Tunnel Information Modeling

Muhammad Bilal (GL)	**NUST201200383**
Umar Bin Abdul Aziz	**NUST201201351**
Ch. Humayun Taffazal	**NUST201200659**
Syed Muhammad Fahad Ali	**NUST201200414**

A report submitted in partial fulfillment

Of

The requirements for the degree of
Bachelors of Engineering
In

Civil Engineering
NUST Institute of Civil Engineering (NICE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences & Technology
Islamabad, Pakistan.

ACKNOWLEDGEMENTS

Carrying out a project requires hard work and sheer determination. But it is never possible without the help and guidance of our teachers, friends and family. First and foremost, all thanks to ALLAH ALMIGHTY without even the slightest change in this world cannot happen.

A special thanks to our university NUST and our department NICE. Without their assistance and dedicated involvement in every step throughout the process, this project would have never been accomplished.

Apart from the efforts, the success of any project depends largely on the encouragement and guidelines of many others. We would like to take this opportunity to express our gratitude to the people who have been instrumental in the successful completion of this project. We would like to show our greatest appreciation to Sir **Asif Riaz** and **Dr.Jamal ud din Thaheem**. We feel motivated and encouraged every time we attend their meeting. Without their encouragement and guidance this project would not have materialized. The guidance and support received from all the members who contributed and who are contributing to this project, was vital for the project. We are grateful for their constant support and help. And last but most importantly, we all like to pay gratitude to our PARENTS who have been supporting us throughout our life and are still supporting us in performing the project.

ABSTRACT

Building Information Modeling (BIM) has been a great innovation in construction industry. It has revolutionized the architect and construction field. Many software are available for information modeling of buildings; however any specific framework for information modeling of tunnels has not been performed yet in any part of the world. Our research is based on developing a framework for Tunnel Information Modeling (TIM) for all types of tunnels. Most of the world is moving towards advancement in technologies and modernization in computer techniques. This includes all the data integration that leads to reduction in work greatly. Certain models are prepared prior to the execution of the project during the planning phase, which gives detailed visualizations of the project at the very start, providing all the stakeholders a very good idea of what the end product would be. The report opens with the introduction to TIM, objectives of our project, our assumptions and limitations of TIM. . It proceeds with a literature review of TIM from different research papers and projects executed in different parts of the world. The literature review describes the different frameworks that can be used for tunneling information model. The research will be leading towards the methodology for developing a framework for TIM, implementing it for the 3D modeling, cost estimation and scheduling of a road tunnel.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

1.1 Background Knowledge

Tireless efforts have been put into the field of Building Information modeling to make the construction process more efficient every day. BIM have become a common practice for large or medium size building projects in most of the developed countries. A little work have also been done for the information modeling for the infrastructure projects like roads, bridges and drainage. Different software tools are available for the information modeling of buildings, bridges roads and drainage. But the information modeling for the tunnel has been done rarely and there is no well-defined software for this. The purpose of this research is to develop a framework for the information modeling of tunnel.

The building information model has been eloquently defined by National Building Information Model Standard Project Committee as:

"Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition."- (Frequently Asked Questions About the National BIM

Standard-United States - National BIM Standard - United States". Nationalbimstandard.org. Retrieved 17 October 2014.)

Another definition can be stated as following: Building information Modeling (BIM) makes explicit the highly interdependent nature of structure, architectural layout, and the MEP systems by technologically coupling project participants together (Dossick and Neff, 2009).

BIM have seven dimensions which are 3-D modeling, 4-D Scheduling of the construction activities, 5-D Quantity takeoff and Cost Estimating, 6-D Sustainability Analysis, 7-D Facility Management Applications. All these dimensions of BIM can be performed for any building project. The software used for BIM is Autodesk Revit. Revit building design software is specifically built for Building Information Modeling (BIM), including features for architectural design, MEP and structural engineering, and construction. BIM helps a lot in construction management. It provides better visualization, increase accuracy, faster quantity take-off and cost estimation, decrease the project cost, performs clash detection and hence improves the over-all efficiency of the project.

Infrastructure information modeling is a new technique to enhance the efficiency of construction management. A very limited work is being performed in this. The software used for this is InfraWorks 360 which is a preliminary design software helps improve your project outcomes. Combine and connect data to better create, view, analyze, share, and manage information to make decisions in context. It is for Bridge, Drainage, and roads. It makes the 3-D models and also quantity take off.

1.2 Problem Statement

Tunnels being the most critical infrastructure require the most efficient construction control and management which can be achieved by creating their information model before construction. So the main objective of this research is to develop a frame work for tunnel information model with its implementation on a real tunnel project.

1.2.1 Research Questions:

- What are the operations and sequences involved in tunnel construction?
- How the operation and sequences can be integrated through information modeling?
- What are the latest trends of information modeling in tunnel construction?
- Which developed soft wares can be incorporated into development of tunnel information modeling?

1.3 Research Objectives

Narrowing down to the research objectives we limit our study to the below mentioned outcomes of this enormous field under consideration.

- To study different parts of tunnel projects including operation and sequences
- To investigate and analyze applicability of Information Modeling to projects completed worldwide especially of underground nature.
- To investigate available software for information modeling of infrastructure projects
- Developing a Tunnel Information Modeling framework preferably IT tool

<u>CHAPTER 2</u>

LITERATURE REVIEW

This part contains the relevant data collected on the subject matter collected from different source such as research paper, international conferences etc. This part discusses use of Building Information Modeling in terms of Construction Management and its use in the Tunneling practices. First the practices of BIM are reviewed in terms of infrastructure. The applications of Building Information Modeling and the software tools will also be discussed in the following section.

2.1 BIM for Infrastructure:

BIM not only converts the data into digital form but also gives an insight on how a particular facility can be created, alters the work flow and changes the key delivery processes involved. BIM however stands for Building Information Modeling, in our case of study we deal with Infrastructure, to break it down even more tunnels are being explored here.

The new term coined for the modeling of Civil Infrastructures using the techniques introduced by BIM is Civil Information Modeling. Civil information modeling (CIM) is a term commonly used in the AEC industry to refer to the application of BIM for civil infrastructure facilities, such as bridges and tunnels. CIM being a newly coined term is being used around the industry with many variants such as, “construction information modeling”, “construction information management” and “civil integrated management”. “Horizontal BIM” and “Heavy BIM” are among other terms being used to refer to this form of BIM. The use of BIM technology in any form of structures other than building is refered to as CIM “Civil Information Modeling”.(Jack C.P. Cheng et al,2016)

2.1.1 Categories of CIM:

CIM being a relatively new branch leaves a lot of room for improvement and research. There are no set rules for categorizing the different types of projects. Different countries have used various categorizing methodologies. With reference to McDraw Gill, Bentley and others, the facilities of civil infrastructures are divided into following categories.

- Transportation Infrastructure
    - Bridges
    - Roads
    - Railways
    - Ports and Harbors
    - Airports
    - Tunnels
- Utility Infrastructure

    - Electricity and pipelines, natural gas, including water and sewage delivery systems
- Energy Infrastructure
    - Distribution terminals, storage, Oil and Gas, wells etc.
    - Power Generation: Including heat, wind, hydro and nuclear power Plants etc.
    - Coal iron ore, Mines, copper ore etc.

- Water Management Infrastructures
    - Water and Waste water facilities
    - Dams, canals and levees
- Recreational Facility Infrastructure:
    - Parks, stadiums etc.

(J.C.P. Cheng et al./ Automation in Construction 67 (2016))

2.1.2 Evaluation of CIM:

The literature review so far states that not much noteworthy work has been documented on this topic. Based on the few articles present a frame work has been developed by the researchers which divides the infrastructure in nine groups and evaluates them as per following diagram.

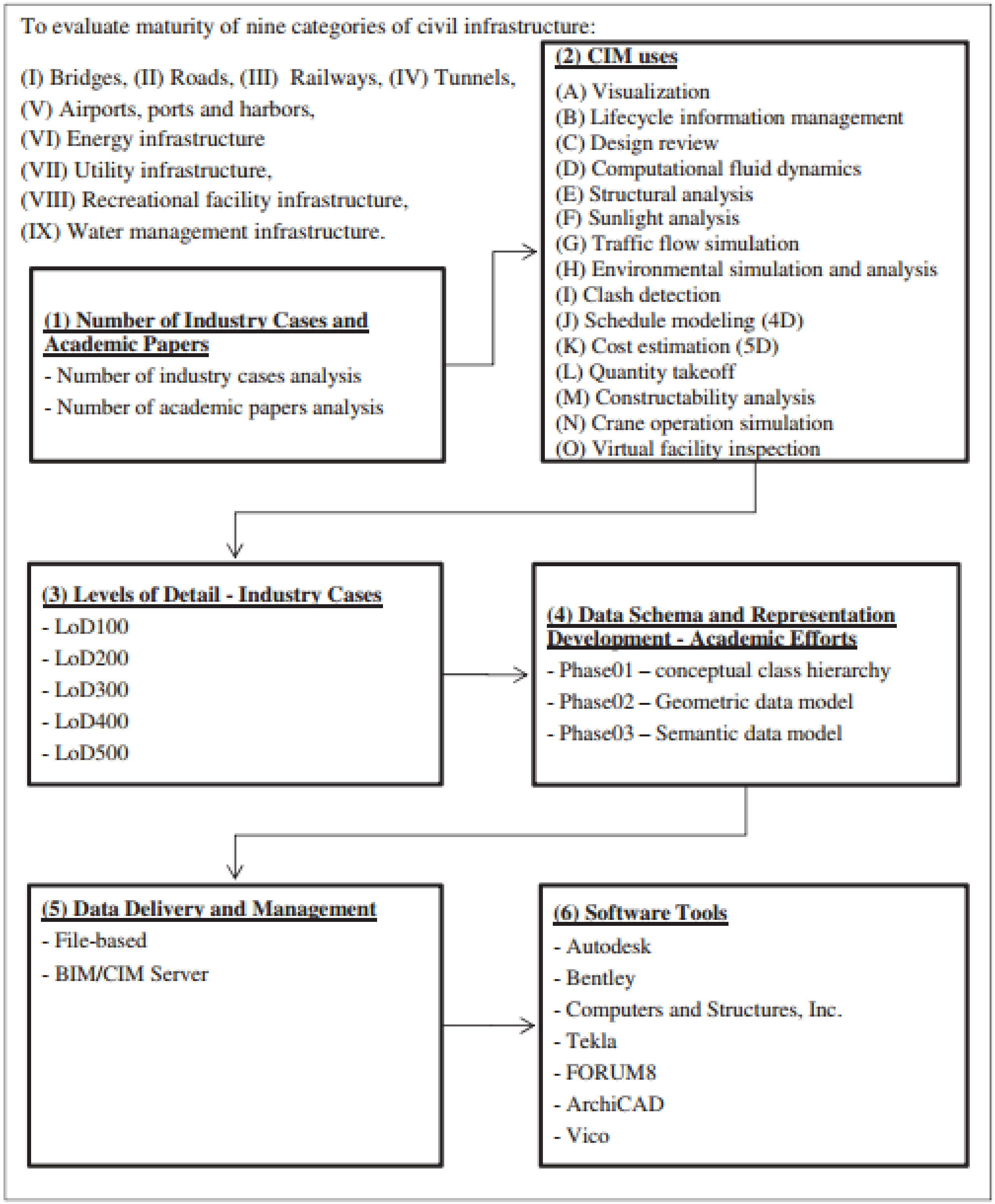


Fig. 2.1 Evaluation of CIM

2.1.3 Uses of CIM:

In a study by Keideret al. the term CIM was firstly proposed and used for the usage of BIM technology in the infrastructure projects. They have studied different types of CIMs and have hence concluded that CIM can perform 25 different operations. The operations can are listed below and the CIM procedure is defined: “a method of applying BIM during a facility’s life cycle to achieve one or more specific objectives”. With reference to the mentioned research papers studied and the cases available online following table shows the basic uses of CIM and its implementation.

Table 4
Relationship between CIM uses and facility delivery phases.

		Facility delivery phases			
		Phase 1	Phase 2	Phase 3	Phase 4
No.	CIM uses	Conceptual design	Detailed design and documentation	Construction	O&M
A	Visualization	√	√	√	√
B	Lifecycle information management	√	√	√	√
C	Design review	√	√		
D	Computational fluid dynamics	√	√		
E	Structural analysis		√		
F	Sunlight analysis		√		
G	Traffic flow simulation		√		
H	Environmental simulation and analysis		√	√	
I	Clash detection		√	√	
J	Schedule modeling (4D)		√	√	
K	Cost estimation (5D)		√	√	
L	Quantity takeoff		√	√	√
M	Constructability analysis			√	
N	Crane operation simulation			√	
O	Virtual facility Inspection				√

Fig. 2.2 Relationship between CIM uses and facility delivery phases

2.2 Civil Information Modeling For Tunnels:

2.2.1 Elements of Tunnel

Tunnels have many variants based on the physical environment, ease of transportation of materials, mechanics of the ground and soil conditions. Since all types of tunnels cannot be discussed here we keep our assumptions to a simplistic Road Tunnel design. Discussing the components of the Road tunnel in detail, following are the components that were studied for the project.

2.2.1 Ventilation

Ventilation is one of the most important features when providing a functional, comfortable and safe tunnel environment for road tunnels, as well as railway tunnels. The type of ventilation depends on the location of the exhaust ducts and the flow of air in general.

- Longitudinal Ventilation
    - Jet fans
    - Axial fans (installed throughout from tunnel entry portal to exit)
- Transverse ventilation
    - Fresh air duct/shaft
    - Exhaust air duct/shaft (both along the length)
- Semi-transverse ventilation
    - Combination of both
    - Ventilation simultaneously through ducts and portals.

2.2.2 Stations

Stations provided after a certain distance includes:

- Rest area/waiting area
- First Aid
- Communication (Phone)
- Storage niches and Background bays (for safe parking of vehicles)
- Tunnel Monitoring Center
- Misc. like Water Coolers, drinks etc.
- Refueling and Repairing (In case of long tunnels)
- Washrooms
- Transformers, Generators
- Information Desk

2.2.3 Electrification

Stations provided after a certain

- Illuminating Lights & other misc. lights (Signals, traffic signs etc)

    - Intelligent light systems (regulates the lighting throughout the tunnel & determines the optimum lightening for human vision inside the tunnel all the time)
- Electric Power Supply throughout (through electric wires/electric plan)
- CCTV Cameras, Loud speakers and Microphones (Audio Tunnel Monitoring & speed detection)
- Smoke/Fire Detectors
- Alert Alarms (for the attention of nearest tunnel monitoring center in case of fire and collisions)

<u>2.2.4 Emergencies</u>

- Exits
    - Leads to walkways which leads to exit. (Provided on both side)
    - Provided at specified distance, (doors marked with special signs)
    - Fire resistance doors
- Phones and alarms
    - Emergency phones and alarm are provided on road side for the passengers to contact police, control center, fire brigade etc
- First Aid and ambulances at stations.

    - Can also include Misc. vehicles like lifter etc.

- Fire Alarm systems
    - Smoke/fire/heat detection system
        - Integrated sprinkler
        - Fire Extinguisher
        - Standpipe system
- Other Emergency alarms
    - Collisions
    - Attacks
- Power
    - In case of blackout, backup power supply
        - Transformers
        - Generators
- Impact absorbers and barriers
    - Air bags or sloped concrete barriers to brake vehicles or orient them back onto the lane in case of a collision.
- Emergency lanes.

2.2.5 Sidewalks

- Provided on both sides along the length
- Shield from roadway by installing a fence

2.2.6 Mechanical

- Drainage system:
    - Provided in order to drain water from portals, wall washing water, groundwater infiltration through the lining, firefighting water & spillages from road tanker.
    - Consisting of channels, pipes, sump and pumps control systems for collection storage, separation and disposal of effluent
- Slot gutters.
    - Water Supply
- Integrated pipes for the water supply of
    - Sprinkle fire system (if used)
    - Water supply at stations
    - Firefighting water for standpipe system if used

2.2.7 Information System

- Road signs

    - Traffic signs
    - Sign boards
    - Information boards
- Radio, Loudspeaker announcements (to make sure drivers are up-to-date of traffic conditions inside the tunnel)

2.2.8 Smooth traffic flow Systems

- The system is directly connected to the tunnel monitoring center or control center through video cameras
- The system automatically detects vehicles in emergency lanes or lay-bys, stationary vehicles and obstacles, pedestrians and congestion, vehicles travelling the wrong way.
- Allows the control center to clear the road as soon as possible in order to maintain a smooth traffic flow.

2.2.9 Structure and Architecture

- Concreting
    - Heat resistant concrete
- Main Reinforcement (shaped as tunnel inner lining)
    - Panels, steel plates
- Concrete lining

- Grouting
- Shafts and ways to access the structure in case of any repairs
- Conveyer belts
- Semicircular shape tunnel
- Rigid and flexible pavements
- Sidewalks on both sides
- Concrete walls
- Waterproof membrane
- False ceiling

2.2.10 Misc.

- Vertical height check mechanism at entrance
- Plant rooms (electrical sub-stations and mechanical, electrical, communications and control equipment may be housed in plant rooms located within the tunnel.)
- Mirrors at sharp turns

2.3 Research Papers

In Finland, efforts to apply BIM to infrastructure projects like roads, streets, railways, bridges etc. are made but underground tunnels and mines have remained out of this. A similar work has been done before in Norway with HB138 specifications. University of Oulu in Finland is also working on a project named “FlexiMine” which aims the same. The purpose of this paper is to throw light on present development situation of 3D and BIM based process model for tunnel design and construction. Bentley provided intelligent mine concept which is being used by two largest tunneling projects in the world, London Crossrail and in Stockholm Bypass. The method discussed in the paper for Tunnel design is first modeling 3D initial data models which include digital terrain model, underground soil model etc. then Tunnel design will be done using fully 3D and information modeling based methods and the measured 3D initial data model as a starting point. For the purpose of experiments, five different tunnel projects in Finland, UK and Sweden were studied. In West Metro project of Helsinki and Espoo Project, Finland**,** Contractor has used more 2D drawings than 3D, except for some cases he used 3d models prepared with 3D Laser scanning. Cross rail UK was studied, BIM is utilized largely, 3d models are produced with equal level of detail using information modeling, saved £8 Million of risk contingency. In the Stockholm Bypass project, BIM is implemented using 3D spatially coordinated and integrated design models**.** The underground Kemi Mine implements BIM using 3D laser scanning systems, all the measured 3D data has been combined into 3D mine model. In Rantatunneli project in Tampere, Finland**,** Tunnels were not modeled using BIM, Roads are designed using 3D modeling and the Infra BIM guidelines**.** The Finnish Infra BIM guidelines do not yet determine the process model and detailed specifications for tunnel design and construction. However, Norwegian HB138 does determine some basics for the BIM process of tunnels. (R. Heikkila, et al,2014)

A research which deals with advantages of 3d model over 2D of a model based approach in design in infrastructure projects. Terrain models in a 3D survey data have proved to be more efficient than traditional 2D topo-geodetic maps. Furthermore better-informed decisions have only become possible due to study of model based design of terrain earlier in the process. The use of Water, energy, materials and land with integrated, accurate energy and environmental analysis can be optimized. Modeling has proven very efficient in large infrastructure projects like roads, Tunnels etc. Design inconsistencies and coordination problems can also be reduced as it eliminates the design inconsistencies with the help foo model based design work. Model-based design also preserves quality by minimizing inconsistencies in design and detecting problems at an early stage of the design process. Using Modeling software, conflicts and clashes are detected automatically and fixed accordingly. A Model based design contains all the design in the model, the intelligent labels make it reliable to use as it updates automatically. The output of Model based design is surfaces and networks–intelligent 3D objects which provide better visualization for the client. This model makes it easy to plan the progress in real time. Apart from 3D Modelling, 4D modeling is used nowadays in which the planner can look inside, move around, under and outside the structures and control the project progress with time constraints. Schedule and cost estimate of a project can also be better managed by incorporating the human resources, material resources and equipment in the BIM model. Executing Project work using 2D drawing without modeling is double work and loss of efficiency. (INNA ROMANDI et al, 2014)

The planning of large infrastructure projects such as subways require collaborative work of experts of many fields, a synchronous, simultaneous and collaborative approach is required for this project, it is not supported by the current software tools because majority of them employ 2D planning approach. Planning process is laborious and prone to errors; the team has to work hard on consistency and preservation of project instead of focusing on the core engineering problems. They used a holistic approach of 3D model techniques, coupling of semantic description with multi scale geometric models, developing a formal method of multitasking that reinforces automated consistency preservation for each levels of detail (LOD), techniques for supporting synchronous collaborative work on basis of shared multi scale models which include developing mechanism which allow engines to work concurrently with disturbing one another and to avoid violating the consistency of overall model. This model is used for exchanging, creating and storing multiple consistency models, the approach is step wise from coarse to fine LOD's, modification at coarse LOD will automatically propagate to fine LOD's, top down approach is used in this model. The LOD models are not isolated from each other but inter related by means of construction history. CAD models are more flexible and generic than BIM models but BIM provides built in classes which are easy to apply but they lack the diversity. The change from finer LOD's to coarser LOD's is not a part of this study but it will be an area of study for future researches. (A.-S. Høyer et al, 2015)

A research which has analyzed the method and process of tunnel engineering geological body modeling, the intent of the paper is to show that overall tunnel engineering geological body is quite suitable for real environments than the simple superposition of general property modeling and geometric modeling. The solution for geological problems are following in the paper, the selection of tunnel location and hole location, analyzing the groundwater, harmful gas and geothermal gas and the stability of the tunnel environment and surrounding. 3D geo-modeling is categorized by 3D GIS and 3D as an extension of 2D, the 2D entities are abstracted as line, surface and point while 3D quantities also include volume. A threshold limit is set for minimum amount of stratification and when the max thickness of the soil layer comes out to be less than this, we ignore the layer and merge upper and bottom layer, after the generalized treatment of layers by age, lithological and thickness and other rules, the contact of the main geotechnical on macro-layer is outlined, highlighting the subject with clear contact relationship, which is a conductive to the next step of 3d modeling work tunnel engineering which is basically the same with underground pipeline in geometric modeling method of 3d visualization, the differences are only between the sectional forms and different sizes. We can form a complete 3d geological model of tunnel project in this way and ultimately apply it into practice. (Xiao Fang Zu wt al, 2012)

To plan a large infrastructure facility, we need both geographic information systems(GIS) and building information model tools(BIM), to perform the required analysis, modeling and to visualize it. Multi-scale modeling being developed already in GIS but it has no approaches in BIM yet. this paper presents a concept for multi-scale model for building information modeling. it discusses extensions for industry foundation classes(IFC) used in BIM to represent different level of detail(LoD) while taking into account semantics and geometry. it describes an approach for transferring multi scale model of 3D city to the field of infrastructure planning, mainly tunneled carriageways. the planning process consists of a top down approach in contrast to the orthodox bottom up approach in cartography and continuously elaborating the design until reaching a final fully detailed model for construction and production. Multi scale modeling is an important part of CityGML standard and is sued in five well-defined levels of detail. This paper develops a new strategy for creating and storing multi scale geometric models for shield tunnels using explicit definition of dependencies between the individual level of detail, they allow for automated consistency checks and preservation. The second main subway track in Munich was chosen as a case study. the introduction of multi-scale concepts into BIM require consideration of highly dynamic planning processes which result in frequent modifications of data stored in BIM. (A. Borrmann et al, 2014)

An efficient approach has been proposed for the quantity takeoff of NATM-tunnels using parametrical modeling. It improves the efficiency of quantity takeoff by developing a standard on the tunnel libraries, levels of detail, parameters, and other parametric relations. Now the challenge was to develop a well-defined library that provides automatic design ability. As quoted by the report published by SMART Korea (bSK), the major hurdle, as described by 66% of the architectural engineers, in adopting BIM is lack of available relevant libraries and relevant content. Additional efforts and knowledge is required to apply the libraries into modeling. Developing a systematic BIM library which would focus on the details of a standard NATM tunnel construction would be an efficient way to solve this problem. BIM's ability to provide automatic design ability and product information that actually means something makes it ideal technology making it ideal intelligent object modeling. The objects are represented as libraries in BIM. Online libraries that are free of any cost, contents, development guidelines and also standard classifications are available online along with various types of libraries at ARCAT, The National BIM Library(NBL), Autodesk Seek, RevitCity, SMARTBIM, etc. To develop a library the most useful tool is parametric modeling that is equipped in most commercial BIM software applications. As the library development process commences one needs to make sure of the following

- relations (assigns, decomposes, associates, define, connects, etc.) among objects,
- properties (material, performance, contextual properties) of objects, and
- metadata and data structure for information management
- geometry representations (extrusion, blend, revolve, sweep,and swept blend).

Parametric modeling is usually defined as the involvement of the definition of objects and relationship among these preconceived objects. Parametric modeling provides an easy way to model a shape instead of doing complex programming to model the shape of any object. There are some built in families in Revit, but it’s very difficult to develop a new family. Now unlike buildings tunnel have small number of elements including rockbolt, drainage channel, shotcrete, concrete lining, perforated drainpipe, excavation lining, waterproof membrane, conduit cover, wall tile, utility and concrete pavement BUT the libraries for these elements are not available in the software tools. Thus the system families or component families are created and customized in an external library are used For example, “concrete lining library” is generated using a beam or wall library in the component families so this way all the elements of the tunnel are modeled. Now the concept of holistic system library was proposed which says that all these above modeled shapes of tunnel elements must combined together to form a single library, this will enhance the speed of tunnel modeling and so the quantity take off the all tunnel elements. (R. Heikkilä et al, 2014)

2.3.1 Tunneling projects:

1 Cross Road London

2 Seattle's massive tunnel

3 Sweden’s Hallandsås Tunnel

4 West Metro project of Helsinki and Espoo Project, Finland

5 the Stockholm Bypass project

6 Rantatunneli project in Tampere, Finland

2.3.1.1 Cross Rails London

Crossrail is a 118-kilometre (73-mile) railway line under construction in London. The large scale project is one of its kind and the scheduled opening of some parts of the project are due in December 2018. The project is one of the biggest of its kind. The project has collected the data from over 25 main design contracts, 30 advanced works contracts and over 60 logistics and main works construction contracts, these above mentioned contractors have intricate connections and interlink ages and all these are understood and better managed by the BIM software catering for the environment of London. all of which have an extraordinary number of interlinked interfaces within the complex and sensitive urban environment of London.

The project is one of the torch bearers in the industry in the field of Tunnel Information Modeling as being one of the first to employ the BIM technology to a tunnel project. A BIM environment of this scale has not been created before on any European project before. Even after the completion of the project the BIM integration will help the railway operators in the future in normal day-to-day functions that further reduces the cost of operation to a great level. The project boasts off a massive reduction in the cost due to the early on detection and diagnosis of any all risks to the project. The Technology has also saved the project labor cost that is no longer necessary in the development of the project. A few of the advantages of the project include the Reduction of risk, Improved Safety, Reduced errors, Improved Collaboration, Reduced Information Losses and Improved project delivery.

2.3.1.2 Alaskan Way Viaduct replacement tunnel

The Alaskan Way Viaduct replacement tunnel is a bored road tunnel that is under construction in the city of Seattle in the U.S. state of Washington. The Seattle Tunnel Partners design-build contractor team hired HNTB to facilitate the design of State Route 99 Tunnel project. The project is 2.8 km long bored tunnel and is indicated to be completed in $1.35 billion.

Various fields such as traffic management, structures, civil engineering, mechanical & electrical systems and architectural elements makes this a very complex project and a challenge for the managing team forcing them to the limit of expanding the their field and expertise. The data is so managed that it is always available to all the stakeholders in real time. With this added benefit the team can better concentrate on creating new solutions rather than solving the IT related issues. Replacement of the viaduct was a huge decision and hence an assurance of seismic safety and fiscal responsibility was also needed by designing a series of alternatives for design considerations. BIM technology has helped the project solve the safety issues regarding the project in wake of the ongoing seismic activity. It has helped design an infrastructure design that has helped in the development of sustainable infrastructure design, evaluation of design alternatives and facilitating outreach project.

<u>2.3.1.3 Hallandsås Tunnel, Swedan</u>

The Hallandsås Ridge Tunnel or Scanlink, is situated in Sweden. Connecting the northern and the southern sides of the Hallandsås geological formation its total length is 8.7 km.

The software tool for the development of the project by the organization in charge, Sweco Infrastructure AB, was selected to be the Bentley's Tekla BIM. Using the software , 200 non-constructible conflicts and 3,000 unique collisions have been detected. Design faults of this project have gone down to 50 percent due to the identification at the design stage and further reducing the cost of corrections. Due to the intervention of BIM the added benefit of saving the cost of about SEK 50 million has been estimated in this SEK700 million project.

BIM objective of enhancing and reusing engineering design information in downstream processes has also been reallized. In addition to providing the construction layout and geometrical drawings, time management, the 3D design model has been prepared to supply data for machine control and guidance, quantities and specifications, survey layout, cost control, analysis, as-built models etc.

2.3.1.4 Stockholm Bypass project, Stockholm

Förbifart Stockholm (Stockholm Bypass) is a series of underground expressway tunnels currently under construction between the south of Stockholm and the north of Stockholm. The total length of this is 21 kilometer and more than 17 km of this is built underground.

The project has been developing BIM based model of the project in collaboration with Bentley using all available software aid. The project has been possible as a result of multiple collaboration between different stakeholders, meaning the resulting issues in data sharing. The project has set some new challenges in the BIM to overcome. The project was intimated by the clients to establish some key factor indicators that would increase the productivity of the project over the project life cycle increase the efficiencies and reduce risks. This project has addressed various basic BIM objectives and functions. These objectives have inlcuded included Implementation of a Common Data Environment (CDE) for all project stakeholders, Continuous review and mark-up process using the latest 3D review technologies, Creation of intelligent, spatially coordinated, 3D models with meta-data, for all disciplines, Asset management from design to construction, operations and maintenance and aspects will be driven using 3D design models with structured object meta-data as the basis.

2.4 Software Study

Various software tools are being used in industry, each with their set of advantages and disadvantages. Following table summarizes the details of a few a software tools details further details of which are given below.

Company	**Software**	**Primary Usage**
Autodesk	Revit	BIM Model Generation
	Naviswork	Clash detection, 4d Scheduling, Quantity Takeoff
	Robot Structural Analysis	Structural Analysis
	Green Building Studio	Energy Analysis
Graphisoft	ArchiCAD	BIM Model Generation
	Estimator	Estimation
	EcoDesigner	Energy Analysis
Bentley	AECOsim	BIM Model Generation
	Project Wise Navigator	Review and Analysis
Tekla	Talka Structures	Structural Model Generation and Detailing
	Tekla BIMsight	Review and Analysis
Vico	Vico Control	4d Scheduling
	Takeoff Manager	Quantity Takeoff
Synchro	Synchro Professional	4 Scheduling
Innovaya	Visual 4d Simulation	4d Scheduling
	Visual Estimating	Estimation
	Visual Quantity Takeoff	Quantity Takeoff
U.S. Cost	Success Estimator	Estimation
On Center	On Center	Quantity Takeoff
Exactal	Exactal	Quantity Takeoff

Table 2.1 Comparison of Different BIM Software Tools

All above mentioned are the different tools once can make use to effectively employ BIM technology. Using these tools makes working on a project much easier as it automates the forms and levels of details, thus significantly reducing the time needed for construction and relevant documents. The relationship between different phases of the project as different aspects of project completion and time life cycle of the project are illustrated by the graph below.

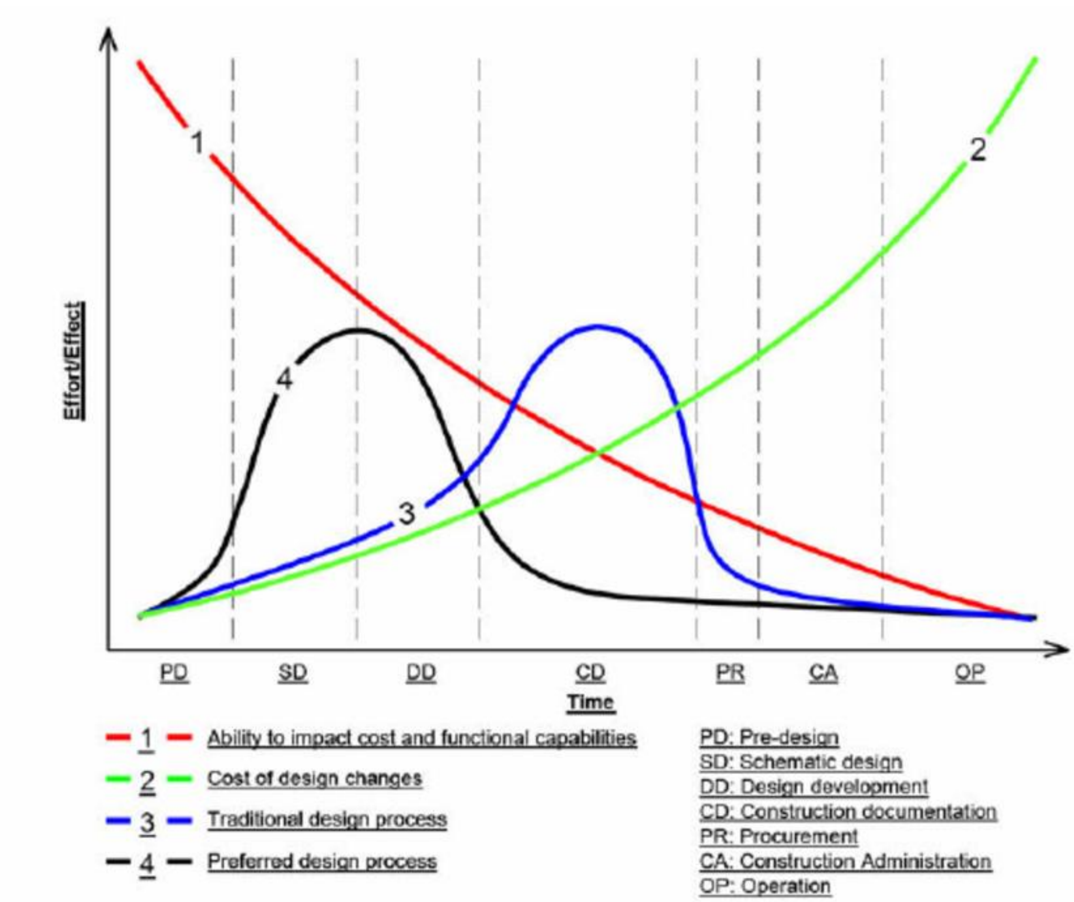


Fig. 2.3 Value added, cost of changes, and current construction compensation distribution for the design services. (Patrick Mac Leamy, CURT 2007)

2.4.1 Infraworks

InfraWorks software has transformed the civil infrastructure design processes. Proposals and early design conepts are more effectively generated and managed for large scale infrastructure models in the context of built environment.. It basically performs information modeling of three major infrastructures which are

2.4.1.1 Drainage

Layout, preliminary design and size of culverts can be designed effectively in by this feature. Drainage Design feature of InfraWorks 360 has helped engineers better design and analysis of drainage in transportation projects. USGS National Ditch State regression equations analyze the watershed hydrology.

2.4.1.2 Bridge Design

InfraWorks 360 bridge design software helps simplify, focus and accelerate the layout of girder bridge design concepts and maintain consistent data and context. Preliminary bridge design options are more effectively explored by visualizing and modeling realistic civil structures in reference to the surroundings of the proposed site.

2.4.1.3 Roadways

InfraWorks 360 has helped highway engineering professionals explore the preliminary design options and optimize project performance by engineering roadway geometry in context. Streamline roadway geometry layout with intersection design and powerful, rules-based toolsets and analysis abilities has helped to uncover potential impacts in the preliminary design phase.

So infraworks have built in modules of roadway, bridge and drainage and each module contain different types for example module of bridge further contains different types of bridges. Moreover it does not model component by component it just directly place the road, Bridge or drainage whatever you are going to model. There is no module of tunnel in it so that's why information model for tunnel can not be created in it. Now what we can do is that we can make the 3-D model of tunnel in civil 3-D then import it in infraworks even then it will not perform quantity take off of the structural elements of the tunnel, clash detection, and scheduling of the construction activities. Hence we conclude that infraworks is not a feasible solution for the information modeling of tunnel.

A very recent release of Autodesk says that a Circular checkbox has been added to the Tunnel style on the Railway tab of the Style Palette. Not all style settings are available. Style definition settings are not supported for this style at this time (Autodesk® InfraWorks®360 release, 2015). Its basically will be best suited for the design of a smart city.

2.4.2 ANSYS

ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. It has been used for different analysis purposes of tunnels but information modeling of tunnels have not been performed. It have been used to study the vibrations produced by railway tunnels in urban areas (W. Gardien andH.G. Stuit, 2003).The stress and strain behavior of RC shield tunneling lining structure have been analyzed using the nonlinear FEM code ANSYS(JUYang1 et el, 2005).

CivilFEM for ANSYS software is a customized version of ANSYS, tailored to the needs for advanced civil/structural-engineering applications. Combining state-of-the-art features of ANSYS—the world leader in simulation—with the high-end civil-engineering structural analysis capabilities of CivilFEM gives engineers access to the world's most advanced, comprehensive and reputable finite element and design software for civil-engineering applications.

CivilFEM software is well suited for its application in seismic calculations, high-rise buildings, bridges, offshore structures, dams and tunnels, power plants, soil mechanics. It has been used for the sequential simulation for the nonlinear bridge and automated tunnel (ANSYSY Conference, 2008).

A 3D model of Tunnel can be prepared but it will not doing quantity take-off, cost estimation, walk through, clash detection and scheduling of construction activities. Hence we conclude that ANSYS is not a feasible solution for the information modeling of tunnel.

2.4.3 Tekla BIMsight

Tekla BIMsight is one of the software tools used in BIM , available free and used in collaborative environments of Civil projects. The collaborative aspect of BIM implemented in this software helps in combination of models, check of clashes etc. Tekla BIMsight enables the participants to see and detect the clashes in the design phase hence reducing a great deal of cost. Main tasks include

- Providing a single platform for all collaboration and dataflow
- Automated clash detection
- Combining various models into a single project model
- Sharing valuable information instantly

It combines civil engineering, structures, architectural elements, mechanical & electrical systems, and traffic management and check for clash detection and communicate the issues. For tunnel information modeling a 3-D models of structural, architectural elements, mechanical & electrical systems of tunnel can be made on any Autodesk 3-D modeling software, and then imported in it. Then it will perform clash detection for all the construction activities.

By combining models from different disciplines and reviewing those models with different navigation features and has captured the areas of interest while designing the state route 99 with the help of Tekla BIM software tool.

2.4.4 ArchiCAD

ArchiCAD has always stayed ahead of the competition when it comes to updating the technology and introducing newest features. In 2008 the software company introduced ArchiCAD 12 with 64-bit supported ArchiCAD 13 in the following year. “Get there faster with ArchiCAD” in the white paper Graphisoft released in 2012 reiterated the benefits of BIM. It was first CAD/CAM application that harnessed the power of the hardware using the multi-processing and multithreading to enhance the performance.

The latest model of ArchiCAD, ArchiCAD 19 has become of its kind as the working and functionality is not dependent on the level of detail anymore all thanks to significant enhancements. The software stays alive till the end of the project due to the end-to-end feature of the software. The newer version, ArchiCAD 18, introdued CineRender rendering engine, enabling the built-in rendering capability of this software tool to be augmented to a much higher quality compared to earlier releases. ArchiCAD 19 focused on improving the visualization experience in real time, while modeling. This was achieved by optimizing the OpenGL engine which was used for the 3D model window, this made 3D navigation significantly smoother, faster, and free from flickering.

On the flip side this version of ArchiCAD significantly slower compared to earlier versions on the aging hardware, the improved versions require new devices to work in effective unison. In order make good use of the application one must keep up-to-date with the latest up gradations.

Analysis results on software tools for CIM.

		Categories of civil infrastructure								
		I	II	III	IV	V	VI	VII	VIII	IX
Vendor	Software tool	Bridges	Roads	Railways	Tunnels	Airports, ports and harbors	Energy infrastructure	Utility infrastructure	Recreational facility infrastructure	Water management infrastructure
Autodesk	Revit	2	3	3		3	1		4	4
	AutoCAD		2	2		1	1		2	6
	AutoCAD Map 3D		3	1					1	2
	AutoCAD Civil 3D	3	10	2			1	1	2	8
	Autodesk InfraWorks (formerly Infrastructure Modeler)		3				1			2
	Structural Bridge Design									
	AutoCAD Utility Design									
	Autodesk 3ds Max Design	2	6	2	1		1			10
	Navisworks	3	6	2		2			2	6
	Sub-total	10	33	12	1	6	5	1	11	38
Bentley	RM Bridge, LEAP Bridge, LARS Bridge	7	2							
	Power Rail Track, Power Rail Overhead Line, MXRAIL	1	1	3		1				
	Power InRoads, Power GEOPAK, MXROAD, and PowerCivil	5	16	8	1	3	4	2		8
	PlantWise, OpenPlant, AutoPLANT, and PlantSpace						23	1		6
	HAMMER, WaterCAD, WaterGEMS, SewerCAD, SewerGEMS, CivilStorm, StormCAD		1							3
	MicroStation	5	13	8	1	4	22	3		12
	AECOsim Building Designer (Bentley Architecture, Structural Modeler)			4		5	10			7
	Prosteel					1	7			2
	Bentley Substation						4			
	Bentley Navigator		1	3		2	13			8
	ProjectWise	1	4	5	1	4	8	2		10
	AutoPIPE and STAAD.Pro	6		6			9	2		5
	Sub-total	25	38	37	3	20	100	10		61
CSI	SAP2000									
	CSiBridge									
Tekla	Tekla Structures									
	Tekla Bimsight									
Graphisoft	ArchiCAD									
Vico	Vico Office Suite									
FORUM8	UC-win/Road									

Fig. 2.4 Analysis Results on Software Tools for CIM (Cheng et al, 2016)

CHAPTER 3

METHODOLOGY

The following flow chart gives a brief overview of the methodology adopted for conduction of the project. Each phase of the flow chart has been described in the following lines.

3.1 LITERATURE REVIEW

To have a deep understanding of the application of BIM, a thorough study of the literature related to BIM and tunnels, which was deemed to be useful in carrying out the project, was done. This literature review enforced the thought that in order to have command on the subject regarding the project, each component of a BIM process that is part of the project needs to be studied thoroughly.

3.2 SOFTWARE LEARNING

Since the modeling work required use of a BIM tool which are relatively new and not taught in undergraduate courses therefor the learning of BIM tools was done through video tutorials and online blogs. A sample theoretical project was made in order to have grip on the software before the start of main work. Following softwares were learned and used in the project:

- Autodesk Revit 2015
- Autodesk Navisworks 2014 and 2015

- Sketch Up 3D
- Primavera

3.3 FAMILY DEVELOPMENT:

Since no families for tunnel elements were already present hence the the process of development had to start from the very beginning. And we had to start with developing each family for each individual element of tunnel. The families developed are loadable families.

Family Development follows the following process (Appendix A)

So we developed loadable families for the following tunnel elements

1. Invert
2. Side Wall
3. Crown
4. Steel Arched Girders
5. Spray Concrete

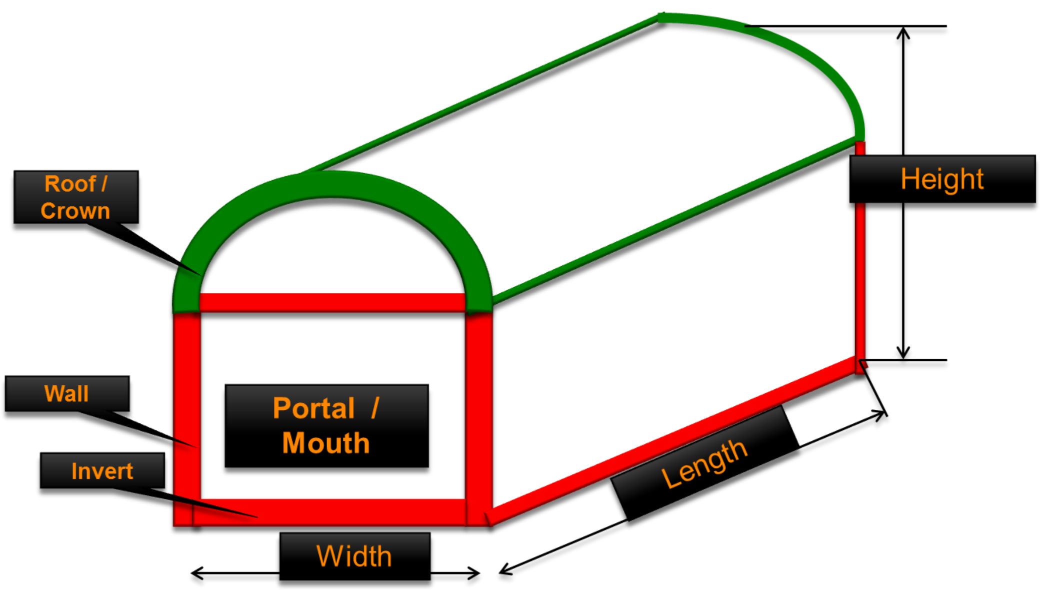


Fig. 3.1 Elements of Tunnel

3.3.1 Families Developed

Following loadable families are developed.

1. Invert Semi Circular

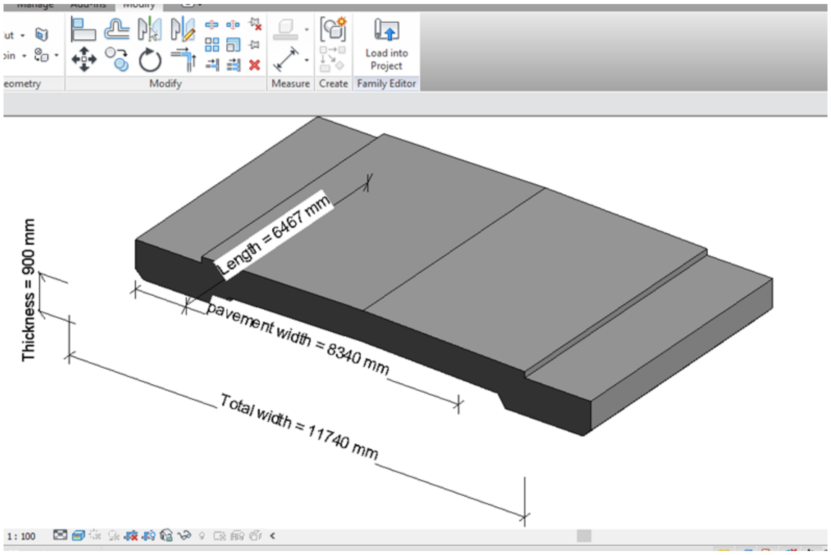


Fig 3.2 Invert Semi Circular

2. Invert Horse Shoe

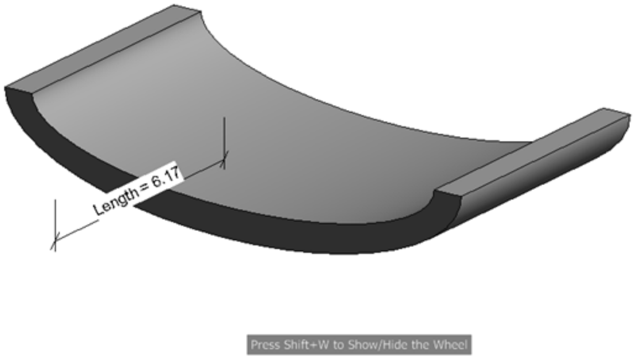


Fig.3.3 Invert Horse Shoe

3. Tunnel Side Wall

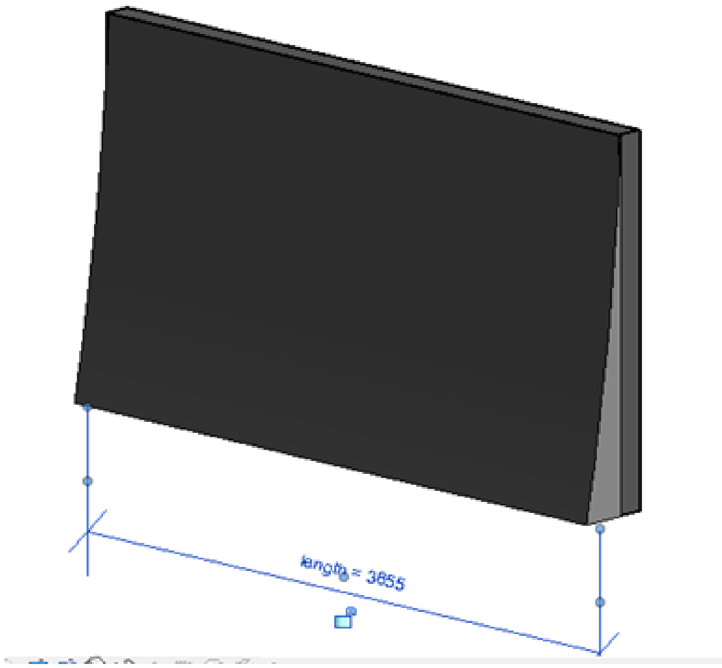


Fig. 3.4 Tunnel Side Wall

4. Tunnel Crown

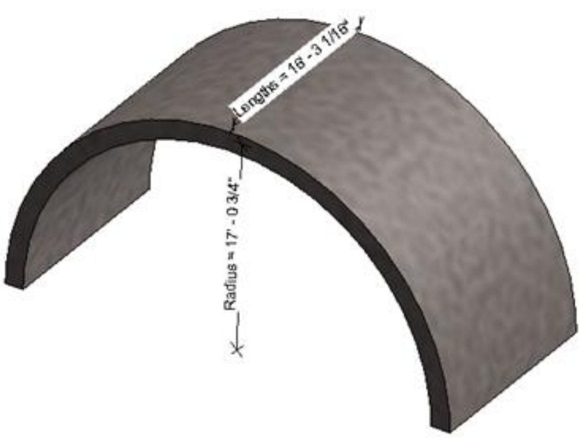


Fig. 3.5 Tunnel Crown

5. Steel Arched Girder

Fig. 3.6 Steel Arched Girder

Steps how these families are created see Appendix B

3.3.2 Tunnel Types

With help of developed families all types of tunnel can be developed. We just form test developed the following types of tunnel by applying these families.

1. .Semi Circular Tunnel (D shape)

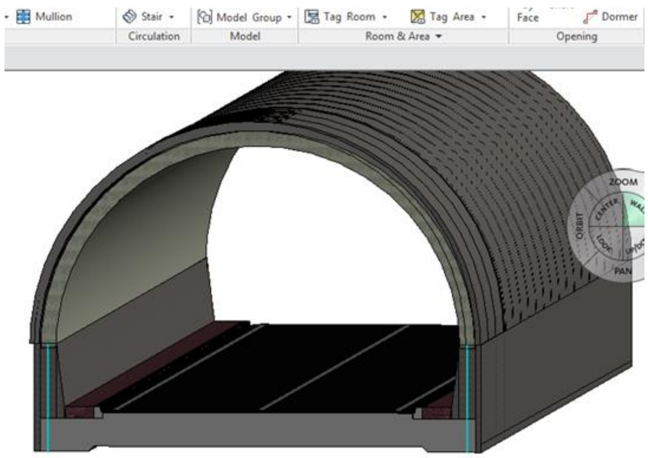


Fig. 3.7 Semi Circular Tunnel (D shape)

2. Horse Shoe Tunnel

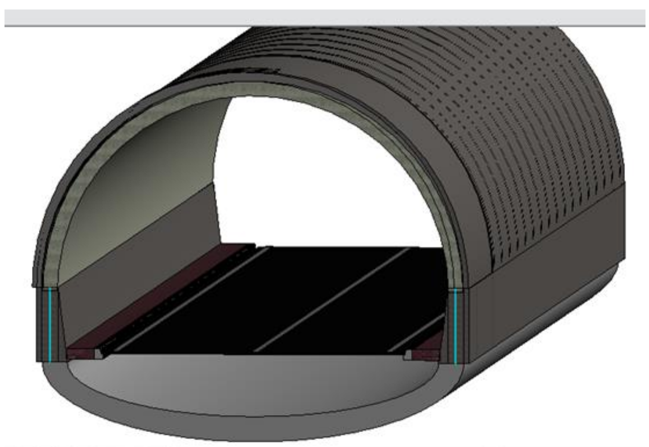


Fig. 3.8 Horse Shoe Tunnel

3. Rectangular Tunnel (Box Tunnel)

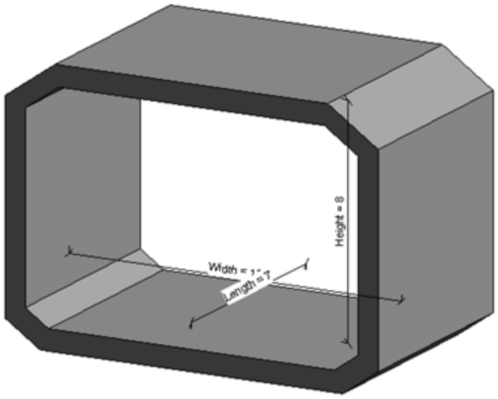


Fig. 3.9 Rectangular Tunnel (Box Tunnel)

4. Circular Tunnel

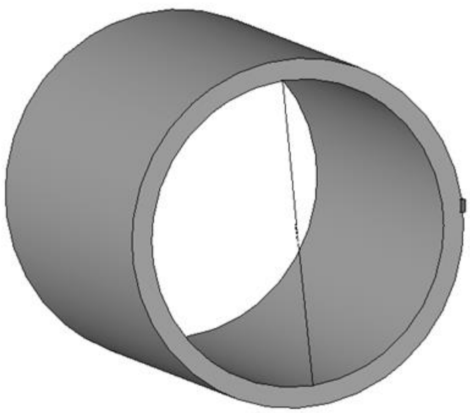


Fig. 3.10 Circular Tunnel

3.4 TIM MODEL (CASE STUDY of Nahakki Tunnel)

An architectural, structural and MEP BIM as planned model was generated through the as planned drawings on Autodesk Revit 2015. Revit built in tools for material takeoff as well as were used for Quantity estimation. Autodesk Naviswork manage was also used for clash detection. We used primavera for scheduling.

3.5 ANALYSIS

Quantities obtained from BIM model were compared with those obtained by traditional approach. Clash detection results and scheduling results were analyzed and compared to know the advantage they offer as compared to the approach used in building.

3.6 RESULTS

Results were deduced in the form of a documentation which are to be used as a comparative study of traditional and BIM approach, for planning and executing a building project. It could also be used for other educational purposes.

3.7 PREPARATION OF REPORT

After results were compiled, a comprehensive report of the entire project describing in detail the different phases of project and the methodology adopted to achieve the required results was compiled. The report will also envisage the hurdles and setbacks faced during project execution.

3.8 PREPARATION OF PRESENTATION

Finally, the findings, conclusions, the knowledge gained and the project execution details were compiled in the form of a power point presentation.

Chapter 4

CONCLUSION

4.1 Introduction:

Main conclusions made are

- Previously, BIM was only limited to Buildings, Tunnel Information Modeling allows us to use information modeling for Tunnels.
- Since families with adjustable parameters for numerous tunnel elements are created, these families can be used for information modeling of any tunneling project.
- This method of modeling can also be extended for all kinds of infrastructure projects. This is actually application of BIM on a large scale.
- Application of this method to infrastructure projects provides the same efficiency and same quality of project management as BIM provides for isolated buildings.
- Using TIM, existing tools of information modeling are used to create tunneling information model.

4.2 Recommendations

After conducting this research, it is recommended that TIM must be adopted by the Tunneling industry because of its numerous advantage over traditional methods of Tunneling project management & execution.

To get familiarize with the process as a first step towards implementation, TIM tools can be used in the current design process to get specific benefits like removing errors from drawings, removing clashes between different disciplines, getting extra sections for detailing etc. High specifications computer infrastructure must be built before starting any BIM project.

4.3 Recommendations for Utillity

Further studies recommended are in the following are

- Comparison of efficiency between various softwares of Tunnel information Modeling
- Use of TIM model to do seven dimensions of BIM upto energy analysis.

Results and Analysis

Quantity Takeoff and Cost Estimation

Quantity take off								
Name of Item	**Area/Length**	**Volume**	**Type**	**Running length**	**Diameter/thickness**	**Quantity**	**Cost per unit(Rupees)**	**Total cost(Rupees)**
Concrete(1:4:8)		5153.943m3					4950	25512300
Concrete lean		7011m3	25Mpa				20300	142323300
Spray Concrete	12233.62m2	2431m3			150mm		8856	1166172159
Rebars				20000m	#9		72 per kg	7302240
Exhaust fans			240V wall mounted			1320	1850	2442000
Lights						1200	1213	1454760
Pipes				660m	125mm	6	23.65	14200
Steel Girder	19478mm	0.096m3	305 x 165 x 40			662	7891.16	101752057.6
Road Markings(Paint)	198m2	1.98m3					5000 per litre	9900000
Footpath tough tiles	1181m2	414m3		0.89m		741	370	436970
Asphalt Concrete	5214m2	782m3					350 per sqft	19643060.6
Concrete Curbs	660					2	1800	2376000
Cable trays				660m		4	50	132000
Ducts			Rectangular PVC	660m		2	150	198000
Rebars				10000m	#6		66 per kg	1478400
								1481137447

Fig. RAS 1 Quantity Takeoff and Cost Estimation

Scheduling using Primavera

Activity List

FYP Final with Raod Construction LSM | Classic Schedule Layout | 20-May-18 04:07

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
FYP Final with Raod Construction LSM		623	19-May-16	08-Oct-18	0
A2040	Geotechnical Stabilization	341	10-Jun-16	29-Sep-17	0
A2170	Project Finish	0		08-Oct-18	0
Finishing		45	07-Aug-18	08-Oct-18	0
A2150	Water Membrane Coating (C)	16	07-Aug-18	28-Aug-18	0
A1190	Wall Tiles (MP)	1	29-Aug-18	29-Aug-18	0
A1340	Paint (MP)	1	29-Aug-18	29-Aug-18	4
A2120	Painters (LP)	1	29-Aug-18	29-Aug-18	4
A2130	Paint (C)	24	30-Aug-18	02-Oct-18	4
A2140	Wall Tiles (C)	28	30-Aug-18	08-Oct-18	0
Pavement Construction		133	09-Jan-18	12-Jul-18	17
Sidewalk		44	14-May-'	12-Jul-18	17
A1310	Footpath Tough Tiles (MP)	1	14-May-'	14-May-18	17
A1730	Curbs (MP)	1	14-May-'	14-May-18	17
A1740	Footpath & Curbs (C)	43	15-May-'	12-Jul-18	17
Pavement		92	09-Jan-18	16-May-18	58
A2110	Subgrade (C)	28	09-Jan-18	15-Feb-18	17
A1300	Asphalt Conrete Material (MP)	1	16-Feb-18	16-Feb-18	17
A1320	Precasted Drains (MP)	1	16-Feb-18	16-Feb-18	17
A1750	Base, Subbase & Coats Material (MP)	1	16-Feb-18	16-Feb-18	17
A2190	Pavement Construction (C)	60	19-Feb-18	11-May-18	17
A1350	Roadway Signs (MP&C)	3	14-May-'	16-May-18	58
Electrical, Mechanical and Plumbing		22	06-Jul-18	06-Aug-18	0
Electrical		17	06-Jul-18	30-Jul-18	5
A2050	Electrical Fixtures (MP)	1	06-Jul-18	06-Jul-18	5
A2060	Electrical Wiring & Installations e.g. Lights, Cameras, Alarms etc. (C)	16	09-Jul-18	30-Jul-18	5
Mechanical		22	06-Jul-18	06-Aug-18	0
A2070	Mechanical Fixtures (MP)	1	06-Jul-18	06-Jul-18	0
A2080	Mechanical Fixtures Installation e.g. Fire Extinguishers, Ventilation System	21	09-Jul-18	06-Aug-18	0
Plumbing		15	06-Jul-18	26-Jul-18	7
A2090	Plumbing Fixtures (MP)	1	06-Jul-18	06-Jul-18	7
A2100	Plumbing Works e.g. Water Connections, Lavatories, etc. (C)	14	09-Jul-18	26-Jul-18	7
Concrete Lining		112	31-Jan-18	05-Jul-18	0
A1290	Lining Concrete (MP)	1	31-Jan-18	31-Jan-18	0
A1420	Concrete Pumps (EP)	1	31-Jan-18	31-Jan-18	0
A1090	Concrete Pouring (C)	84	01-Feb-18	29-May-18	0
A1570	Curing (C)	3	30-May-'	01-Jun-18	0
A1100	Strip Forms (C)	24	04-Jun-18	05-Jul-18	0
Reinforcement		87	02-Oct-17	30-Jan-18	0
A1280	Formwork (MP)	3	02-Oct-17	04-Oct-17	0
A1490	Formwork party (LP)	1	02-Oct-17	02-Oct-17	2
A1080	Formwork (C)	32	05-Oct-17	17-Nov-17	0
A1270	Reinforcement Bars & Ties (MP)	4	20-Nov-17	23-Nov-17	0
A1460	Steel Fixers (LP)	1	20-Nov-17	20-Nov-17	3
A1070	Tie up Reinforcement Bars (C)	48	24-Nov-17	30-Jan-18	0

Page 1 of 2 | TASK filter: All Activities

© Oracle Corporation

Fig. RAS 2 Scheduling using PrimaveraActivity List

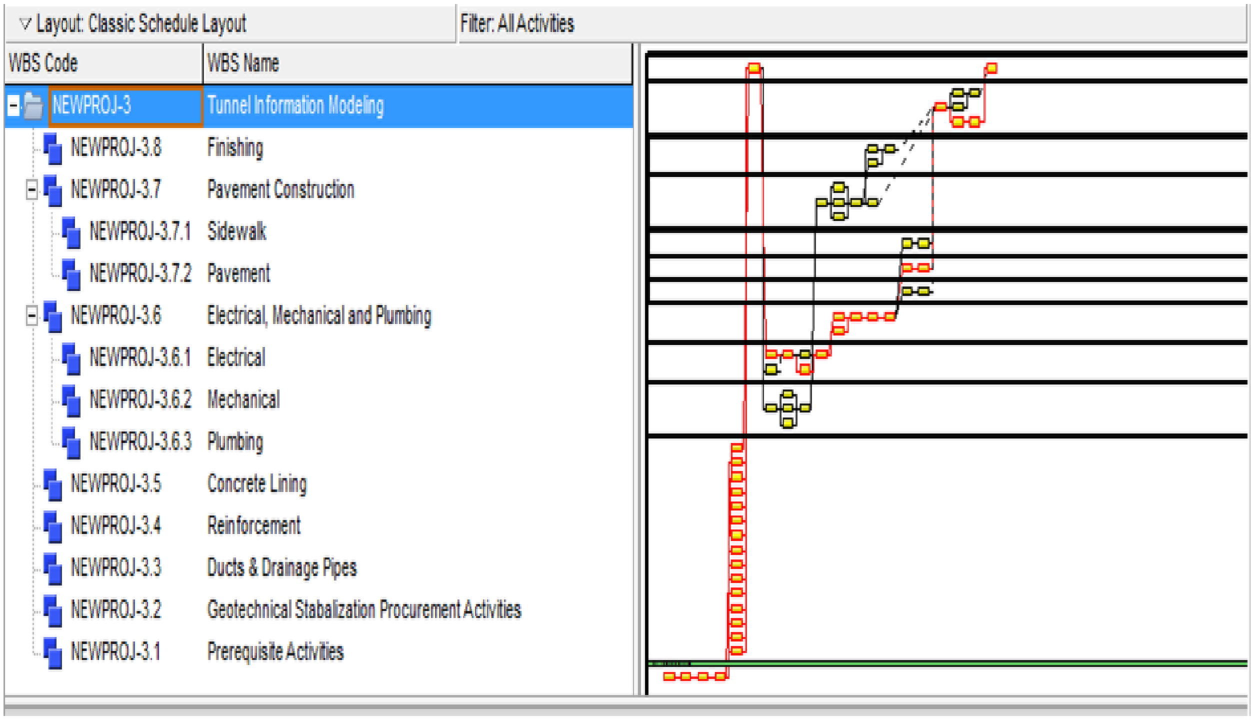
FYP Final with Raod Construction LSM	Classic Schedule Layout	20-May-16 04:07

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
Ducts & Drainage Pipes		71	02-Oct-17	08-Jan-18	17
A1560	Excavation for Underground Drainage & Utilities (C)	42	02-Oct-17	28-Nov-17	17
A1250	Drainage Pipes (MP)	1	29-Nov-17	29-Nov-17	17
A1260	Electrical & Mechanical Ducts & Trays (MP)	1	29-Nov-17	29-Nov-17	17
A1470	Electricians and Plumbers (LP)	1	29-Nov-17	29-Nov-17	17
A1060	Placement of Underground Ducts & Drainage Pipes (C)	28	30-Nov-17	08-Jan-18	17
Geotechnical Stabalization Procurement Activities		16	19-May-'	09-Jun-16	607
A2180	New Activity	5	19-May-'	25-May-16	618
A1220	Blasting Material (MP)	1	09-Jun-16	09-Jun-16	0
A1230	Spray Concrete 2500psi (MP)	1	09-Jun-16	09-Jun-16	0
A1240	Steel Arch Girders (MP)	1	09-Jun-16	09-Jun-16	0
A1360	Drilling Machine (EP)	1	09-Jun-16	09-Jun-16	0
A1370	Haulage Dumb Trucks and Hand Trolleys (EP)	1	09-Jun-16	09-Jun-16	0
A1380	Spray Concrete Equipment (EP)	1	09-Jun-16	09-Jun-16	0
A1390	Rock Bolting Machine (EP)	1	09-Jun-16	09-Jun-16	0
A1430	Drilling Labours (LP)	1	09-Jun-16	09-Jun-16	0
A1440	Haul and Dump Labours (PL)	1	09-Jun-16	09-Jun-16	0
A1450	Spray Concrete & Rock Bolting Technician (LP)	1	09-Jun-16	09-Jun-16	0
A1710	Rock Bolts (MP)	1	09-Jun-16	09-Jun-16	0
A1500	Profile Clearing Equipment (EP)	1	09-Jun-16	09-Jun-16	0
A1540	Profile Clearing Labours (LP)	1	09-Jun-16	09-Jun-16	0
A1760	Steel Arch Girders Installation Labours (LP)	1	09-Jun-16	09-Jun-16	0
A2030	Steel Arch Girders Machine (EP)	1	09-Jun-16	09-Jun-16	0
Prerequisite Activities		15	19-May-'	08-Jun-16	0
A1480	Site Engineer, Supervisor, and Project Manager (Preq. LP)	1	19-May-'	19-May-16	0
A1530	Site selection fo tunnel construction (Preq.)	10	20-May-'	02-Jun-16	0
A1520	Site Clearance	1	03-Jun-16	03-Jun-16	0
A1550	Site Mobalization	3	06-Jun-16	08-Jun-16	0

	Page 2 of 2	TASK filter: All Activities © Oracle Corporation

Fig. RAS 3 Scheduling using PrimaveraActivity List

Network Diagram



<u>Fig. RAS 4 Network Diagram</u>

Gant Chart

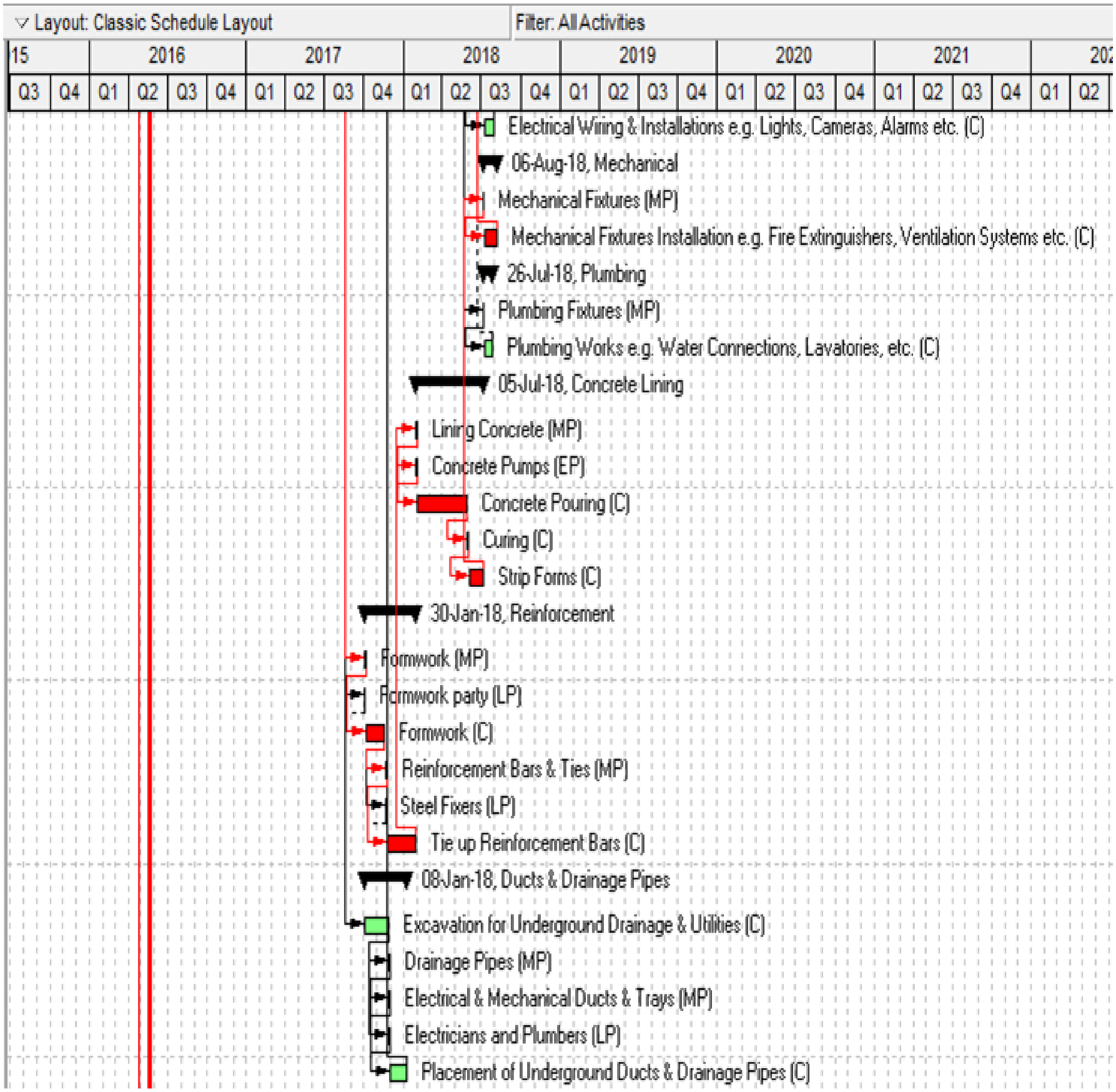


Fig. RAS 4 Gant Chart

Clash detection Reports

Autodesk® Navisworks® **Clash Report**

Floor vs Pipes	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
	0.001m	2	2	0	0	0	0	Hard	OK

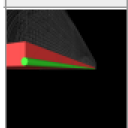
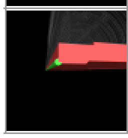
							Item 1				Item 2			
Image	**Clash Name**	**Status**	**Distance**	**Description**	**Date Found**	**Clash Point**	**Item ID**	**Layer**	**Item Name**	**Item Type**	**Item ID**	**Layer**	**Item Name**	**Item Type**
	Clash1	New	-0.092	Hard	2016/6/5 16:15.38	x:-4.537, y:37.239, z:-0.748	*Element ID*: 267999	<No level>	Floor1	Solid	*Element ID*: 281254	Level 5	Steel, Carbon	Solid
	Clash2	New	-0.039	Hard	2016/6/5 16:15.38	x:-16.132, y:14.617, z:-1.050	*Element ID*: 267999	<No level>	Floor1	Solid	*Element ID*: 281309	Level 5	Steel, Carbon	Solid

Fig. RAS 5 Clash detection Reports

References:

- Information Modelling based Tunnel Design and Construction Process

(R. Heikkilä, A. Kaaranka and T. Makkonen,Construction technology Research Center,

University of Oulu, Finland)

- IMPLEMENTING MODEL-BASED DESIGN IN INFRASTRUCTURE PROJECTS

INNA ROMANDI, IVO VALLAS2

1,3Ramboll Estonia AS, Tallinn, Estonia

- 3D geological modelling of a complex buried-valley network delineated from borehole and

AEM data

A.-S. Høyera, F. Jørgensena, P.B.E. Sandersena, A. Viezzolib, I. Møllera

- 3D Modeling of Tunnel Engineering based on Geological Body

Xiao Fang Zu, Bao Yi Zhang , Jin Luo , Wei Hua Hua , Wei Sheng Hou.

- Borrmann, A., Kolbe, T. H., Donaubauer, A., Steuer, H., Jubierre, J. R., & Flurl, M. (2015). Multi-scale geometric-semantic modeling of shield tunnels for GIS and BIM applications. Computer-Aided Civil and Infrastructure Engineering, 30(4), 263-281.

- Cho, D., Cho, N. S., Cho, H. H., & Kang, K. I. (2012, December). Parametric modelling based approach for efficient quantity takeoff of NATM-Tunnels. In 29th International Symposium of Automation and Robotics in Construction, ISARC 2012.

- Stascheit, J., Koch, C., Hegemann, F., König, M., & Meschke, G. (2013). Process-oriented numerical simulation of mechanized tunneling using an IFC-based tunnel product model. In Proceedings of the 13th International Conference on Construction Applications of Virtual Reality. London, UK.

- Ninic, J., Koch, C., Freitag, S., Meschke, G., & König, M. SIMULATION AND MONITORING-BASED STEERING FOR MECHANIZED TUNNELING USING PROJECT DATA OF WEHRHAHN-LINIE.9. The application of bim technology in the construction of hagzhou zizhi tunnel

- Ghaznavi, M. (2013). Developing an Information Modeling Framework for Tunnel Construction Projects (Doctoral dissertation, University of Alberta).

- Zhang, Y., Moghani, E., AbouRizk, S. M., & Fernando, S. (2010, December). 3D CAD modeling and visualization of the tunnel construction process in a distributed simulation environment. In Proceedings of the Winter Simulation Conference (pp. 3189-3200). Winter Simulation Conference.

- Lee, S. H., & Kim, B. G. (2011). IFC extension for road structures and digital modeling. Procedia Engineering, 14, 1037-1042.

- Chen, J., Granier, X., Lin, N., & Peng, Q. (2010, November). On-line visualization of underground structures using context features. In Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology (pp. 167-170). ACM.

- Blanco, F. G. B., & Chen, H. (2014). The Implementation of Building Information Modelling in the United Kingdom by the Transport Industry. Procedia-Social and Behavioral Sciences, 138, 510-520.

- ALSAHLY, A., STASCHEIT, J., & MESCHKE, G. (2013). Three Dimensional Re-Meshing for Real Time Modeling of Advancing Process in Mechanized Tunneling. Adaptive Modeling and Simulation (ADMOS2013), 75-88.

- Carnevale, M., Young, G., Paiva, J., Lawlor, O., Maglio, K., Hager, J., & Carnevale, M. C. (2000). Large Scale Data Acquisition & Management: MetroWest Water Supply Tunnel Project. In North American Tunneling 2000.

- Deulofeu, C., Schwarz, H., Maidl, U., & Comulada, M. (2007). Data management for highly mechanized shield tunneling in the construction of the L9 metro BCN. Underground space—the 4th dimension of metropolises.

- Wu, Xiaodong, et al. "As-built modeling and visual simulation of tunnels using real-time TBM positioning data." Simulation Conference (WSC), 2013 Winter. IEEE, 2013.

- Wu, X., Lu, M., Mao, S., & Shen, X. (2013, December). As-built modeling and visual simulation of tunnels using real-time TBM positioning data. In Simulation Conference (WSC), 2013 Winter (pp. 3066-3073). IEEE.

- JU, Y., XU, G. Q., MAO, L. T., DUAN, Q. Q., & ZHAO, T. S. (2005). 3D NUMERICAL SIMULATION OF STRESS AND STRAIN PROPERTIES OF CONCRETE SHIELD TUNNEL LINING AND MODELING EXPERIMENTS [J]. Engineering Mechanics, 3, 027.

- Cheng, Jack CP, Qiqi Lu, and Yichuan Deng. "Analytical review and evaluation of civil information modeling." Automation in Construction 67 (2016): 31-47.

Appendix A

Process of family Development

Family development follows the below mentioned steps

1- Planning a loadable family

Identify the basic requirements such as sizes, displays, detail levels, probable host, and origin point. Defining present sizes to in order to generate most common elements adds convenience to the modeling process. It is necessary to identify if the component needs a specific view (plan, elevation, or section). Identifying the origin of the family helps to realize the insertion point when the component is loaded into the project view. For instance, for a shaft collar, the insertion point can be defined as the center of the shaft element and a minimum distance from the

ground level.

2- Choosing a family template

Create a new family file with a suitable family template. Each template contains the major information required to start the family creation. Revit has various templates, which covers the minimum requirements of specific components with a default insertion point. It is necessary to mention the host-based families (wallbased, ceiling-based, floor-based, and roof-based) require the presence of the host type element in order to load the created family into the project view.

3- Creating family sub-categories

Creating the sub-categories for a family component helps to control its visibility and geometry. This is especially useful for defining kinds of material, color, lineweight to a group of elements in a family component.

4- Defining the family origin

Define the insertion point for the family. This point is where the family is going to be loaded into the project view. The intersection of two reference planes can be a insertion point. Sometimes it is possible to apply construction codes with the family origin. For instance, it is possible to define a certain distance for a reinforcing bar to comply with the minimum concrete cover in a tunnel lining segment.

5- Laying out and dimensioning the reference planes

The reference planes help in sketching the family geometry. The reference planes are usually created aligned with the main lines of the family component. Placing dimensions between the reference planes/lines facilitates the foundation for defining the parametric relationships between different dimensions in the family. The reference plane dimension helps to define the parameters and then assigning component dimension to these parameters to create ruled relationship between dimensions.

6- Labeling dimensions to create parameters

It is recommended to label the dimensions. Therefore, it will be possible to modify the family parameters later during the modeling process.

7- Flexing the family framework

Flexing in Revit, means testing the created parameters to make sure that they are correctly assigned to the right reference planes and they change accordingly in case of any modification.

8- Creating the family types

Family types refer to the different sizes for a family component, which can create various customizations for the family's parameters.

9- Creating the family geometry

Create the shape geometry of the family. The shape geometry represents the element's best conceptual shape in the actual project. It is possible to specify the element's visibility and material. The visibility of a family defines which parts of the family shape will be visible in different views.

10- Testing the family

Repeat step 7 in order to test the created parameters, visibility, geometry, and reference planes after defining the family's actual shape and representation.

11- Creating a type catalogue

In order to create a type catalogue, a test file (TXT) is needed that contains the parameters and parameter values, which have been used to create different types in a specific Revit family.

Revit offers a variety of family templates to begin designing a loadable family which help to use a common representation and save time instead of starting from scratch. The most suitable template for the tunnel components is the "Metric Generic Model.rft". It is a general description which allows modeling a generic model without any default reference lines or family origin. It is not possible to change the category or the template that the family originally was assigned with. Moreover, It is not possible to copy and paste model geometry from one family to another.

Appendix B

Visual Guide to Family Development

1. First of all open revit and make new family.

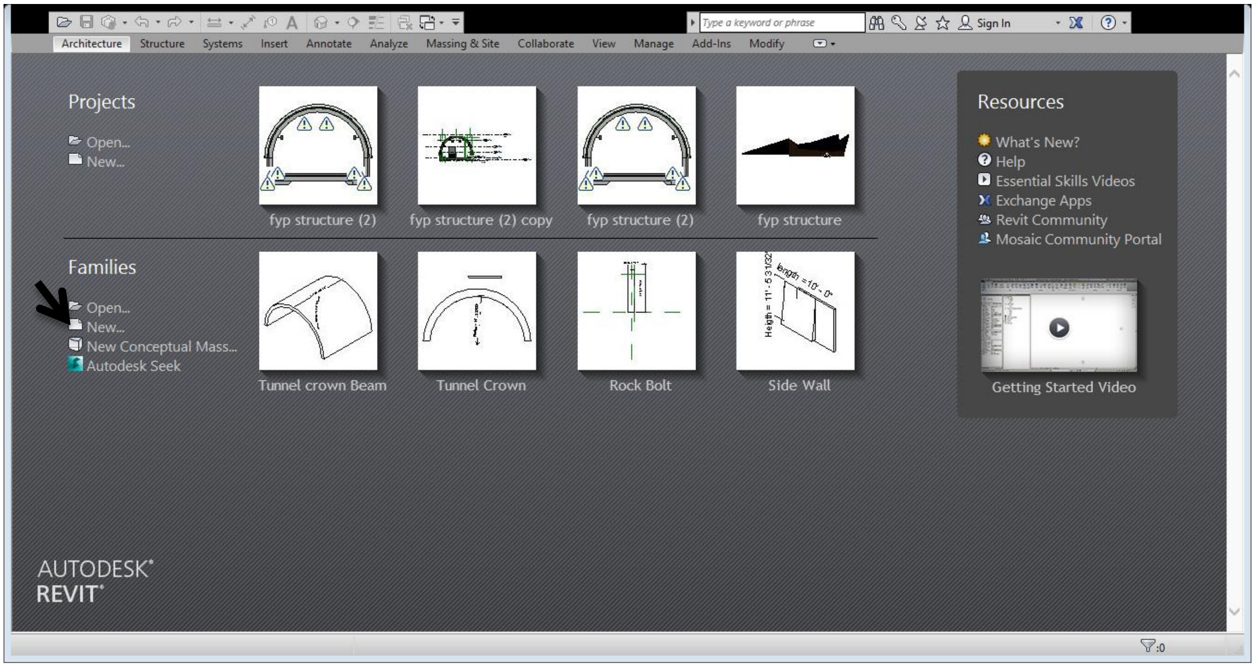


Fig. App. B 1 Visual Guide to Family Development

2. Select a suitable family template for your family. In this case I will use "Generic model floor based". Then Click open.

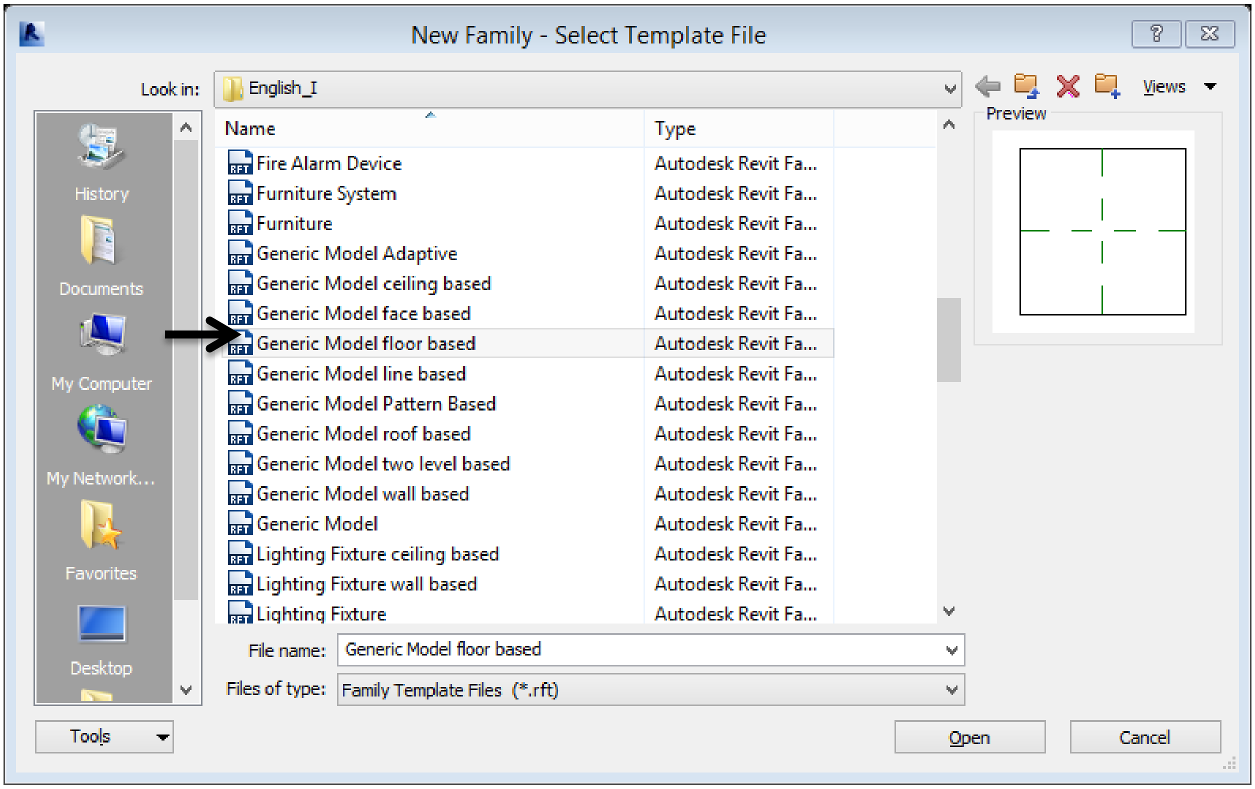


Fig. App. B 2 Visual Guide to Family Development

3. A window like this will be opened.

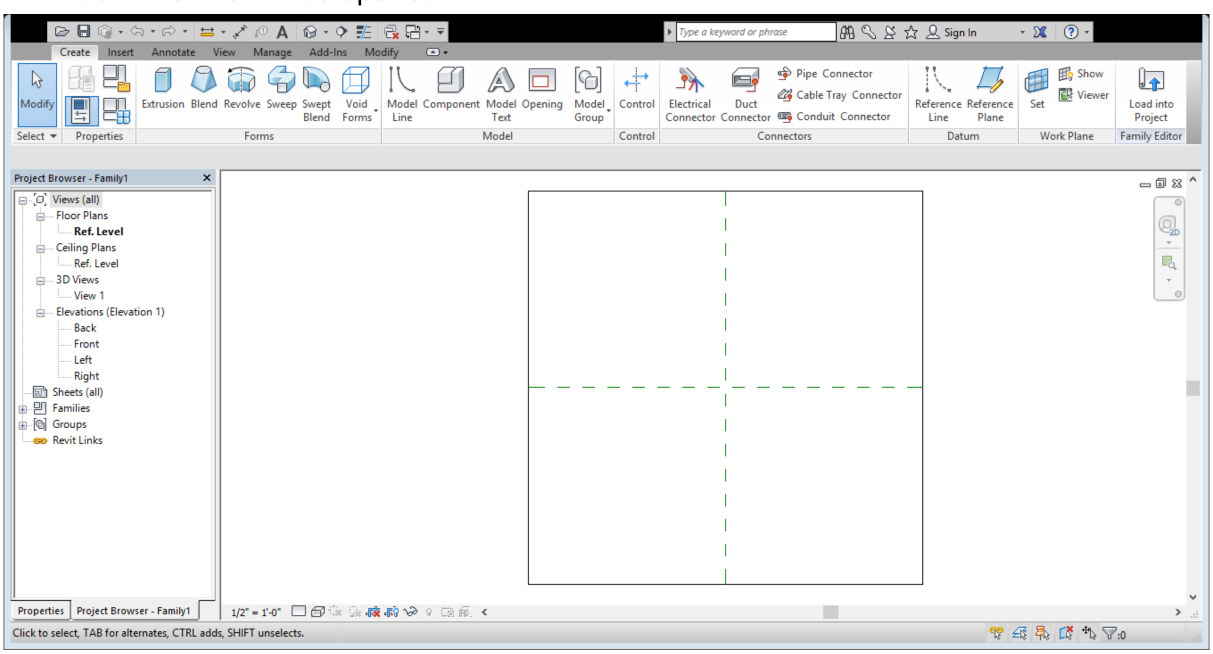


Fig. App. B 3 Visual Guide to Family Development

4. In Project browser go to elevations and click on front elevation.

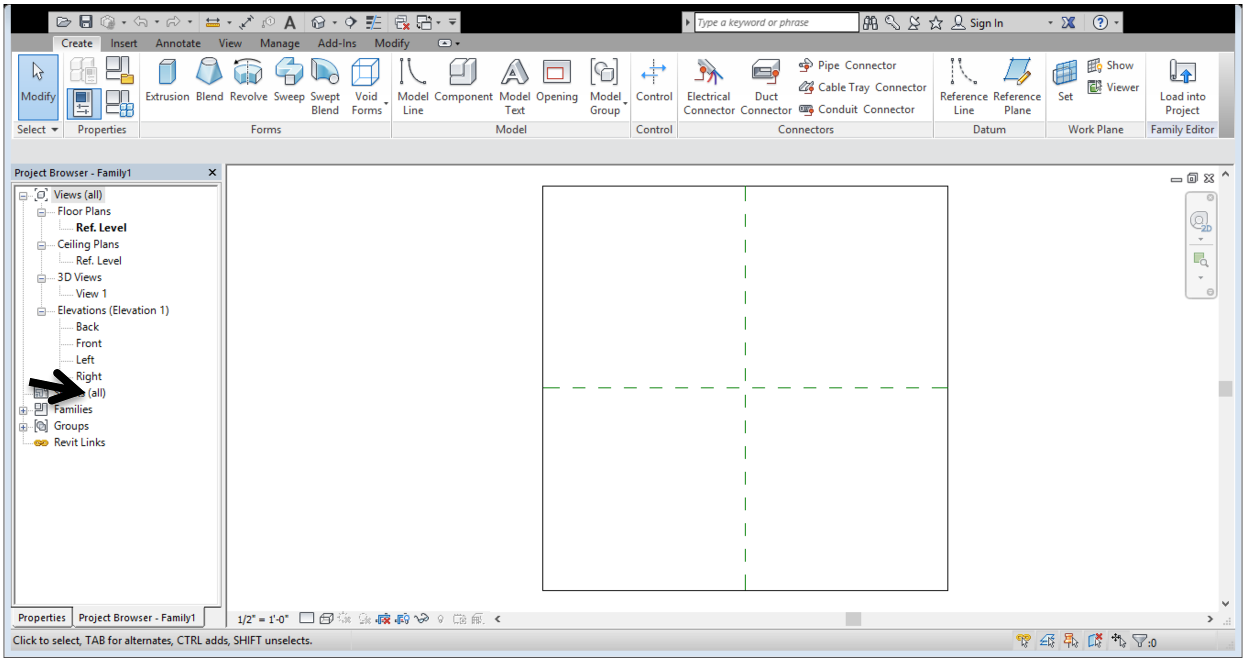


Fig. App. B 4 Visual Guide to Family Development

5. Something like this will be opened.

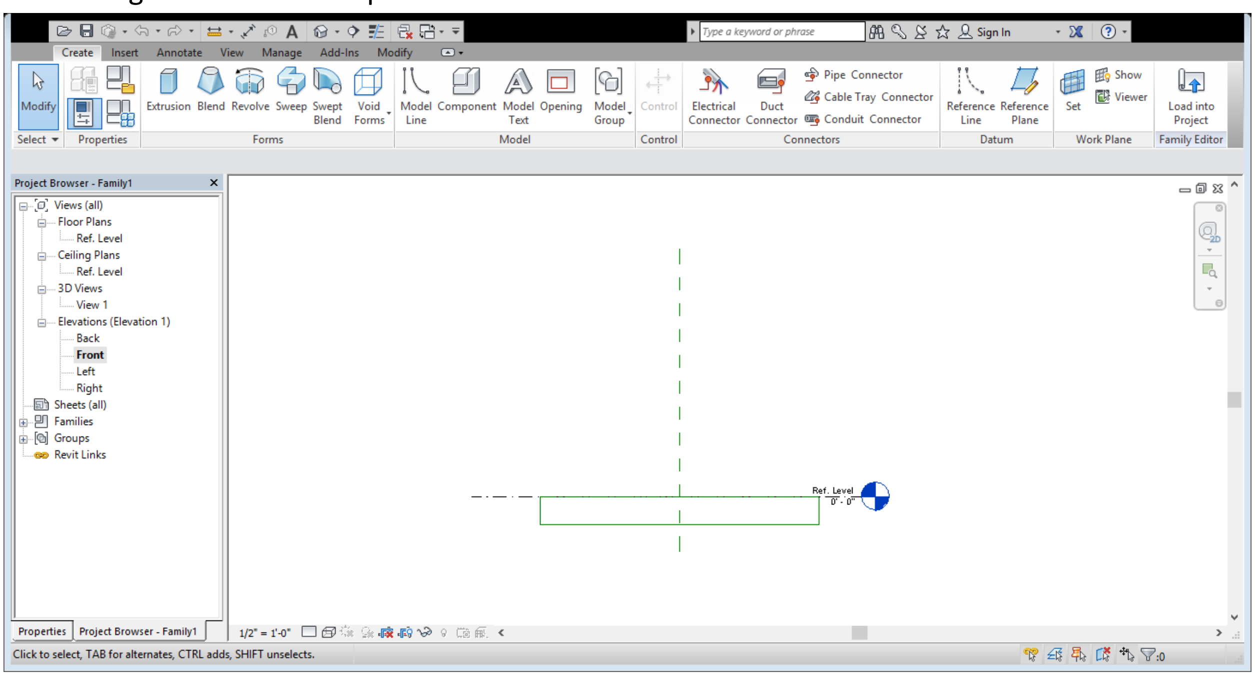


Fig. App. B 5 Visual Guide to Family Development

6. Before you draw anything fist set your units, for that click on manage and then project units.

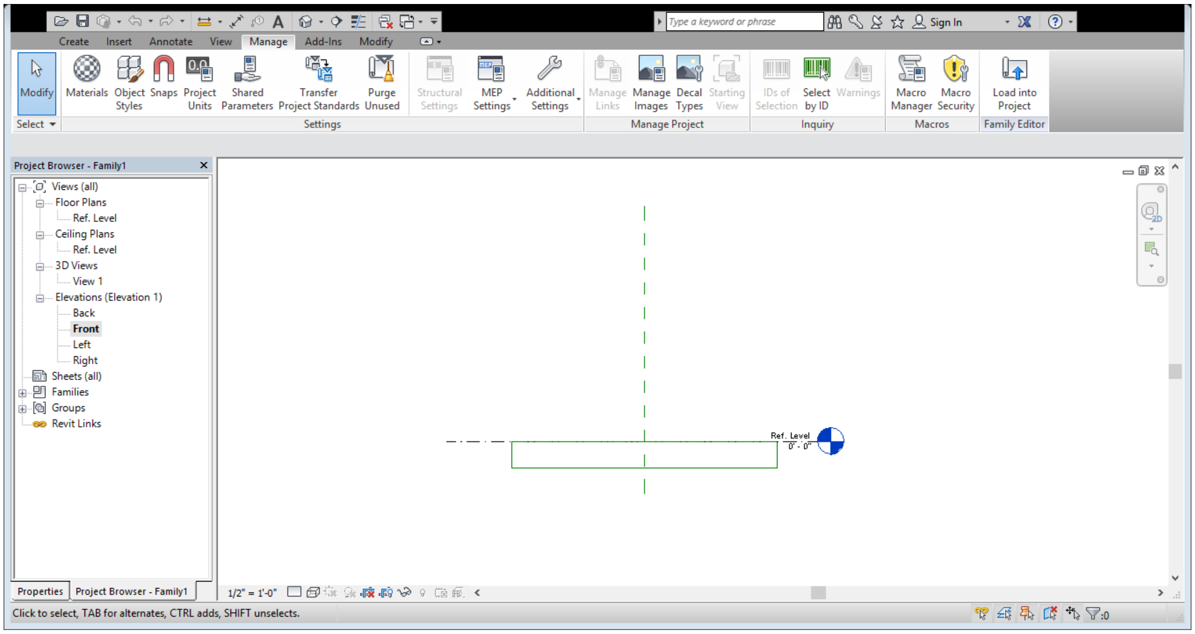


Fig. App. B 6 Visual Guide to Family Development

7. A window like this will be opened. For this family I want it to be in metric system so I will change accordingly.

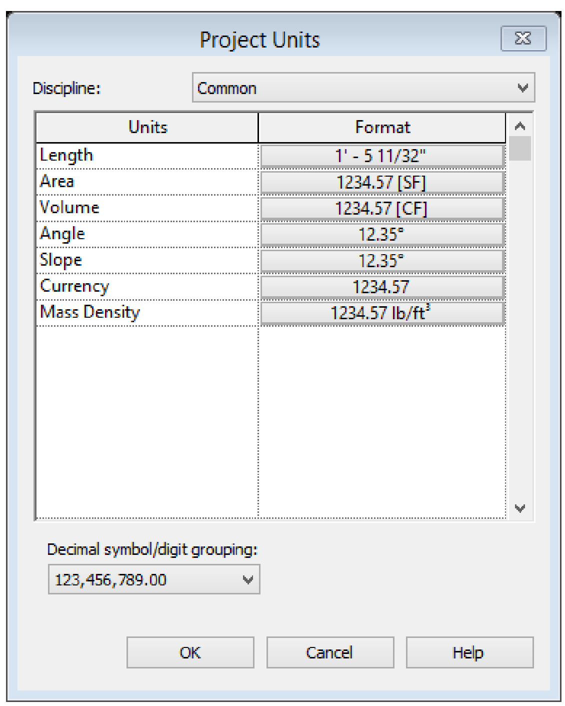
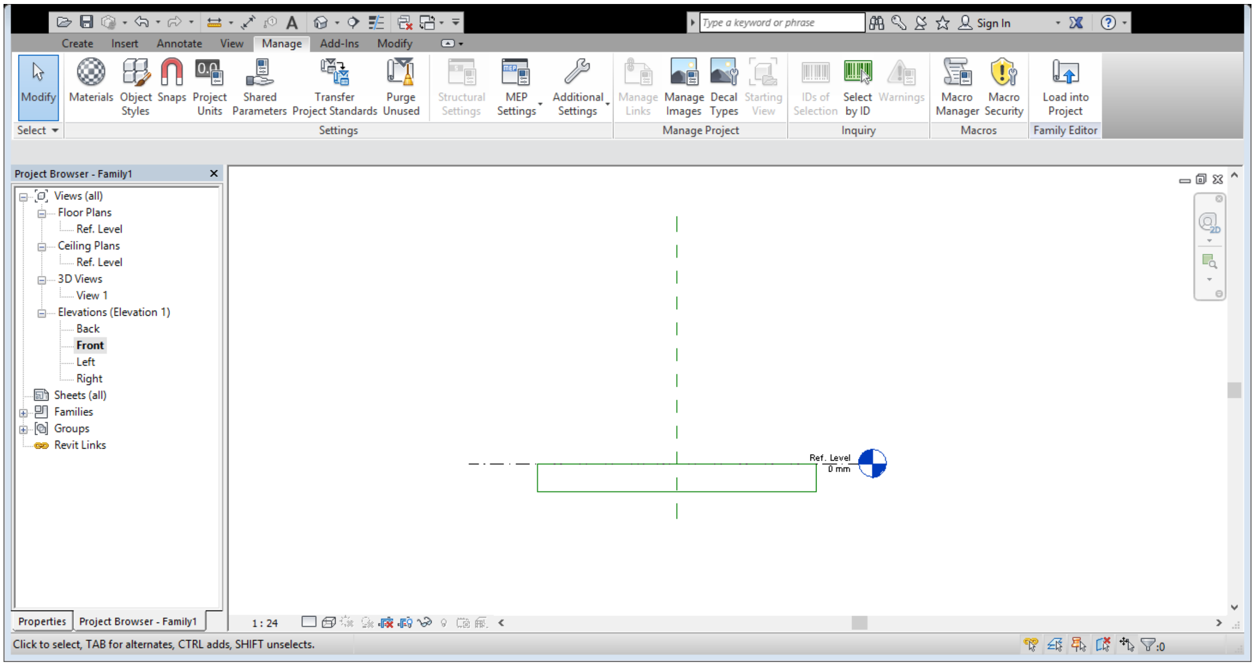


Fig. App. B 7 Visual Guide to Family Development

8. To assign material click on material.



9. Fig. App. B 8 Visual Guide to Family Development

10. A window like this will be opened. If your desired material is there then just select that otherwise like in this case select default click on + and then add physical .

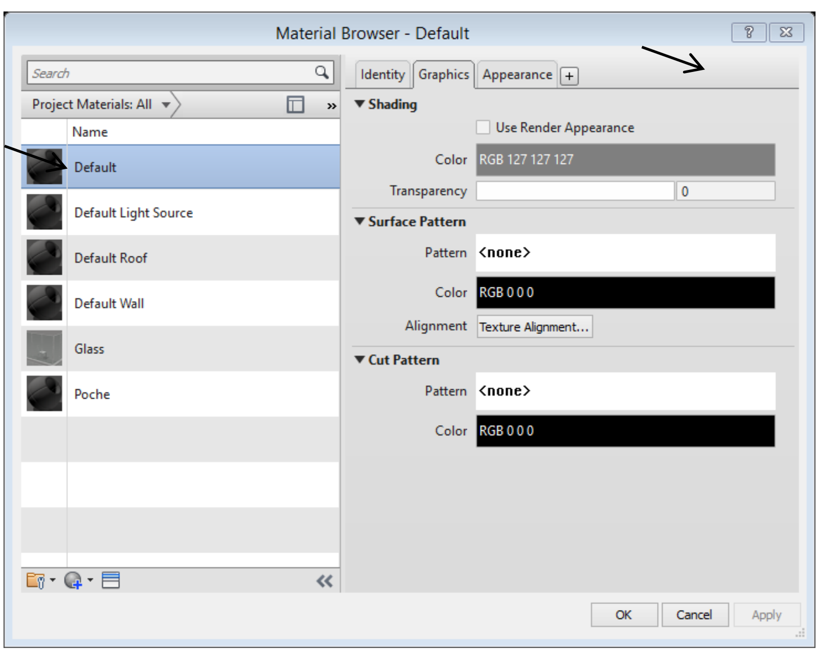


Fig. App. B 9 Visual Guide to Family Development

11. A window like this will be opened. For my family I selected Concrete 3.0 ksi.

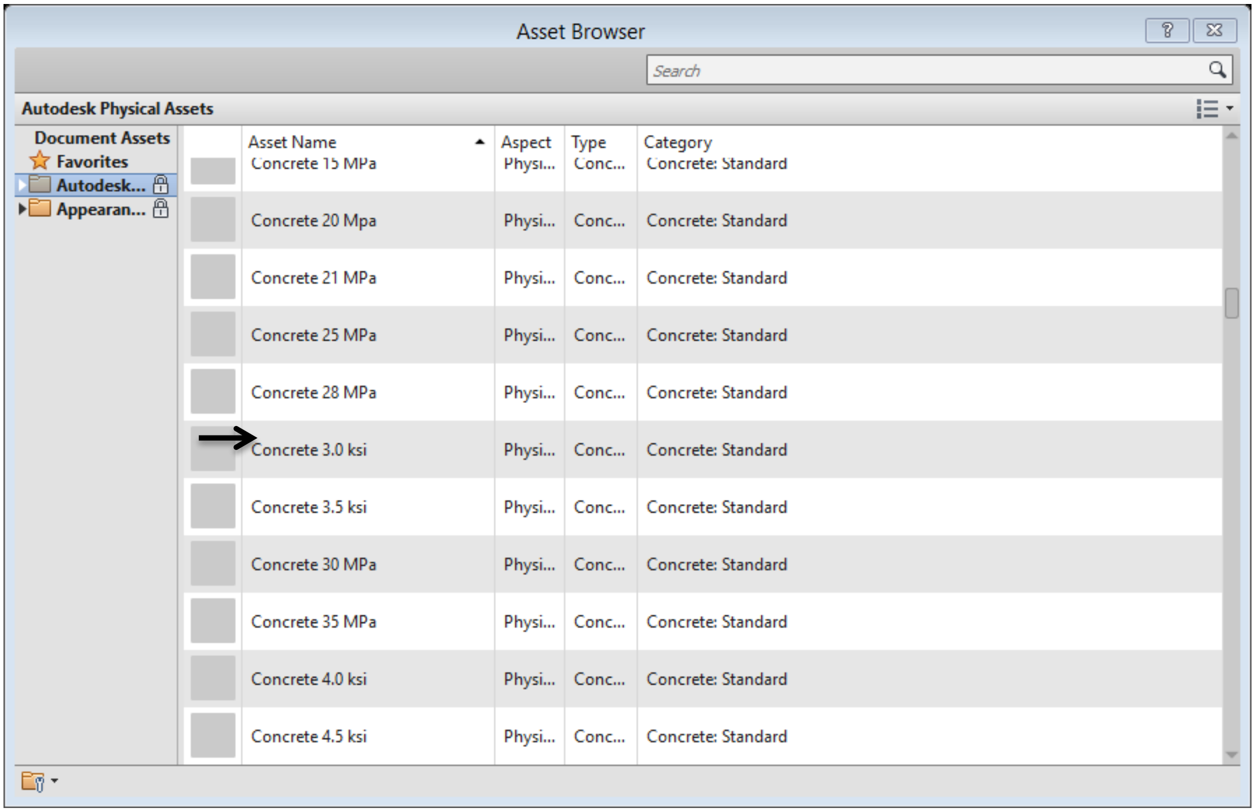


Fig. App. B 10 Visual Guide to Family Development

12. Now physical properties have been added to our default material. Now just click ok.

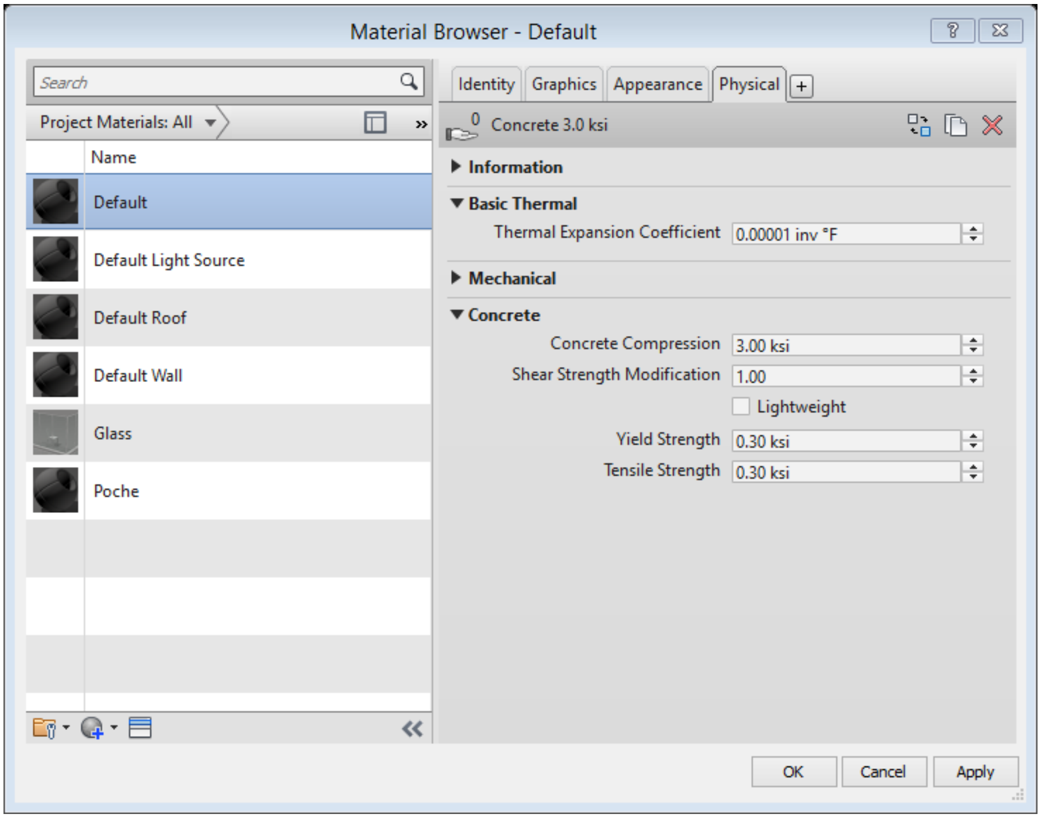


Fig. App. B 11 Visual Guide to Family Development

13. Now a window like this will be opened. Now under create click on extrusion.

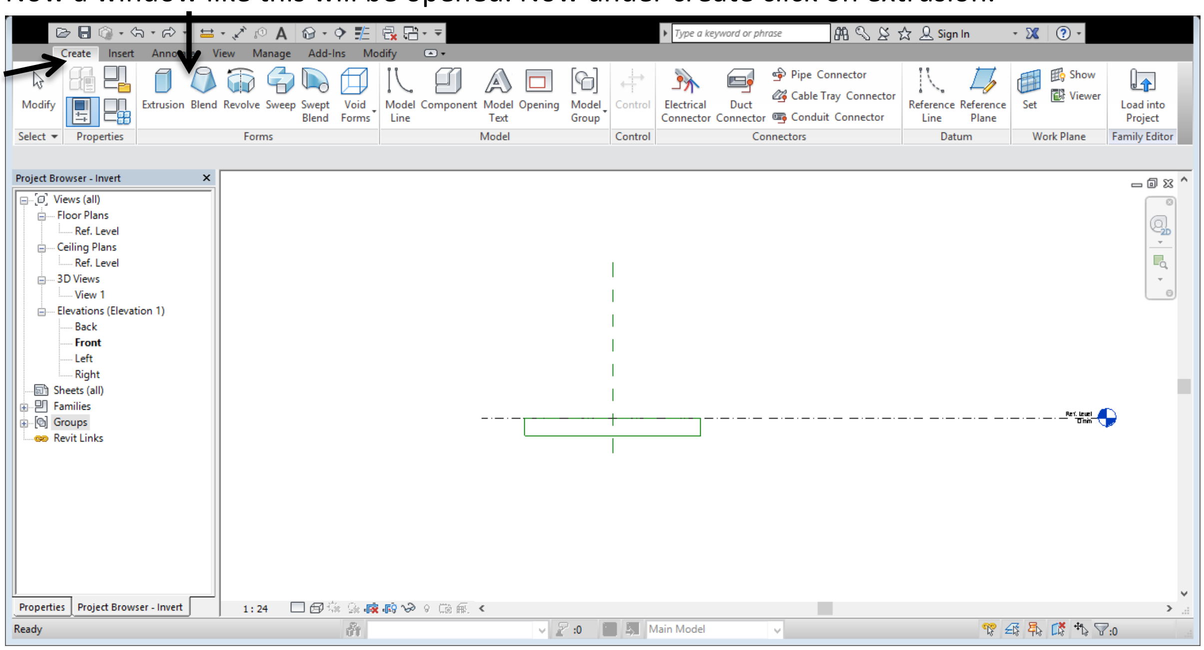


Fig. App. B 12 Visual Guide to Family Development

14. Now a window like this will be opened. Now under draw select simple straight line.

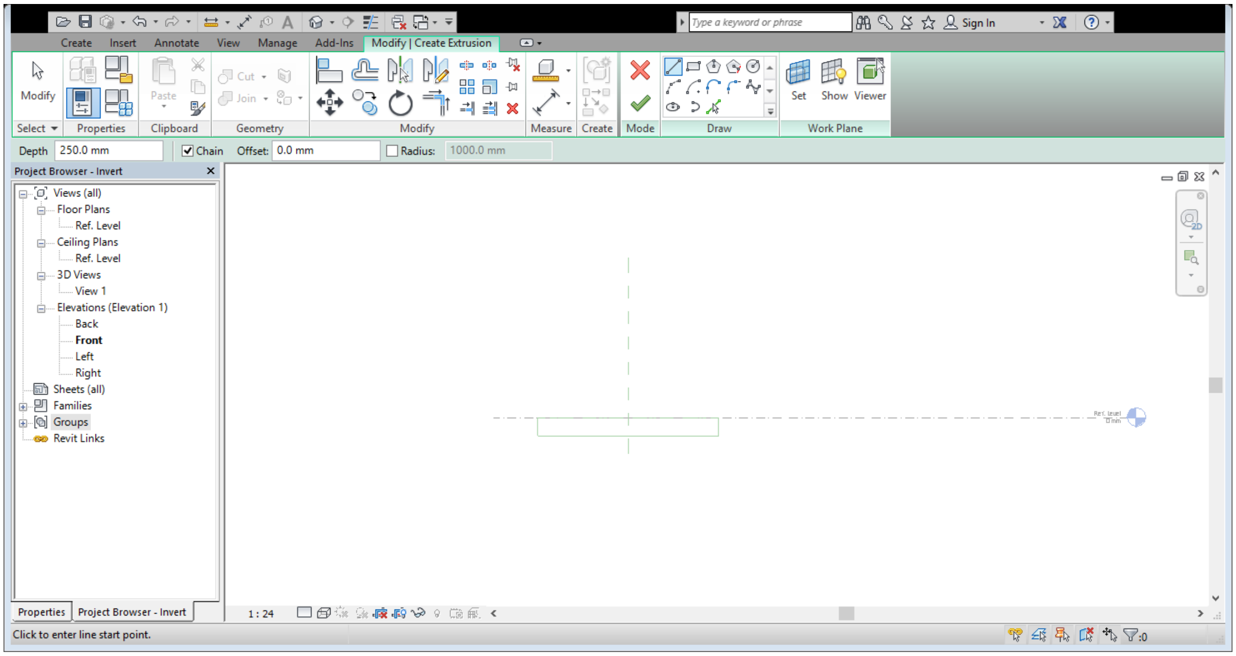


Fig. App. B 13 Visual Guide to Family Development

15. Now we are going to draw the cross section of our tunnel invert. First of all I draw the half side of invert like shown in this fig.

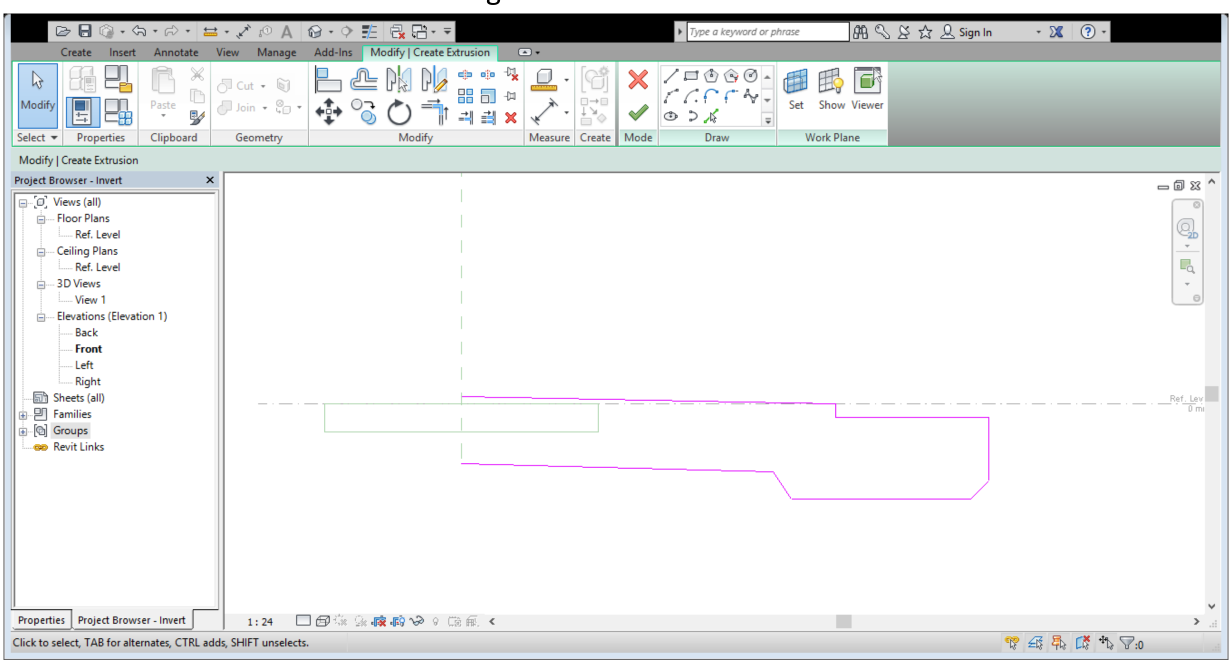


Fig. App. B 14 Visual Guide to Family Development

16. Now I will mirror it on the other side using pic mirror axis command. For this I will select only self-drawn lines, click on pic axis mirror command and then click on the vertical

reference.

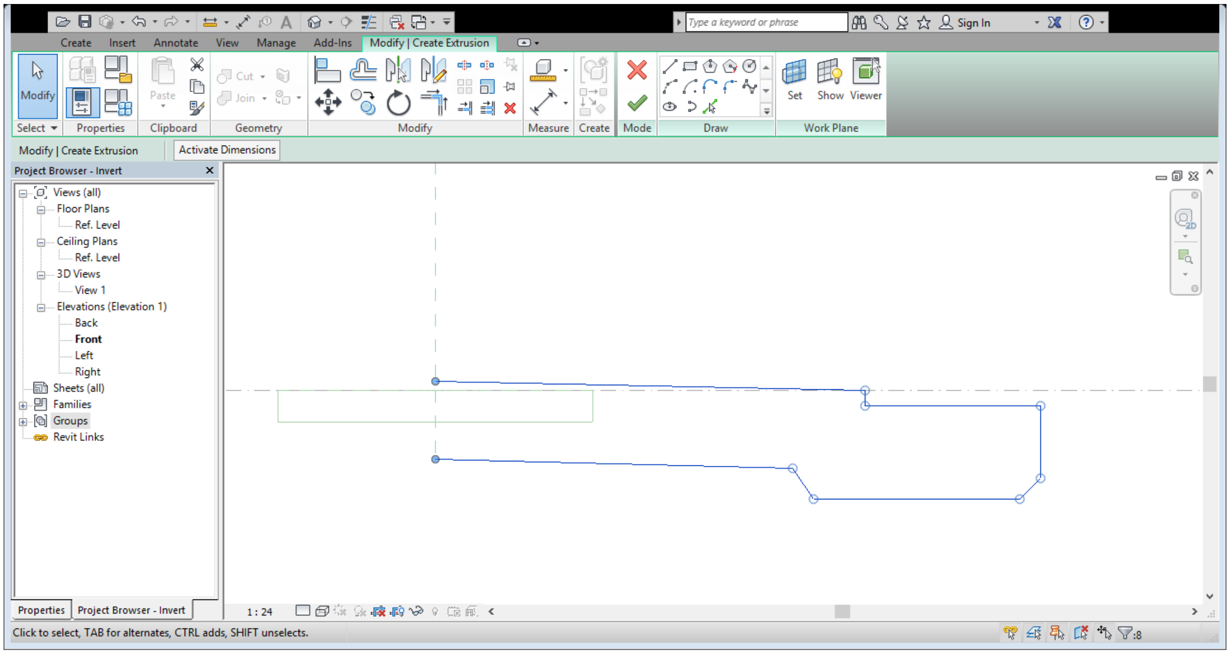


Fig. App. B 15 Visual Guide to Family Development

17. Now it is mirrored.

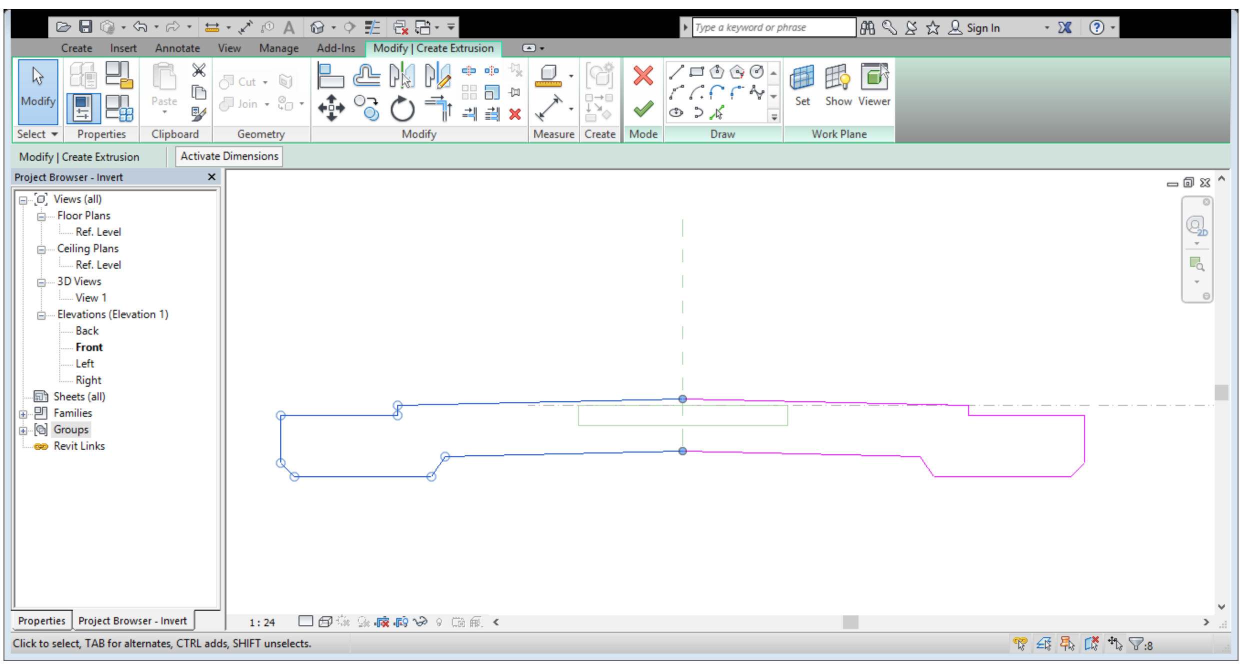


Fig. App. B 16 Visual Guide to Family Development

18. Now the cross section of our tunnel invert in drawn. Note it must be in a closed loop. After this I will click on green tick.

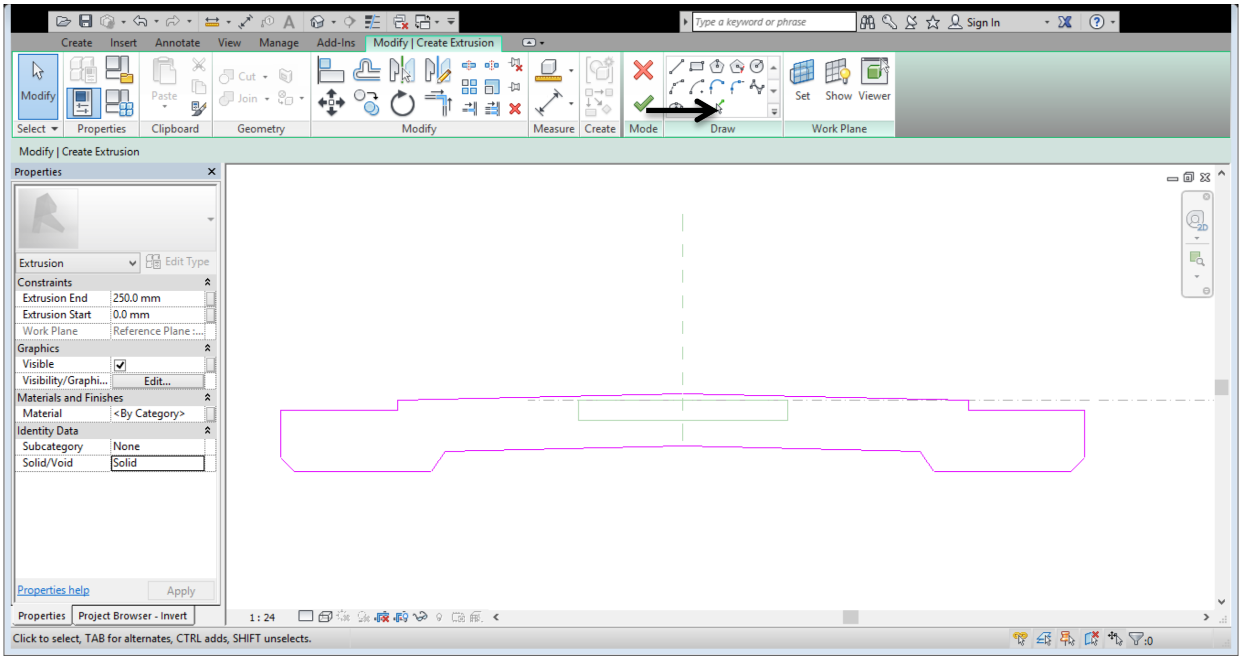


Fig. App. B 17 Visual Guide to Family Development

19. Now click on visual style framing and click on realistic.

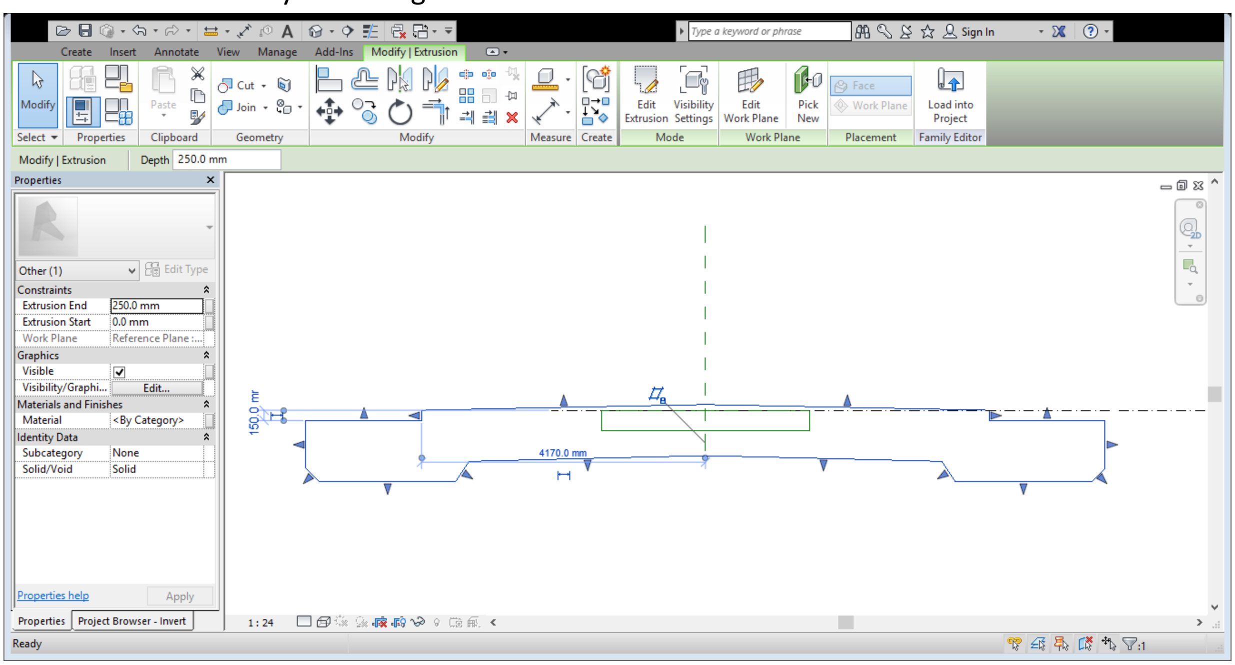


Fig. App. B 18 Visual Guide to Family Development

20. Now it would look like this.

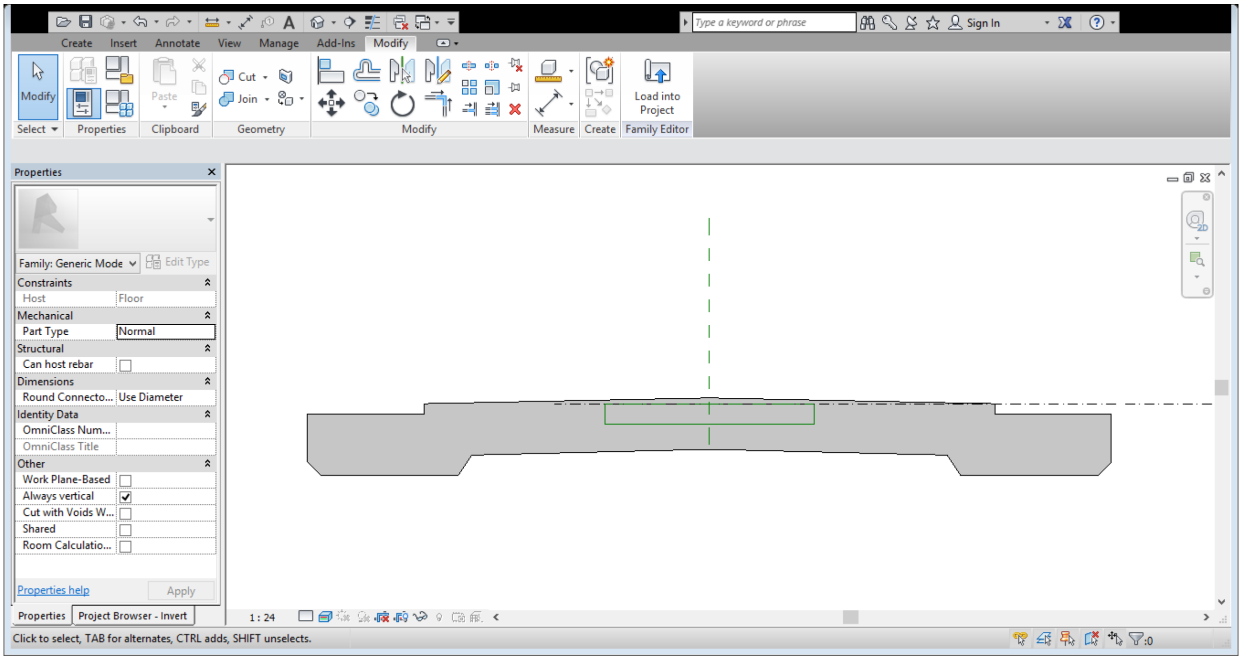


Fig. App. B 19 Visual Guide to Family Development

21. Click on “can host bar” so that we could put reinforcement bars in it.

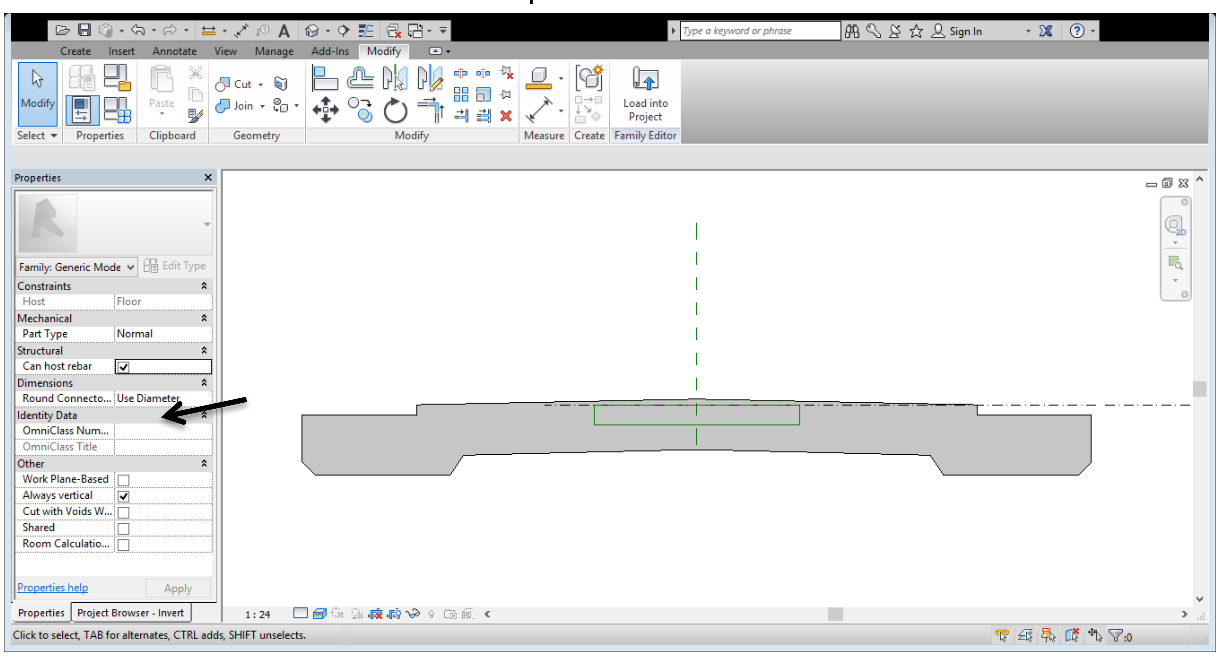


Fig. App. B 20 Visual Guide to Family Development

22. Now our family is complete and ready to be used in any project but to make it flexible I will add parameters to it so that we can change its dimensions to whatever value our project need to. For this I will first add dimensions to it, click on measure and select

aligned

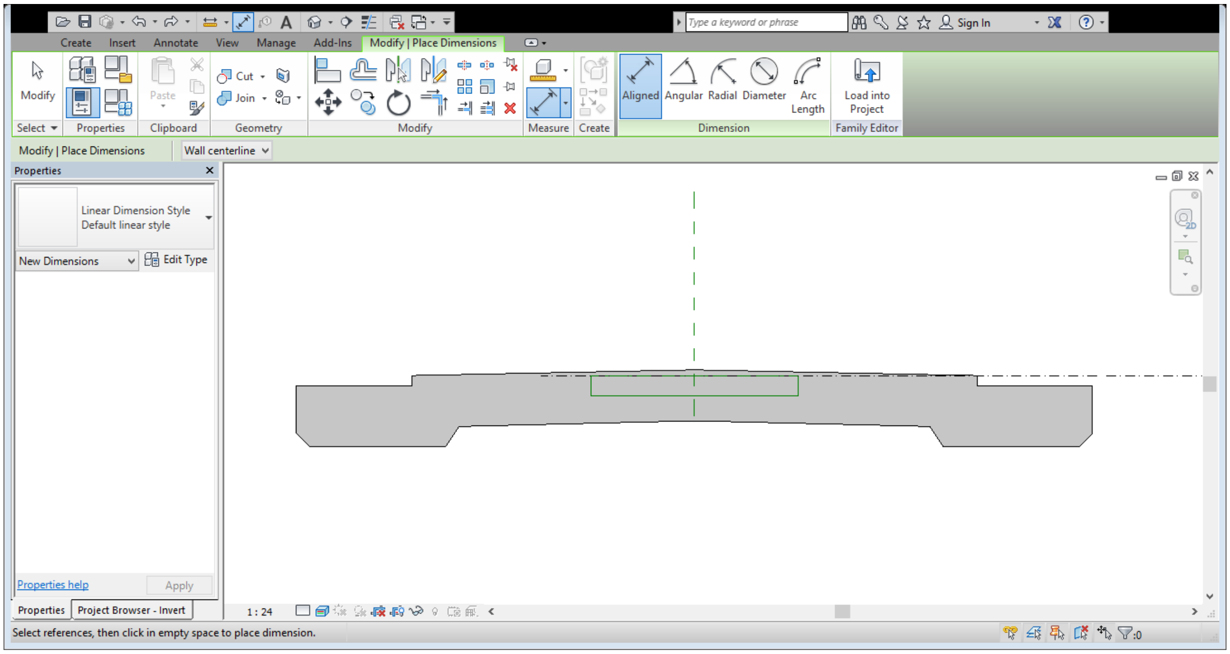


Fig. App. B 21 Visual Guide to Family Development

23. Now I draw the dimensions as shown.

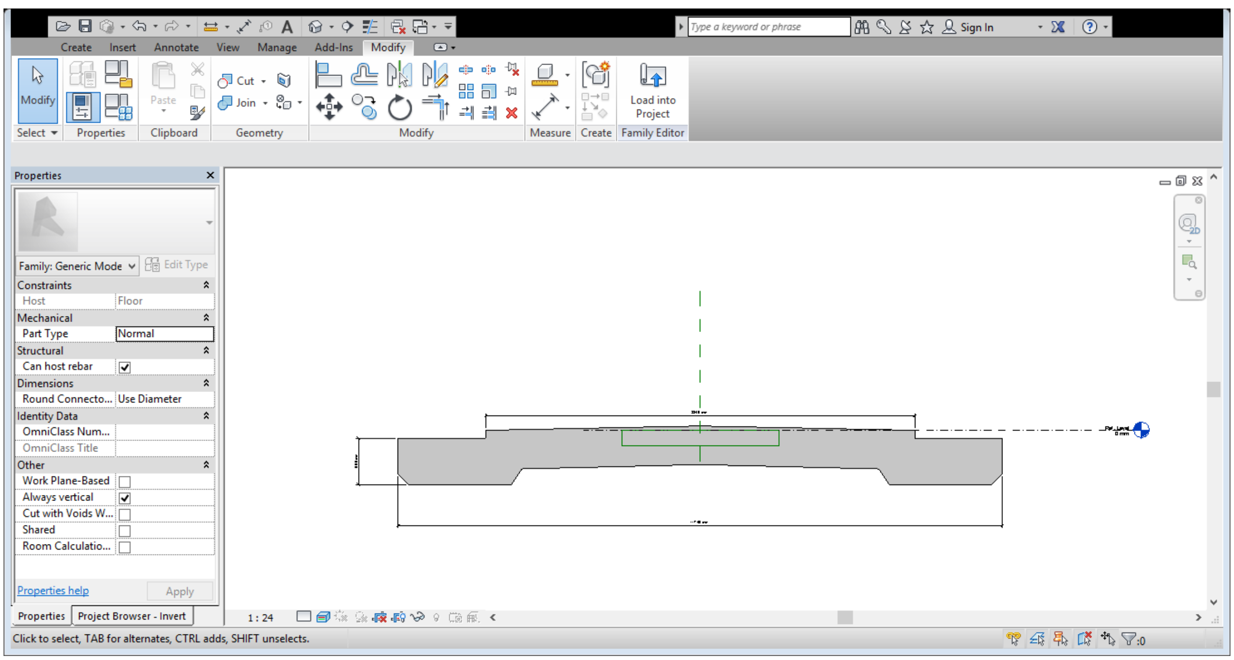


Fig. App. B 22 Visual Guide to Family Development

24. To dimension the length of invert click on Project browser and under Elevation open the left Elevation.

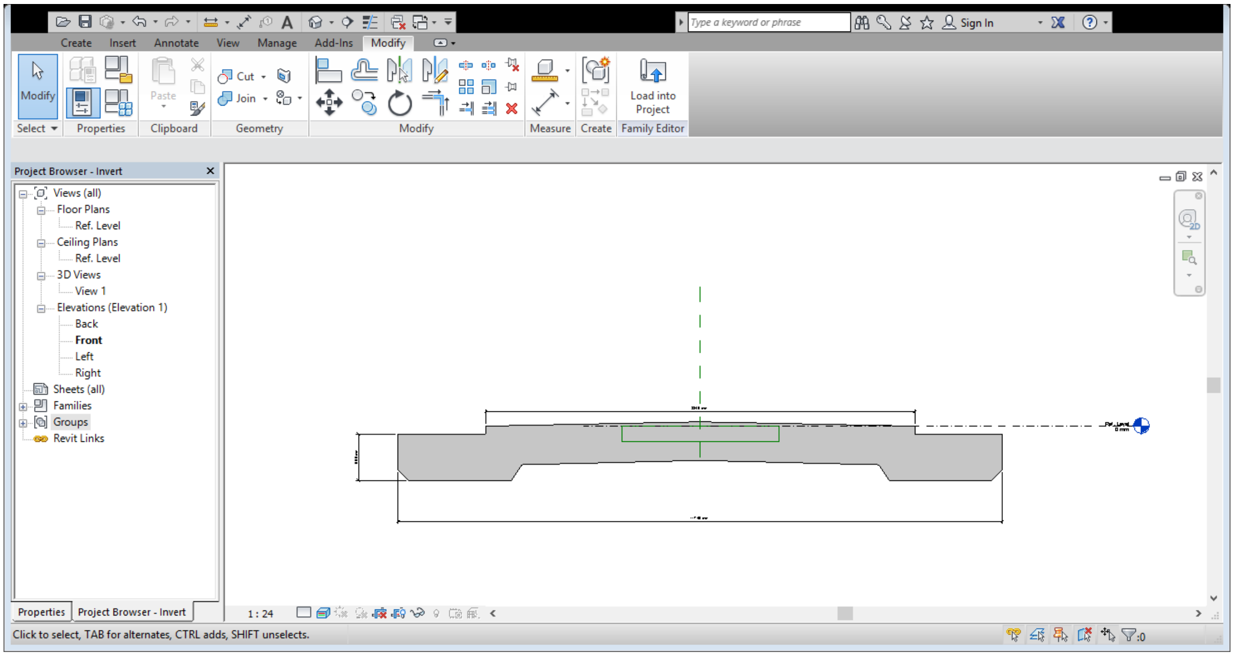


Fig. App. B 23 Visual Guide to Family Development

25. Window like this will be opened.

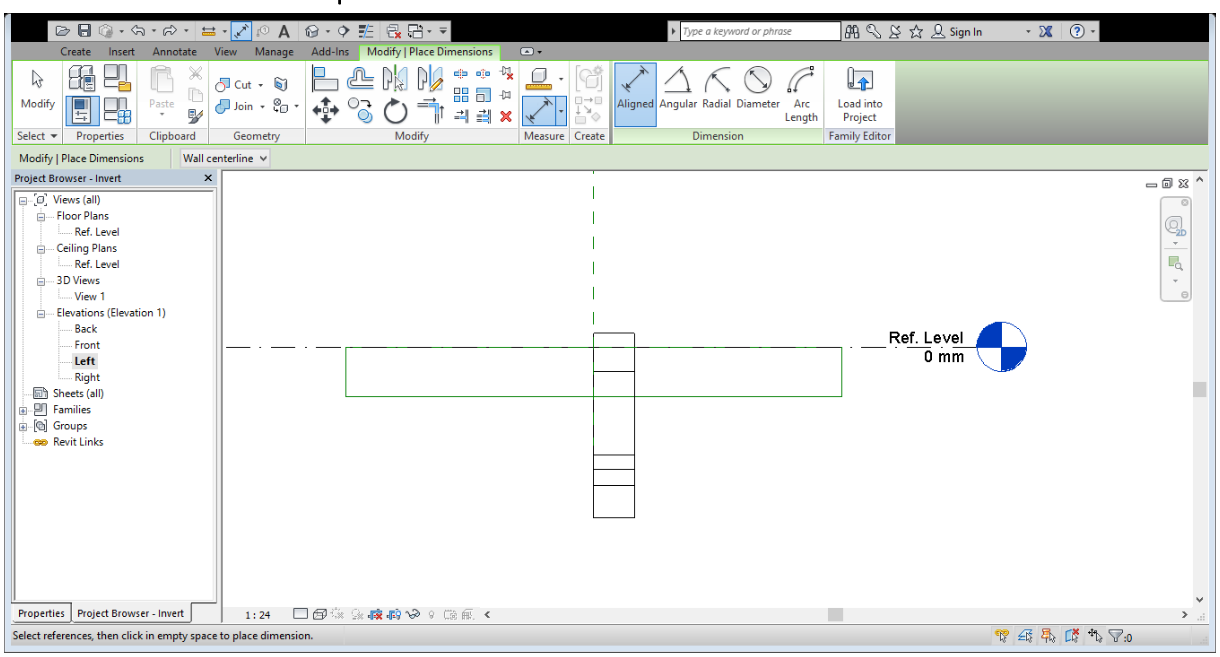


Fig. App. B 24 Visual Guide to Family Development

26. Now add dimension to it with same previous procedure.

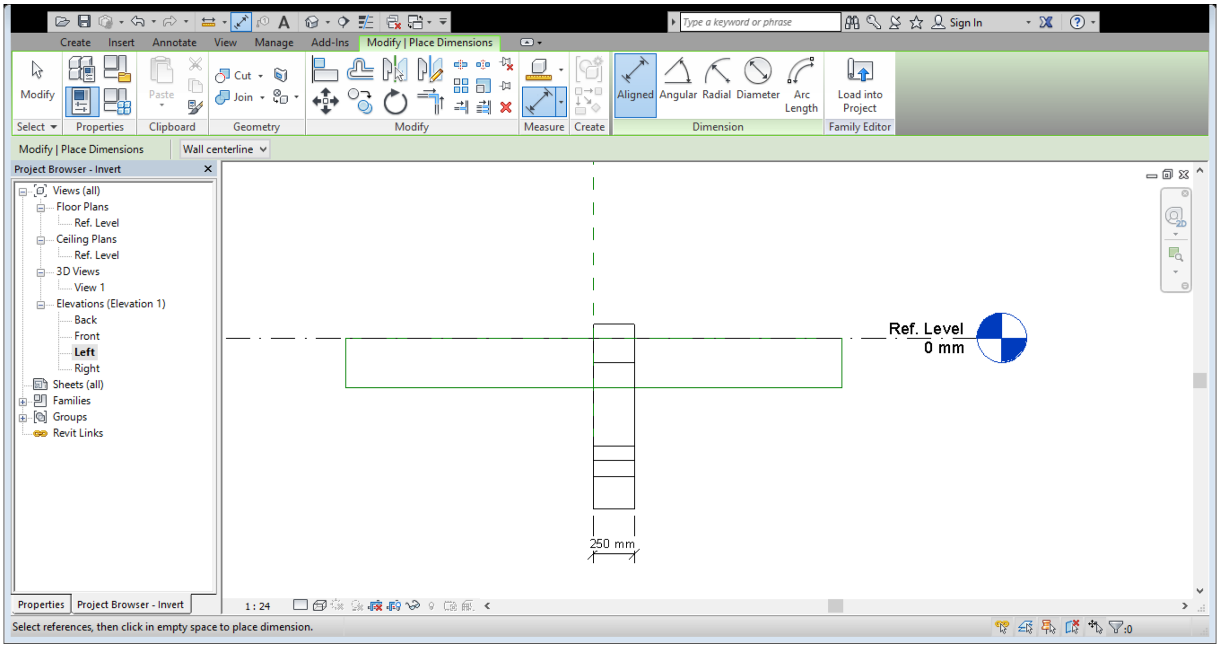


Fig. App. B 25 Visual Guide to Family Development

27. Now hit escape. Now click on family type in properties box.

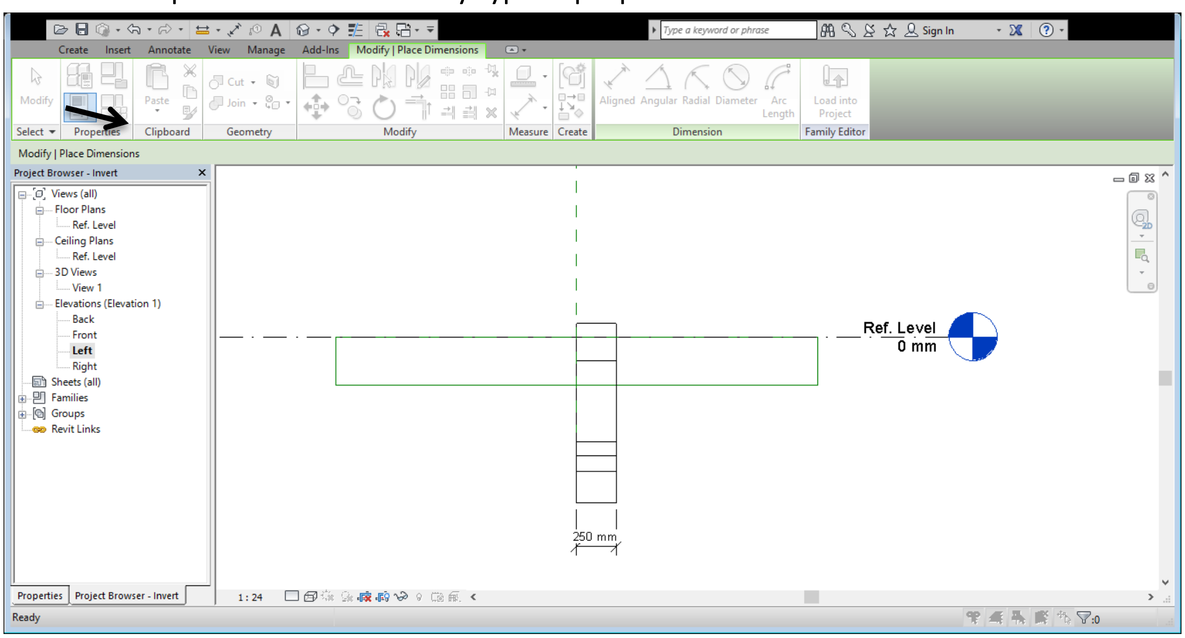


Fig. App. B 26 Visual Guide to Family Development

28. A window like this will be opened. Now click on Add to add parameters.

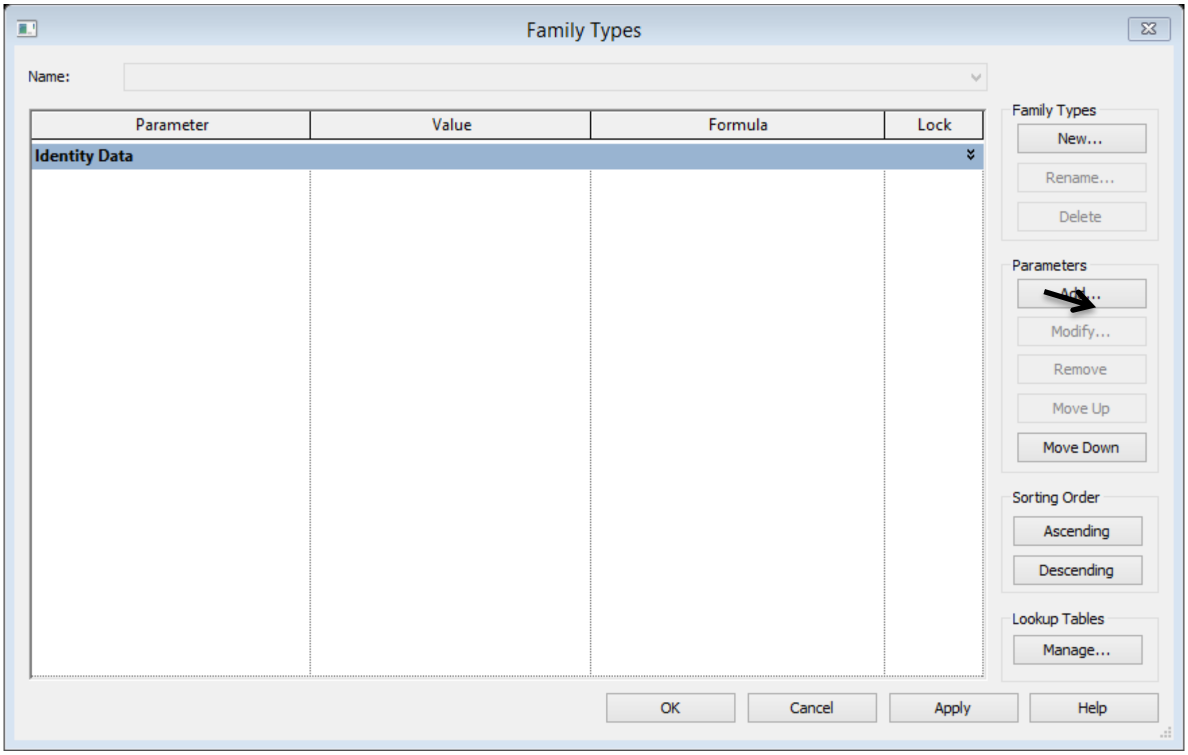


Fig. App. B 27 Visual Guide to Family Development

29. A window like this will be opened. Check family parameter and type. Then enter the name of parameter. Then click ok.

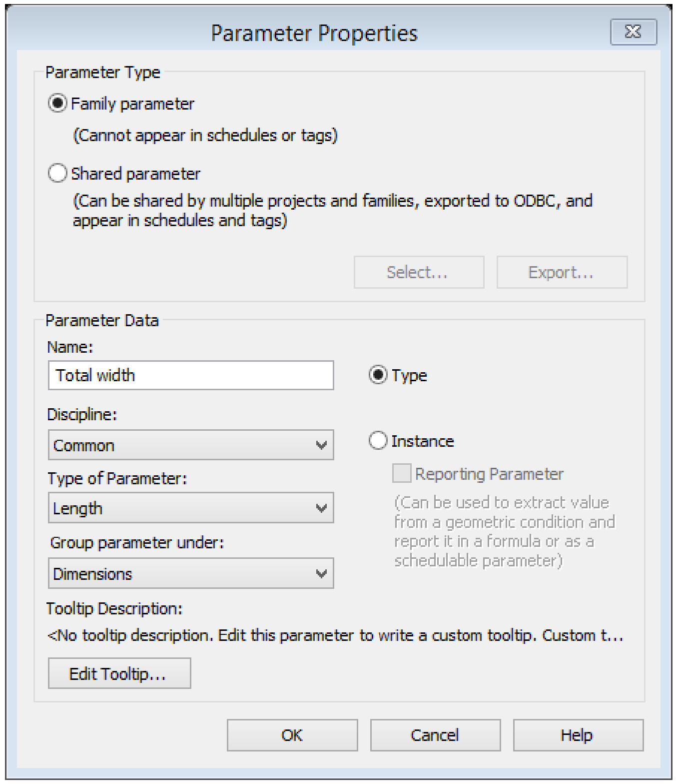


Fig. App. B 28 Visual Guide to Family Development

30. You will be taken back to the previous window this window will be closed.it will look like this.

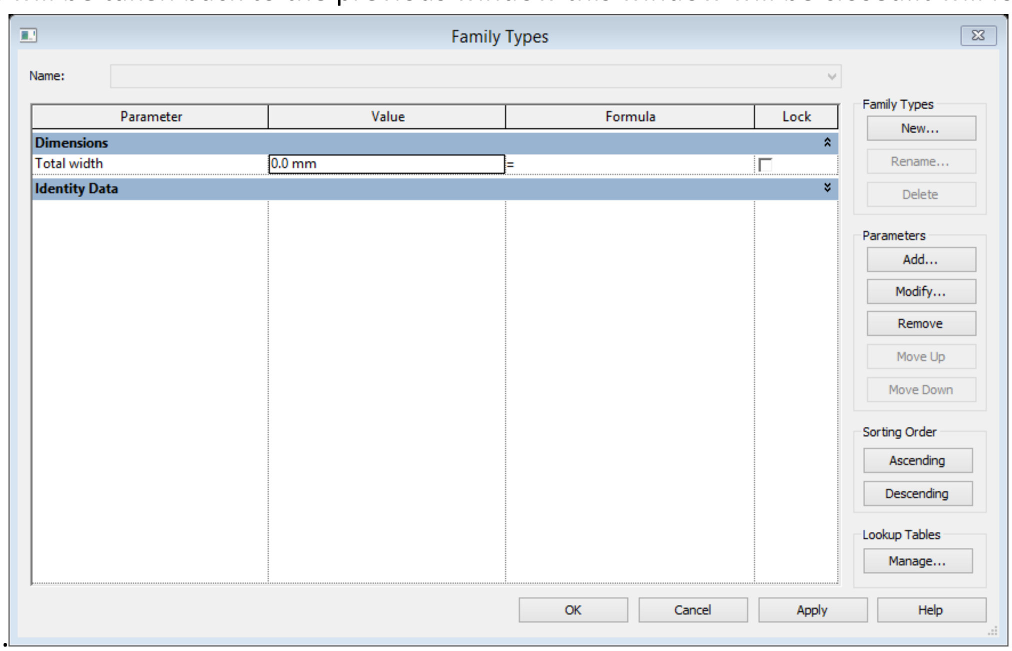


Fig. App. B 29 Visual Guide to Family Development

31. Repeat the procedure to add all the parameter you want add and then click ok. It will look like this.

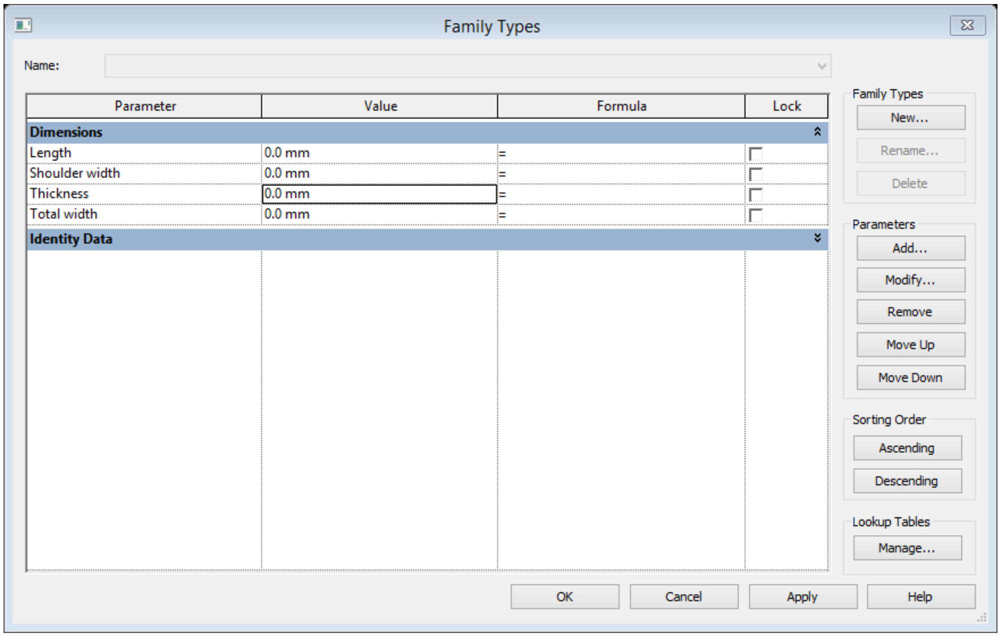


Fig. App. B 30 Visual Guide to Family Development

32. Now you will be taken back to the main window. Click on the dimension, a panel will appear, click on label and click on the respective parameter you your selected dimension to be assigned.

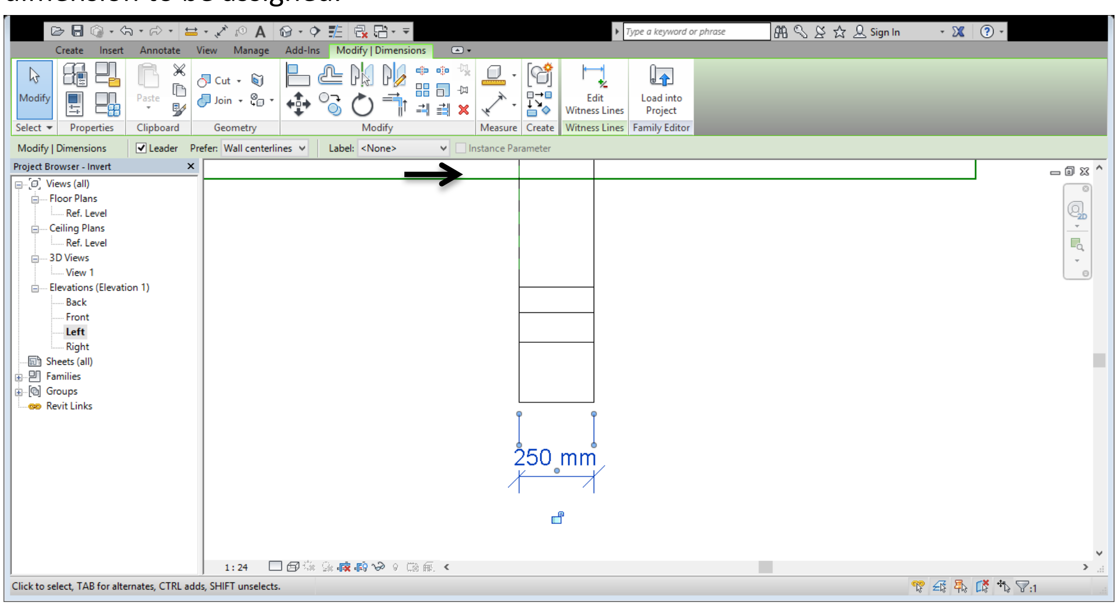


Fig. App. B 31 Visual Guide to Family Development

33. Now go back to the front elevation and assign the rest of dimensions, their respective parameters. Assigning these parameters we will be able to change these dimensions to any value a certain project need. Now these dimensions will appear by their parameter name.

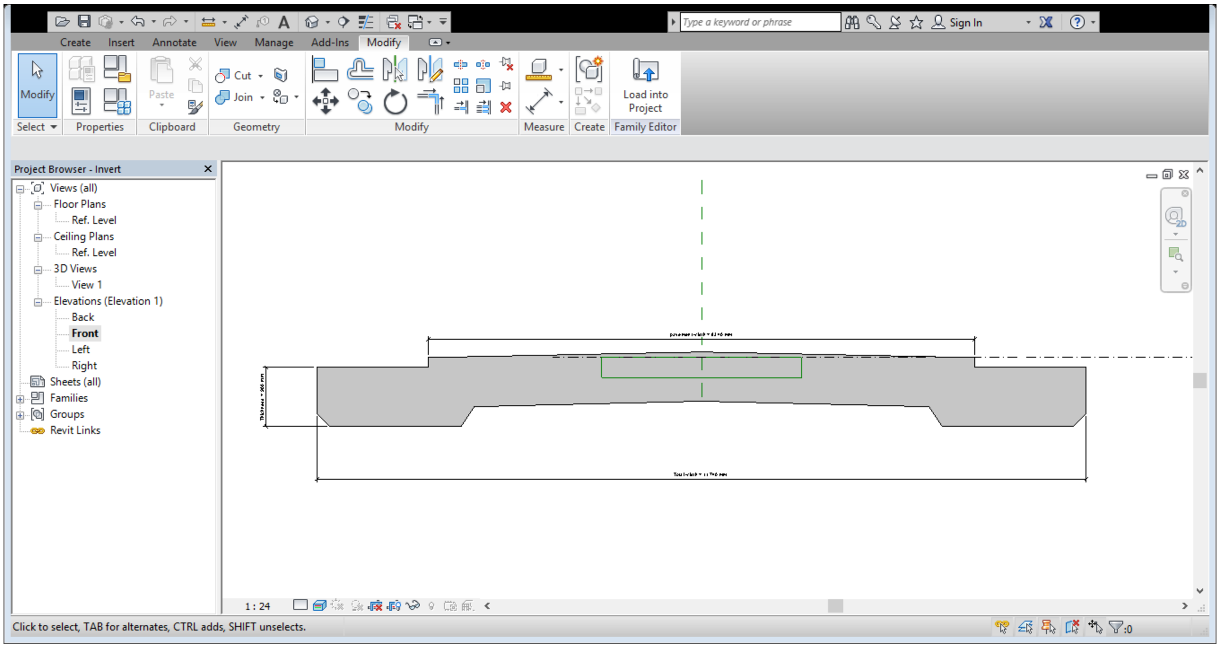


Fig. App. B 32 Visual Guide to Family Development

34. Hence our Family is fully developed to see it in 3D either click on 3D view in project browser or click on 3D object in main control panel.

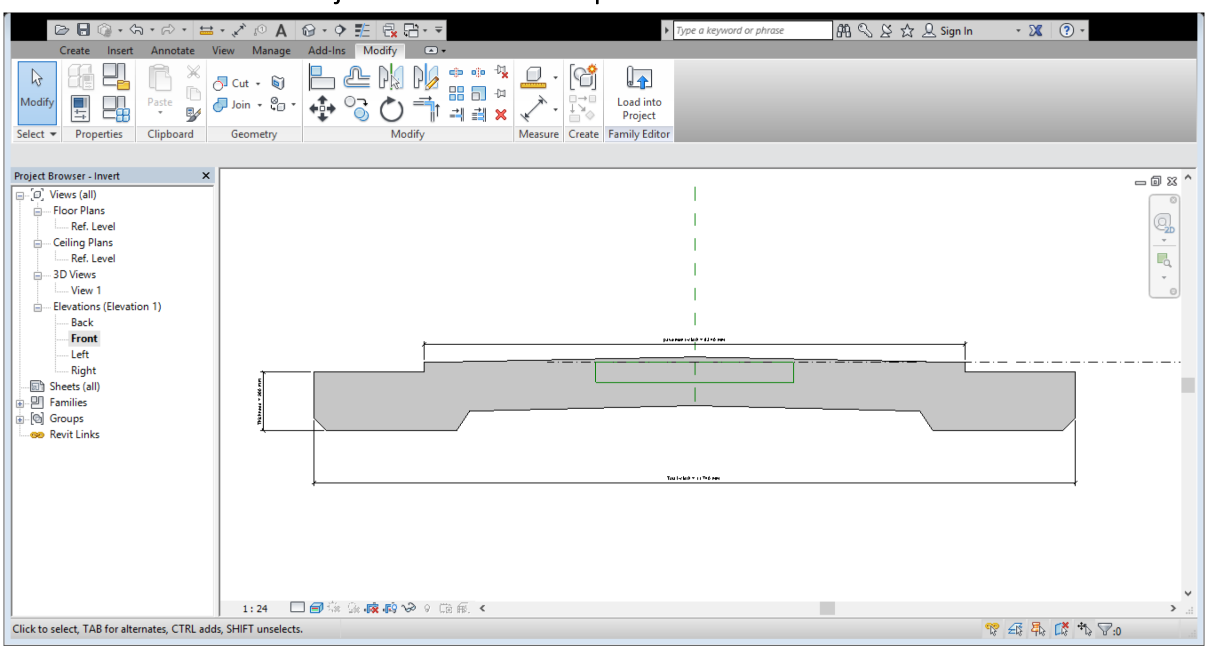


Fig. App. B 33 Visual Guide to Family Development

35. It will look like this.

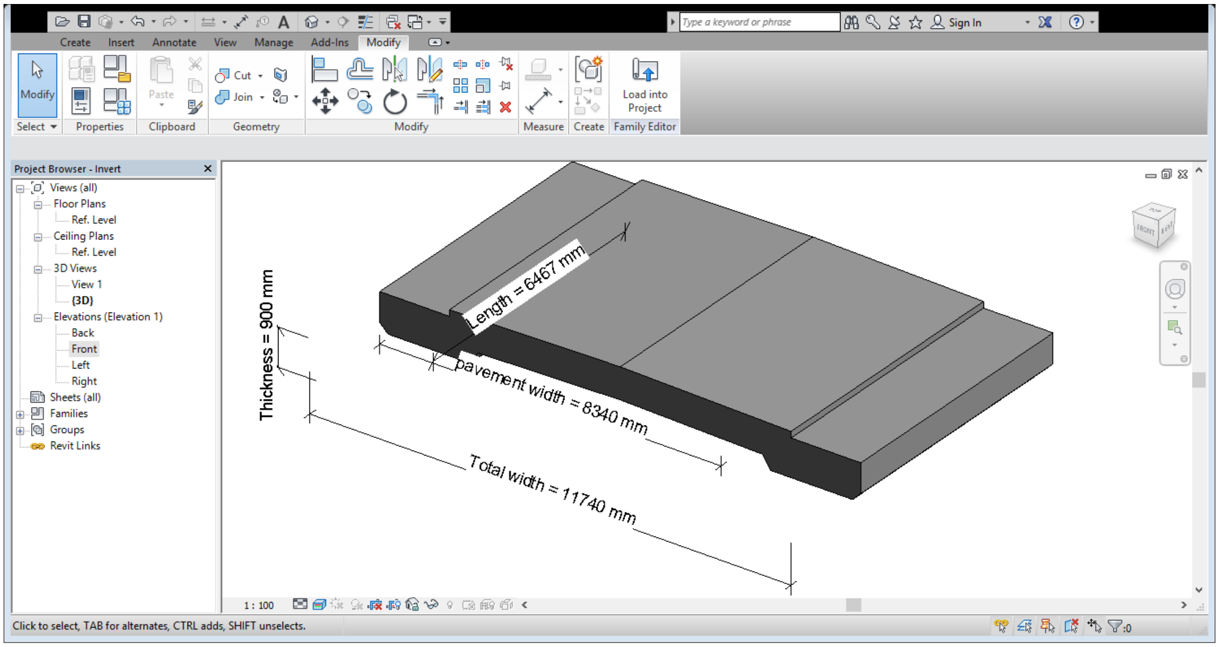


Fig. App. B 34 Visual Guide to Family Development

36. Now save your family click on main R then save as and then Family.

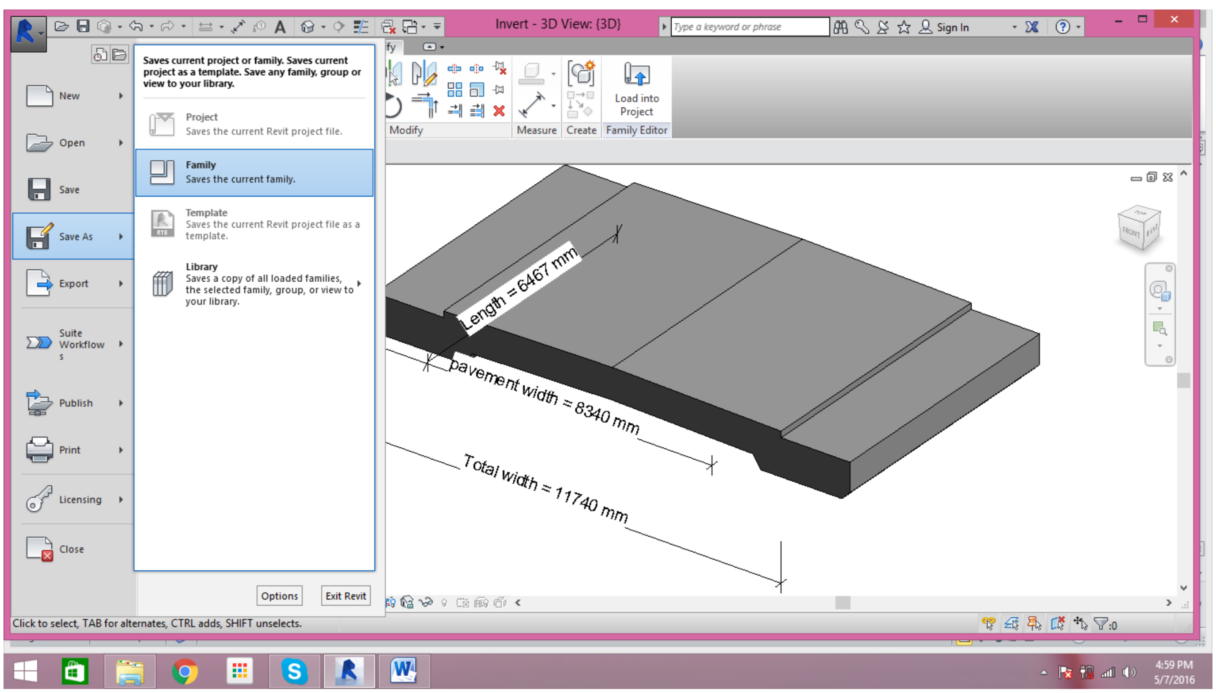


Fig. App. B 35 Visual Guide to Family Development

A window like this will be opened. Save your family where ever location and name you want. And click save.

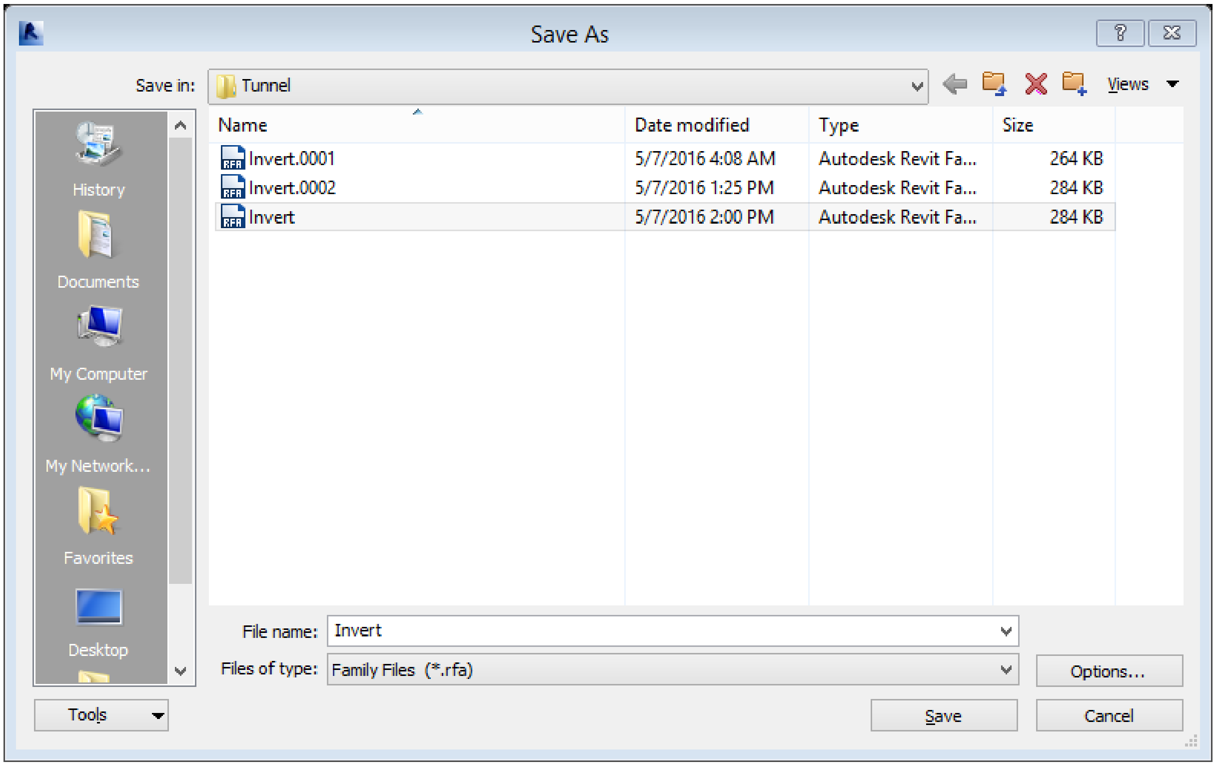


Fig. App. B 36 Visual Guide to Family Development

IN THESE WAY FAMILIES OF ALL THE ELEMENTS OF TUNNEL CAN BE DEVELOPED WHICH CAN BE USED ON ANY PROJECT.