFA	15,955	kg/m^2	NT	11000	kg/del	1,45E-03	del/m^2
4.6	Mineral wool								
4.6.1	Mineral wool, all types	GFA	1,213	m^2/m^2	TwT	1835	m^2/del	6,61E-04	del/m^2

4.6.2	Spacer pipes	GFA	0,009	pack/m²	TwT	-		-	del/m²
4.6.3	Caulking	GFA	0,06	m/m²	TwT	2800	m/del	2,14E-05	del/m²
4.6.4	Insulation, joints	GFA	0,437	m/m²	TwT	1120	m/del	3,90E-04	del/m²
4.6.5	Insulation, sill	GFA	0,048	m/m²	TwT	2800	m/del	1,71E-05	del/m²
4.7	Plastic material								
4.7.1	Plastic foil	GFA	0,152	kg/m²	NT	11000	kg/del	1,38E-05	del/m²
4.7.2	Windbreak	GFA	0,043	kg/m²	NT	11000	kg/del	3,91E-06	del/m²
4.7.3	Sealing tape		-		NT	-		-	
4.8	Building paper								
4.8.1	Bitumen felt	BA	2,517	kg/m²	NT	11000	kg/del	2,29E-04	del/m²
4.9	Glulam								del/m²
4.9.1	Glulam beams	GFA	0,564	kg/m²	NT	11000	kg/del	5,13E-05	del/m²
4.9.2	Glulam columns	GFA	0,162	kg/m²	NT	11000	kg/del	1,47E-05	del/m²
4.10	Windows and doors								
4.10.1	Windows	GFA	0,048	pcs/m²	TwT	50	pcs/del	9,60E-04	del/m²
4.10.2	Small windows	GFA	0,013	pcs/m²	TwT	50	pcs/del	2,60E-04	del/m²
4.10.3	Casement doors, balconies	GFA	0,011	pcs/m²	TwT	50	pcs/del	2,20E-04	del/m²
4.10.4	Interior entrance doors		1	pcs/apt	TwT	50	pcs/del	2,00E-02	del/apt
4.10.5	Interior wooden	GFA	0,036	pcs/m²	TwT	50	pcs/del	7,20E-04	del/m²

	doors								
4.10.6	Storage doors, steel	GFA	0,005	pcs/m^2	TwT	50	pcs/del	1,00E-04	del/m^2
4.10.7	Wooden front doors, storage	GFA	0,003	pcs/m^2	TwT	50	pcs/del	6,00E-05	del/m^2
4.11	Mounting hardware		-		NT	-		1,00E+00	del/da y
4.12	Leveling underlayment	GFA	19,3	kg/m^2	TwT	12000	kg/del	1,61E-03	del/m^2
4.13	Suspended ceiling	Fl	-		NT	-		1,00E+00	del/fl
4.14	Sheet metal	GFA	-		NT	-		1,00E-03	del/m^2
4.15	Extra material		-		NT	-		1,00E+00	del/da y
4.16	Garbage Truck	-	-		NT	-		0,05	del/del
5.	**Interior**								
5.1	Floor covering	GFA	0,645	m^2/m^2	NT	250	m^2/del	2,58E-03	del/m^2
5.2	Kitchen lighting	Apt	-		LT	-		1,25E-01	del/ap t
5.3	Kitchen appliances	Apt	3	m^3/apt	NT	11	m^3/del	2,73E-01	del/ap t
5.4	Laundry	Bd	1	room/bl	TwT	1	room/de l	1,00E+00	del/bd
5.5	Water and heating equip.	Apt	1	psc/apt	TwT	6	pcs/del	1,67E-01	del/ap t

5.6	Interior fittings		-		LT	-		1,00E+00	del/bd
5.7	Banisters								
5.7.1	Steel	GFA	0,0287	kg/m^2	NT	11000	kg/del	2,61E-06	del/m^2
5.7.2	Wood	GFA	0,0119	kg/m^2	NT	11000	kg/del	1,08E-06	del/m^2
5.8	Kitchen cabinets	Apt	1	pcs/apt	NT	5	pcs/del	2,00E-01	del/apt
5.9	Cabinets	Apt	4	pcs/apt	LT	8	pcs/del	5,00E-01	del/apt
5.10	Painter	Apt	-		NT	-		1,00E+00	del/apt
5.11	Garbage Truck	-	-		NT	-		0,05	del/del
6.	**Installations**								
6.1	Ventilation								
6.1.1	Ventilation pipes	Fl	-		NT	-		2,00E-01	del/fl
6.1.2	Ventilation shaft	Bd	-		NT	-		1,00E+00	del/bd
6.2	Plumbing	Apt	-		NT	-		7,50E-01	del/apt
6.3	Heat	Apt	-		NT	-		7,50E-01	del/apt
6.4	Electrical installations								
6.4.1	Cable trays	Fl	-		NT	-		1,00E+00	del/fl

6.4.2	Cable drums	Fl	-		NT	-		3,00E+00	del/fl
6.4.3	Distribution board	Fl	-		NT	-		1,00E+00	del/fl
6.4.4	Window sills	Fl	-		NT	-		1,00E+00	del/fl
6.4.5	Fixtures	Fl	-		NT	-		1,00E+00	del/fl
6.5	Security systems	Fl	-		Car	-		2,00E+00	del/fl
6.6	Elevators	Bd	1	pcs/bd	TwT	2	psc/bd	5,00E-01	del/bd
6.7	Garbage Truck	-	-		NT	-		0,05	del/del