Cost and Time Analysis of Walls (Load-bearing and Non-load-bearing) for Multi-family Houses

Master thesis

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Conceptual Formulation

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Conceptual Formulation

Master Thesis for: Mr. Sureshraja Venkatachalam

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Topic: Cost and Time Analysis of Walls (load bearing and non-load bearing) for Multi-family Houses

Background

In Germany, nearly 54% of the population lives in rented accommodation and only 46% own an apartment or a house. Most of them live in multi-family houses like apartments. The need for housing in Germany is increasing, as many immigrants come to Germany's popular cities for work and education. Due to an increase in population and demand for accommodation, the rent is subsequently higher in many metropolitan cities.

To overcome this situation, multi-family housing investors are demanding a detailed and most accurate cost and time schedule of building works. This helps the investors to provide the necessary deadline to the clients.

Problem Statement

In Germany, the construction of a new building is comparatively less to renovating an old building. Identification of load-bearing and non-load bearing walls in an old building will be very much helpful for the renovation process, as non-load bearing walls don't need much attention or safety during the demolition and reconstruction phase. Cost and time calculations of these walls are needed by the stakeholders at an early stage. For a country with a dense population and very less dwelling area, it is necessary to provide these data well advanced.

Proposal

The proposal is to understand the multi-family housing needs in Germany and to discuss the cost estimation and time schedule of the building works (construction of walls) in the early stage. This can be achieved by considering plans and drawings of a completed project or entirely a new project. Later, a BIM model is created and all the necessary wall elements are applied to the plan. Finally, a cost-time model is generated using the estimated values.

Data collection and Analysis

To study this topic, various literatures are reviewed; German norms and standards (DIN 276) are applied for different construction activities. Suitable drawings and plans, room areas and living spaces are analyzed. The actual number of walls, different wall types and, functions are identified on each floor. Types of material used in each wall are carefully examined and noted down for further calculation.

Methodology

For cost estimation, analytical calculations using labour cost and area of the walls in each floor considering different wall types and functions are calculated respectively. Likewise, construction time also calculated in the same manner using the available parameters. The calculations are made using an Excel Spreadsheet. A BIM software (ArchiCAD/Revit) is used to recreate the plans with detailed wall materials and types for better visual understanding. Finally, a cost-time schedule model is been generated from the estimated values.

Impact

The result of this proposal will be very much helpful for the investors, as it offers a detailed and sound knowledge about the cost and time calculations of walls. Also, better consultation is possible if the estimation is done at an early stage before the design phase. The results can also be considered in a real-life project, as the estimated values are more accurate.

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Abstract

A project's budget and completion time are the most critical factors for an investor in the construction industry. These two factors dramatically define a project's success and failure, as budget overrun and time delay can cost so much for the investors. This research aims to explain the importance of early but detailed cost estimations and scheduling of a residential project, specifically for the wall elements.

The research is statistically based on the theoretical framework of various literature pieces to identify the most suitable methods of cost and time estimation. The S-curve model generated from the cost and time estimation values can help project monitoring and control and avoid cost overrun. The thesis also provides a BIM model of multi-layered wall elements created using ArchiCAD software.

The research concludes that the calculation results can be implemented in real-life projects for its accuracy and sound knowledge to the investors in the early stages.

Keywords: Cost estimation, Scheduling, S-curve model, BIM, Residential buildings

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List of Abbreviations

1BHK	1 Bedroom, Hall and Kitchen
1BK	1 Bedroom and Kitchen
2BHK	2 Bedroom, Hall and Kitchen
2D	2-dimensional
3D	3-dimensional
AACE	American Association of Cost Engineering
BIM	Building Information Modeling
BKI	Baukosteninformationszentrum
BOQs	Bill of Quantities
CAD	Computer-Aided Design
CBS	Cost Breakdown Structure
CEE	Central and Eastern European
CO_2	Carbon dioxide
DIN	Deutsche Institut für Normung
EPS	Expanded Polystyrene
ETI	External Thermal Insulation
Fig.	Figure
FD	French Door
FF	Finish-Finish
FS	Finish-Start
ITI	Internal Thermal Insulation
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
MD	Main Door

MFH	Multi-Family House/Housing
MS	Microsoft
NE	North East
NM	North Middle
PM	Project Management/Manager
SE	South East
SF	Start-Finish
SS	Start-Start
SW	South West
Tab.	Table
VSP	Vico Schedule Planner
WBS	Work Breakdown Structure
WC	Water Closet

List of Symbols

€	Euro

1. Introduction

1.1 Background

Cost and time are the two main challenges the project managers face in a construction project, as incorrect budgeting or poor schedule forecasting can create a significant loss to the investors and stakeholders (El-Sawalhi and Shehatto 2014). In the past, scientific researchers and construction professionals have appreciated the initial planning outcomes and started to offer particular importance on the initial planning process (Wang et al. 2012).

The need for preliminary cost and time estimates in a construction project keeps on increasing day by day, as the investors demand those details well before the start of a new project to get an impression of the budget and time needed to complete a project. The cost development over time also helps oversee the necessary resources during the construction project life cycle (Torp et al. 2016).

In construction literature, the study on project cost and time calculations using mathematical and computerised methods got more attention. However, a single construction activity like the different wall elements for a whole multi-family housing (MFH) is never studied. The types of walls in an MFH building varies according to its position and nature. In order to understand the cost and time parameters of different wall elements of an MFH building, a well-detailed cost and time calculations are taken into account. The resulting values of cost and time calculations help to plot a progressive curve (S-curve). The S-curve is a tool that helps to plan and control the construction progress.

Germany, one of the most famous countries in Europe, is densely populated as people from different parts of the world travel to work and study. The need for housing in Berlin, Germany's capital city, is very high in the past few decades. The construction of new buildings is comparatively low as the old building stocks need retrofitting measures to reduce CO_2 emissions and control energy demand.

During the renovation of an old building, the identification of load-bearing and non-load-bearing walls will be beneficial since the needed attention during the demolition and reconstruction of non-load-bearing walls is significantly less. The investors show much interest in the initial cost and time estimations to predict future progress.

1.2 Research Aim

This research aims to develop a BIM model illustrating the details of different wall elements of a load-bearing masonry wall created using ArchiCAD software. This model offers a visual description of various materials or layers used to construct the wall elements. The cost and schedule calculations of the wall activities result in a progressive curve, useful for planning construction projects at an early stage. The S-curve helps to track the activities and predict the future progression of the project.

1.3 Research Objectives

The key objectives of this study are:

1. To understand the different construction practices and needs of the residential housing sector in Germany.
2. To identify the different wall types (load-bearing and non-load-bearing) for further evaluation.
3. To evaluate the cost and time estimation of the building activities corresponding to wall elements in the early stage.

1.4 Research Methodology

The methods used for the cost estimation varies depending upon the needs and practice of the project manager. However, using labour rates, material rates and area of the walls on each floor considering different wall types and functions are calculated respectively in the detailed estimation process, using an Excel spreadsheet. The more comprehensive and accurate method to calculate the construction schedule is with the use of Vico schedule planner provided by Vico Office. Vico Office is a BIM tool extensively used for the cost calculations, cost optimization, project scheduling, quantity take-offs and much more.

1.5 Research Scope

This research focuses on the cost and schedule of a residential building prepared using the traditional and computerised methods. The cost estimation is a long process as different materials present in different building elements and each should be carefully determined for flawless estimation.

The ArchiCAD 22 BIM software is used to create the 3D models of the 2D CAD (Computer-Aided Design) drawings. The ArchiCAD 22 software offers the user to create detailed building elements for visual understanding. The 4D BIM software Vico Schedule Planner (VSP) is used to prepare the schedule of the residential building. VSP software is built-in with various graphical views, very much helpful in navigating and tracking the project progression.

2. Literature Review – Theoretical Framework

2.1 Housing needs and construction practices

The Central and Eastern European (CEE) economic state experienced a significant upset after the crash of the socialist system. The demand for housing needs significantly increased due to governments departure by cutting down the state subsidies and direct supply. The production of housing development significantly decreased in the early 1990s in CEE countries. In the mid-1990s the housing market steadily began to recover in the CEE regions of the Czech Republic and Hungary. The economic downfall in the early 1990s severely affected the housing production in 2000, and the housing rate never reached the levels of production in 1990s. The housing market recovery during the second half of the 1990s is mainly due to the population decline during the transition period. Fig. 2. illustrates the housing production output during 1990 and 2000 (Stanilov 2007).

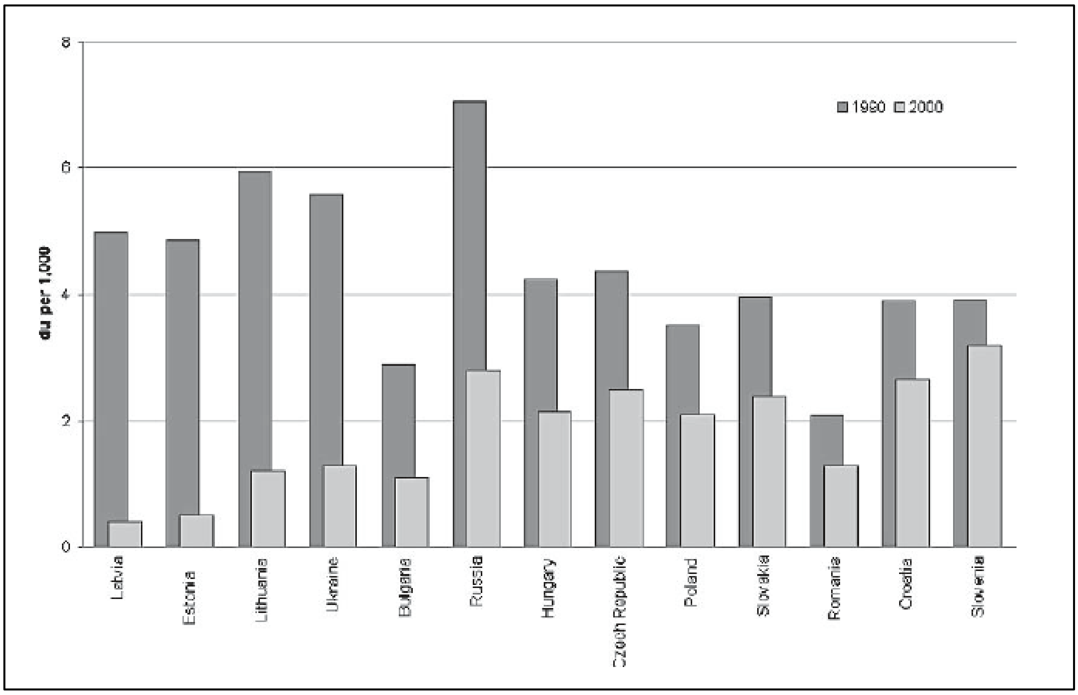

Fig. 1: Housing production output in CEE countries, 1990 and 2000. Source: (Stanilov 2007, p. 174)

In Germany, the tradition of co-housing becoming more attractive day by day. The term "co-housing" means the projects developed for the inhabitants who are willing to live a closer life with other inhabitants and socialise every day. The co-housing communities in Germany range from single-family houses to large and eco-friendly communities planned for a group of families. Germany is one of the ageing societies in Europe; the rise for such housing needs resulted from further developments. However, the number of households, even after ageing and shrinking society, remains stable and is an essential element for the housing sector (Ache and Fedrowitz 2012).

Dipasquale et al. (2019), explains the retrofitting solutions impact the energy efficiency of residential building stocks in Europe and the exploitation of these solutions due to building typology and climatic factors. The authors discuss the method to develop reliable retrofit solutions for buildings blocks in different climatic regions. The results are stored in a database and compared with over 250,000 groupings of building types, building age, climatic conditions and energy performance.

Pohoryles et al. (2020), focuses on the need for renovation of the current and ageing building stocks in Europe, as retrofitting improves the energy performance and structural safety of the building. The environmental impact due to the existing building stock is responsible for sizeable CO_2 emission, as most of the buildings in Europe are 50 years older. The residential building sector shares a significant (75%) amount in Europen building stock. Some combined retrofitting methods such as exoskeleton or double-skin solution implemented for energy performance and structural strengthening of the buildings (Pohoryles et al. 2020).

Rodrigues et al. (2018), discusses the importance of regulations imposed by European countries to improve the energy efficiency of buildings using low thermal transfer envelopes. In order to achieve lower U-values, the authors considered thousands of residential buildings of several European countries with random U-values and geometries. The buildings were grouped according to the thermal envelope transfer, and six geometry indexes were linked to the energy performance. They concluded by explaining that different climatic regions have different U-values and thereby making the geometry effect less significant.

Niemelä et al. (2017), discusses the need for deep renovation in Finnish (cold climate) brick apartment buildings and explores the effects of different renovation methods on the energy performance of the building. The authors explain the various renovation techniques that can apply to energy-saving and cost-effectiveness of brick buildings. The authors choose a case study building in Finland for the deep renovation process and compare the results with old building parameters. They conclude that the renovation of buildings dramatically reduces environmental impact and promote energy saving.

van Gulck et al. (2020), discusses the outdated building stocks in Belgium and how it affects the energy standards and environment. They explain that the demolition and creation of a new building are not feasible and sustainable. They explain the economic and environmental effects that occur due to façade renovation techniques through Life Cycle Analysis (LCA) and Life Cycle Cost Assessment (LCC). They conclude by recommending the use of right material, and construction practices benefit the environmental and financial aspects.

2.2 Cost estimation methods

The cost estimation is the assessment of future costs, even before completing the given work. The methods used for construction cost estimation are of various types, serving a variety of purposes, and each depends on different factors (market trend, client needs, builder planning the estimate). The taking off process leads to cost estimation in the construction industry (Pratt 2012). Tab.1 lists the different types of cost estimation for different residential markets and contracts.

According to Pratt (2012), the cost estimation helps to determine if a project is feasible or not, to calculate the budget of a project, and to set the sales and bidding prices. Pratt discussed two methods of cost estimation, the price per unit method and detailed cost estimation method. The detailed estimation method is the preferable one for him because it is accurate and chosen by most builders for cost calculations.

Types of Estimate	Residential Market	Types of Contract
• Feasibility Estimate	• Speculative Homes	• Home Purchase
• Preliminary Estimate	• Production Homes	• Firm Price Lump Sum
• Bill of Material	• Semi-Custom Homes	• Variable Price Lump Sum
• Detailed Estimate	• Custom Homes	• Cost Plus Percentage
• Budget Estimate	• Townhouses	• Cost Plus Fixed Fee
• Cost Control Estimate	• Condominiums	• Cost Plus Variable Fee

Tab. 1: Estimation types, Residential market and Contract types. Source: (Pratt 2012, p. 2)

Stewart (1991), discusses the cost estimation process in a detailed manner by comparing the process to a manufacturing unit. He focuses on labour rates, man-hours, material quantities. The labour skills and time also plays an essential role in the cost estimation process, as these factors might provoke cost overruns. Fig. 2. illustrates graphically the detailed anatomy of an estimate depicting man-hours and material quantities.

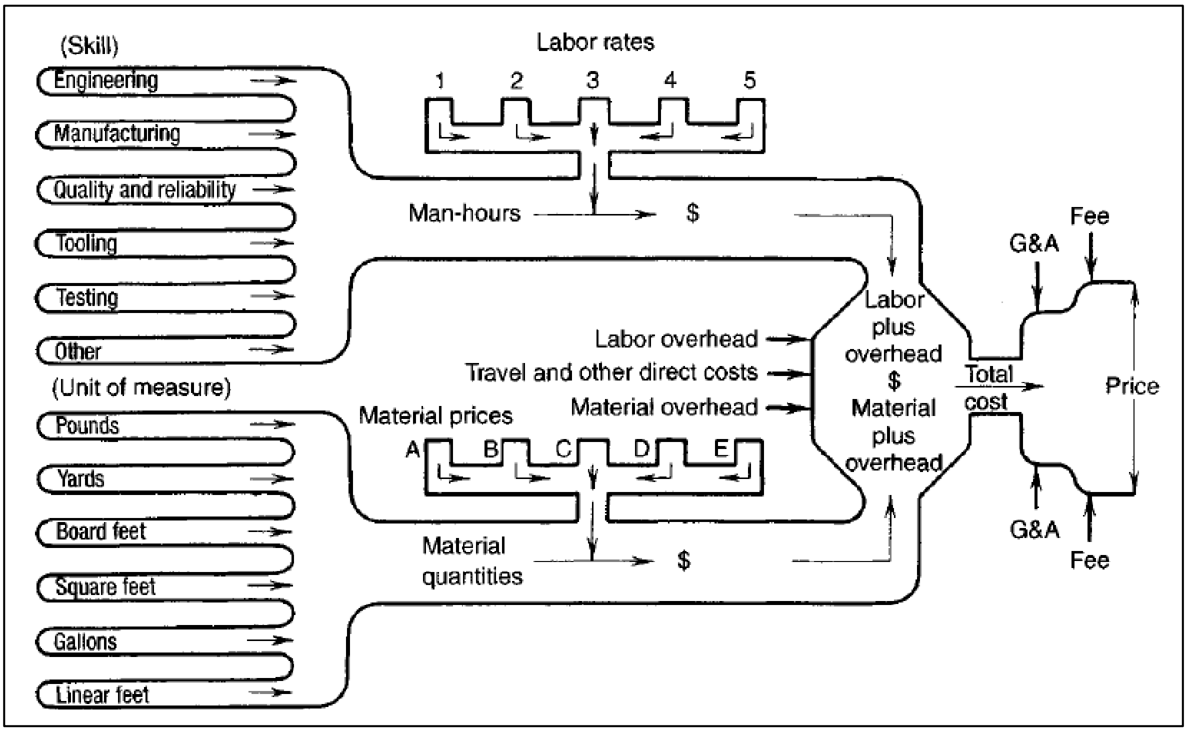

Fig. 2: Anatomy of an estimate. Source (Stewart 1991)

Holm (2005), discusses the three different types of estimates: conceptual, semi-detailed and detailed cost estimates, used at different phases of the construction project. Tab. 2 illustrates the differences among these methods, as the accuracy varies among each method. From the table given below, it is understood that the detailed cost estimation is the most effective among the three methods due to its expected percentage error which is more or less 2 to 4%. With the given plans and specifications, it is possible to achieve accurate cost calculations.

Type of Estimate	Construction Development	Expected Percent Error
Conceptual	Programming and schematic design	± 10-20%
Semi-Detailed	Design development	± 5-10%
Detailed	Plans and specification	± 2-4%

Tab. 2: Construction cost estimation methods. Source: (Holm 2005)

Navarrete and Cole (2001), discusses the cost estimation importance as an estimate is incomplete without engineering input. The estimator should always review the cost parameters with an engineer before making it official. During an execution planning, the estimate should also deal with construction hours in correlation with costs, as it helps to calculate the duration and resources (men and material) required for the project. The authors describe various methods of cost estimation, such as proportioned, factored, computerised simulations, detailed and sem-detailed. The detailed method is more time consuming and extensive compared to other methods and needs a team effort during the estimation process. This method is significantly used by the contractors to prepare bid estimates on a lump sum basis.

Oberlender (2000), defines the early estimate as a critical project parameter to the project team, as it offers execution strategies and also acts as a basis to the planning process. The success and performance of a project team are critically measured by comparing the early cost estimate and the final budget of the project, and however, in most of the cases, the final costs often exceed the early estimates. The author illustrates the various estimates and reestimates taking place throughout the project duration in Fig. 3.

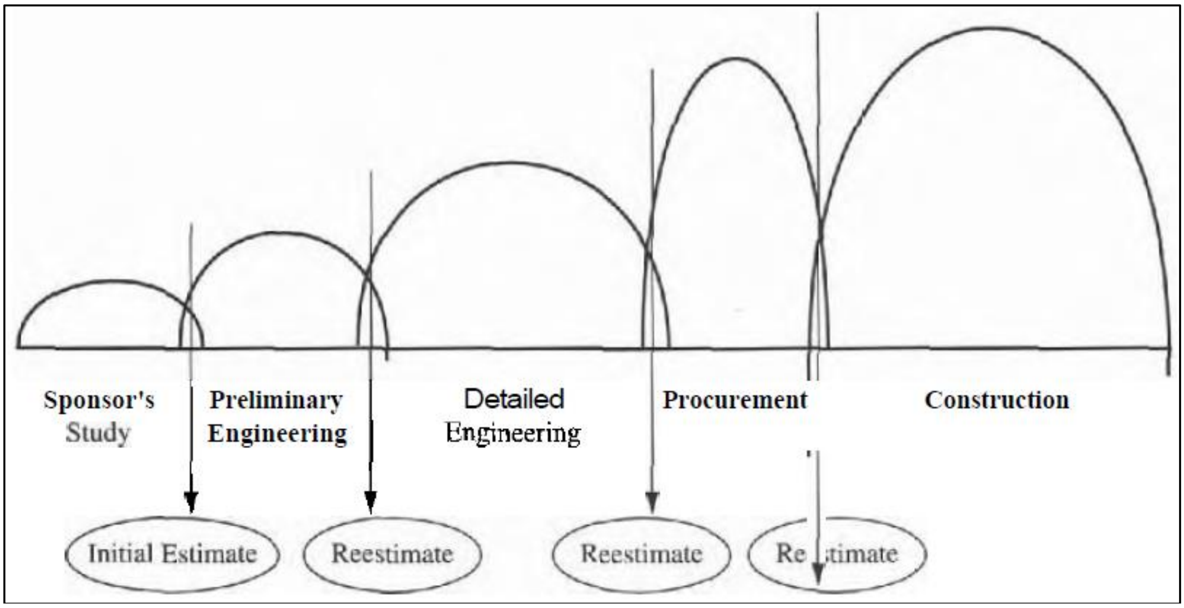

Fig. 3: Estimates and reestimates throughout the development process. Source: (Oberlender 2000, p. 48)

Brook (2005), explains the degree of certainty, which is the accuracy of the cost estimate increases as the planning and design stages evolve in a construction project. Fig. 4 illustrates the declining cost range of a project from feasibility stage to the final project completion stage. The relation between varies stages of the project from the unit of accommodation to the final account and possible cost over-run or under-run is measured using the certainty range.

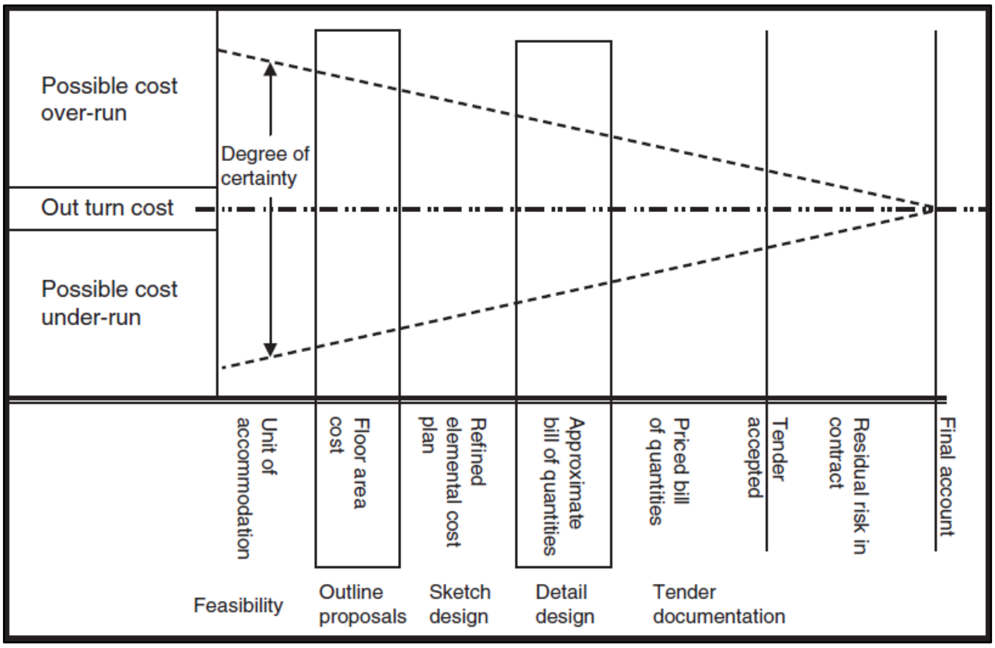

Fig. 4: Degree of certainty of a construction project. Source: (Brook 2005, p. 70)

Lee et al. (2020), discusses the preliminary estimation during the initial stage of the project is very much crucial for decision making and progress determination of the project. The authors explain the estimation methods as a preliminary and detailed estimation. In contrast, both the methods have its purposes of use, accuracy level and accepted errors in each phase according to the American Association of Cost Engineering (AACE) classification presented in Tab. 3.

Primary Characteristic		Secondary Characteristic		
Estimate class	Maturity level of project definition deliverables	End usage	Methodology	Expected accuracy range
Class 5	0 – 2%	Concept screening	Capacity factor, parametric models, judgment, or analogy	L: −20% to −50% H: +30% to +100%
Class 4	1 – 15%	Study or feasibility	Equipment factor or parametric models	L: −15% to −30% H: +20% to +50%
Class 3	10 – 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: −10% to −20% H: +10% to +30%
Class 2	30 – 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: −5% to −15% H: +5% to +20%
Class 1	65 – 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: −3% to −10% H: +3% to +15%

Tab. 3: Cost estimation classification by AACE. Source: (Lee et al. 2020)

Pujitha and Venkatesh (2020), discussed the unit based estimation model to calculate the construction cost for a case study project. They collected necessary data of labour details and work progression of the project by a daily and weekly basis. They listed different skilled and unskilled labours with respective daily wages. With the help of work breakdown structure (WBS), they divided the major construction activities such as beams, columns and slabs into products for an efficient quantity calculation and cost estimation. They compared the resulted cost values with other projects for accuracy.

2.3 Cost and schedule integration

Whitaker (2016), defines project time management as the process of developing a schedule plan, calculating activities and overall project duration, confirming the project progression and milestones are reached, and evaluating any changes to the project schedule. Likewise, he defines cost management as the process of estimating cost activities, developing a cost management plan, preparing a project budget, recording project performance, and influencing any budget changes in the project.

Mubarak (2015), discusses the need for scheduling of a project, as every project has a start and finish point. The stakeholders involved in a project make use of the project schedule in many different perspectives. The contractors use the schedule to calculate the completion of project date, to find specific activities start and end date, to overcome conflicts between subcontractors, to predict project cash flow and it serves as an efficient tool for project control (Mubarak 2015).

Henry L. Gantt developed the Gantt chart (bar chart) in 1917, and it immediately got famous in the construction industry due to its simple and clear graphical representation of the project activities. The project must be broken down into many tasks or activities before a bar chart is constructed (Mubarak 2015). Fig. 5 is an example of a bar chart illustrating the placing of a simple slab on a grade.

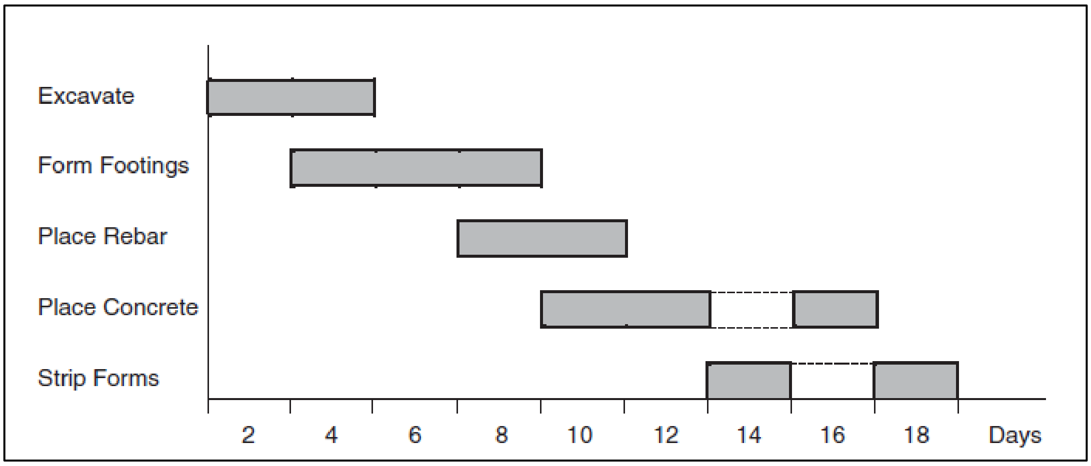

Fig. 5: Bar chart of a slab placed on a grade. Source: (Mubarak 2015, p. 17)

Ignacio Manzanera (2014), describes the primary objectives of a planning engineer are fulfilling tasks in a short time possible, reducing overall costs and risks, and organising the works within the given specifications. Ignacio defines scheduling as a tool to control cost and manage project activities. Bar charts, S-curves and network schedules were some of the standard methods used by scholars, but not as a cost expenditure control tool (Ignacio Manzanera 2014).

Marco (2011), explains how a project can be stripped down into numerous activities in the form of WBS. WBS is an easy method for dividing a complex project into work packages and simpler activities. DelPico discusses three common WBS types – Project WBS, Standard WBS and Contract WBS. He mentions the use Gantt chart for the scheduling purpose like many other authors, as it shows a clear connection between the construction activities of a project. Fig. 6 illustrates a standard WBS of a warehouse project which includes feasibility, design, construction and commissioning phases. Fig. 7 illustrates the Gantt chart of activities of the project.

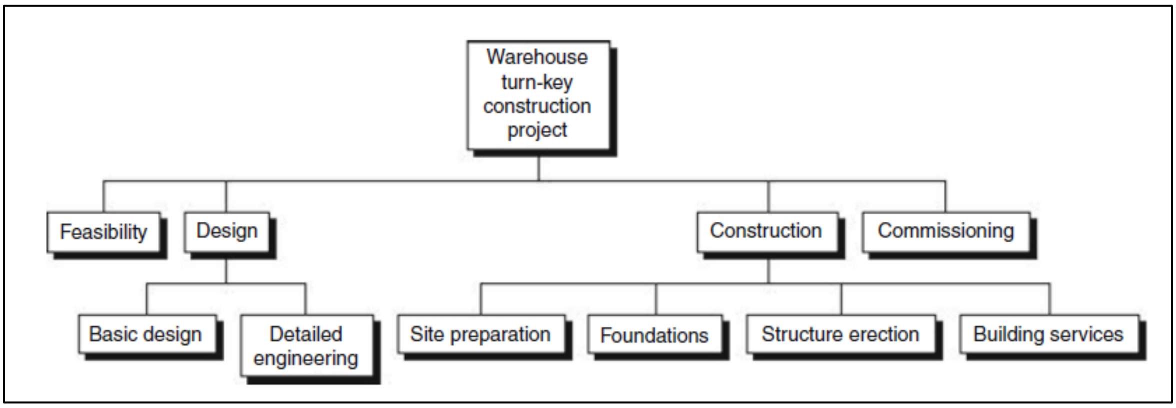

Fig. 6: Standard WBS of a Warehouse construction project. Source: (Marco 2011, p. 92)

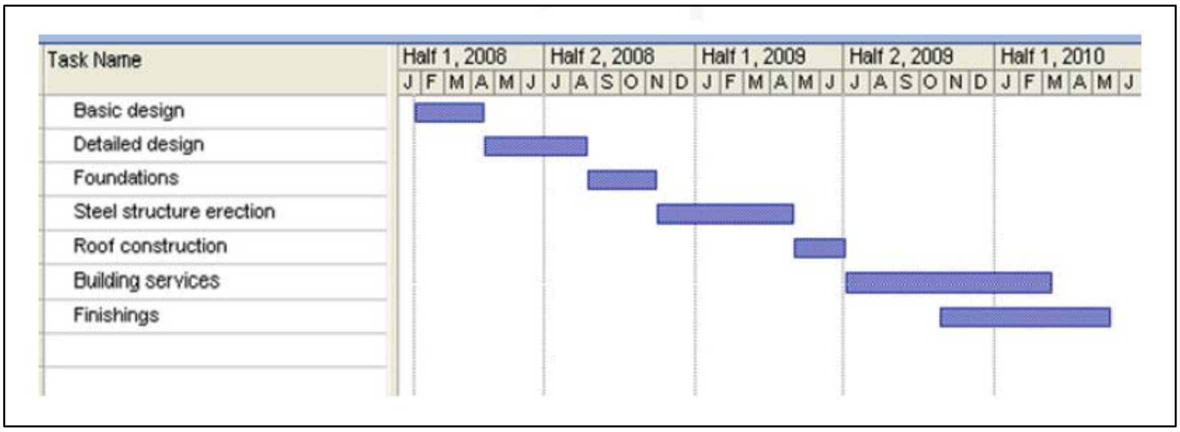

Fig. 7: Gantt chart example. Source: (Marco 2011, p. 98)

Rashmi J V et al. (2017), focused on the overall time and cost needed for a multi-family residential building by using project management techniques and tools. The tools quickly help to develop a schedule plan, assign connection between various activities, define required resources and to track the progress of the work. Rashmi J V compared the conventional approach and project management approach for a case study project and concluded that the project management approach is more reliable as it reduces the total cost and time of construction activities without changing the quality of the construction activities.

Heldman (2002), defines the time scheduling process as the core of the project management group. He discusses the various inputs (calendars, leads/lags and activity description) needed for the development of schedule, as some of these inputs are the outputs gained from the previous planning process. Heldman focuses on different scheduling tools and techniques such as mathematical analysis (Critical Path Method, Program Evaluation Review Technique) and Project management software (MS Project). The PM software automates the mathematical computations and also works on the resource levelling functions. He mentions the different software used for simple to complex projects, depending upon the level of use of the project manager.

Wang et al. (2016), discuss the use of BIM 3D objects to integrate cost and scheduling activities in cost breakdown structure (CBS) and work breakdown structure (WBS). Fig. 8 illustrates the CBS with two levels of details and WBS with three levels of details.

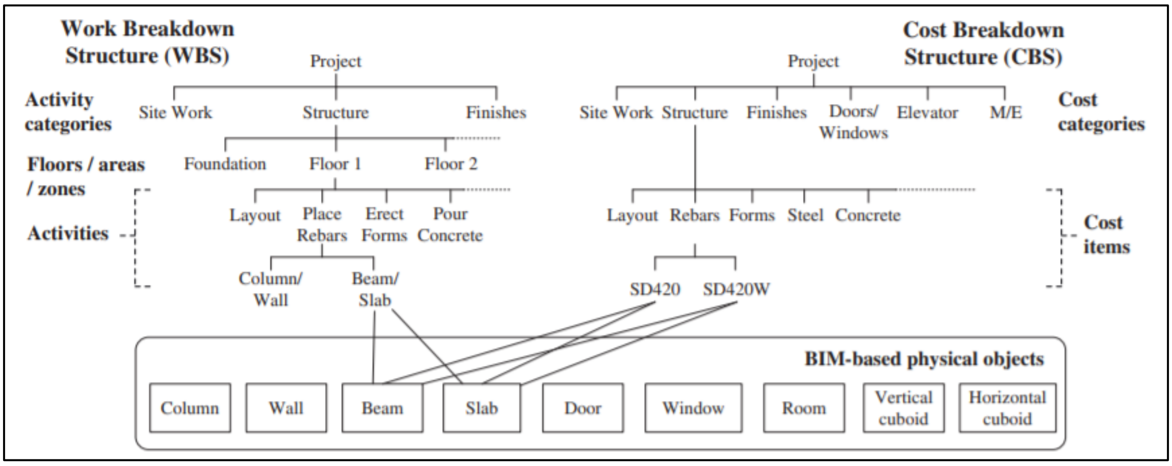

Fig. 8: WBS and CBS integrated into BIM objects. Source: (Wang et al. 2016)

Konior and Szóstak (2020b), used the S-curve as a tool for controlling and planning the construction progress. The financial expenses of the project are graphically presented against the timeline of the activities. The progressive curve forms an "S" shape from start to middle of the project progression. The initial and final stages of the curve are flatter, the middle stage shows a steeper curve due to the implementation of more resources and thereby increasing the cost compared to the initial slower stages. The authors concluded by modifying the classic method into different ways for the planning purpose.

Rasdorf and Abudayyeh (1991), discusses various models related to cost and schedule integration. The work-packaging model helps to achieve the desired cost and time integration. It depends on the WBS for dividing a project into smaller work packages. The tasks are the lowest level of work-packaging models and are used in the project's network of activities. Fig. 9 illustrates the WBS, which is used by the world-packaging model to combine cost and schedule control. In the work-packaging model, CBS is eliminated by adding the cost data to the WBS.

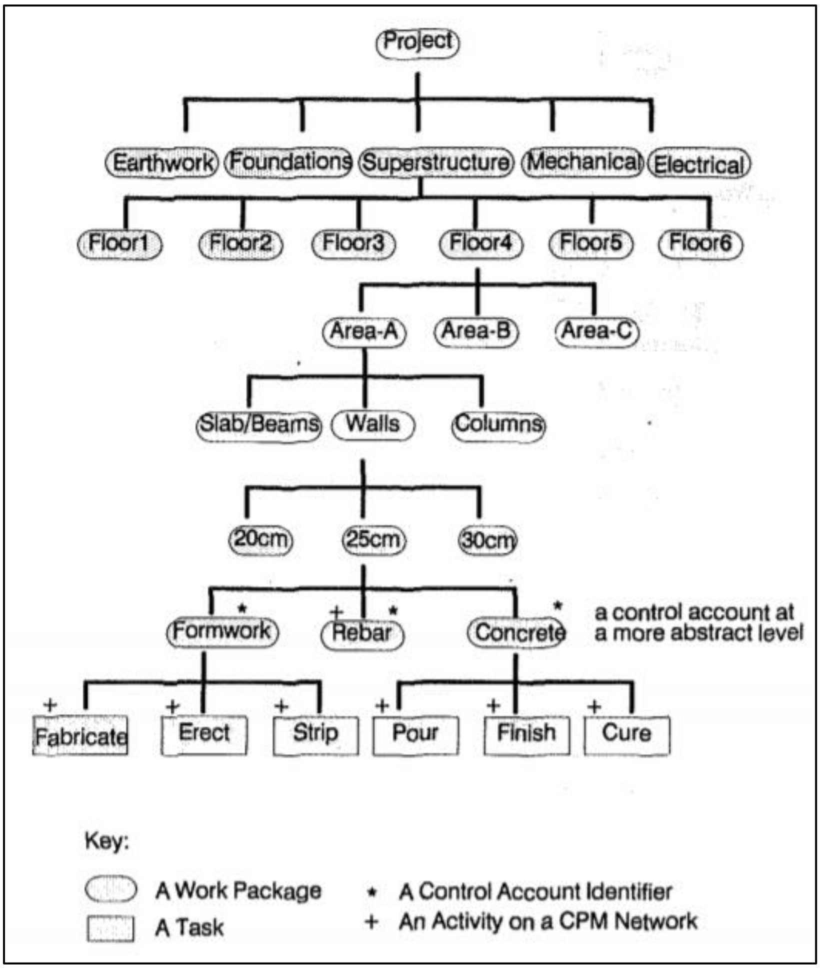

Fig. 9: The Work-Packaging Model. Source: (Rasdorf and Abudayyeh 1991)

Jung and Woo (2004), discusses the issues related to cost and schedule integration systems. The system faced a challenge of collecting and maintaining a precise date. The authors proposed a flexible WBS numbering system which utilizes the standard classification codes and has a different hierarchy for different components and implemented the system on a case study to analyse the results. The authors concluded that the proposed model is suitable for contractors, managers, architects and owners for a realistic cost and schedule integration.

Wang et al. (2016), focuses on the S-curve to control the construction schedules by comparing costs related to different scheduling activities. They perform the integration of BIM object to obtain error-free and accurate S-curve. The S-curve usually starts with a small slope, which shows the construction activities at the early stage are very slow. The curve starts to pick up its phase in the middle, as many activities start to take place and then gradually the curve decreases, forming a small slope at the end. The S-curves are very much helpful to track the project, report and predict future progression when compared with the actual work progression.

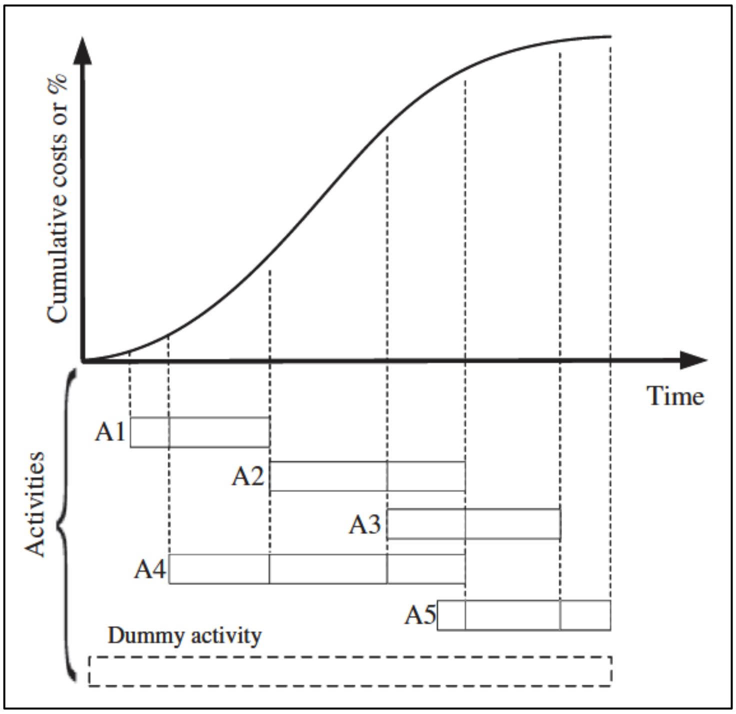

Fig. 10: S-curve with related activities. Source: (Wang et al. 2016)

Konior and Szóstak (2020a), focused on various other methods to monitor and control of the construction projects. The use of S-curve for cumulative costs is to present the investment in a project from start to finish. They focussed this method to forecast cash flows, and it is unlikely to expect the project to move as planned. The authors conclude by developing a model for an accurate S-curve by obtaining and processing of the data of the completed projects, developing of S-curve area for cost planning and testing the accuracy of the S-curve.

2.4 Standards, norms and minimum requirements

The minimum recommended thickness of exterior load-bearing walls for buildings of 35 feet (10.67m) height should be 12 inches (304.8 mm) and for every successive 35 feet above that, a thickness of 4 inches (101.6 mm) is considered. A wall thickness of 8 inches (203.2 mm) is recommended for single-storey buildings given that they do not surpass 12 feet (3.65 m) unsupported height. Due to the standardisation of the brick sizes, the wall thickness is now commonly expressed as 8, 12 and 16 inches (Woolson 1924).

The wall thickness is necessary for the calculation of quantities and is calculated, excluding the surface finishes most of the time. The use of different kinds of brick in construction practice greatly influence the thickness. For a traditional brick, the nominal thickness ranges from 9 inches (228.6 mm) to 18 inches (457.2 mm). For a modular brick, the thickness is between 200 mm and 400 mm (Bureau of Indian Standards 1991b). The walls subjected to lateral loads, a minimum of 230 mm wall thickness for a 0.86 m height is used in standard practice (Bureau of Indian Standards 1991a).

The primary use of gypsum blocks is in the interior partitions of a building and also used as a protection of columns and elevator shafts against fire. The dimensions and sizes are illustrated in the table Tab. below (Bureau of Indian Standards 1983).

(All dimensions in millimetres.)

Length	Height	Breadth	Hollow Blocks Side and Edge Thickness, *Min*	
			Circular Holes	Elliptical or Rectangular Holes
L	*H*	*B*	*t*	*t*
(1)	(2)	(3)	(4)	(5)
700 Max in multiples of 100	300 Max in multiples of 100	75	15	20
		100	20	20
		125	25	30
		150	15	20

NOTE — Dimensions other than length, height and breadth are for guidance only.

Tab. 4: Dimensions of gypsum blocks. Source: (Bureau of Indian Standards 1983)

Kolaitis et al. (2013), discussed the comparative study of external and internal thermal insulation of a residential building. In this study, three different types of insulation configuration are compared and evaluated. They used an Expanded Polystyrene (EPS) of thickness 80 mm for external and internal thermal insulation of exterior walls and compared the results of respective U-values and thickness of the wall. Fig. 9 visually indicates the walls in which the wall with no insulation (NO), insulation applied externally (ETI) and insulation applied internally (ITI) with respective wall finishes.

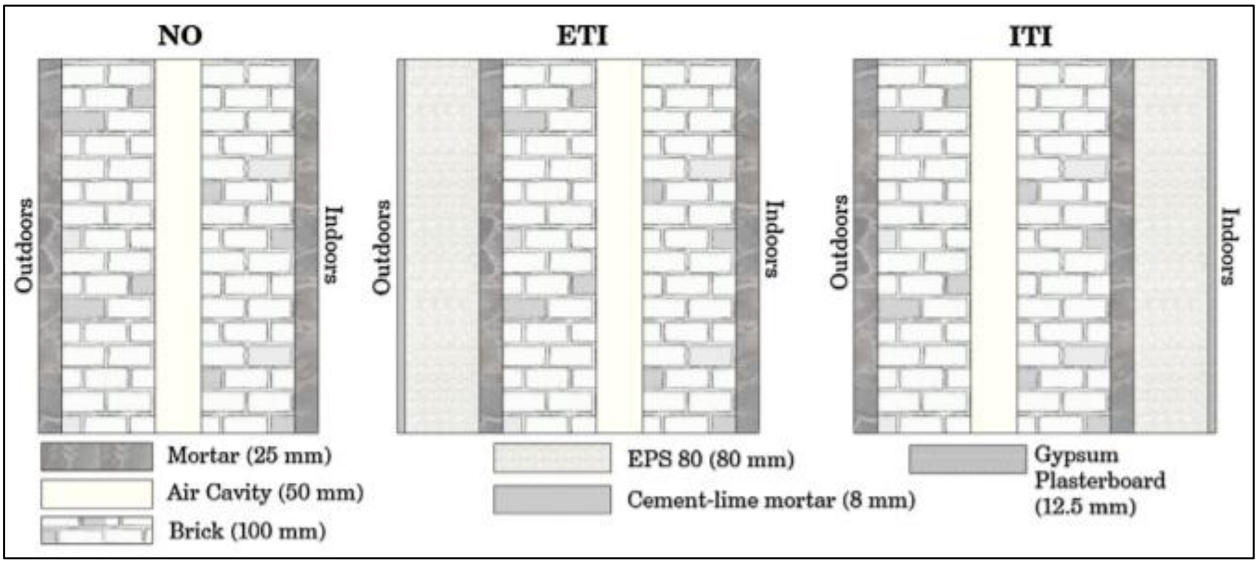

Fig. 11: Examined wall assemblies: no insulation (NO), external thermal insulation (ETI) and internal thermal insulation. Source: (Kolaitis et al. 2013)

Papadopoulos (2005), discusses the current thermal insulation materials available in the market and its importance in designing and creating an energy-efficient building. He also compares the thicknesses of insulation used by some Europen countries in the past few decades. The different materials used in thermal insulation significantly affects the U-values of the building. He concludes by pointing out some performance issues of the materials in terms of environmental aspects, physical properties, cost and structural problems. Fig. 10 illustrates the evolution of wall insulation thickness over different years in some parts of Europe.

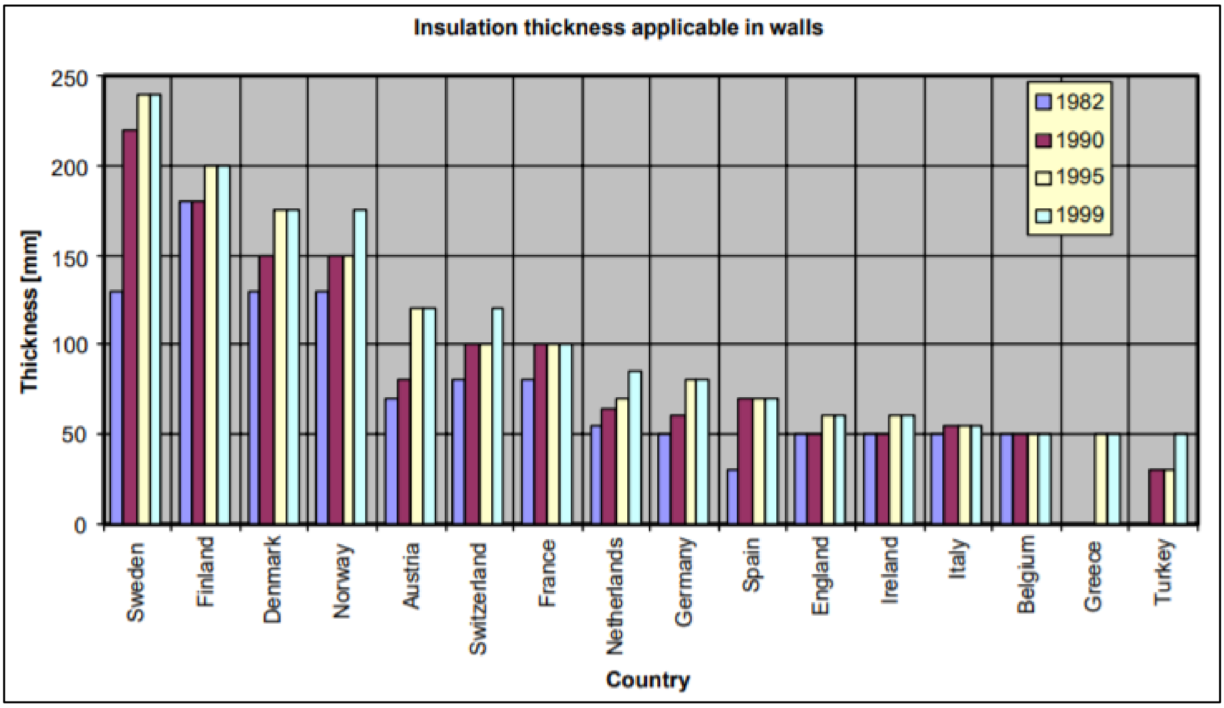

Fig. 12: Wall insulation thickness evolution in Europe. Source: (Papadopoulos 2005)

3. Methodology and validation of data

In the literature review, the different methods used for the construction cost estimation purpose by different authors provided an overall view of the estimation methods. However, the detailed cost estimation method, which is a long and time-consuming process in which the error percentage is comparatively less when compared with other methods. The accuracy of this method is far more precise and generally used by the contractors for bid purpose.

In this thesis, the detailed cost estimation method with the help of an Excel spreadsheet has been used for the cost calculations. For well detailed and precise cost estimation, it is required to understand the building parameters and other necessary information of the building taken into account.

3.1 Cost estimation steps

The required data at the starting stage of a project is very much helpful for preliminary cost estimation and, as the project progresses, it will be useful to create a more detailed cost calculation. The following factors are to be analysed in detail to achieve precise cost estimation of walls.

1. Creating an appropriate plan
2. Analysis of floor plans and flat sizes
3. Number of walls and corresponding types
4. Detailed cost calculations of walls

3.1.1 Plan creation

The required plan for the cost calculation of the Multi-Family House (MFH) building is recreated using the ArchiCAD software. ArchiCAD is a 3D modelling software used by Architects during the planning and designing phase. The software uses library materials such that the building element creation is more realistic and unique. The workspace of the ArchiCAD provides creation of both 2D drawings and easy conversion of 2D to 3D models in a click. Appendix 1 illustrates the standard workspace of the ArchiCAD 22 software.

The plan of MFH building created using accepted room dimensions for different groups of people. The mean idea of the MFH building is to accommodate at least 20 to 25 families. The location of the building is assumed to be in Berlin, Germany. Therefore, the building components and cost calculations are entirely dependant on German norms and standards Deutsche Institut für Normung (DIN 276) and Baukosteninformationszentrum (BKI). Important parameters of the building plans are as follows:

Dimensions:	27.8 x 16.6 m
Area of one floor:	464.52 m^2
The total area of the building:	2332.60 m^2 (5 floors)

Appendix 2 illustrates the gridline drawing of the MFH building, the vertical (numbers) and horizontal (alphabets) lines intersect at a point denoting the column placement of the building. Gridline drawings are very much helpful in marking of columns during the earlier stages of the construction. The dimensions between each gridline all together provide the total length and width of the building.

Fig. 11 illustrates the simplified ground floor plan of the MFH, generated in ArchiCAD 22 software. The plan indicates a simple layout of rooms with different wall types and grid lines corresponding to columns.

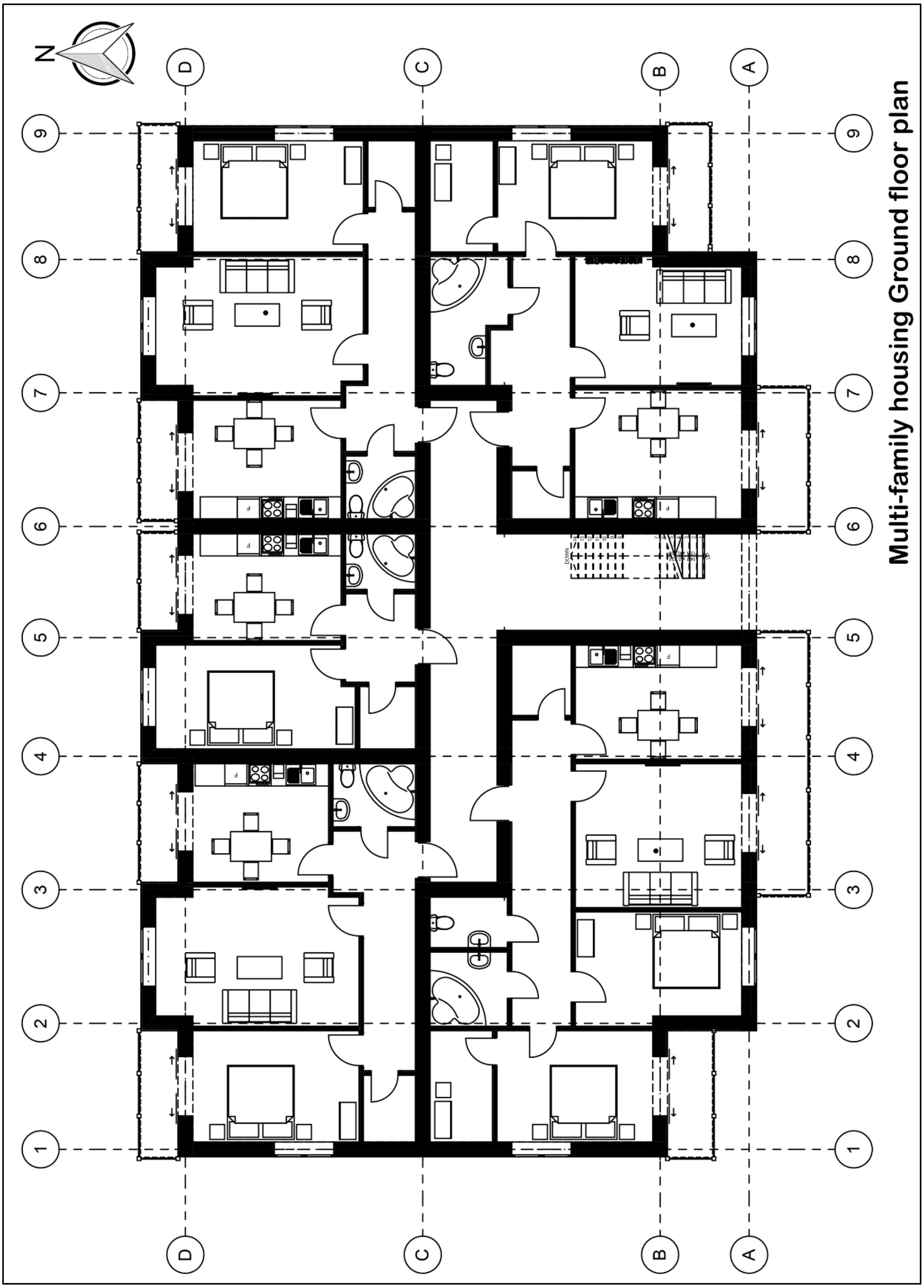

Fig. 13: Ground floor plan created using ArchiCAD 22 software. Source: (By Author)

3.1.2 Analysis of floor plans

After creating and validating the MFH building plan, it is recommended to analysis the room sizes and floor plans of the project. The detailed analysis helps to understand different rooms in each apartment/flat. The MFH building includes three different apartment types, and each floor has a total of five apartments. The total amount of residences in the building is 25.

- **2BHK – Apartment 001**

The 2BHK apartment is in the South-West direction of the building, and it covers the largest area in the floor plan, designated as Apartment 001 or Flat 001 on the Ground floor. The apartment has two bedrooms with attached bathroom and water closet (WC), a spacious living room and kitchen with dining area. The total area of the 2BHK flat is 101 m^2. Fig. 12 illustrates a visual representation of different room areas.

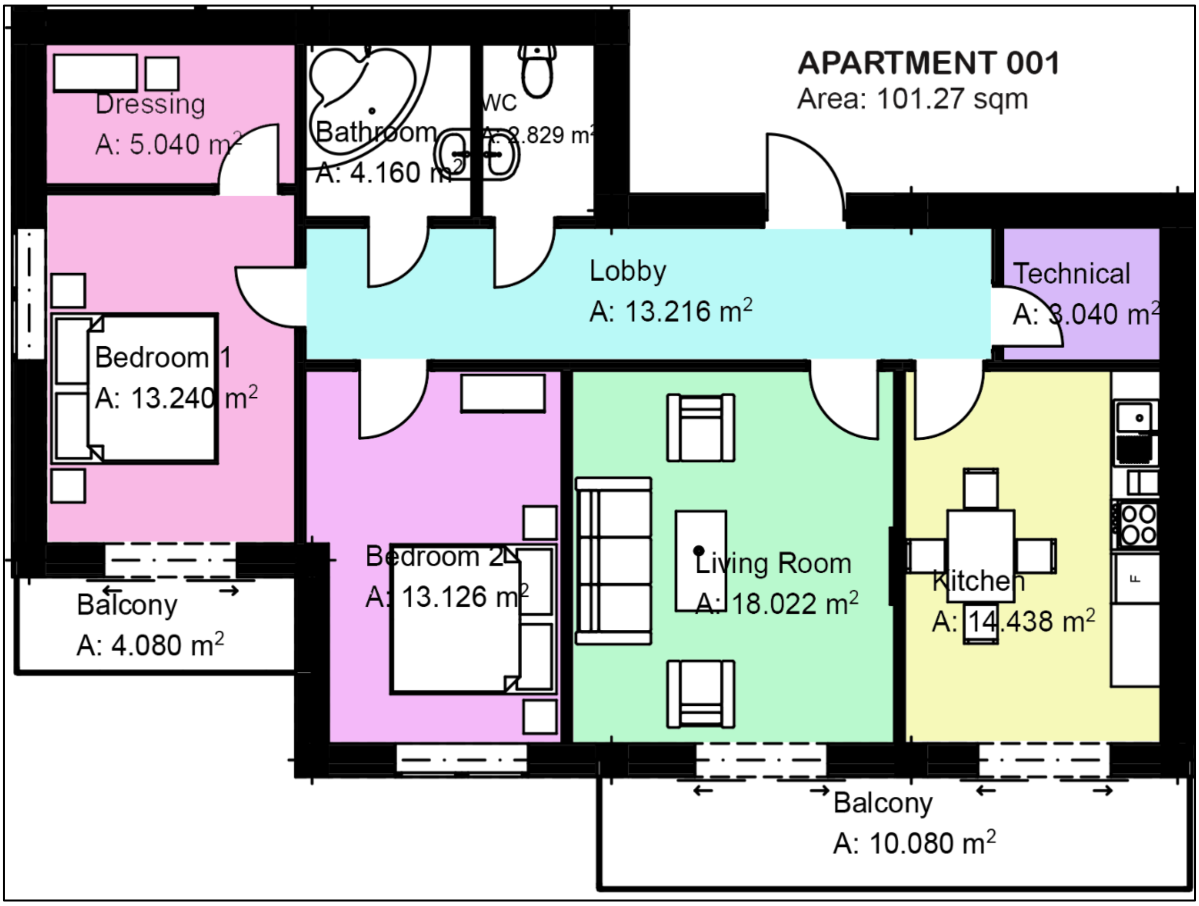

Fig. 14: 2BHK Flat specifications – Ground floor. Source: (By Author)

- **1BHK – Apartment 002, 003 and 005**

The MFH building has three 1BHK apartments namely, 002, 003 and 005 with areas ranging from 65 m^2 to 70 m^2. Each located in South East (SE), North East (NE) and North West (NW) directions respectively. Fig. 13 illustrates the details of the 1BHK apartments with respective room areas and location.

Fig. 15: 1BHK Flat specifications – Ground floor. Source: (By Author)

- **1BK – Apartment 004**

Fig. 14 illustrates the smallest flat (004) in the building is located in-between flat 003 and 005. The total area of the flat is 40 m^2 and most suitable for students and single working professionals. The flat has a bedroom with bath, kitchen and a balcony as shown below.

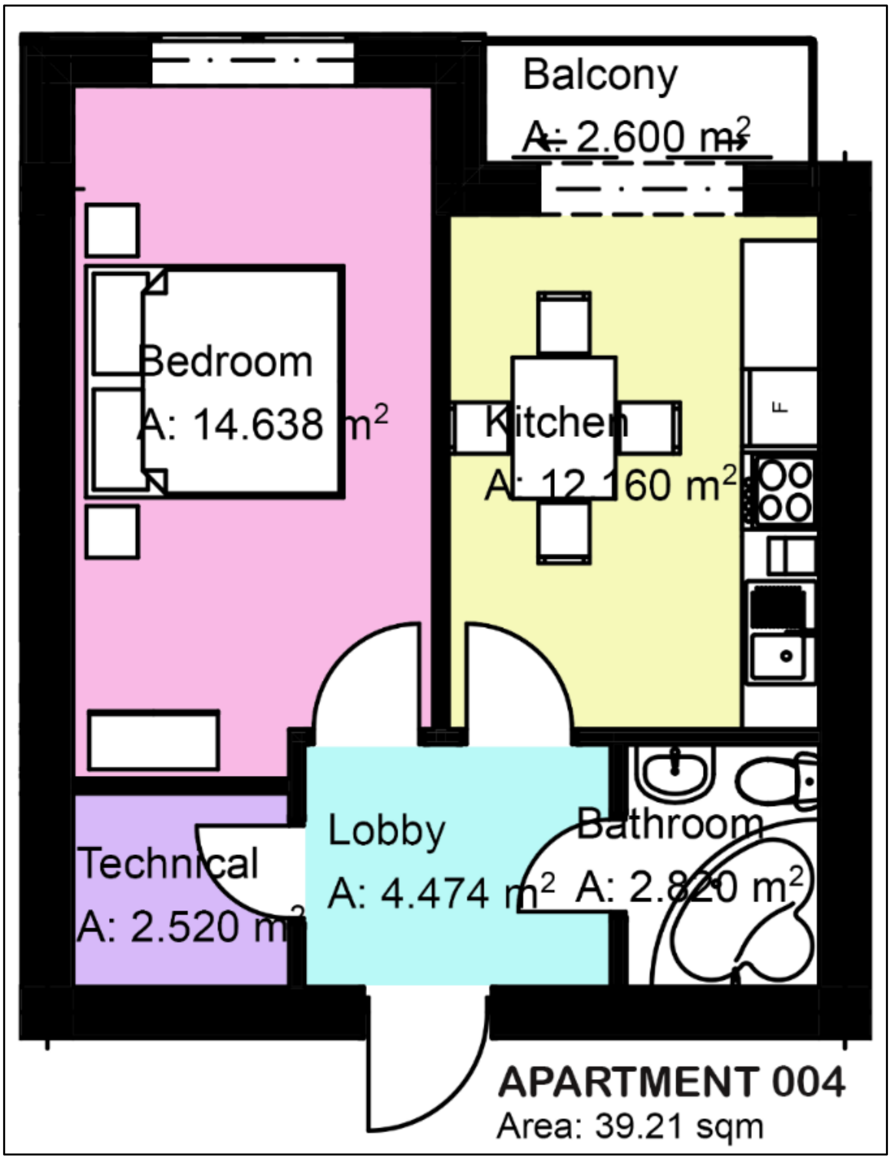

Fig. 16: 1BK Flat specifications – Ground floor. Source: (By Author)

The flat and room specifications described above gives an impression of the different rooms available in the building. Every flat has at least one bedroom with attached bath and kitchen. The housing needs of the inhabitants are noted during the plan creation. The plan is just an example, but the dimensions and rooms sizes can be altered according to the buyer's suitability.

Tab. 5 presents the overall flat numbers of the MFH building in each floor, their respective location and total usable area. The area of all flats on each floor is the same and corresponding to the described location.

Floor level	Flat number	Location	Area in m^2
Ground floor	Apartment 001	South West	101.27
	Apartment 002	South East	66.78
	Apartment 003	North East	69.54
	Apartment 004	North (between 003 & 005)	39.21
	Apartment 005	North West	69.54
First floor	Apartment 101	South West	101.27
	Apartment 102	South East	66.78
	Apartment 103	North East	69.54
	Apartment 104	North (between 003 & 005)	39.21
	Apartment 105	North West	69.54
Second floor	Apartment 201	South West	101.27
	Apartment 202	South East	66.78
	Apartment 203	North East	69.54
	Apartment 204	North (between 003 & 005)	39.21
	Apartment 205	North West	69.54
Third floor	Apartment 301	South West	101.27
	Apartment 302	South East	66.78
	Apartment 303	North East	69.54
	Apartment 304	North (between 003 & 005)	39.21
	Apartment 305	North West	69.54
Fourth floor – Top floor	Apartment 401	South West	101.27
	Apartment 402	South East	66.78
	Apartment 403	North East	69.54
	Apartment 404	North (between 003 & 005)	39.21
	Apartment 405	North West	69.54

Tab. 5: Details of flat area**.** Source: (By Author)

Fig. 15 illustrates the floor plans of first to fourth floors with detailed specifications of room areas and types. The full plan, along with apartment details and annotations, helps for a better visual understanding of the MFH building. However, the 3D view and elevation of the building created using ArchiCAD software give another perspective of the building presented in Appendix 3 and 4.

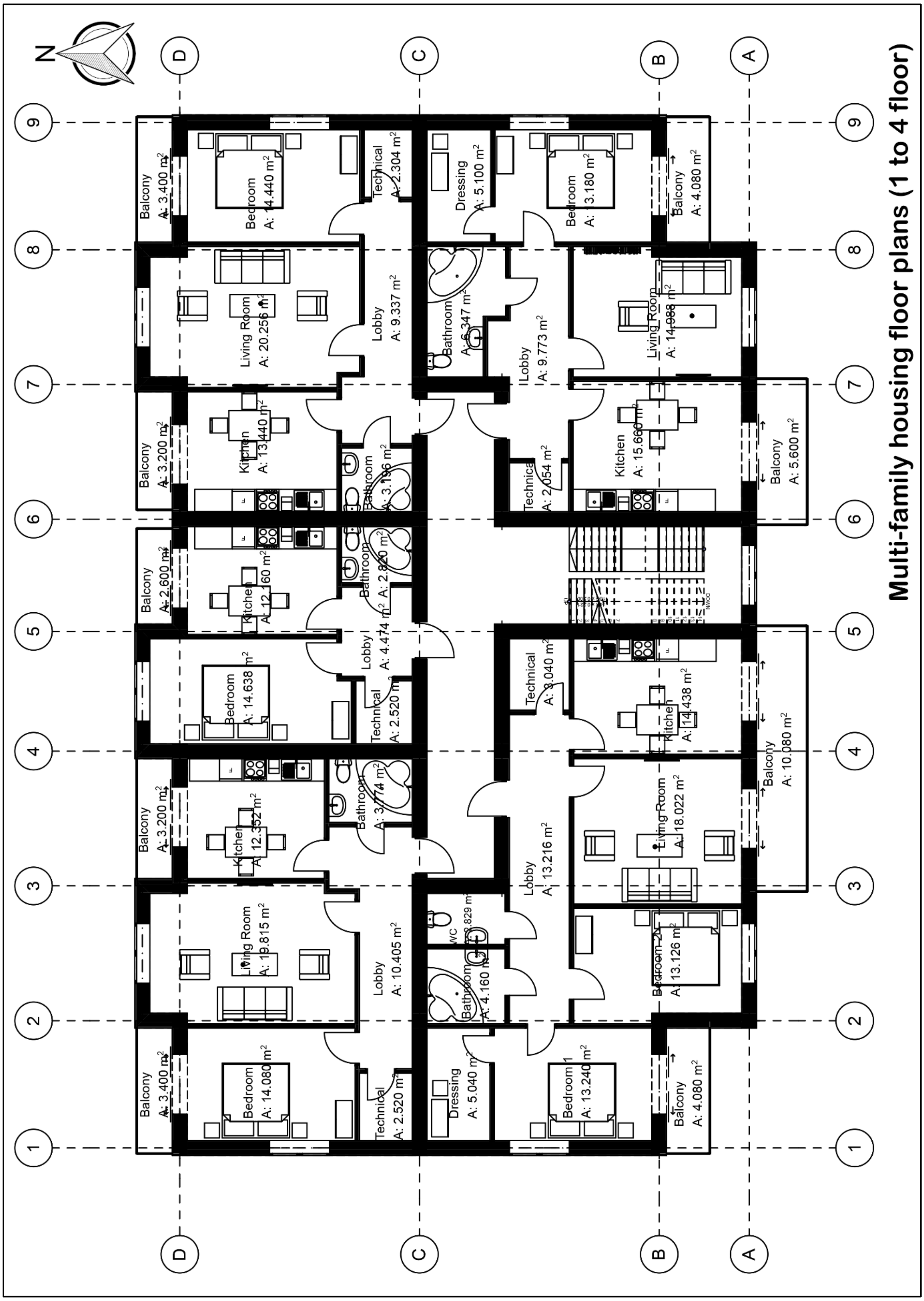

Fig. 17: Detailed floor plan – 1st to 4th floor. Source: (By Author)

3.1.3 Identification and analysis of walls

In the thesis, the adopted MFH building is a five-floor tall structure (approximately 16 m). The structural components, namely beams, columns and slabs, should be designed with vital importance and minimum requirements. The wall elements are concentrated more in the thesis, as construction costs and schedule of walls are the crucial objectives. The external and internal load-bearing walls are of brick materials, and the internal non-load bearing wall is of gypsum board material. The detailed analysis of the wall elements of the building is discussed below.

- **External and Internal load-bearing walls**

In the thesis, the MFH building has many different wall types and materials. The external walls are the most significant and plays a vital role in protecting the building from extreme weather conditions, unlike internal load-bearing walls. They also act predominantly as load-bearing walls in many situations. The external walls are capable of withstanding lateral wind pressure and vertical loads.

In the literature, the minimum wall dimensions used in most of the residential projects range from 230 mm to 400 mm. Therefore, a thickness of 400 mm is taken into consideration for the load-bearing walls. The load-bearing walls can be single or multi-layered (thermal insulation) depending upon the characteristics of the building. The wall materials also vary according to the building requirements and budget of the client. The commonly used materials for wall construction are bricks, concrete, and prefabricated elements.

- **Non-load-bearing walls**

The non-load-bearing walls usually constructed inside a building acts as a partition or division separating other rooms. These walls usually are less thick compared when compared with load-bearing walls. According to the literature, these walls range from 75 mm to 150 mm thickness.

In the thesis, the adopted thickness of the non-load-bearing walls is 100 mm with acoustics insulation. These walls are lightweight, consumes less time for construction, and not much safety needed as it is built inside the building. Just like load-bearing walls, these walls can be single or multi-layered, and the wall materials used for the construction are bricks, gypsum board, glass panels, prefabricated elements, and wood panels.

- **Analysis of walls elements**

After selecting the appropriate wall thickness with the help of standards and previous works of literature, wall materials and respective properties of different walls, it is recommended to create the model accordingly. Using ArchiCAD software, easy implementation of wall materials and thickness are possible. The software serves a link between 2D (plan) drawings and 3D models. It also provides various other information such as building elevations, sections, and documentation of drawings.

The different wall elements of the MFH building created using ArchiCAD software for better visualisation and understanding. It helps to recognise the presence of different walls and the actual number of walls supportive for cost calculations.

Fig. 16 illustrates the visual characteristics of different wall elements of the MFH building. The purple colour denotes the external load-bearing walls of 400 mm thickness; the orange colour indicates the internal load-bearing walls of 400 mm thickness and the light blue shade implies internal non-load-bearing walls which are of 100 mm thickness. This visual representation helps to observe the wall types and the total number of walls in the building for the cost estimation process.

The horizontal and vertical load-bearing wall elements running between the columns are numbered separately, such that it provides an uncomplicated understanding. The external load-bearing walls on the ground floor and remaining floors are the same. However, the ground floor needs an entrance, and one wall element is less when compared with other floors. The non-load- bearing wall elements in all floors has the same numbers, and the calculations of the walls are made according to authors convenience. Tab. 6 provides the total number of different wall elements on each floor with their corresponding location.

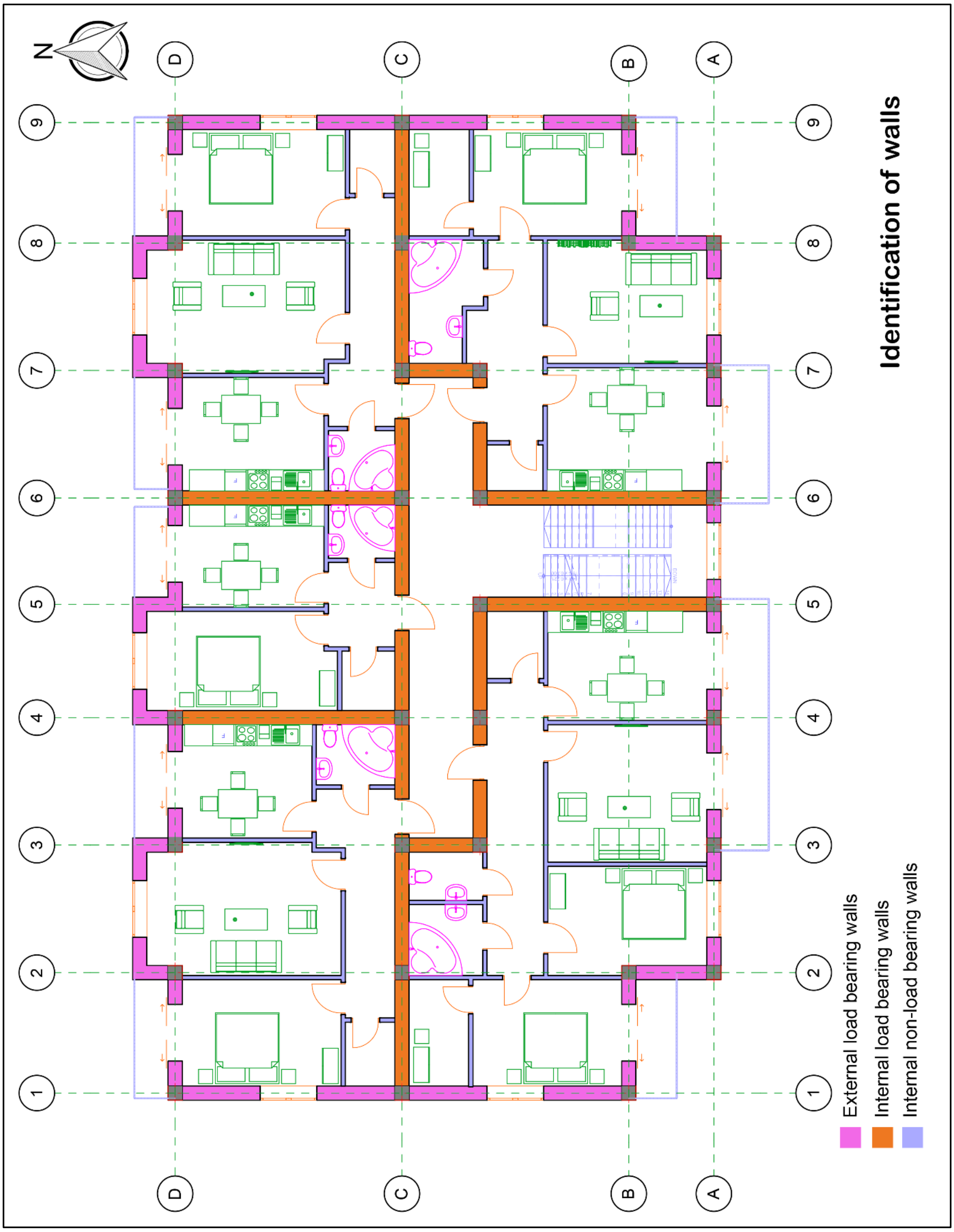

Fig. 18: Visual identification of walls. Source: (By Author)

Ground floor		
External load-bearing walls – 400 mm	Direction/Location	Total Number
	North (Left to right)	7
	South (Left to right)	7
	West (Top to Bottom)	3
	East (Top to Bottom)	3
	Total	**20**
Internal load-bearing walls – 400 mm	Direction/Location	Total Number
	North to South	6
	West to East	10
	Total	**16**
Internal non-load-bearing walls – 100 mm	Direction/Location	Total Number
	North to South	19
	West to East	12
	Total	**31**
1st to 4th floor		
External load-bearing walls – 400 mm	Direction/Location	Total Number
	North (Left to right)	7
	South (Left to right)	8
	West (Top to Bottom)	3
	East (Top to Bottom)	3
	Total	**21**
Internal load-bearing walls – 400 mm	Direction/Location	Total Number
	North to South	6
	West to East	10
	Total	**16**
Internal non-load-bearing walls – 100 mm	Direction/Location	Total Number
	North to South	19
	West to East	12
	Total	**31**

Tab. 6: Total number of walls on each floor. Source: (By Author)

3.1.4 Cost estimation of wall elements

- **Detailed cost estimation**

The cost estimation or calculation of walls is one of the main objectives of the thesis. As discussed earlier in the literature, there are various methods available for the cost estimation process. The detailed cost estimation is the adopted method to calculate construction costs of walls, as it provides a thorough cost calculation of different elements in a construction project. The error percentage is comprehensively low, and the results are very accurate, as discussed by many researchers.

There are two steps in the detailed cost estimation method:

i. Details of Measurement (Quantity)
ii. Abstract of Estimated quantities (Final costs)

The quantities of the building elements are necessary for the cost estimation process. Generally, the cost estimator or engineer with the provision of detailed plans and specifications creates a various list to prepare BOQs (bill of quantities). Building components are of two types, substructure and superstructure. In the substructure component, the construction activities primarily take place below the ground level, and the activities above ground level correspond to the superstructure. Each component has its critical activities, and separate BOQs are created in a precise manner.

The thesis concentrates only on the wall elements of the superstructure component. The overall construction activities of wall elements can be segregated into many different elements such as brickwork, insulation, base and finishing coat, gypsum board installation and plaster finish. It is also known as WBS (work breakdown structure), deliverable decomposition of a project into simpler or smaller components or activities. Fig. 18 illustrates the WBS of the MFH building showing the activities of wall elements, brickwork and gypsum walls.

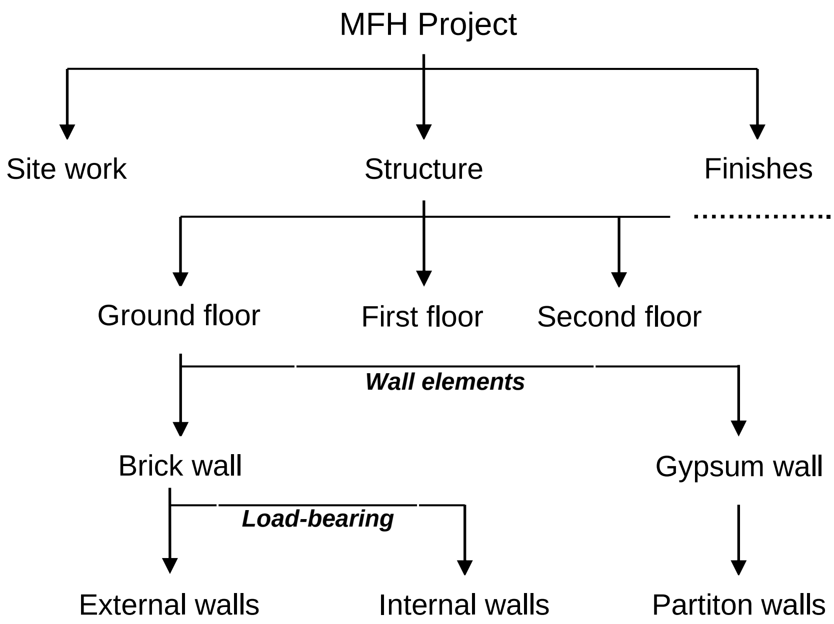

Fig. 19: WBS of the MFH building. Source: (By Author modified from Wang et al.)

The measurements of each simpler components of the wall elements are noted for quantity calculations. The plans and other structural drawings come handy during the early stage quantity calculations. It is necessary to understand the labour rates and material costs well before the estimation process.

Tab. 7 presents a standard Excel spreadsheet used for the calculation of quantities. The particulars column denotes the different components of the wall elements, their respective measurements in the dimensions column, necessary deductions such as windows or doors, and finally, the total area of each wall can be calculated.

The standard method of quantity calculation was usually prepared in pen and paper during the old times, which is very time-consuming. Excel spreadsheet is a crucial tool for the cost estimation process. Inbuilt formulas and user-friendly commands make the calculations accurate and fast.

Item	Particulars	No.	Dimensions (m)		Deductions (-)	Area (m²)	Total area (m²)
			L	**H**			

Tab. 7: Details of Measurement. Source: (By Author)

The calculation of quantities is the first step of the cost estimation process. The engineer reevaluates the calculated quantities to discover mistakes if any. The reevaluation process also time-consuming as the engineer or the responsible person has to check thoroughly with the help of plans and specifications.

The final costs are then calculated by multiplying the desired prices for each particular of the wall elements. The provision of labour rates and material cost varies accordingly to different locations and requirement. However, some countries provide these data in the form of standards or norms. In some countries, the government officials publish this information on their official websites.

In Germany, with the help of standards and norms, the cost estimation process is carried out. The DIN 276 is a German norm, especially for calculating construction costs, prepared by Normenausschuss Bauwesen NABau (Construction Standards Committee). This standard helps to identify different construction elements and provides a detailed cost classification (Beuth.de 2006).

The cost groups 330 and 340 of DIN 276 provides a detailed classification of wall elements. These groups segregate the wall elements into various simpler activities. Each activity has a group number which helps to identify the costs more precisely. The classification of the activities reduces the risk of errors and accurate estimation.

- **Spreadsheet quantity calculations**

An Excel spreadsheet is an MS Office tool specially designed to deal with mathematical analysis of all aspects. It is the most popular software among the construction experts for the estimation process. The software is easy to use, user-friendly and requires only basic knowledge to understand. It is flexible for all users and can be used anywhere. The critical point of using this software for estimation is the ability to handle mathematical problems accurately without any issues. Different equations and mathematical combinations make the estimation process simple. The ability to transform the data into graphs and charts is another importance of the software.

The measurements of wall elements and corresponding door, window and empty openings are also crucial for a precise calculation. The necessary deduction of these openings according to their dimensions should be made. The presence of vertical column and horizontal beam elements should also be considered before the calculation of wall areas. Tab. 8 provides the necessary dimensions of different elements in the MFH building.

Elements	Dimensions (mm)
Column	400x400
Beam	450x400
Main door MD	1000x2500
D1 – Kitchen, Bed and Living room	900x2500
D2 – Bath, WC and Technical room	800x2500
French Door FD – Balcony	1600x2650
Window W1	1600x1650
Other dimensions (mm)	
Height of one floor	3100
400 mm wall height	2650
100 mm wall height	2970
Slab thickness	130
Window sill level	1000

Tab. 8: Necessary dimensions. Source: (By Author)

Tab. 9 shows an elaborated calculation of wall quantities for external and internal load-bearing walls, and internal non-load-bearing walls using an Excel spreadsheet. The dimensions length (L) column in the spreadsheet denotes the overall length of the wall in a particular direction with necessary deductions if any. For a detailed quantity calculation of individual wall elements of each floor, refer to Appendix 5.

Details of Measurement							
Item	Particulars	No.	Dimensions (m)		Deductions (-)	Area (m²)	Total area (m²)
			L	H			
1	**External load-bearing walls 400 mm**						
	North direction	1	30.60	2.65		81.09	
	Door FD	5	1.60	2.65	21.20		
	Window	3	1.60	1.65	7.92		
	Wall area						**51.97**
	South direction	1	21.60	2.65		57.24	
	Door FD	5	1.60	2.65	21.20		
	Window	2	1.60	1.65	5.28		
	Wall area						**30.76**
	West direction	1	14.20	2.65		37.63	
	Window	2	1.60	1.65	5.28		
	Wall area						**32.35**
	East direction	1	14.20	2.65		37.63	
	Window	2	1.60	1.65	5.28		
	Wall area						**32.35**
	Staircase wall from 1 to 4 floors	1	2.60	2.65		6.89	
	Window	1	1.60	1.65	2.64		
	Wall area						**4.25**
	Area of external walls on the ground floor						**147.43**
	Area of external walls from 1 to 4 floors						**151.68**
	Area for all floors	**G+4 = 5 floors**					**754.15**
2	**Internal load-bearing walls 400 mm**						
	N to S direction	1	28.40	2.65		75.26	

	Wall area						**75.26**
	E to W direction	1	33.80	2.65		89.57	
	Main door MD	5	1.00	2.50	12.50		
	Wall area						**77.07**
	Area of internal walls on one floor						**152.33**
	Area of all floors	**G+4 = 5 floors**					**761.65**
3	**Internal non-load-bearing walls 100 mm**						
	Apartment 001-401 SW						
	N to S direction	1	18.70	2.97		55.54	
	E to W direction	1	16.80	2.97		49.90	
	Door D1	4	0.90	2.50	9.00		
	Door D2	4	0.80	2.50	8.00		
	Wall area						**88.44**
	Apartment 002-402 SE						
	N to S direction	1	12.10	2.97		35.94	
	E to W direction	1	14.20	2.97		42.17	
	Door D1	3	0.90	2.50	6.75		
	Door D2	6	0.80	2.50	12.00		
	Wall area						**59.36**
	Apartment 003-403 NE						
	N to S direction	1	12.20	2.97		36.23	
	E to W direction	1	10.80	2.97		32.08	
	Door D1	3	0.90	2.50	6.75		
	Door D2	2	0.80	2.50	4.00		
	Wall area						**57.56**
	Apartment 004-404 NM						
	N to S direction	1	8.30	2.97		24.65	
	E to W direction	1	5.70	2.97		16.93	
	Door D1	2	0.90	2.50	4.50		
	Door D2	2	0.80	2.50	4.00		

	Wall area						**33.08**
	Apartment 005-405 NW						
	N to S direction	1	12.20	2.97		36.23	
	E to W direction	1	10.80	2.97		32.08	
	Door D1	3	0.90	2.50	6.75		
	Door D2	2	0.80	2.50	4.00		
	Wall area						**57.56**
	Duct walls		1.00	1.00			**1**
	Area of internal non-load-bearing walls for one floor						**297.00**
	Area of all floors	**G+4 = 5 floors**					**1484.98**

Tab. 9: Spreadsheet calculations – Details of Measurement. Source: (By Author)

The labour cost and material cost together with the calculated quantity, provides the cost estimation data of the project. In Germany, BKI Kostenplanung offers a wide range of costs for different building elements and also for different buildings. The residential buildings then subdivided into single and double family houses, semi-detached and row houses, apartment buildings of various floors, senior housing and dormitories. The family houses and apartment buildings have simple, medium and high costs standards. The thesis uses the medium cost standard for cost calculation.

The total wall quantities of each floor multiplied with the respective cost units (€/m$^{2)}$ according to the standards DIN 276 and BKI. The DIN 276 gives a detailed cost group construction classification. The BKI Kostenplanung serves as a benchmark for construction costs with qualified comparison data and methods. The BKI (Baukosten Bauelemente Neubau, Part 2) in association with DIN 276 provides cost parameters of various building elements in detail (Ritter et al. 2018). Tab. 10 illustrates the detailed cost parameters of wall elements for a multi-family apartment building with 20 or more units, medium standard. The rates published in BKI includes labour and material costs altogether.

Cost groups	Elements	From (€/m²)	Medium (€/m²)	To (€/m²)
330	***External walls***	***Rate***		
331	Load-bearing external walls	80.00	**120.00**	184.00
332	Non-load-bearing external walls	85.00	**163.00**	242.00
333	External supports (m)	87.00	**138.00**	179.00
334	External doors and windows	241.00	**407.00**	538.00
335	External wall cladding outside	80.00	**114.00**	174.00
336	External wall cladding inside	19.00	**27.00**	39.00
337	Elemental external walls	512.00	**764.00**	1.129.00
338	Sun/solar protection	114.00	**253.00**	406.00
339	External wall, other	18.00	**33.00**	69.00
340	***Internal walls***			
341	Load-bearing internal walls	77.00	**99.00**	170.00
342	Non-load-bearing internal walls	52.00	**58.00**	68.00
343	Internal supports (m)	128.00	**178.00**	273.00
344	Internal doors and windows	258.00	**336.00**	432.00
345	Internal wall cladding	15.00	**21.00**	30.00
346	Elemental internal walls	38.00	**44.00**	49.00
349	Internal wall, other	1.70	**2.00**	2.30

Tab. 10: Building elements cost parameters for MFH with 20 or more units, medium standard. Source: (Beuth.de 2006),

3.2 Schedule using Vico schedule planner

The scheduling, as discussed in various literature, is another crucial factor in the project. Accurate scheduling is challenging for most of the project managers, as unpredicted delays may occur due to natural conditions and human errors. Scheduling is a very long process, like cost estimation and needs careful evaluation. The Vico schedule planner is a BIM tool used for the scheduling purpose.

By interpolating the calculated quantities into the Vico software, scheduling is carried out for the wall elements. The WBS of the project offers a list of simpler activities for precise scheduling. The Vico schedule planner estimates the construction time according to given resources and quantities. The resources and shifts (working hours) can be adjusted in the schedule planner so that the activities do not collide with other activities.

Fig. 20 represents screen capture of the schedule planner software showing the bill of quantities of MFH building's wall construction activities with the corresponding unit price and resources utilised for completing those activities. Vico schedule planner automatically calculates the consumption rate using the quantities and number of shifts allotted to the activities.

Target bill of quantities Task type: Schedule ◉ Structure/method view ○ Resource view Cost type

Hierarchy	Approv	Name	Quantity	Unit	€ / units	€	Consum	Man hours	Resources
+1	☐	ELBW BRICK WORK	754.15	M2	120	90 498	1.273	960	Mason: 3; Helper: 3
+2	☐	INTERNAL LBW BRICK WORK	761.65	M2	99	75 403	1.2604	960	Mason: 3; Helper: 3
+8	☐	PLASTERING ILBW	1523.3	M2	21	31 989	0.2101	320	Mason: 2.5; Helper: 2.5
+5	☐	PLASTERING ELBW INSIDE	754.15	M2	27	20 362	0.4243	320	Mason: 2; Helper: 2
+4	☐	INSULATION ELBW	754.15	M2	114	85 973	0.5092	384	Mason: 3; Helper: 3
+6	☐	BASE COAT ELBW	754.15	M2	114	85 973	0.4243	320	Mason: 2.5; Helper: 2.5
+7	☐	FINISH RENDER ELBW	754.15	M2	114	85 973	0.2546	192	Mason: 1.5; Helper: 1.5
+3	☐	INTERNAL NLBW GYPSUM BOARD INSTALL	1485	M2	58	86 130	0.3879	576	Tech 1: 3; Tech 2: 3
+9	☐	INSUALTION IGW	1485	M2	21	31 185	0.1077	160	Ins 1: 1; Ins 2: 1
+10	☐	PLASTERIMG IGW	2970	M2	21	62 370	0.0539	160	Mason: 1; Helper: 1
		Free quantities							

Fig. 20: Bill of quantities - Vico schedule planner. Source: (By Author)

In the thesis, the assumed starting date of the wall activities is 4 January 2021 for an easy understanding. Fig. 21 describes the screen capture of the schedule planner software showing the flowline view of the various wall construction activities in different colours. The central point of the flowline view is to monitor the activities and to understand visually that each activity is not colliding with one another. Each activity is dependent on successive or previous activities, sometimes both. The flowline is generated using the resources and number of shifts of each activity.

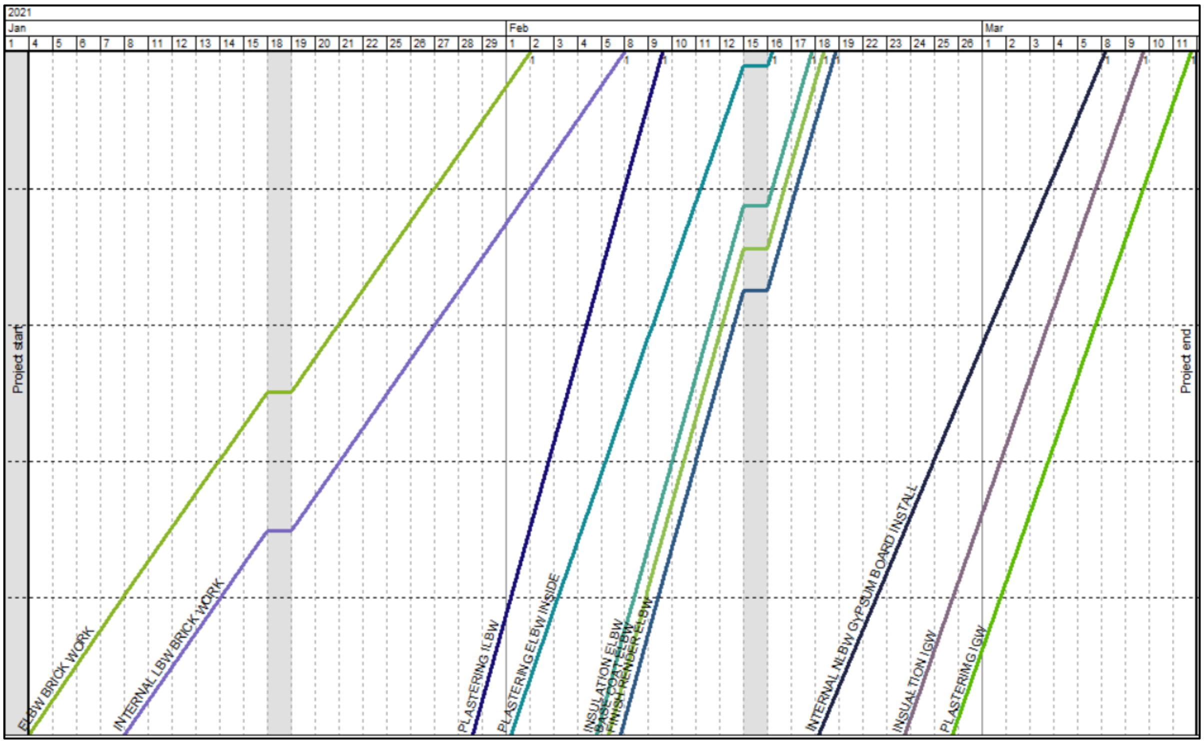

Fig. 21: Flowline view of the activities. Source: (By Author)

The schedule planner has a lot of different views to monitor and control the activities. The network view in the schedule planner is a typical flow chart of activities connected to at least one of the successive activity. Fig. 22 illustrates the network view of the activities starting from the left and branching towards the right end. The dependencies can be FS (Finish-Start), SS (Start-Finish), SF (Start-Finish) and FF (Finish-Finish). The activities assigned using these dependencies in which the network view differentiates the dependencies of each activity. Some activities can only start when their predecessor's activities are competed (FS), and some activities can start together with their predecessor's activities (SS) but with some buffer delays. For instance, the installation of gypsum boards can start only after completing the plastering works of external and internal load-bearing walls. However, the activities like base coat and finishing render can start simultaneously on the same day with some buffer if needed.

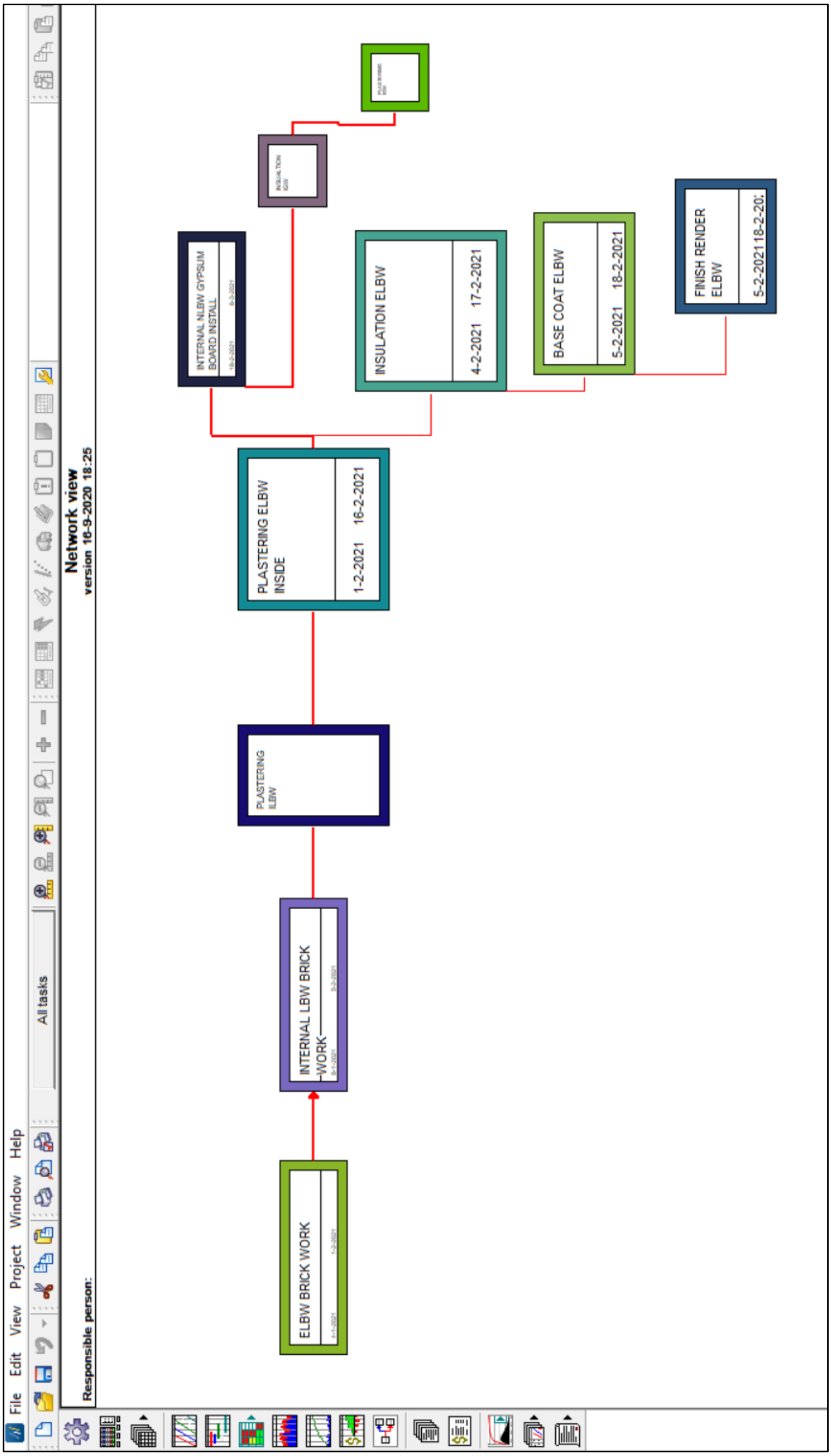

Fig. 22: Network view of the activities. Source: (By Author)

The resource graph view of the software typically explains the different resources used for each construction activity throughout the timeline of the project. The different colours in the graph represent the different labours allocated for the activities. The resource graph provides a visual image of the project progression; during the start and end of the project, the usage of resources is less compared to the middle stage of the project. It is common in any project because, in the middle stage, the need for resources is more due to continuous workflow. Fig. 23 illustrates the various resources and resource graph of the wall activities captured from the schedule planner. The resources can be controlled and monitored as per the project manager's needs and situation.

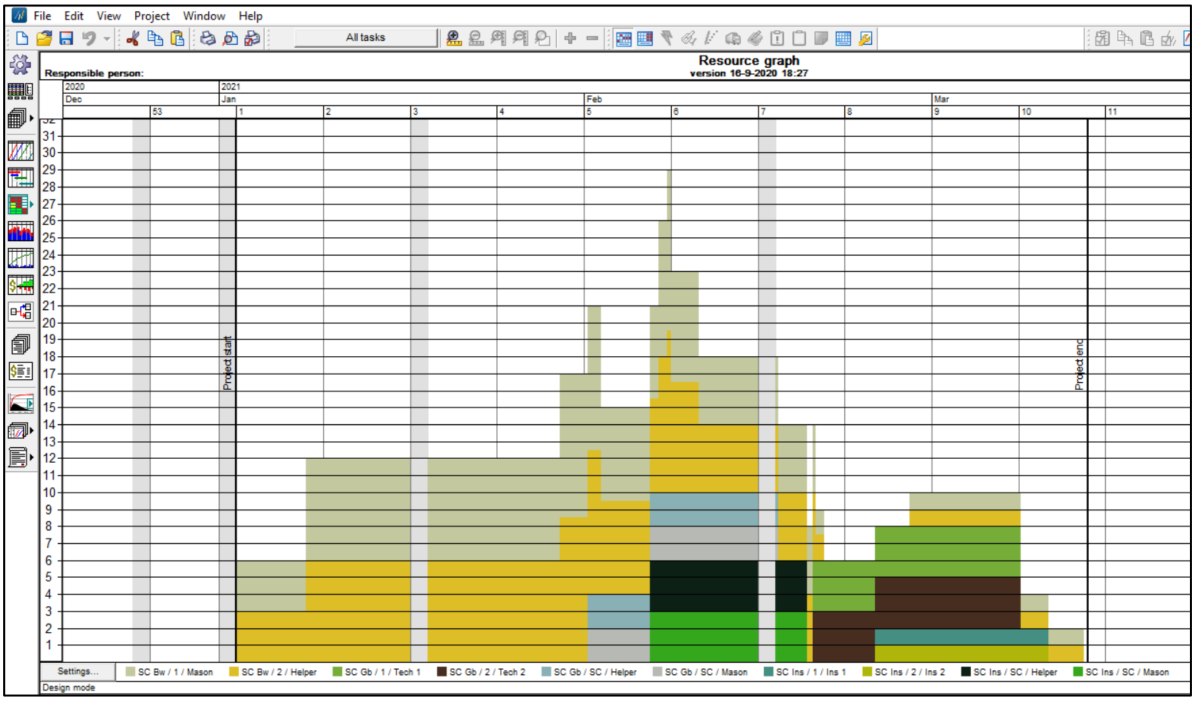

Fig. 23: Resource graph of the wall activities. Source: (By Author)

Fig. 24 illustrates the Gantt view chart captured from Vico schedule planner software showing two separate sections, in which one section lists the details of the activities such as total duration (start and end date), the following predecessor activities and the resources allocated to each activity. The other section illustrates the visual understanding of each activity in a bar chart view. The starting of wall construction activities are designated as the project start and finishing as project end. The dependencies of each activity are connected, respectively. The construction and finishing of wall activities end on 10 March 2021 (10 weeks), with the given resources and consumption on each working days.

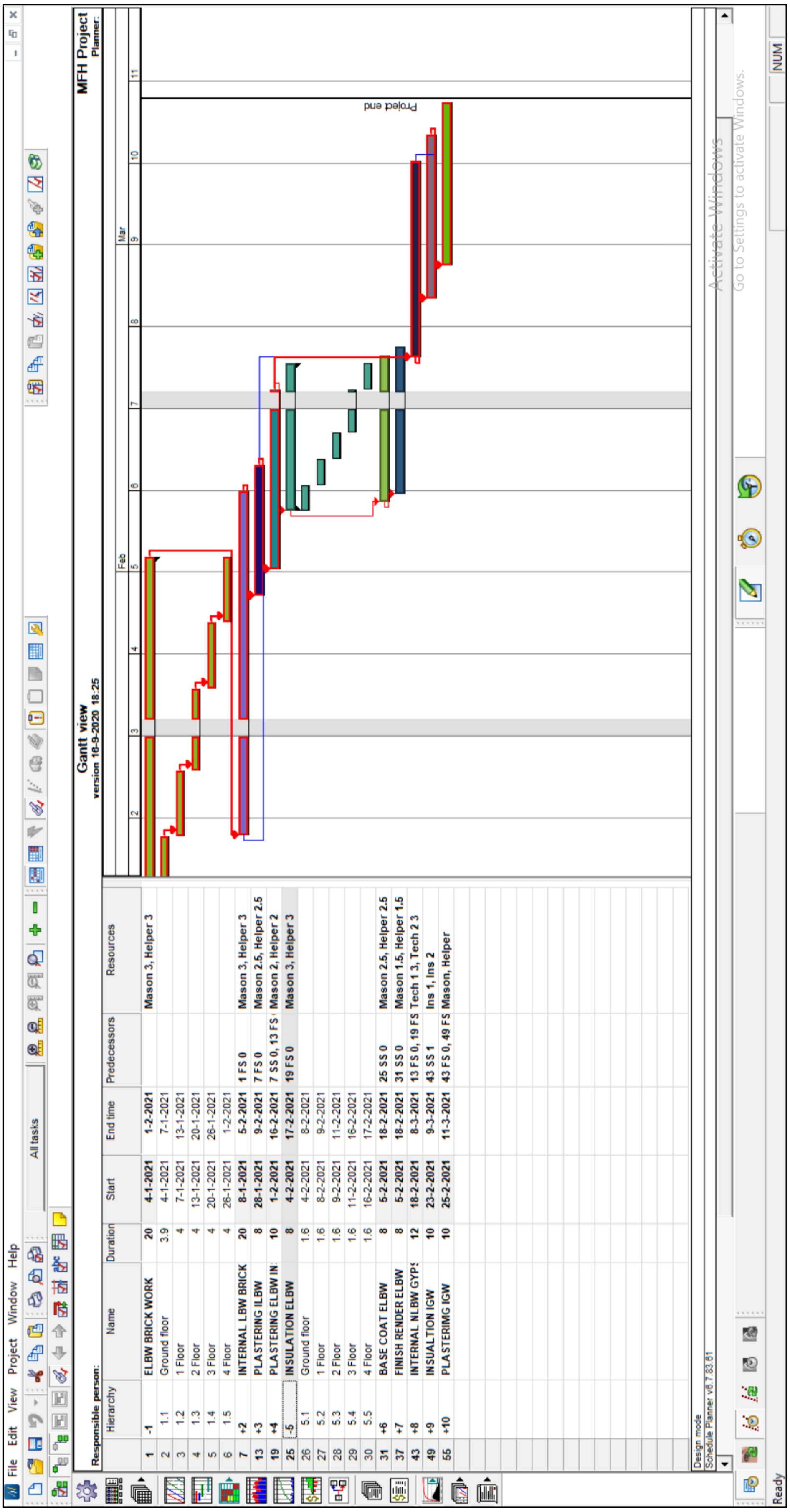

Fig. 24: Gannt view of the wall elements. Source: (By Author)

4. Results & Findings

4.1 Final cost calculations

The results of the final cost calculation of wall elements are briefly explained below. The overall wall quantities calculated using the Excel spreadsheet are applied to another spreadsheet called "Abstract of cost" as discussed in the methodology.

The necessary data and calculations were prepared with a suitable methodology to reach the final goal, the cost calculations. The DIN 276 and BKI provides all the information required for an accurate estimation. Tab. 11 presents the overall quantities of all the different wall elements of MFH building.

Details of Measurement		
No.	**Particulars**	**Calculated quantities**
1.	Quantities of external load-bearing walls	754.15 m²
2.	Quantities of internal load-bearing walls	761.65 m²
3.	Quantities of internal non-load-bearing walls	1484.98 m²

Tab. 11: Overview of wall quantities. Source: (By Author)

The cost calculation of walls is to be precise to achieve the most accurate results. The activities listed with the help of WBS is again helping to calculate the costs of different wall elements. The BKI medium costs (from Tab. 10) for different activities considered for the different wall elements. Tab. 12 demonstrates the final cost calculations of walls. In the last column, the DIN 276 cost group defines the different wall elements for easy understanding. The total cost of the wall construction including insulation of walls, base coat, finishing render, gypsum board installation, inner plastering for an MFH of 5 floors is 655,855 €.

Abstract of Cost						
Load-bearing walls						
Item	**Quantity**	**Unit**	**Particulars**	**Rate (€/m²)**	**Amount (€)**	***DIN 276 - cost group***
1	754.15	m²	External load-bearing walls - Brick work	120.00	**90,498**	***331***
2	761.65	m²	Internal load-bearing walls - Brick work	99.00	**75,403**	***341***
3	754.15	m²	Insulation of external load-bearing walls - external cladding	114.00	**85,973**	***335***
4	754.15	m²	Base coat of external load-bearing walls - external cladding	114.00	**85,973**	***335***
5	754.15	m²	Finishing render of external load-bearing walls - external cladding	114.00	**85,973**	***335***
6	754.15	m²	Plaster finish of external load-bearing walls - internal cladding	27.00	**20,362**	***336***
7	1,523.30	m²	Plaster finish of internal load-bearing walls - internal cladding (2*761.65)	21.00	**31,989**	***345***
Non-load-bearing walls						
8	1,484.98	m²	Internal non-load-bearing walls - Installation of Gypsum board	58.00	**86,129**	***342***
9	1,484.98	m²	Insulation of internal non-load-bearing walls - internal linings	21.00	**31,185**	***345***
10	2,969.96	m²	Plaster finish of internal non-load-bearing walls - internal linings (2*1484.98)	21.00	**62,369**	***345***
Total cost					**655,855 €**	

Tab. 12: Final cost calculations. Source: (By Author)

4.2 Detailed wall elements – ArchiCAD Model (BIM)

The recreation of plans using ArchiCAD 22 software not only transforms the simple plan into a 3D model but also provides the user to apply various materials to different construction elements like columns, beams, slabs and wall elements.

The different kinds of materials and various layers used in the external walls cannot be visible in a real-life situation, but a 3D model can illustrate more accurately to the viewers. This visual presentation is very much useful to understand the multi-layered wall elements of the building and is readily applicable to new buildings.

Fig. 25 illustrates a screen capture demonstrating the section of the MFH building cut in the middle. The section helps to identify the different layers present in the wall elements. The label D-01 and D-02 in the figure represents the details of the external multi-layered load-bearing wall and internal multi-layered non-load-bearing wall. The software creates wall details in a separate window, where the scale of the model details can be adjusted for better insight.

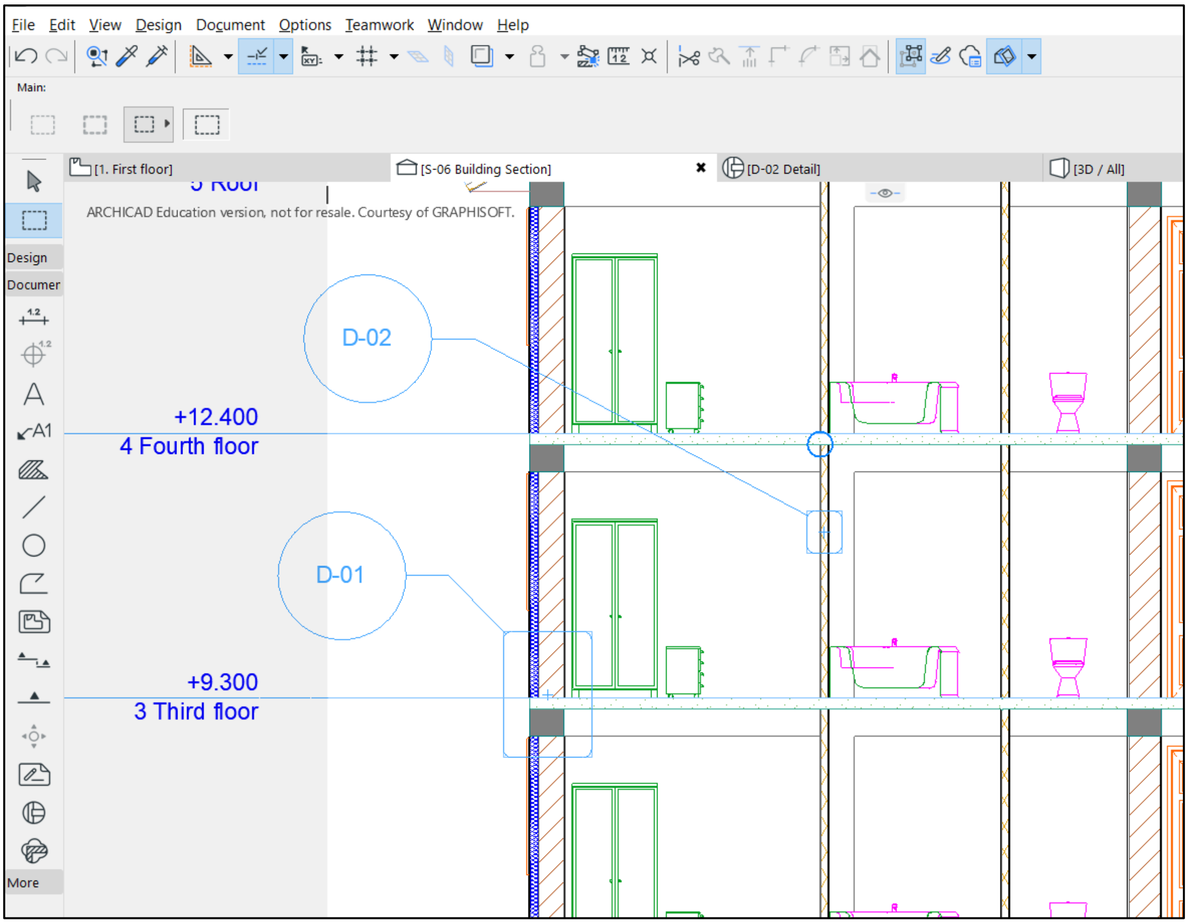

Fig. 25: Screen capture showing the section of the MFH building. Source: (By Author)

The ArchiCAD software has many different in-built views to document a project's section, elevation, 3D model, detailing, final rendering, and different other documentation related to the project model.

Fig. 26 and Fig. 27 presented below illustrates the visual outcome of an external multi-layered load-bearing wall and internal multi-layered non-load-bearing wall, respectively. The external load-bearing wall layers include 300 mm brick wall and 100 mm thermal insulation as the main components. The insulation dramatically reduces the escape of heat energy from the building and sufficiently decreases the heat demand of the building. The layers in Fig. 26 also shows finishing coats and renders, which are not much visible to the naked eye.

The internal non-load-bearing wall (Fig. 27) includes layers of 80 mm acoustic insulation in between 10 mm gypsum board attached on either side of the frame. The insulation helps to reduce noises from adjacent rooms and keeps the wall intact.

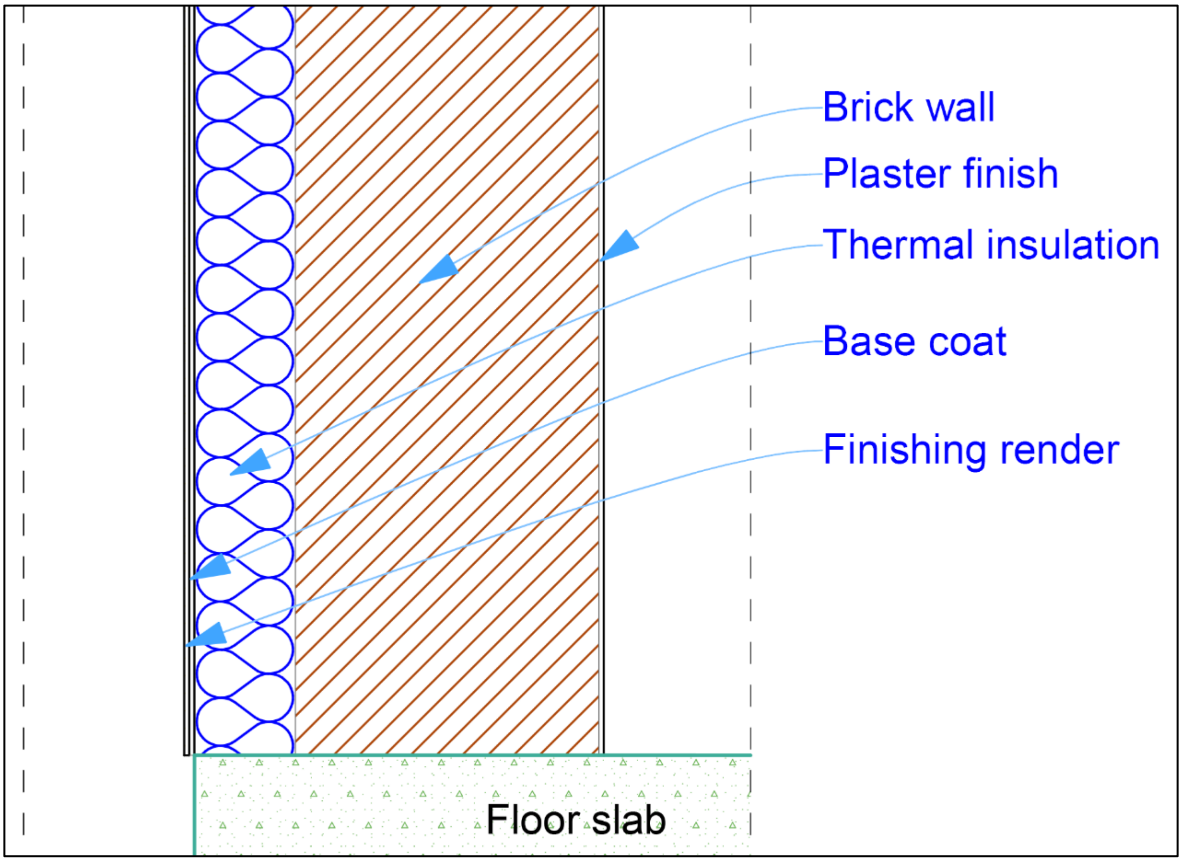

Fig. 26: Layer details of the external load-bearing wall (D-01). Source: (By Author)

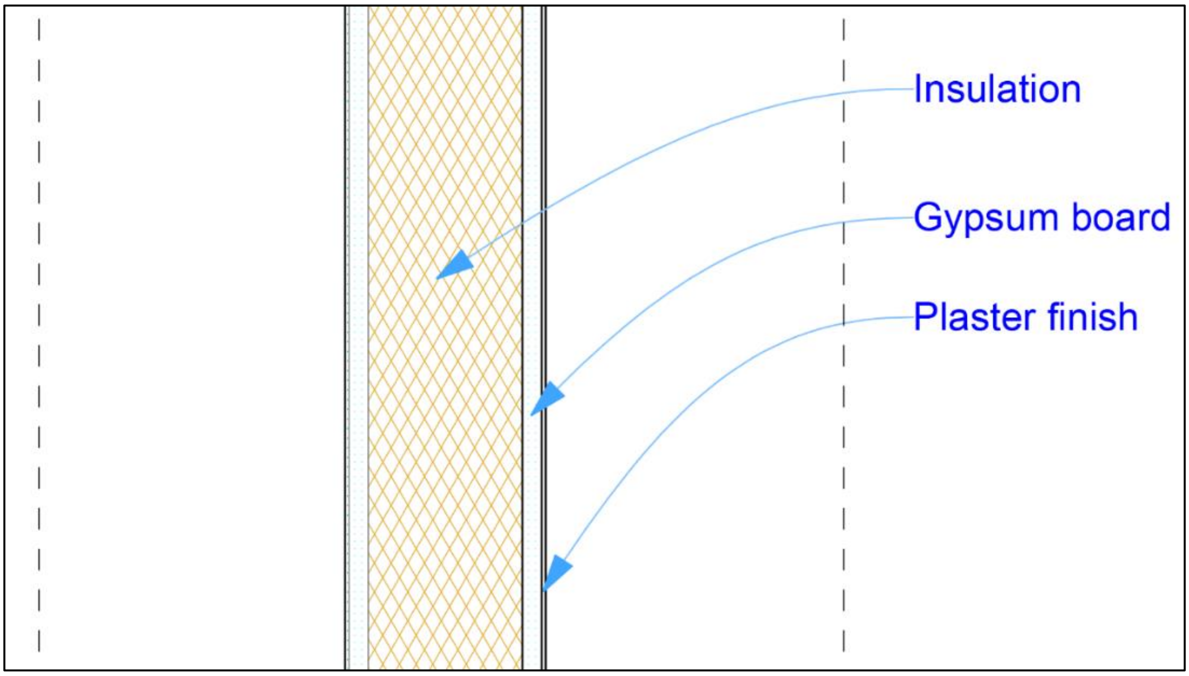

Fig. 27: Layer details of the internal non-load-bearing wall (D-02). Source: (By Author)

The ArchiCAD software loaded with innovative materials and details helps to create a visual rendering model of the wall materials. The final rendering model of the external load-bearing walls shows multiple layers presented in a manner to differentiate the layers and respective thickness. The model demonstrates the layers in a detailed manner, as the software renders the image with high-quality materials and characteristics. Fig. 28 represents the final model of the multi-layered external load-bearing wall.

Fig. 28: ArchiCAD rendered model of the external multi-layered wall. Source: (By Author)

4.3 Cost – Time progressive model (S-curve)

In the literature, many authors used the S-curve as a tool to monitor the project progression. This tool also helps to predict the future project completion date, resource monitoring and construction activities.

The scheduling of wall activities with the help of schedule planner provided a result of 10 weeks to complete the different wall elements of the MFH building. The S-curve using an Excel spreadsheet is generated by comparing the money spent on different stages of the construction works. As discussed earlier, the activities at the early stage of the construction start at a slow rate and pick up the phase in the middle, forming an S-curve when plotted in a graph.

Fig. 29 demonstrates the S-curve of the wall construction of the MFH building. The X and Y axes correspond to construction time and construction costs, respectively. The curve results from assuming a certain degree of work are completed in each week starting from the first week and the costs derived from the assumed percentage of total costs as presented in Appendix 6.

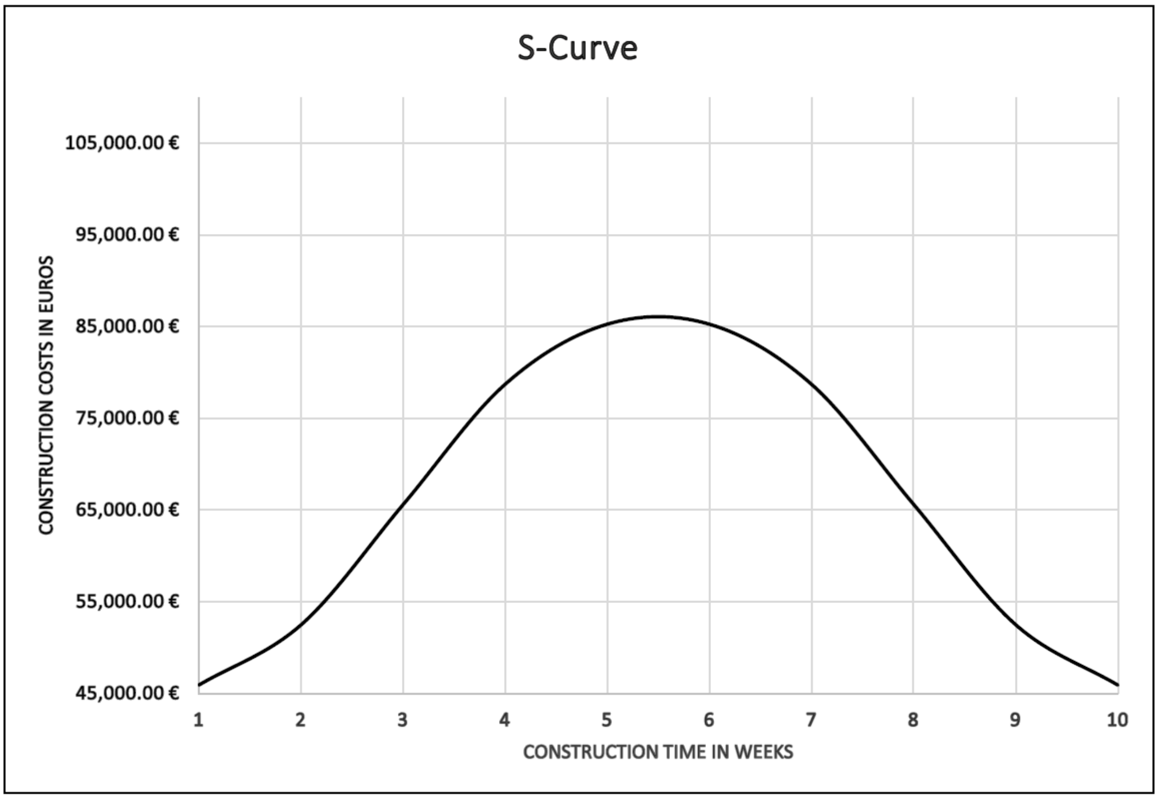

Fig. 29: Cost – Time progressive model (S-curve). Source: (By Author)

The budget S-curve is also related to the progressive S-curve illustrated above (Fig. 29). In this model, the percentage of cost spent on each week during the work progression is added until project completion. So every week, the completion of the project grows, forming a curve in "S" shape. The project managers use this model to monitor the overruns and underruns of costs. Fig. 30 illustrates the budget S-curve derived from the degree of work completion and scheduling as per Appendix 7.

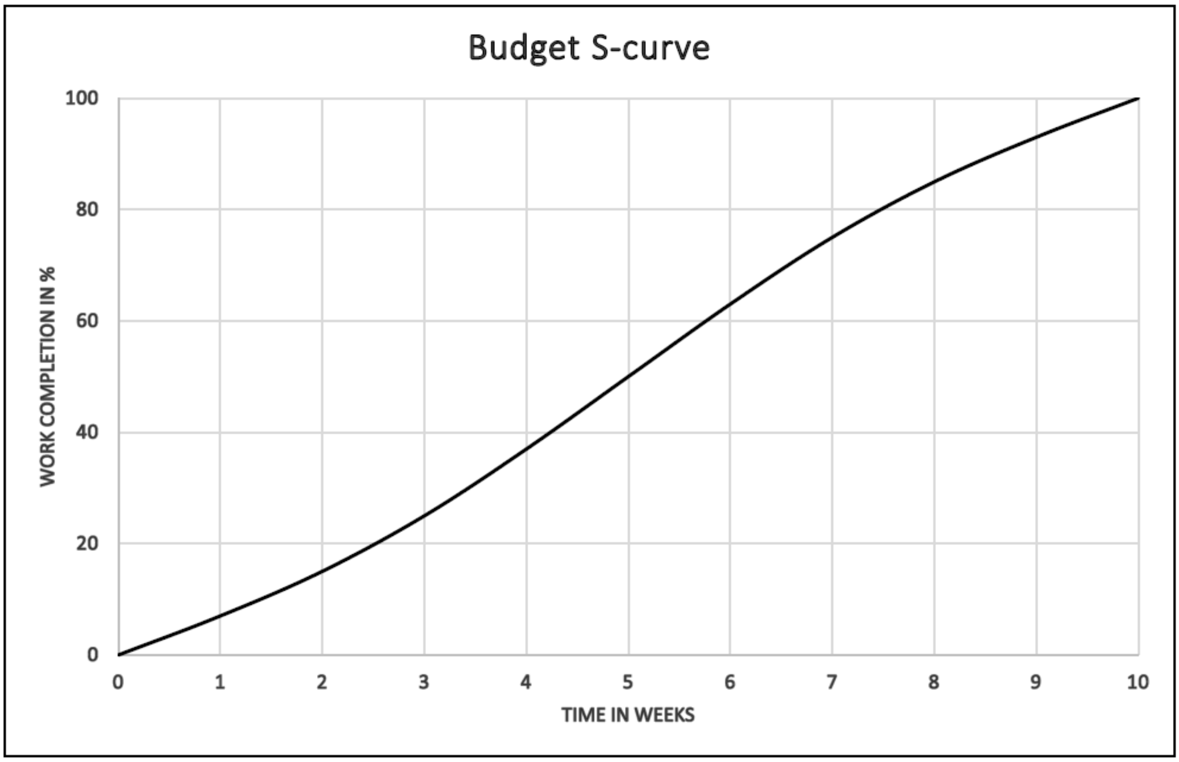

Fig. 30: Budget S-curve. Source: (By Author)

5. Conclusion & Recommendation

This research aimed to identify the cost and time calculations of wall elements for a multi-family housing building. Based on the research of qualitative and quantitive analysis of housing needs, different cost estimation methods, and time duration, it can be concluded that the results are accurate and sound to the investor. The more detailed information in the early stages can be used for better consultation between the stakeholders. The results can be implemented in real-life projects of the same geometry, and maximum accuracy can be expected. The resulted S-curve models can be useful in project tracking, resource planning and monitoring of cost-related issues.

To better recognize the implications of these results, future studies could address, a more complex project with the help of BIM tools for quantity take-offs directly from the created models used in 4D scheduling and cost estimation. A study on carbon footprint calculations for the wall elements can be studied together with energy retrofitting.

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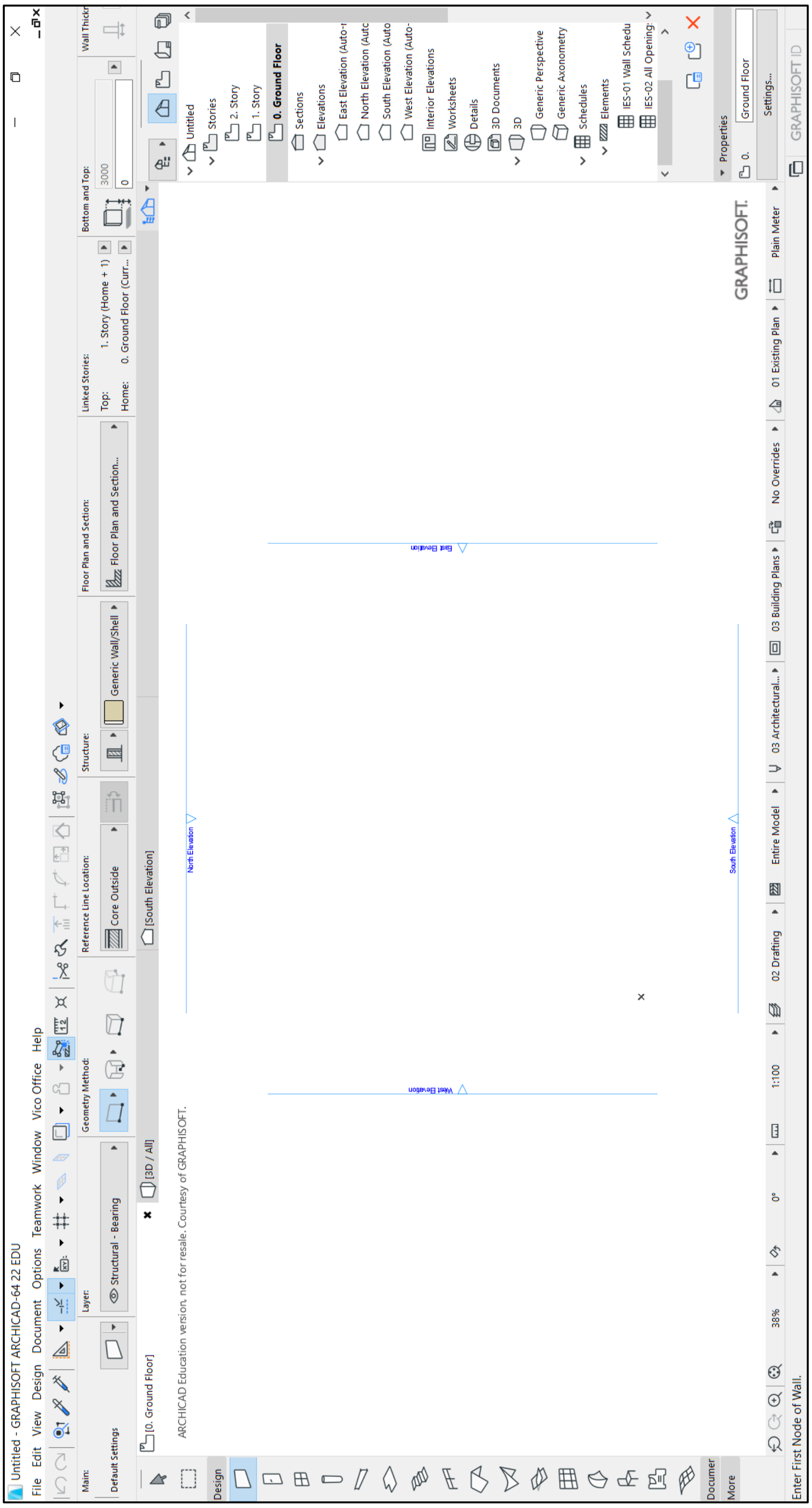
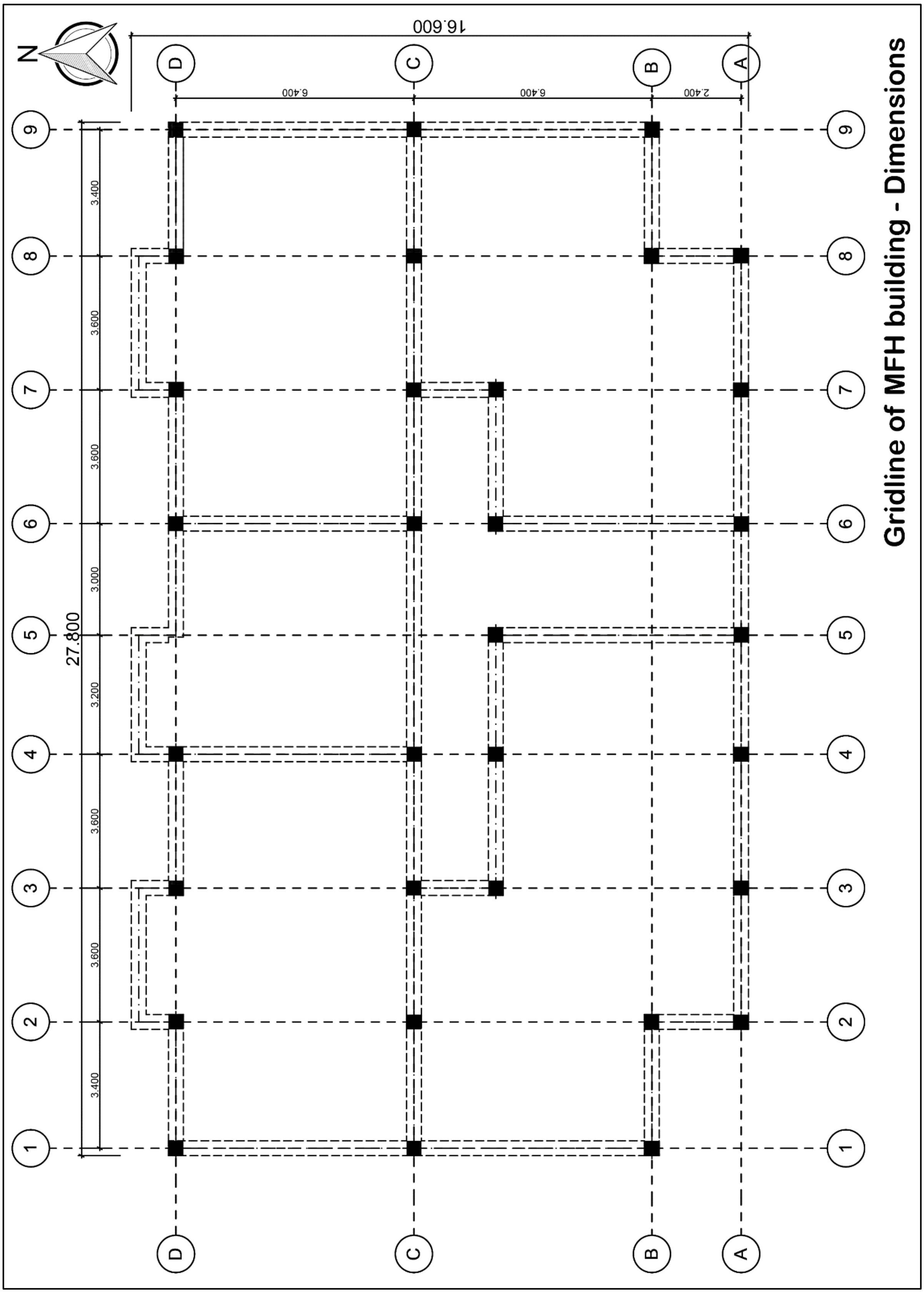
Appendix

Appendix 1 – Screen capture of ArchiCAD 22 workspace



Appendix 1: ArchiCAD 22 workspace. Source: (By Author)

Appendix 2 – Dimensions of MFH building

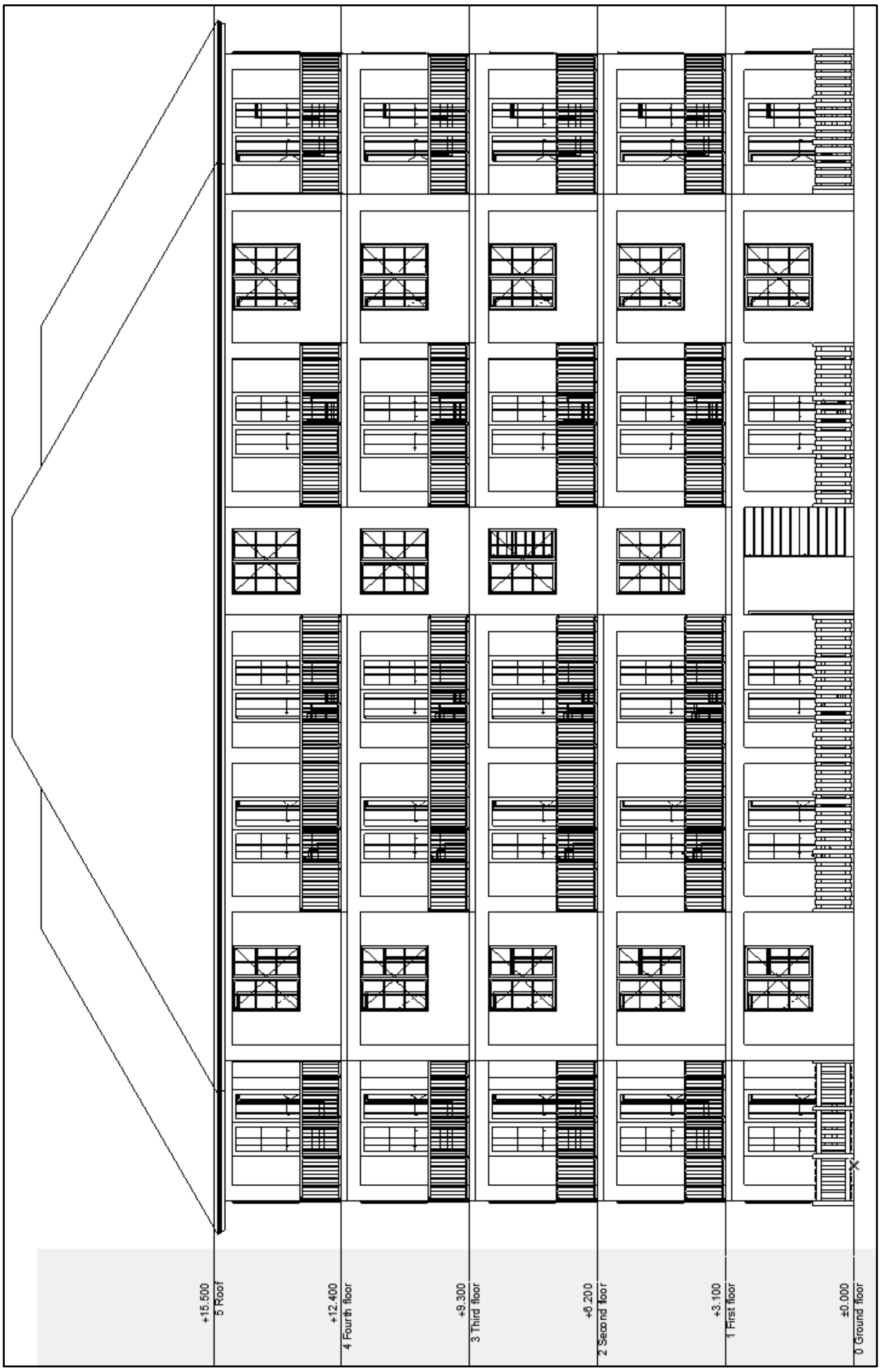


Appendix 2: Gridline drawing of MFH building with dimensions. Source: (By Author)

Appendix 3 – 3D Model of the MFH building

Appendix 3: 3D model view created using ArchiCAD 22. Source: (By Author)

Appendix 4 – Elevation of the MFH building



Appendix 4: Elevation view created using ArchiCAD 22. Source: (By Author)

Appendix 5 – Individual quantity calculation of wall elements

Load bearing individual wall quantities - Ground floor				
External load-bearing walls				
North direction	**No.**	**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	4.00	2.65	10.60
Deduct door	1	-1.60	2.65	-4.24
Wall 2	1	4.20	2.65	11.13
Deduct window	1	-1.60	1.65	-2.64
Wall 3	1	3.20	2.65	8.48
Deduct door	1	-1.60	2.65	-4.24
Wall 4	1	7.80	2.65	20.67
Deduct door	1	-1.60	2.65	-4.24
Deduct window	1	-1.60	1.65	-2.64
Wall 5	1	3.20	2.65	8.48
Deduct door	1	-1.60	2.65	-4.24
Wall 6	1	4.20	2.65	11.13
Deduct window	1	-1.60	1.65	-2.64
Wall 7	1	4.00	2.65	10.60
Deduct door	1	-1.60	2.65	-4.24
Total wall area in North direction				**51.97**
South direction		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	3.00	2.65	7.95
Deduct door	1	-1.60	2.65	-4.24
Wall 2	1	3.20	2.65	8.48
Deduct window	1	-1.60	1.65	-2.64
Wall 3	1	3.20	2.65	8.48
Deduct door	1	-1.60	2.65	-4.24
Wall 4	1	2.80	2.65	7.42
Deduct door	1	-1.60	2.65	-4.24
Wall 5	1	3.20	2.65	8.48
Deduct door	1	-1.60	2.65	-4.24
Wall 6	1	3.20	2.65	8.48
Deduct window	1	-1.60	1.65	-2.64
Wall 7	1	3.00	2.65	7.95
Deduct door	1	-1.60	2.65	-4.24
Total wall area in South direction				**30.76**
West direction		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	6.20	2.65	16.43

Deduct window	1	-1.60	1.65	-2.64
Wall 2	1	6.00	2.65	15.90
Deduct window	1	-1.60	1.65	-2.64
Wall 3	1	2.00	2.65	5.30
Total wall area in West direction				**32.35**
East direction		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	6.20	2.65	16.43
Deduct window	1	-1.60	1.65	-2.64
Wall 2	1	6.00	2.65	15.90
Deduct window	1	-1.60	1.65	-2.64
Wall 3	1	2.00	2.65	5.30
Total wall area in East direction				**32.35**
Internal load-bearing walls				
N to S direction		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1 (line 3)	1	1.80	2.65	4.77
Wall 2 (line 4)	1	6.20	2.65	16.43
Wall 3 (line 5)	1	6.20	2.65	16.43
Wall 4 (line 6 T)	1	6.20	2.65	16.43
Wall 5 (line 6 B)	1	6.20	2.65	16.43
Wall 6 (linne 7)	1	1.80	2.65	4.77
Total wall area				**75.26**
E to W direction		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1 (from L)	1	3.00	2.65	7.95
Wall 2	1	3.20	2.65	8.48
Wall 3	1	3.20	2.65	8.48
Deduct MD	1	-2.50	1.00	-2.50
Wall 4	1	5.80	2.65	15.37
Deduct MD	1	-2.50	1.00	-2.50
Wall 5	1	3.20	2.65	8.48
Deduct MD	1	-2.50	1.00	-2.50
Wall 6	1	3.20	2.65	8.48
Wall 7 (R end)	1	3.00	2.65	7.95
Wall 8	1	3.20	2.65	8.48
Deduct MD	1	-2.50	1.00	-2.50
Wall 9	1	2.80	2.65	7.42
Wall 10	1	3.20	2.65	8.48
Deduct MD	1	-2.50	1.00	-2.50
Total wall area				**77.07**

Non-load-bearing individual wall quantities - All floors				
Apartment 1 SW				
N to S	**No.**	**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	6.00	2.97	17.82
Deduct D1	1	-0.90	2.50	-2.25
Wall 2	1	2.10	2.97	6.24
Wall 3	1	4.50	2.97	13.37
Wall 4	1	4.50	2.97	13.37
Wall 5	1	1.60	2.97	4.75
Deduct D2	1	-0.80	2.50	-2.00
Total wall area				**51.29**
E to W		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	3.00	2.97	8.91
Deduct D2	1	-0.80	2.50	-2.00
Wall 2	1	3.50	2.97	10.40
Deduct D2	2	-0.80	2.50	-4.00
Wall 3	1	10.30	2.97	30.59
Deduct D1	3	-0.90	2.50	-6.75
Total wall area				**37.15**
Apartment 2 SE				
N to S	**No.**	**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	1.60	2.97	4.75
Deduct D2	1	-0.80	2.50	-2.00
Wall 2	1	4.50	2.97	13.37
Wall 3	1	6.00	2.97	17.82
Deduct D1	1	-0.90	2.50	-2.25
Total wall area				**31.69**
E to W		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	7.10	2.97	21.09
Deduct D1	2	-0.90	2.50	-4.50
Wall 2	1	4.10	2.97	12.18
Deduct D2	2	-0.80	2.50	-4.00
Wall 3	1	3.00	2.97	8.91
Deduct D2	3	-0.80	2.50	-6.00
Total wall area				**27.67**
Apartment 3 NE				

N to S	No.	Length (m)	Height (m)	Area (m²)
Wall 1	1	4.00	2.97	11.88
Wall 2	1	4.60	2.97	13.66
Wall 3	1	2.10	2.97	6.24
Deduct D2	1	-0.80	2.50	-2.00
Wall 4	1	1.50	2.97	4.46
Deduct D2	1	-0.80	2.50	-2.00
Total wall area				**32.23**
E to W		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	4.20	2.97	12.47
Deduct D1	1	-0.90	2.50	-2.25
Wall 2	1	6.60	2.97	19.60
Deduct D1	2	-0.90	2.50	-4.50
Total wall area				**25.33**
Apartment 4 NM				
N to S	**No.**	**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	4.00	2.97	11.88
Wall 2	1	2.20	2.97	6.53
Deduct D2	1	-0.80	2.50	-2.00
Wall 3	1	2.10	2.97	6.24
Deduct D2	1	-0.80	2.50	-2.00
Total wall area				**20.65**
E to W		**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	1.70	2.97	5.05
Wall 2	1	4.00	2.97	11.88
Deduct D1	2	-0.90	2.50	-4.50
Total wall area				**12.43**
Apartment 5 NW				
N to S	**No.**	**Length (m)**	**Height (m)**	**Area (m²)**
Wall 1	1	4.60	2.97	13.66
Wall 2	1	4.00	2.97	11.88
Wall 3	1	1.50	2.97	4.46
Deduct D2	1	-0.80	2.50	-2.00
Wall 4	1	2.10	2.97	6.24
Deduct D2	1	-0.80	2.50	-2.00
Total wall area				**32.23**
E to W		**Length (m)**	**Height (m)**	**Area (m²)**

Wall 1	1	6.70	2.97	19.90
Wall 2	1	4.10	2.97	12.18
Deduct D1	3	-0.90	2.50	-6.75
Total wall area				**25.33**
Duct walls		1.00	1.00	**1.00**
Total area of non-load-bearing walls				**297.00**

Appendix 5: Individual cost calculations using Excel spreadsheet. Source: (By Author)

Appendix 6 – Degree of work completion and estimated costs (S-curve)

Construction time in weeks (X-axis)	Work completed in %	Estimated cost in Euros (Y-axis)
0	0	0
1	7	45910
2	8	52468
3	10	65585
4	12	78703
5	13	85261
6	13	85261
7	12	78703
8	10	65586
9	8	52468
10	7	45910

Appendix 6: Data for the S-curve model generation using an Excel spreadsheet. Source: (By Author)

Appendix 7 – Budget S-curve

Construction time in weeks	Work completed in %	Budget estimated cost in Euros
0	0	0
1	7	45910
2	15	98378
3	25	163964
4	37	242666
5	50	327927
6	63	413188
7	75	491891
8	85	557476
9	93	609945
10	100	655855

Appendix 7: Data for Budget curve generation using an Excel Spreadsheet. Source: (By Author)

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