People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
Ecole Nationale Polytechnique

Civil Engineering Department

Laboratory of Seismic Engineering and Dynamics of Structures

Final Year Project Report Presented in Partial Fulfilment of the Requirements for the Degree of

Engineering Degree
In: Civil Engineering

Optimization of Cold Formed Steel Structures Using Genetic Algorithm in a BIM Environment

Presented by:
Abdeslam SKOUDARLI
Adelane SEREIR EL HIRTSI

Supervisors:
M. N. BOURAHLA
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Defended on 07/07/2020

Jury members:

President	M. Abderrahim BALI	Prof.	ENP
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Examiner	M. Brahim Khalil BENAZZOUZ	M.C.A	ENP
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Dedications

I dedicate this modest work

To my beloved parents, who have been my source of inspiration and gave me the strength when I thought of giving up, who continually provide their moral, spiritual, emotional and financial support.

To my relatives and closest friends Haifa and Yanis who shared their words of advice and encouragement to finish this study.

To 2017/2020 Civil engineering promotion and all those to come.

Adelane SEREIR EL HIRTSI

I dedicate my dissertation work to my family and many friends.

A special feeling of gratitude to my parents and family, whose words of encouragement and push for tenacity ring in my ears.

To everyone who provided me with support, everyone who have been affected in every way possible by this quest,

I dedicate this work and give special thanks to my best friends and class mates.

Abdeslam SKOUDARLI

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We also extend our thanks to all the teachers of the Civil Engineering Department of the Ecole Nationale Polytechnique for their support and encouragement during our studies. we want to make tribute to their human and scientific qualities.

Finally, we want to thank all the people who helped us throughout this work.

ملخص

نظرا للتطور التكنولوجي السريع، يواجه مجال البناء العمراني و التشييد عدة تحديات ليتم بلوغ مستويات عالية من الإنتاجية و الاداء. استخدام منصات BIM يساعد على رفع هاته الأخيرة من خلال تسهيل عمليات نقل و مشاركة المعلومات بين مختلف التخصصات المشاركة في هذا المجال.

في هذا السياق، هذه الاطروحة تقترح دراسة منهجية تستخدم الخوارزمية الجينية كأداة لإنشاء تصاميم هيكلية تلقائيا للصلب المشكل على البارد على منصة BIM. يقصد بالصلب المشكل على البارد (CFS) إلى عملية خاصة من التصنيع، حيث يتم لف الصفائح المعدنية الرقيقة و المطلية عبر آلات مخصصة تسمى آلات الدرفلة وضمن درجة حرارة معتدلة لتشكيل عناصر هيكلية من مختلف الأشكال المستعرضة المستخدمة للمباني ذات الارتفاع المنخفض و المتوسط. في الجزائر، استخدام قطع CFS كعناصر هيكلية رئيسية في المباني لا يزال في بدايته، حيث أن البنايات الاولى من هذا النوع قد تم تشييدها في بداية العقد الماضي.

يعتمد مفهوم الخوارزمية المقترحة على عملية تحسين متعددة الأهداف تولد أفضل تصميم هيكلي لنموذج BIM معين للشكل المعماري. لأغراض توضيحية، تم تطبيق المنهجية المقترحة على العديد من المباني النموذجية ،حيث قد أظهرت النتائج المتحصل عليها من التكوينات المعمارية المعتبرة ، أن النهج المقترح فعال للغاية في إنشاء الهياكل المثلى ، موافق للمعايير المحددة مسبقًا و يلبي كل متطلبات التصميم.

كلمات مفتاحية

أقسام صلب مشكلة على البارد، نمذجة معلومات المباني BIM ، التحسين الهيكلي، تصميم المباني، الخوارزمية الجينية، مشاريع البناء.

Résumé

En raison des progrès technologiques rapides, l'industrie de la construction est mise au défi d'atteindre un haut niveau de performance. L'utilisation de la plateforme BIM a amélioré la productivité grâce à l'amélioration du partage des connaissances et de l'interface entre les disciplines impliquées dans le processus de construction.

Dans ce contexte, la présente thèse propose une méthodologie basée sur un algorithme génétique pour intégrer une conception structurelle automatique de structures en acier formé à froid (CFS) dans une plateforme BIM. Le CFS désigne un procédé de fabrication où des tôles galvanisées sont laminées à la température ambiante pour former des éléments structuraux de diverses formes de section transversale utilisés pour les bâtiments de faible et de moyenne hauteur. En Algérie, l'utilisation des profils CFS comme principaux éléments structuraux dans les bâtiments sont à ses débuts, les premiers bâtiments multi-étages CFS ont été érigés au début de la dernière décennie.

Le concept de l'algorithme proposé est basé sur un processus d'optimisation multi-objectifs qui génère la meilleure disposition structurelle pour un modèle BIM donné d'une configuration architecturale. À titre indicatif, la méthodologie proposée est appliquée à plusieurs bâtiments prototypes et les résultats obtenus ont démontré que, dans le cas des configurations architecturales considérées, l'approche proposée est très efficace pour produire des structures optimales, qui sont conformes aux critères prédéfinis et qui satisfont aux exigences de conception structurale.

Mots Clés

Éléments en charpente légère (Profilés laminé à froid), BIM, optimisation structurelles, conceptions des bâtiments, algorithme génétique, projet de construction.

Abstract

Due to the rapid technology advancement, the construction industry is being challenged to achieve a high level of performance. The use of BIM platform has enhanced the productivity through the improvement of the knowledge sharing and interface between the disciplines involved in the construction process.

In this context, the present study proposes a methodology based on genetic algorithm to integrate an automatic structural design of Cold Formed Steel (CFS) structures in a BIM platform. CFS refers to a manufacturing process where metallic-coated sheet steel is roll-formed at ambient temperature into structural elements of various cross-section shapes used for low and mid-rise buildings. In Algeria, the use of CFS profiles as the primary structural members in buildings is in its beginning, the first CFS multi-storey buildings were erected early last decade.

The concept of the proposed algorithm is based on a multi-objective optimization process that generates a best structural layout for a given BIM model of an architectural configuration. For illustrative purposes, the proposed methodology is applied to several prototype buildings and the obtained results have demonstrated that, in the case of the considered architectural configurations, the proposed approach is very efficient in generating optimal structures, which are consistent with the predefined criteria and fulfilling the structural design requirements

Keywords

Cold Formed Steel, BIM, structural optimization, building design, Genetic algorithm, building project.

Summary

Tables

Figures

Abbreviations

CFS: Cold Formed Steel

AEC: Architecture Engineering Construction

GA: Genetic algorithm.

IFC: Industry Foundation Classes

BIM: Building Information Modelling

CAD: Computer aided design

SWP: Shear wall panels

AISI: American Iron and Steel Institute

RPA: Règlement Parasismique Algérien (Algerian Seismic Code)

General Introduction

General Introduction

This study has been carried out in the framework of the final year project (PFE) proposed by the Earthquake Engineering and Structural Dynamics Laboratory (LGSDS) at the Civil engineering Department. It presents an innovative approach for cold formed steel structures, based on a genetic algorithm that automatically derive an optimal structure for a given architectural configuration in a BIM platform.

Motivation and scope

With the development trend in automation technologies in construction and civil engineering, new schemes, components, and tools are expected to be invented to ease and enhance the whole process of the construction industry. In this context, this study presents an innovative approach related to the process of design to help automatize the interface between disciplines especially architecture and structural engineering which can be easily implemented in a BIM environment. This is a 3D intelligent model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.

Objectives

The main objective of this study, is to apply the automatic structural design to cold formed steel (CFS) structures, by implementing design rules and criteria deduced from the codes of practice of cold formed steel frames in a BIM platform.

The procedure is based on an optimization by a genetic algorithm that will allow to generate in an automatic way; multiple variants of optimal structural layouts that are compatible with the architecture at the stage of the preliminary design.

Outline of the dissertation

This report starts with a general introduction that describes the study in a general way, specifying the motivation, the scope, the objective and the adopted methodology.

The first chapter consists of a bibliography review that includes the mechanical and physical proprieties of the light steel material, generalities about cold formed steel structural members, and a presentation of the standards and a set of design rules used in the conception of cold formed steel structures. An in-depth survey that informs about the integration of BIM process into the construction field in general and the implementation of the cold formed steel frame projects into BIM environment is presented.

The second chapter outlines the steps taken in the development of a level 2 numerical models of cold formed steel structure in a BIM platform using Autodesk Revit 2020 and other BIM software especially developed for cold formed steel frame system, Vertex BD.

The third chapter contains the necessary steps to create and elaborate a 3D BIM model using one of the widely used BIM platforms, Autodesk Revit.

The fourth chapter presents an approach based on an evolutionary algorithm that generates from the architectural layout an optimal solution for distribution of shear walls to resist the lateral seismic load. A tool related to this approach is developed to propose an optimal direction of the joists of the slab on the basis of the cold formed steel standards.

The fifth chapter is dedicated to present the performance of the genetic algorithm applied to several realistic CFS buildings together with a critic evaluation of the results.

And finally, we will present the main conclusions and perspectives issues from this study.

Chapter One
Cold Formed Steel

1.1. Introduction

Steel material is widely used in the construction industry for more than a century around the world. Characterized by its high reliability and sustainability, various fields of constructions have used this material, such as industrial buildings with important width, skyscrapers for offices and used use, great trade centres, ...etc Several great cities around the world became famous by their emblematic buildings, that are mostly constructed by using the steel material.

However, steel construction remains less used in some countries with a traditional design considered as uneconomical for landed properties. In many parts of the world, timber or structural brickwork is preferred whereas in Algeria, reinforced concrete construction is usually preferred for landed properties.

Over the years, the steel construction industry has improved by developing a various method system, that allows their use in the countries with a limited financial capability. Among these new designs, we have the light steel frame that is recognized for its ease to use and economical aspect, this kind of structures has increasingly used in the steel structure industry through the world, where that is widely used in America, Europe, Australia, New Zealand and even in Algeria.

This structural system is developed through a cold-formed process without the use of heat. This process enables to produce light-weight high tensile steel sheets. The sheet surface is coated with a zinc alloy that completely covers the steel surface and seals it from the corrosive action of its environment. This results in buildings that are more solid, rigid, stronger, durable and easier to build.

1.2. Manufacturing processes of Cold Formed Steel

Cold-formed members are usually manufactured by one of two processes: roll forming and brake forming.

1.2.1. Roll forming

Roll forming consists of feeding a continuous steel strip through a series of opposing rolls to progressively deform the steel plastically to form the desired shape (Figure 1-1).

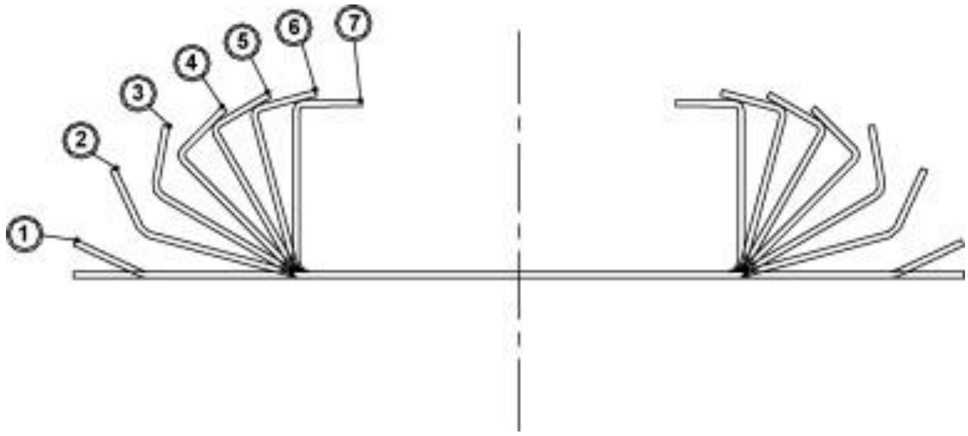


Figure 1-1 Typical roll-forming sequence for a Z-section [38]

Each pair of rolls produces a fixed amount of deformation in a sequence of the type shown in Figure 1-1, In this example, a Z section is formed by first developing the bends to form the lip stiffeners and then producing the bends to form the flanges.

1.2.2. Brake forming

Brake forming involves producing one complete fold at a time along the full length of the section, using a machine called a press brake, such as the one shown in Figure 1-2.

Figure 1-2 Cold-forming tools: brake press dies [16]

For sections with several folds, it is necessary to move the steel plate in the press and to repeat the braking operation several times. The completed section is then removed from the press and a new piece of plate is inserted for manufacture of the next section.

1.3. Mechanical proprieties of Cold Formed Steel

- The modulus of elasticity: E = 210 000 MPa
- Poisson ratio: $\nu = 0,3$
- Shear modulus: $G = E/2(1+\nu)$ MPa
- The coefficient of the linear expansion: $\alpha = 12 \times 10^{-6}\ C^{-1}$
- Density: $\gamma = 7850\ kg/m^3$

The galvanized strip steel, from which the light steel framing is formed, is generally supplied in grades of S350 to S450. These designations indicate a yield strength between 350 and 450 N/mm^2. The strip steel is galvanized with a minimum G275 coating. Cold formed steel sections are usually rolled from galvanized sheet steel that is 1.0 – 4.0 mm thick (1.2 to 2.4 mm typically used). The normal thickness of zinc coating (275 g/m^2) has excellent durability performance.

1.3.1. Influence of cold forming on mechanical properties of steel

The mechanical properties of cold-formed steel sections are different from those of the steel sheet, strip, plate, or bar before forming. This is because the cold-forming operation increases the yield stress and tensile strength and at the same time decreases the ductility.

Results of investigations conducted on the influence of cold work indicate that the changes of mechanical properties due to cold work are caused mainly by strain hardening and strain aging, as illustrated in Figure 1-3.

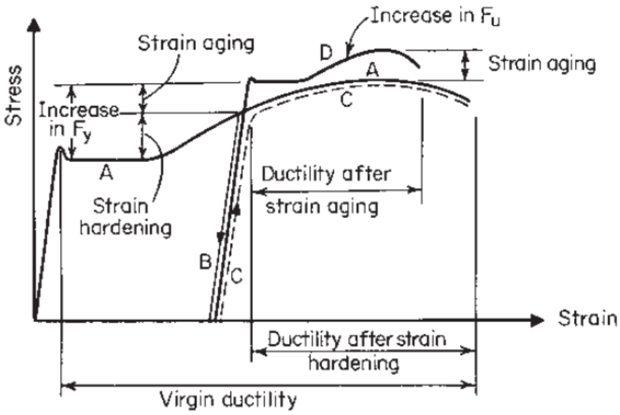


Figure 1-3 Effects of strain hardening and strain aging on stress–strain characteristics [38]

- Curve A represents the stress–strain curve of the virgin material.
- Curve B is due to unloading in the strain-hardening range.
- Curve C represents immediate reloading.
- Curve D is the stress–strain curve of reloading after strain aging.

It is interesting to note that the yield stresses of both curves C and D are higher than the yield stress of the virgin material and that the ductility decrease after strain hardening and strain aging.

The effects of cold work on the mechanical properties of corners usually depend on:

- The type of steel.
- The type of stress (compression or tension).
- The direction of stress with respect to the direction of cold work
- The ultimate strength - yield strength ratio.
- The inside radius–thickness ratio.
- The amount of cold work.

1.4. Structural composites of Cold Formed Steel structures

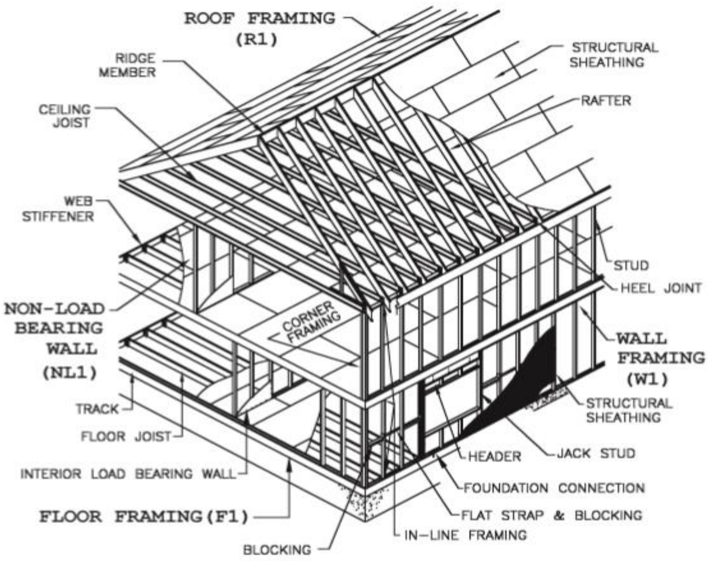


Figure 1-4 Schematic of typical Structural composites of Cold Formed Steel structures [24]

1.4.1. Structural shapes

Various shapes are produced, they include open sections, closed sections, and built-up sections, such as Cee sections (also called lipped channels), Zee sections, double channel I beams with stiffened flanges, hat sections with and without intermediate stiffeners, box sections, U sections and others. These are used in buildings for such structural functions as eave struts, purlins, and girts as well as joists and studs and other components (Table 1-1).

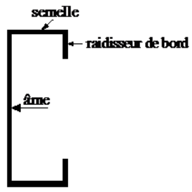
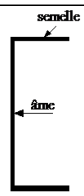
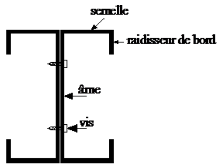
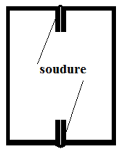
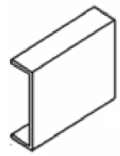
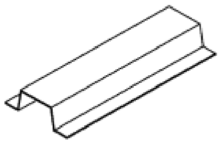
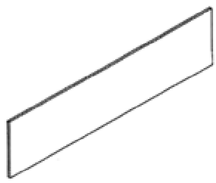
Sections	Use	Shape
Stiffened C Section (stud)	Structural Elements (Joists, Studs, Lintels, Panels).	
Non – stiffened C Section (track)	Closing Elements	
I Section	Lintels, Studs (in case the load is unsupportable using C section elements)	
Box	Lintels, Studs near wall openings	
Channel U section	Lateral Support	
Furring Channel	Lateral Support	
Flat Strap	Lateral Support for Joists	

Table 1-1 Type of sections used in cold-formed steel construction

The identification of cold formed steel system was developed in 1996 by the American Iron and Steel Institute (AISI) [2], in order to standardize the usage of this type of elements.

The identification of sections is based on the shape and thickness of the material (steel), it designates four parameters, the first one indicates the web depth; the second value represents the product code / section type, the third indicates flange width and the last represents minimum base metal thickness (Figure 1-5).

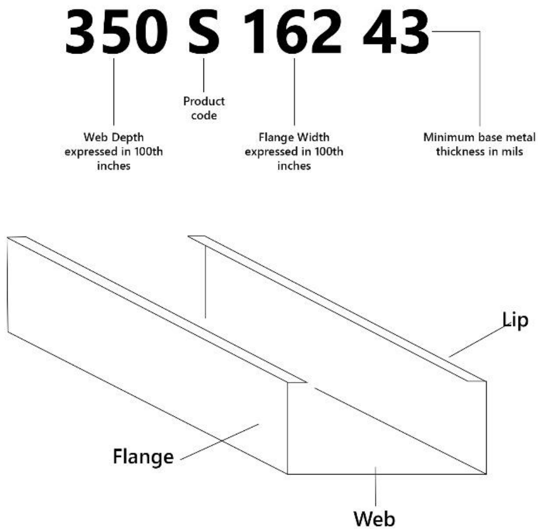


Figure 1-5 Identification of CFS Sections

1.4.2. Wall construction

Cold-formed steel products are used for wall coverings and wall framing:

Wall Covering: Wall panels are widely used as wall covering for metal buildings and office buildings. With technology improvement, wall panels can be made with a variety of shapes and textures, such as embossed, sand-finished metals, to meet structural and architectural requirements. Insulated wall panels can greatly simplify the construction process an achieve significant cost savings.

Wall Framing: In a metal building, C- or Z-shaped cold-formed steel girts are often used to provide lateral support to the metal wall panels. They are normally connected to the rigid frame at each end and are suspended from the roof for vertical support. Cold-formed steel stud wall framing has been widely used in commercial buildings for both exterior and interior wall construction (Figure 1-6)

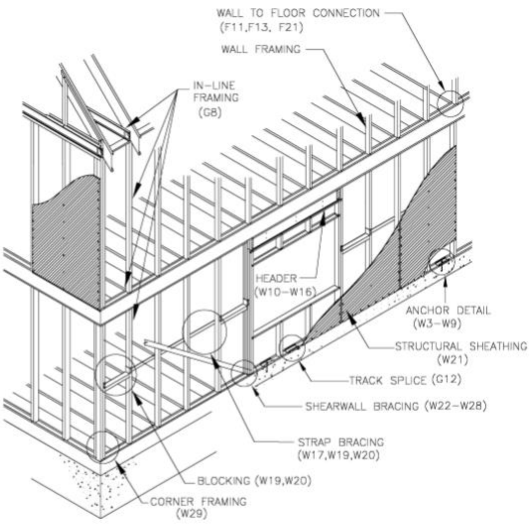


Figure 1-6 Wall Framing [24]

There are two basics types of Walls using light steel framing:

Load-bearing Panels:

This type presents a load-bearing steel frame, to resist lateral forces. The Cold Formed Steel Shear Wall Panels (CFS-SWP) using wood or steel sheathing is a code approved lateral load resisting system for low-rise and medium-rise CFS buildings (Figure 1-7). This structural component owes its post-elastic behaviour to the inelastic behaviour that develops in the connection zone between the CFS frame and sheathing.

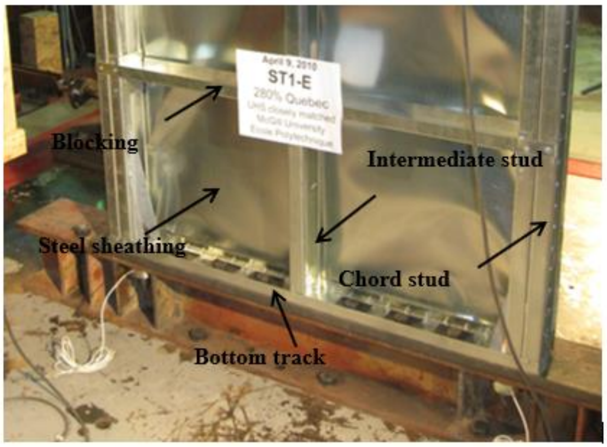


Figure 1-7 Details of a steel-sheathed CFS-SWP

Non-load-bearing Panels:

This type is supported by a structural frame or on a concrete floor. These panels can be located between the primary structural members.

1.4.3. Floor construction

In floor construction, floor decks, steel joists (studs) and trusses are often used as floor coverings, diaphragms and floor framing, respectively.

Floor Deck:

Cold-formed steel decks are widely used in commercial and institutional building construction. They are made by forming cold-formed steel sheet into corrugated profiles, which greatly increases the bending capacity of the sheet steel and results in a very high strength-to weight ratio (Figure 1-8). One of the great advantages of using steel deck in building construction is that it can function as a working platform and serve as a stay-in-place form that carries construction loads and concrete weight during construction, and as a permanent part of load resistance system in service.

There are two types of floor decks: form deck and composite deck. While both types are widely used in building construction, the composite decks usually provide means such as embossments to interlock the deck to the concrete so that higher shear resistance can be achieved. The composite decks usually possess higher strength and are capable of achieving a longer span.

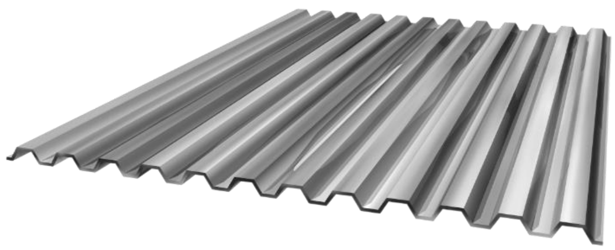


Figure 1-8 Floor Deck in cold-formed steel construction

Floor framing:

Cold-formed steel can also be used as a part of sub-floor structures. They usually consist of C-shaped cold-formed joists or cold-formed steel trusses spaced at 30 cm. or 60 cm. on centre and braced with diagonal or horizontal bridging at 240 to 300 cm on centre. Either concrete or plywood floors can be installed on top of the cold-formed steel sub-floor (Figure 1-9).

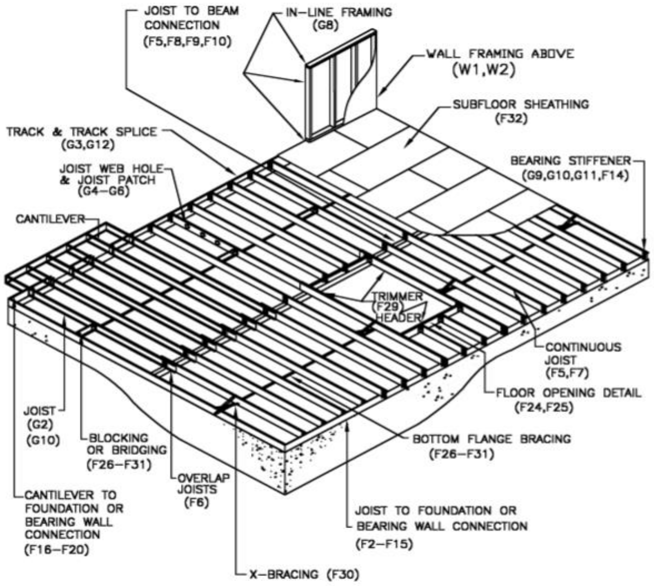


Figure 1-9 Floor Framing Details [24]

1.4.4. Balconies

Balconies may be manufactured as lightweight prefabricated units and attached to the light steel walls via steel plates or connected to square hollow section posts that are installed as part of the light steel framework package. A good example is shown in figure 1-10.

Figure 1-10 Light Steel balcony units attached to light steel framing [39]

1.5. Cold Formed Steel standards

1.5.1. Standards

Starting in the mid-1990s, there began an increased interest in cold-formed steel for residential and light commercial framing in the United States and worldwide. These applications include wall, floor, and roof framing in a number of building types.

Although the AISI North American specification had gained acceptance and was in widespread use, a number of framing-specific design issues were not adequately addressed for this emerging market such as built-up header assemblies Figure 1-11, roof trusses, and shear walls. New design rules were needed to recognize the efficiencies inherent to these assemblies.

It seemed logical to accommodate this activity under the existing AISI structure. However, it was decided that a new committee should be formed, called the Committee on Framing Standards. The Committee on Specifications would retain responsibility for the Specification, as well its test procedures, design manuals, and design guides.

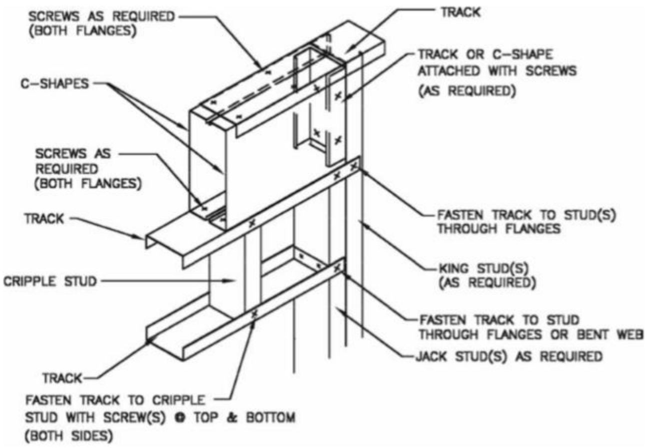


Figure 1-11 Built-up header assembly [24]

In 2007 it was the first time that the standards were specifically for North America, the AISI (Edition 2007) was the new designation for North American Specification for the Design of Cold Formed Steel Structural Members. Which contains:

- AISI S200: This standard addresses those design aspects that are common to engineered and prescriptive design and applies to the design, construction, and installation of structural and non-structural cold-formed steel framing members where: the specified minimum base metal thickness, material specifications, corrosion protection, products, member design, member condition, installation, and connections.
- AISI S201: This standard is intended to establish and encourage the production and use of standardized products. It provides criteria for cold-formed steel utilized in structural and non-structural framing applications and defines standard material grades and specifications, minimum base steel and design thickness, and coatings for corrosion protection.
- AISI S210: This standard is intended for the design and installation of cold-formed steel framing for floor and roof systems in buildings.
- AISI S211: This standard provides technical information and specifications for designing wall studs made from cold-formed steel.
- AISI S213: This standard contains design requirements for shear walls, diagonal strap bracing that is part of a structural wall, and diaphragms that provide lateral support to a building structure.
- AISI S214: This standard provides technical information and design provisions for cold-formed steel truss construction and applies to cold formed steel trusses used for load-carrying purposes in buildings.
- Code of Standard Practice for Cold-Formed Steel Structural Framing: This document defines accepted norms of good practice for fabrication and installation of cold-formed steel structural framing. It helps define the lines of responsibility in cold-formed steel framing design and construction, which have previously been vague and unclear.

The American Iron and Steel Institute (AISI) has published AISI S240-15, North American Standard for Cold-Formed Steel Structural Framing, 2015 Edition, to add new specifications and address new requirements for building construction with cold-formed steel structural framing that are common to prescriptive and engineered design. It applies like the 2007 version, to the design and installation of structural members and connections utilized in cold-formed steel light-frame construction applications, including floor and roof systems, structural walls, shear walls, strap braced walls and diaphragms to resist in-plane lateral loads, and trusses for load-carrying purposes.

1.5.2. Design rules and specifications

From the previous standards we can deduce some architectural rules, conception and design conditions:

- The openings must be aligned vertically to ensure load path continuity along wall studs. Also, to mitigate stress concentration, which causes additional loads that cannot be supported by CFS elements. Consequently, the structure must be reinforced by hot rolled form elements.
- Since the studied type of structures is Cold Formed Steel constructions, and in this type, slabs are exposed to the risk of being deflected due to material characteristics, the span is fixed at 6 meters. if the span is bigger than 6 meters due to architectural design, the structure is strengthened by hot rolled form elements (generally beams).
- Open spaces must be minimized, in order to have a sufficient number of load-bearing walls in the structure.
- A minimum distance of 24 inches between consequent wall studs.
- Load path continuity must be respected, and vertical wall offset must be avoided.

1.6. Advantages of Cold Formed Steel [23]

- Lightweight: Cold-formed steel components weigh approximately 35% to 50% less than their wood counterparts, which means that they are easy to handle during construction and transportation. Also, this results in a reduced seismic load.
- High-strength and stiffness: As a result of the cold-forming process, cold-formed steel possesses one of the highest strength-to-weight ratios of any building material. This high strength and stiffness result in more design options, wider spans and better material usage.
- Fast and easy erection and installation: Building components made of cold-formed steel can be fabricated with high accuracy in a plant and then assembled on construction sites, which greatly increases erection efficiency and ensures construction quality.
- Dimensionally stable material: Cold-formed steel does not expand or contract with moisture content. In addition, it does not split or warp with time. Therefore, it is dimensionally stable.
- No formwork needed: The use of cold-formed steel decks eliminates the formwork for pouring concrete. In addition, composite action between the steel deck and concrete increases floor strength and stiffness.
- Sustainable material: Cold-formed steel is durable because it is resistant to termite infestations and deterioration. In addition, galvanized cold-formed steel products provide long-term resistance to corrosion.
- Economy in transportation and handling: Lightweight cold-formed members or panels are easy to handle and transport. In addition, they can be nested and bundled, reducing the required shipping and storage space.
- Non-combustible material: Steel is a non-combustible material and will not contribute fuel to the spread of a fire. This results in better fire resistance and lower insurance premiums.

- Recyclable nature: Steel is North America’s No. 1 recycled construction material, with a minimum 25% recycled content. Steel products used in construction are infinitely recyclable, with no degradation in structural properties. It can be recycled and reused.
- Energy efficiency: A variety of colour options for metal roofs and panels provides consumers with many choices to select products that save energy.
- The CFS construction system has shown very high structural performance with regard to the various gravity and lateral loads and in particular the seismic loads, where numerous studies throughout the world have proven in recent years the effectiveness of this system in terms of strength, security, and durability. [38, 39]

1.7. Conclusion

Cold-formed steel structures have been used for residential housings and commercial centres since decades, because of the many advantages that this system offers, such as being lightweight, high strength and stiffness, uniform quality, dimensional stability, ease of manufacture and mass production, economy in transportation and handling, ease and speed of installation, non-combustibility, and the fact that it is termite and rot proof.

As mentioned earlier the calculation and dimensioning of the element sections using code formulas is still relatively complicated, because of instability of slender members having unusual cross sections.

To fulfil this gap and facilitate the exploitation for the users, various building industry stakeholders have investigated on the improvement of this structural design by using the computers tools, where many advanced technics have been developed in this aspect such as the necessary data for the preparation of the graphical charts and element shape tables, introduction of this structural system in the Building information modelling (BIM) environment for analysis and design of cold-formed steel members and structures, production of finite element models, as well as some other advantages that will be noted in the next Chapter.

Chapter Two

Building Information Modelling

BIM for CFS Structures

2.1. Introduction

Recently, the implementation of digitalization technology in the industrial building sector has seen a noticeable improvement in productivity, quality and variety of products. The digital tools have been designed so that they are adapted to the needs of the construction industry on the aspects of design, construction and operation. However, the massive and continuous use of data throughout the construction process requires good control and compatibility when exchanging these data between AEC stockholders (Architecture, Engineering and Construction) in order to avoid any loss of information and data that can cause fatal errors and delays during project execution.

Generally, the exchanges of information are done in a graphical way in the format of drawings (plan views, horizontal and vertical sections, detailed views, etc.), where the software's used for the production of these data are almost limited to a simple two-dimensional (2D) presentation. It is through the development of the field of IT in terms of tools and programs, that a new approach has entered in the field of this industry, known by three-dimensional modelling, allowing the description of a building in 3D format. Since then, users have invested in further improving the functionality of this type of modelling, and thus widening the scope of its exploitation.

Building information modelling (BIM) is one of these latest emerging technologies that is performed in the construction design industry in order to facilitate the access to the data exchange to enhance communication among all the project stakeholders AEC. In Addition, the use of the BIM technology has already begun changing the working philosophy between the designers and their consultants and builders, as well as the ability to guide the construction industry into a more economical and environmental aspect.

This chapter discuss the background of the BIM technology, the benefits that BIM can add in general to the construction industry, and a special highlighting cold formed structural design building that BIM can help will be developed.

2.2. Definitions of the BIM

The acronym BIM stands for two main definitions in the building industry:

1- "Building Information Modelling": which describes both the process of creating three-dimensional digital models as well as that of maintenance, use and exchange of data over the life of the project, with a method inter-professional collaborative work.

2- "Building information Model": represents the results of the modelling process, with the establishment of a multidimensional digital representation comprising all the useful information of the building.

The BIM model rallies all the necessary information for the AEC actors, where the data are saved by a parametric way, and interconnected. Any changes to an object within the model are instantly and automatically updated into the building project. A BIM model contains the building's actual construction advancement and assemblies rather than a two-dimensional representation of the building that is commonly found in usual (CAD)- based drawings. (See Figure 2-1)

Figure 2-1 3D BIM Model

BIM is defined also as the creation and the use of a synchronized, consistent, information about a building project in design (parametric information used for design decision making, production of high), the quality of the construction documents, the prediction of building performance, the cost estimating, and the construction schedule (Figure 2-2).

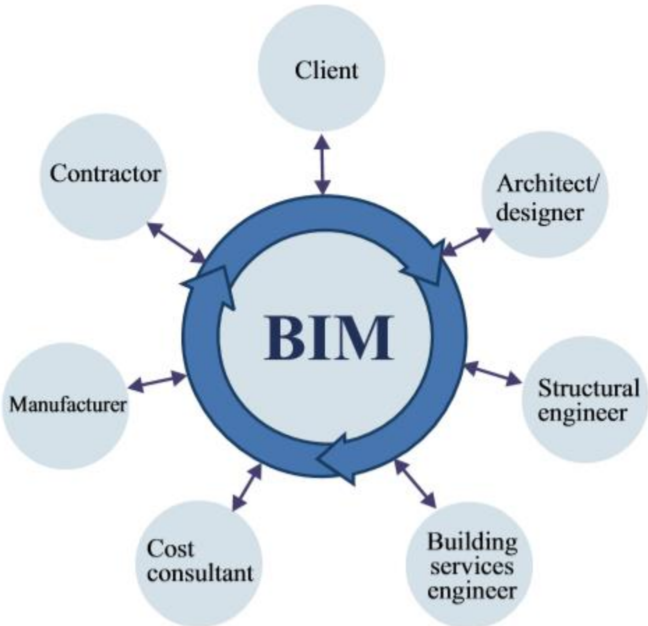


Figure 2-2 Major Participants in a BIM using structured information on a new construction project [33]

BIM allows the development of models at several levels of information, namely: 3D model representing the geometry of the building with these parametric objects; 4D model integrates the schedule of materials, people, space, in overtime during the construction; 5D model includes the lists of supplies as well as the cost aspect in the project; and the 6D (with 7D) models takes into account the management of the installations, as well as their environmental impacts. The following figure summarized the links between the different BIM dimensions (Figure 2-3).

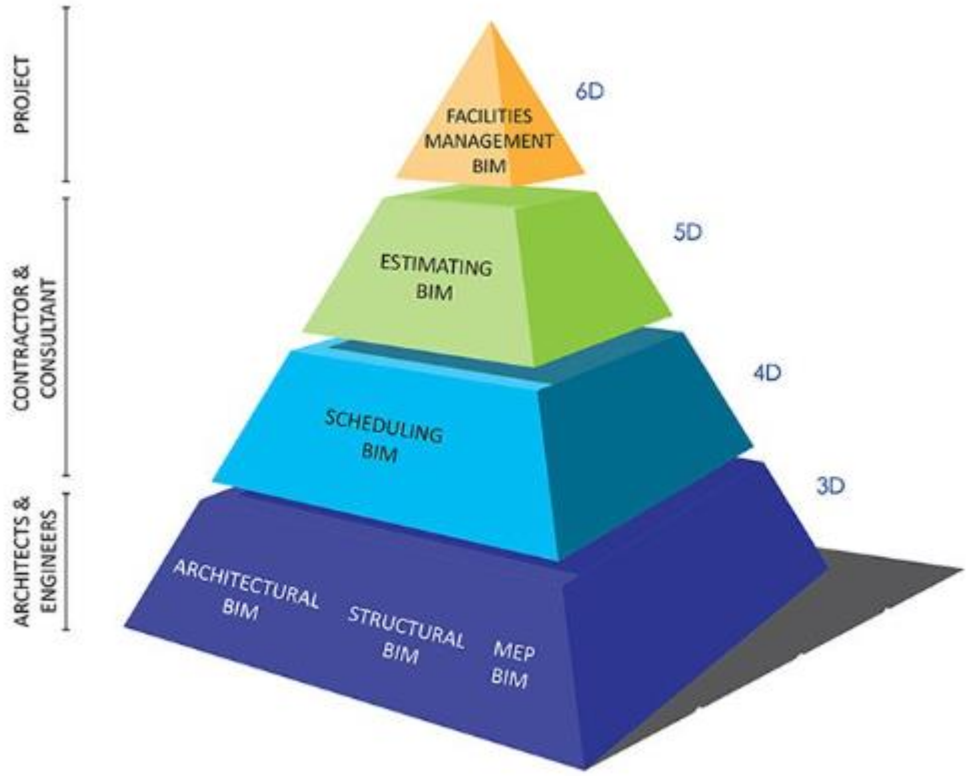


Figure 2-3 BIM dimensions during the construction project [6]

2.3. BIM Maturity Levels

BIM adoption is progressive, and often described as a 'journey'. The milestones on that journey are the BIM Levels.

The concept of 'BIM Levels' has become the accepted definition of what criteria are required to be deemed BIM-compliant, by seeing the adoption process as the next steps in a journey that has taken the industry from the drawing board to the computer and, ultimately, into the digital age.

BIM has several levels of maturity, where these levels are stages oriented towards collaborative BIM. A total of 4 levels are defined, from the basic level corresponding to a simple drawing with lines, to the collaborative three-dimensional level. a detailed description is presented below for all levels:

Level 0 BIM:

In its simplest form, level 0 effectively means no collaboration. 2D Computer-Aided Design (CAD) drafting only is utilised, mainly for Production Information. Output and distribution are via paper or electronic prints, or a mixture of both. The majority of the industry is already well ahead of this now.

Level 1 BIM:

This typically comprises a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and Production Information. CAD standards are managed to a specific code, and electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor.

To achieve this Level 1 of BIM, the following requirements are to be respected:

- Roles and responsibilities should be agreed upon
- Naming conventions should be adopted
- Arrangements should be put in place to create and maintain the project specific codes and project spatial co-ordination
- A "Common Data Environment" (CDE) for example a project extranet or electronic document management system (EDMS) should be adopted, to allow information to be shared between all members of the project team
- A suitable information hierarchy should be agreed which supports the concepts of the CDE and the document repository.

Level 2 BIM:

Level 2 BIM is distinguished by collaborative working, and requires "an information exchange process which is specific to that project and coordinated between various systems and project participants"

Any CAD software that each party uses must be capable of exporting to one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This is the method of working that has been set as a minimum target by some governments for all work on public-sector work.

Level 3 BIM:

Level 3 anticipates the following 'key measures' to be secured:

- The creation of a set of new, international ‘Open Data’ standards which would pave the way for easy sharing of data across the entire market
- The establishment of a new contractual framework for projects which have been procured with BIM to ensure consistency, avoid confusion and encourage, open, collaborative working.
- The creation of a cultural environment which is co-operative, seeks to learn and share
- Training the public sector client in the use of BIM techniques such as, data requirements, operational methods and contractual processes

Driving domestic and international growth and jobs in technology and construction.

Figure 2-4 below summarizes the 4 levels of maturity of BIM.

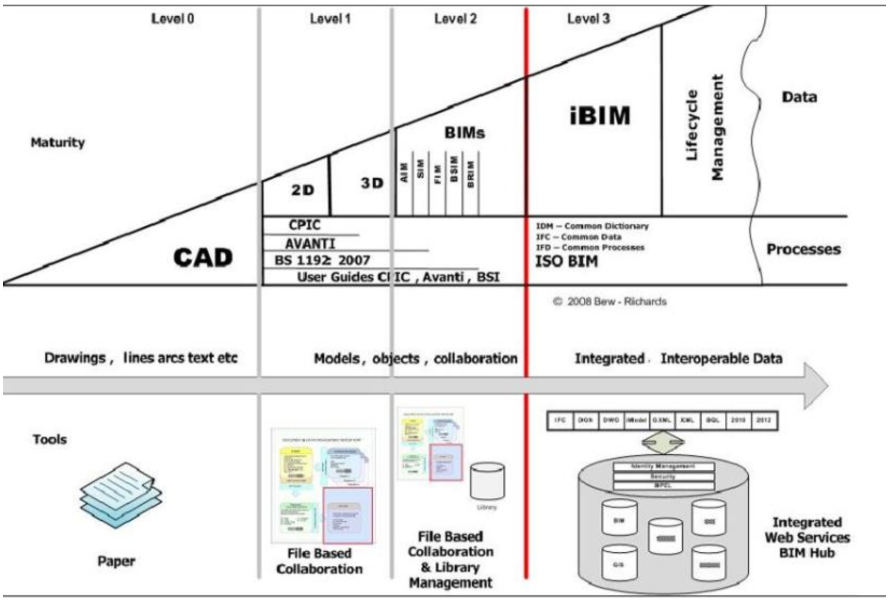


Figure 2-4 BIM's Maturity Levels [33]

2.4. Benefit of BIM in the construction project

As the project partners share information via the BIM, the project is able to progress more smoothly.

Project benefits include:

- Entering data only once and reusing it throughout the life cycle of the project.
- Combination between the geospatial data and building information for schedule.
- Reducing requests for information and change orders.
- Reducing Rework
- improving awareness of progress and current status
- Avoiding clashes
- Reducing cycle time between reviews.
- Creating a time-based simulation of construction activities.
- Reducing costs
- Ensuring lower whole-life costs for the asset through sustainable design.

The diagram in Figure 2-5 below presents the advantages of the BIM use during the life cycle of a construction project

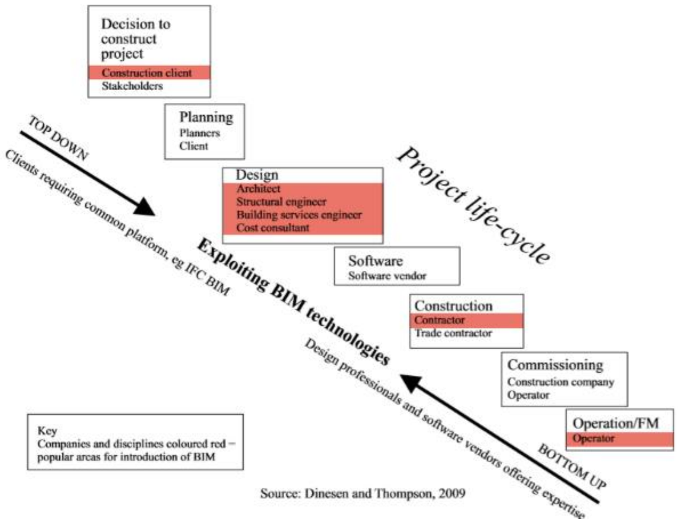


Figure 2-5 Areas where the benefits of BIM are being felt [33]

The table 2-1 shows comparison between the use of BIM technology and the CAD classical method during a construction project

BIM	CAD
All project data is stored in the single environment	Stores and retrieves project data from multiple files
When dimension values change, the objects associated to dimensions are changed	Dimensions only display the distance between two entities
Uses system of categories and subcategories to organize information	Uses traditional 2D/3D drafting capabilities
Creates own intelligent parametric objects & quickly customize the existing ones	Can't create own intelligent parametric objects or layers
Provides access to single file and multiple users with the possibility of defining ownership for some elements or areas.	One person at a time can access and work on a file
Multiple design view with a flexible interface Detail library & material Take-off functionalities	Single design view

Table 2-1 Main Differences between BIM and CAD project [15]

2.5. BIM Protocol

Developed by a government facility of construction Industry Council, the BIM Protocol is generally developed as a complementary standardised legal agreement that can incorporate into professional service appointments and construction contracts by a simple amendment. The protocol consists to standardize the intervention of actors AEC in a BIM project, basing on the contract and the chart that legally committing the stakeholders to stand for the smooth running of the project and to ensure quality of deliverable to the owner in accordance with his expectations.

The BIM Protocol creates additional obligations and rights for the Employer and the others contracted Parties, based on the direct contractual relationship between the Employer and the Supplier.

The BIM protocol, thus makes it possible to control the environment of the project, in particular on the following aspects: [31]

- What role for which person?
- What speaker?
- What project structure?
- What is the mission of each speaker?
- What level of BIM maturity is expected on the project?
- What level of detail should be addressed in each phase of the project?
- Project typology and main characteristics

The answers to the above questions, and by including the IT tools ensure that the project will be well organized and that the role of each actor and what is expected of him will clearly defined, from where through the definition of the levels of detail and maturity will guides to the choice of the good software and their deployment.

2.6. BIM interoperability with calculation software

2.6.1. Interoperability in BIM

Interoperability is a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions.

The term interoperability is used to describe the exchange data capability between the different programs through a common set of file formats, that allows the reading and writing of information by using the same protocols.

One common use case for software interoperability is for the customers freedom to switch from one product to another while keeping the data intact after the transfer. This is especially important for use cases where the data will stay in one system for a long time.

The interoperability parameter plays a leading role in the construction industry between the different stakeholders AEC, where the data exchange will be done in a centralized and a safe BIM platform, ensuring the share of the information and data generated in one time to be usable without a new re-entry for others phases.

2.6.2. BIM interoperability standards

In order to guarantee effective interoperability between AEC players, several open and standardized file formats have been produced and invested by researchers as well as institutions in the building industry, so that software can be able to "read" and exploit these files produced by different software designed by several publishers.

Among the standardized formats:

- IFC: Provides a framework for organizations to produce interoperable software to exchange information on building objects and processes to creates a language that can be shared among the building disciplined.
- XML: Set of rules for designing text formats to structure information. XML supports data transaction between different software applications, leading to a better way to communicate information.
- gbXML: is the most widely supported data format for the exchange of building information between BIM/CAD and energy performance applications.
- BIMXML: an XML schema developed to represent a simplified subset of BIM data for web services.
- IDM: Information Delivery Manual, the business case specification for exchange BIM data, including end user Exchange Requirements.
- RVT: This is Autodesk's proprietary format for Revit files. These can vary significantly in size depending on the level of development. They can only be opened in Revit.
- BCF: BIM Collaboration Format, an XML schema that encodes messages to enable workflow communication between different BIM software tools.
- IFD: Describes what kind of information is exchanged by providing a mechanism that allows the creation of unique IFD IDs, to connect information from existing databases to IFC data models.
- DWF: Design Web Format, originally developed by Autodesk, as a PDF alternative for CAD data/documentation.
- PDF: Portable Document Format originally developed by Adobe for the electronic exchange of any printable document.
- OGC: Open Geospatial Consortium, international industry consortium for developing standards for geospatial data-enabled technologies.

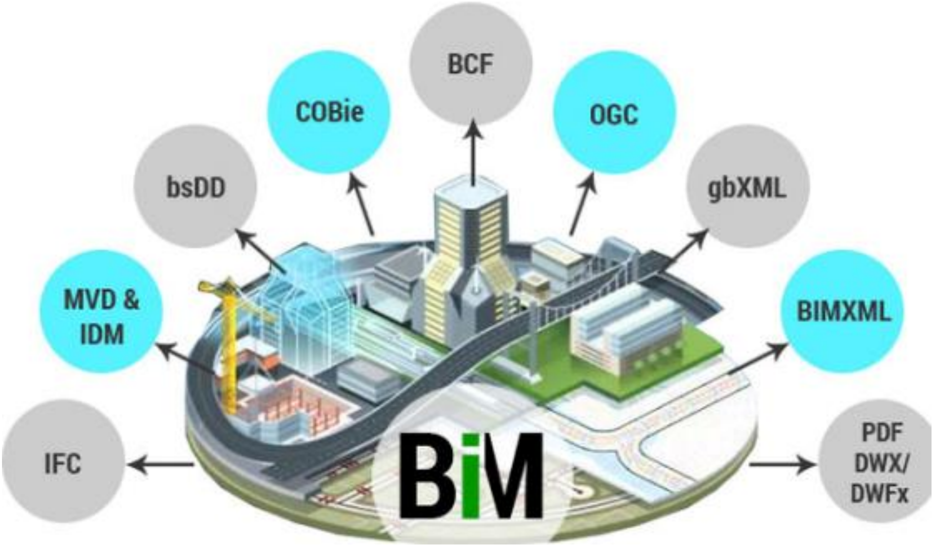


Figure 2-6 Open Standards for BIM interoperability

2.7. Implantation of BIM into CFS buildings

Cold-formed steel construction (CFS) has proven to be a worthy alternative to traditional building systems due to its high strength to weight ratio, high degree of dimensional exactness and sustainability. The information integration provided by Building Information Modelling (BIM) can be utilized to enhance the efficiency of this construction system. Programming tools specific to CFS residential buildings can be utilized during the different project phases to facilitate BIM implementation.

The first step in the procedure is to identify the high value BIM Goals and Uses during project planning, design, construction and operational stages. The guide [8] identifies twenty-five BIM uses which are organized by these project phases. Out of these BIM uses, the following uses shall be employed to enhance the efficiency of CFS residential projects [1]:

- During Planning Phase: Programming.
- During Design Phase: Structural Analysis and Design Authoring.
- During Construction Phase: Digital Fabrication.

2.7.1. During Planning Phase: Programming

Programming, in BIM terminology [4], is a process in which a spatial program is used to assess design performance in regard to spatial requirements. The development of the BIM model can help us to understand and analyse the complexity of space standards and regulations.

In this phase, one of the major obstacles that can causes a disturbing during the structural design of the building, is the variability of the layouts of the architectural floor plans, especially the distribution of the walls and rooms. A possible solution to this problem, is to industrialize the process to make prefabrication and mass production of building elements feasible (Figures 2-7 and 2-8).

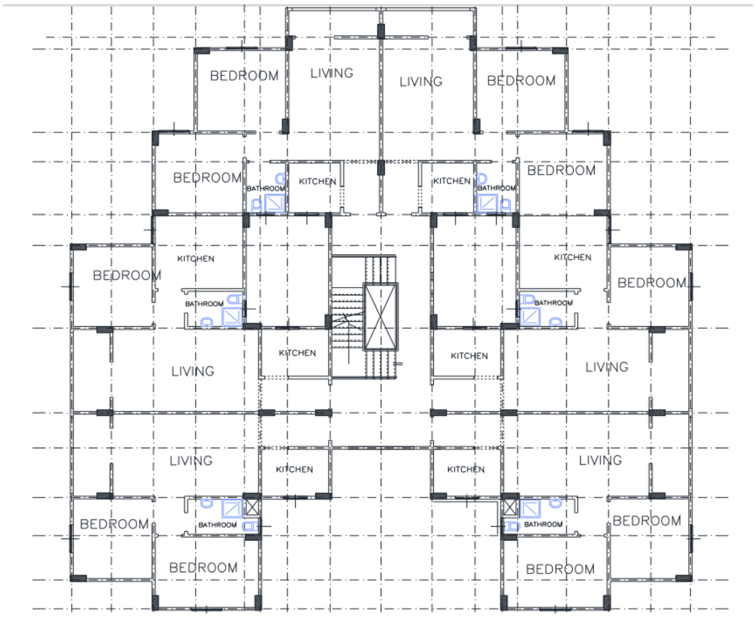


Figure 2-7 Floor plan created from three basic modules [1]

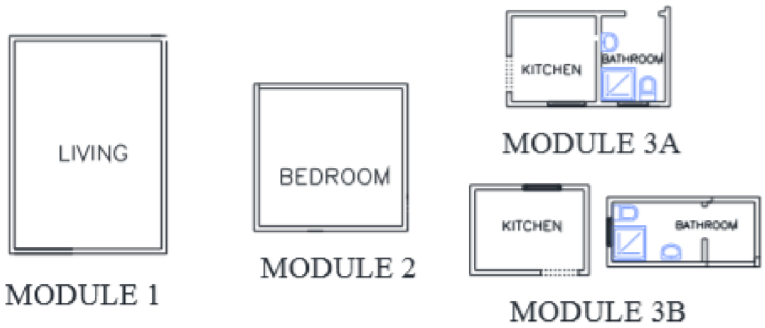


Figure 2-8 Basic three modules used in floor plan creation [1]

2.7.2. During Design Phase: Structural Analysis

Structural Analysis, in BIM terminology [8], means process in which analytical modelling software utilizes the BIM design authoring model to determine the behaviour of a given structural system.

The work on cold-formed steel structures usually involves studies of the structural behaviour and instability of plate components, individual members, and/or the entire assembly, so it's very difficult to represent all the members and theirs details in the 3D model, but once it is done, the structural analysis can be performed under different loading conditions using the 3D model and information provided by BIM. With the adoption of the direct-strength method for cold-formed steel design, the use of a numerical method is explicitly permitted. In fact, a numerical method is required in order to determine the elastic buckling load for the member as a whole rather than an element-by-element local buckling analysis.

It is necessary to mention that although there are many studies carried out on FE modelling of cold-formed thin walled structures, very few of them have implemented all structural characteristics such as the material's non-linear behaviour, geometric imperfections, residual stresses and section perforations concurrently.

The past efforts in modelling the seismic response of CFS-framed buildings typically rely on simplifications to save computational cost: most commonly the shear wall is idealized as a nonlinear spring or a pair of nonlinear braces ; the gravity system is ignored (except as a leaning P Delta column); and the diaphragms are assumed to be rigid. The authors' work [reference to be added] initiated on a similar path, but the predicted results deviated significantly from tested response. For example, predicted first mode period was 100% larger than the measured building natural period. (structural only) building with a model using these protocols.

This realization led to the development of higher precision models that reject common modelling simplifications to provide reliable prediction of CFS-framed building system response under seismic excitations.

Due to the flexibility in manufacturing, cold-formed steel has great advantage to maximize the material efficiency through cross-sectional shapes. Although the sections in the industry [35] hold some advantage in large amount of production, they may not be the most efficient sections to use in the design. Using optimization techniques, the least weight section to satisfy both the strength and serviceability constraints can be found.

2.7.3. During Design Phase: Design Authoring

Building Information Model (BIM) can be described as a method to increase the productivity of construction industry. Within BIM, the building is represented by a group of interrelated objects such as walls, windows, doors …etc. These objects properties are pre-defined in one or more databases. As a result, the model becomes rich with information and details of the building and its objects, also, it is considered to be useful during the lifecycle of the building including construction and maintenance processes.

This system, is based on parametric modelling, meaning all objects are related to each other according to certain parameters, and these relations can be updated by changing only one of the properties. This model, can be linked to schedules, means, costs and methods, in order to provide easier and faster information sharing.

- Development of BIM CFS Objects:

In the BIM terminology, each building component belongs to a Family. Examples of these are “Wall Family”, “Floor Family”, “Floor Plans”, “Sections”, and so on.

Families can be created or modified from other component families through parametric modelling. The strength of any BIM software lies in the ability to create suitable parametric component families from available family templates to represent a specific building.

The basic procedure for creating parametric component families is as follows:

- Select a suitable Family Template from the software library.
- Define the major parameter that control the new family such as size, material, paint, etc.
- Create and constrain model geometry by defining reference planes and geometry constraints.
- Create Family types if needed.

This procedure can be applied to create the necessary component families needed to model a typical cold formed steel building, such as: CFS Walls, CFS Floors, Wall Bracings and Footings.

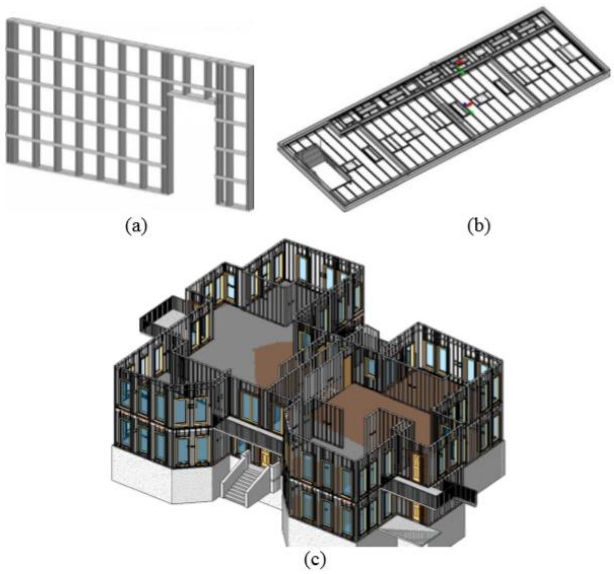


Figure 2-9 BIM Parametric Objects [1]

(a) Wall panel object

(b) Floor panel object

(c) Entire building created from wall and floor objects

2.7.4. During Design Phase: digital fabrication

Digital Fabrication, in BIM terminology [14], is a process that uses digitized information to facilitate the fabrication of construction materials or assemblies. The advantage of this process can be well appreciated during the manufacture by ensuring a lower rate of defects and wastes. Furthermore, the model can be used to produce the workshop drawings [25].

2.8. Application of 4D and 5D BIM In CFS constructions

Once the 3D building model has been created, available BIM tools can then be used efficiently to explore and evaluate the project's constructability before it is built, visualize construction processes through schedule simulation and monitor the cost at different construction stages.

2.8.1. Project scheduling in BIM (4D BIM model)

The project schedule dictates the pace at which construction is performed and sets a timeline for project completion. Project schedules are vital to the construction process, making massive projects manageable by dividing them into individual parts.

Project scheduling can be implemented in BIM by linking the 3D BIM model to the project schedule so that the construction progress over time can be visualized. The developed model, called 4D BIM Model, integrates the three-dimensional building model database information with the fourth dimension that is the time. In other words, a Visual 4D model combines 3D models with construction sequencing activities to display progression of construction over time, thus, improving the quality of construction documents and schedules. Accordingly, planning of construction projects, and communication and coordination among the different project stakeholders will be enhanced.

Several techniques exist for the development of 4D BIM. These can be classified as: [18]

2.8.1.1. Built-in 4D features in a 3D or BIM tool

In these methods a "phase" of a BIM object is assigned to the object property or parameter by adding the "phase" parameter to the BIM object.

However, the built-in 4D capability in BIM tools is for basic project phasing since the phases defined are not based on the "date" and "time". For users who need to track a more accurate project schedule such as the Actual start date, Actual end date, planned start date, planned end date, etc., the direct integration with schedules generated by professional scheduling software tools is more applicable.

2.8.1.2. Export 3D BIM to 4D tool and import schedule

The limitations of previous BIM 4D method encouraged the software developers to find out a way which can fully integrate the scheduling software with the 3D model. Generally, the steps involve importing the existing 3D BIM model into the BIM software tool, importing the schedule created by another scheduling software tool (such as Primavera) and then linking the schedule with its relevant objects in the BIM model.

2.8.2. Cost estimation in BIM (5d BIM model)

The two main elements of a cost estimate are quantity take-off and pricing. Quantities from a Building Information Model can be extracted to a cost database or an excel file. However, pricing cannot be attained from the model. Cost estimating requires the expertise of the cost estimator to analyse the components of a material and how they get installed.

The cost estimating process involves performing quantity take-off (QTO) and adding cost data to the QTO list. Traditional QTO process with CAD drawings involves selecting individual elements in CAD drawings, using the software to automatically determine the dimensions for the take-off, and inputting the quantities into the QTO list. This process requires estimators to spend substantial amount of time on generating the QTO of the entire drawing. Since BIM models are object-based with built-in parametric information, it will be more accurate with less errors to capture the quantities of the objects directly from the BIM model using quantity take off tools. The QTO process is also expedited– it can require 50% to 80% of a cost estimator's time on a project. QTO process can be enhanced with higher accuracy and less time using BIM technology. Mapping the QTO list with cost databases, which can be built-in in BIM models or a standalone external cost database, estimators can generate a more accurate and reliable cost estimate of the building with minimal effort.

The resulting BIM model is called 5D BIM model in which project cost is integrated with the 3D model of the building making it possible to forecast and track the project cost throughout all the phases of construction (Figure 2-10).

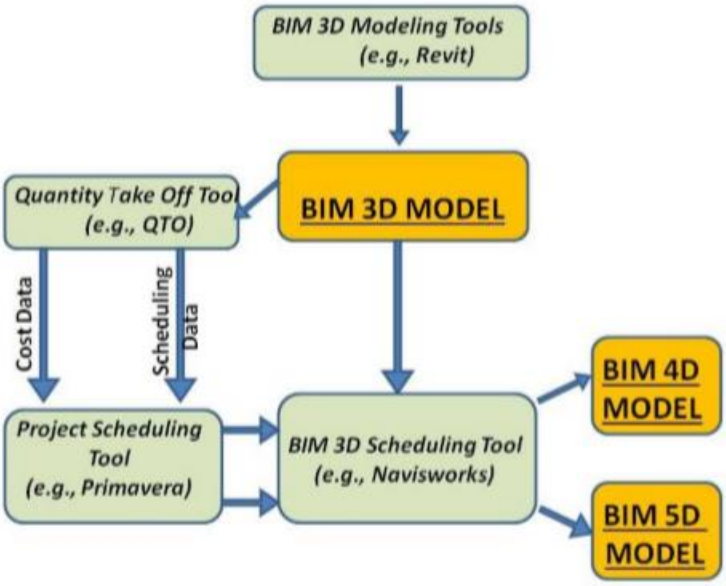


Figure 2-10 Schematic diagram for developing 4D and 5D BIM Models [18]

2.9. Level of development of BIM

The Level of Development (LOD) allows project teams to specify the level of the content and reliability of the BIM Models at a various stage in the design and construction process.[9]

Using a scale from 100 to 500, LOD applies to each element included in a BIM. It does not characterize the overall project level of detail or the phase of a project. Rather, LOD establishes requirements useful in a collaborative environment. LOD provides the project team with the data they need to support design planning, clash detection, construction sequencing, and other coordinating functions associated with the element (Figure 2-11).

Level of Development	Basic definition	Cold Formed Steel Framing Examples
LOD 100	Informational content related to an assembly. Assembly depth, thickness, size, and location are still flexible.	Approximate CFS framing dimensions. CFS cost per square foot.
LOD 200	Graphical content for generic assemblies with approximate quantity, size, shape, location, and orientation. May include non-graphical information.	Rough CFS quantities and member depth. Desired CFS member spacing
LOD 300	Graphical content for specific assemblies. Precise quantity, size, shape, location, and orientation for the element can be measured from the model.	Specific CFS quantities, depth, spacing, locations, and geometries. LOD 300 is common for typical CFS framing coordination.
LOD 350	Includes LOD 300 with the parts needed to coordinate the element with other nearby or attached elements.	CFS framing assemblies modelled precisely at wall bottoms, tops, and sides. Includes bridging, strap, and other support information.
LOD 400	Requires sufficient detail and precision in order to fabricate the assembly or system component.	CFS fabrication, panelization, and installation information. CFS fabrication part numbers. All parts required to complete CFS installation. Includes CFS weld and connection information

Table 2-2 Level of Development [27]

Figure 2-11 LOD in CFS walls

2.10.BIM Platforms

BIM software is widely used by many construction businesses (big and small) especially in the AEC sector. So, there is a plenty of BIM software solutions available:

- Autodesk BIM360: is a cloud-based web service that provides teams access to data to improve decision-making and avoid expensive delays.
- Autodesk Revit: It is one of the most popular software packages developed by the CAD giant Autodesk. It is developed to be used by all the AEC actors, such us, architects, Civil engineers, drafters, MEP & Electrical engineers, contractors, and landscape architects, among others.
- Tekla structure: considered to be famous competitive product to Autodesk, is an easy and efficient program -to- use, leading the same functions like Revit.
- Navisworks: is also built by Autodesk. The difference between Navisworks and Revit is that Navisworks functions as a project review software tool for AEC professionals.
- Tekla BIMsight: leading the same functions to Navisworks, but especially for the Tekla models, actually replaced by Trimble connect.
- Trimble Connect: is a cloud-based platform that specializes in connecting the right data to the right people at the right time. This solution is designed for architects, engineers, general contractors, subcontractors, and owner-operators. It brings people, technology, and information together in an environment that empowers collaboration.
- BIMobject: is a BIM content open source platform. It is a cloud solution used by architects, engineers, contractors, and designers to access manufacturer-specific BIM objects.
- BIMx: is a collection of desktop and mobile software tools to present BIM models in 3D models and 2D documentation. The integrated 2D and 3D building project navigation bridge the gap between the design studio and the construction site.
- ArchiCAD: is a 3D architectural BIM tool for design and modelling. it is used by urban planners, architects, and designers to enhance their design workflow processes.
- Vertex BD: is a BIM platform for Cold formed steel frame.

In this study, we opted in the generation of the digital platform for Autodesk Revit 2020. Owing to its capability to minimize the risk of errors caused by miscommunication as all process goes through a single system. Coordination is also achieved via its multiple project contributors features to avoid rework and clashes. Revit also allows the user to simulate and reiterate designs for Cold formed steel frame systems and structures. This 4D BIM is capable of tracking the construction process' entire lifecycle from conceptualization to maintenance, and even demolition.

2.11.Software Description [10]

Autodesk Revit is Building Information Modelling (BIM) software offering a multi-disciplinary and collaborative approach to design and construction projects. Revit empowers architecture, engineering, and construction professionals to produce consistent, coordinated, and complete model-based designs for buildings and infrastructure. By unifying powerful tools for architecture, MEP, and structural engineering into a single interface.

Revit also has extensive uses. It has gained its immense popularity and prestige owing to the series of ways it has been used in this digital era. The efficient use and designing of Revit have led to exceptional models and projects which are still known in the world.

Revit software would help produce exceptionally well-coordinated, consistent, well-compiled building structures and designs as well as documentations which are mostly model based. It makes use of 3D visualizations to have an idea of the buildings it will be growing in the near future. It is essential to have a clear idea about the construction process.

Revit is an extremely viable option for 3-D viewing of different sections of the architecture. It is recommended for its extensive use of tools that enhance architectural and structural designs. Revit has been used across multiple disciplines with its use of work-sharing that share projects by dividing around work across various disciplines.

The workflows could also be enhanced immensely with regional solutions, which could be customized as per third-party partners. Revit could also be used to connect various teams as well as data on singular projects on the BIM 360 platform.

2.12.Conclusion

During the last years, the CFS (cold form steel) construction system has recognized a significant advancement in the building industry worldwide, with a particular use for the small and medium buildings less than 18 m in total height. This is principally due to the efficiency of this system in structural aspect, and also the cost/time rate in project, that has been proved in a different project through various countries. With the advancement of CFS manufacture technologies, it is now in a position to be more competitive to other structural systems in the market of the construction industry.

Integrated in a BIM environment, the CFS structural system will become more interesting, competitive and enable to have promising result by comparing to the others structural design such us wood, or reinforced concrete, etc...

Currently, with the advanced and easier BIM tools, the CFS system can be more investigated to aid the transition and the implementation of this design, to be in same level with other construction systems.

Chapter Three

Elaboration of CFS models on BIM platform

3.1. Introduction

During a building information modelling process, project teams contribute information and data about a proposed building or structure in a shared digital space known as a Common Data Environment (CDE). This enables all parties to access it to develop and co-ordinate their respective contributions.

In this chapter, we will present the basic steps that is followed for the elaboration of a cold formed steel frame structural projects in a BIM environment using the software Autodesk Revit. Subsequently, three realistic structures are modelled and exported in IFC format for further processing using the genetic algorithm.

3.2. Work Hypotheses

All the structural members used in the design of the structures are Cold formed steel material only, except for the strengthening frames with a hot rolled material member that is not considered in the design of the structures treated by the optimization algorithm.

From another point, in order to make it possible for the algorithm to determine automatically the bearing direction of the joists while taking into account the dimensions of the rooms and the openings. All rooms of the structure are considered rectangular.

In CFS frame system for low rise buildings, generally the minimum total length of shear walls required to ensure the stability of the building does not change drastically from a level to another.

3.3. Presentation of the CFS buildings

The model 1 (Figure 3-1) consists of a two-storey medical office building with a one-story annex framed with cold-formed steel. implanted In Sidi Bel Abbes.

The model 2 (Figure 3-2) is a five-storey building located in the wilaya of Chlef.

The model 3 (Figure 3-3) is also a five-storey building located in Constantine.

All the buildings are designed and constructed in accordance with the rules of construction, with respect for the safety and comfort of the occupants.

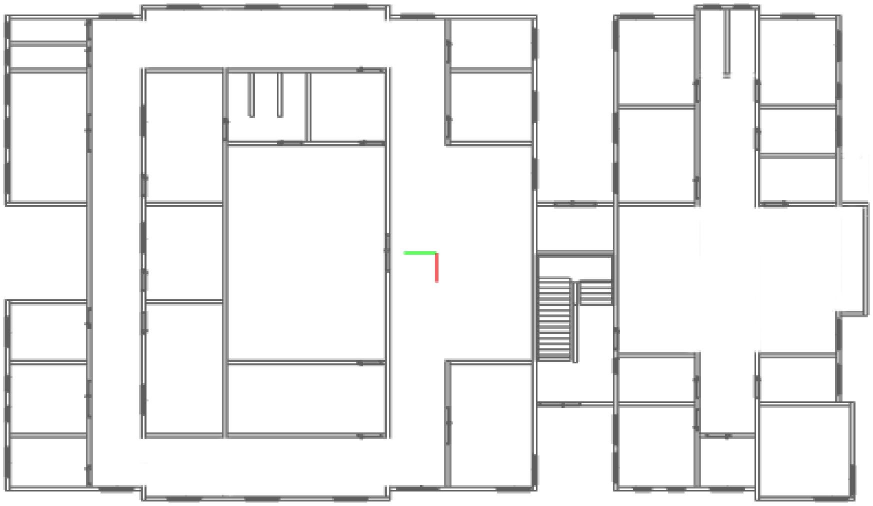


Figure 3-1 Model 1 Plan

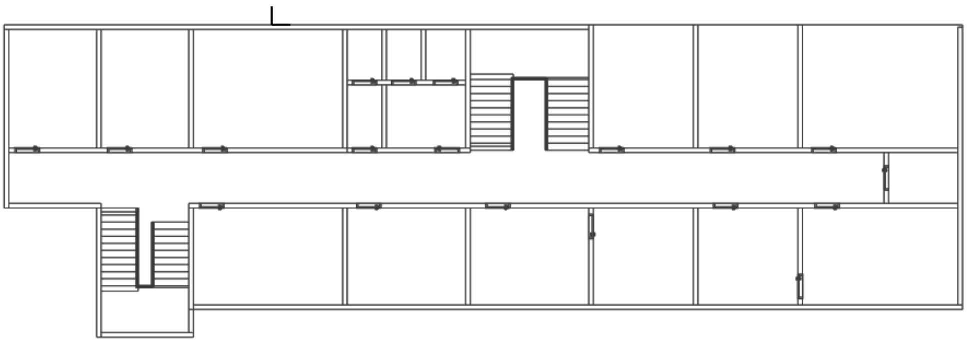


Figure 3-2 Model 2 plan

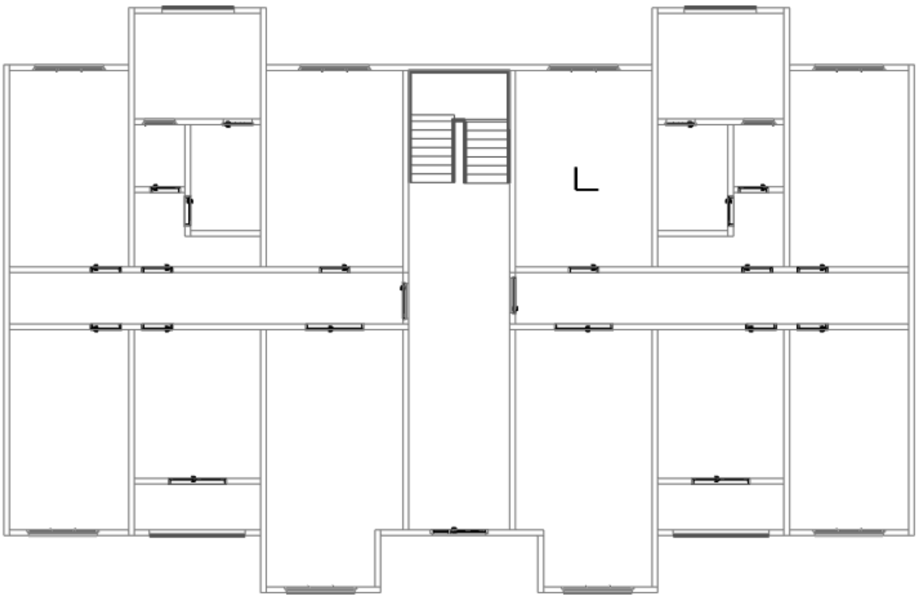


Figure 3-3 Model 3 plan

3.3.1. Structural design and systems summary

The three structures are made of cold formed profiles with light concrete floors. The sheathing of interior and exterior walls is made of magnesium plates called «Magboard» of dimensions 1.22 x 2.44 m with a thickness of 12mm.

The floors and roofs are composed of panels assembled of several cold formed steel structural elements, to support vertical loads, as well as to ensure better thermal and sound insulation.

The floors are composed of cold-formed C-Profile joists arranged in a constant spacing of 60 cm between axes.

The decks are made of ribbed sheet metal, receiving a thin layer of concrete (5cm).

The connection between the panels and the floors of the structure is done by means of self-bearing screws.

The partition walls as well as the exterior walls are made of panels composed of C-shaped cold-formed profile posts, the panels are bordered on the top and bottom by cross-members of U-section.

The stability and the bracing are ensured by shear wall in both directions, these panels are composed of cold formed profiles (type S, T, U and F) 60 cm apart on which plates (sheathings) are applied on one or two sides depending on the shear resistance of the panel.

3.3.2. Mechanicals proprieties of Cold Formed Steel members

- The modulus of elasticity: $E = 210\ 000$ MPa
- Poisson ratio: $\nu = 0,3$
- Shear modulus: $G = E/2(1+\nu)$ MPa
- The coefficient of the linear expansion: $\alpha = 12 \times 10^{-6}\ C^{-1}$
- Density: $\gamma = 7850\ kg/m^3$

3.4. Revit families

In Revit, components and other content are referred to as families. Some of these elements can be created and edited within the project environment, and some are created and edited outside of a project file. Revit comes with a built-in family-editing application called the Family Editor that is tailored for making all types of content, from doors and windows, to annotation symbols, to stand-alone furniture.

All elements in Revit are considered families. When we open Revit, a standard set of architectural objects and annotation symbols is already created and ready to use. These are all "families."

System families are created in the context of a Revit project. The only way that allow us to create a new kind of system family is by duplicating an existing family and then changing its properties. Here is a list of some of the families that fall into this category:

- Walls
- Roofs
- Stairs and Railings
- Floors
- Ceilings

- Ramps
- Mullions
- Topography

To create a new system family, select the one that is most similar to the requirements, duplicate its type, rename it, and modify the properties.

3.5. Setting Up Project Environment

Project Units: Revit has its default units fairly well defined (Figure 3-4).

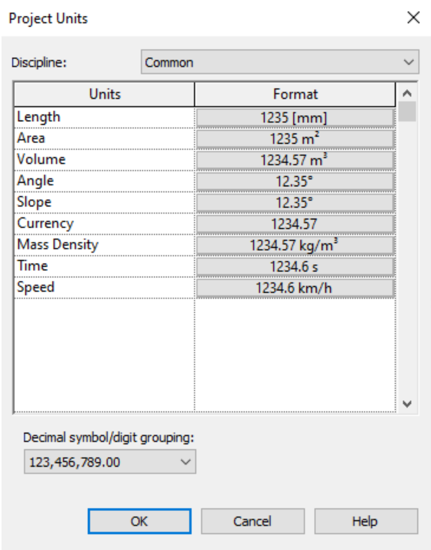


Figure 3-4 Units

Slope: Various settings for slope are in the Format column in the Project Units dialog box accessible from the Manage tab in the Project Settings panel (Figure 3-5).

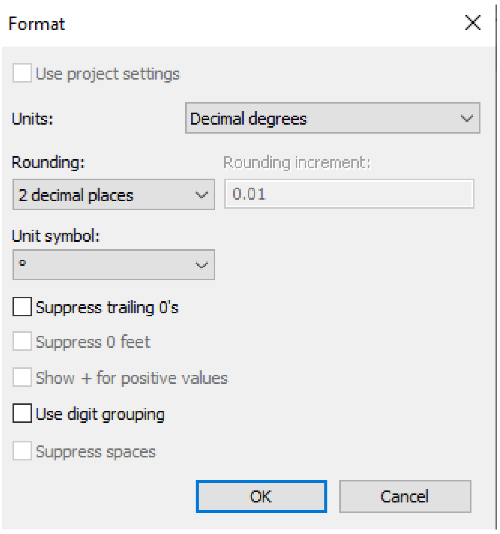


Figure 3-5 Slope Settings

Currency: When making schedules. add currency information when calculating cost, and Revit improvement accommodates that need (Figure 3-6).

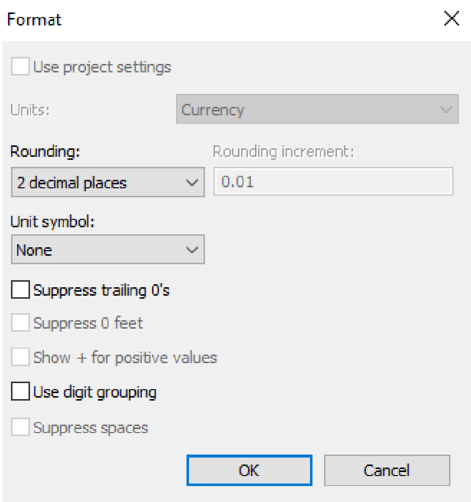


Figure 3-6 Currency Settings

Snaps: Snaps are a great help for precise placement and modification of elements. In Revit, snaps be defined inside "Manage" tab (Figure 3-7).

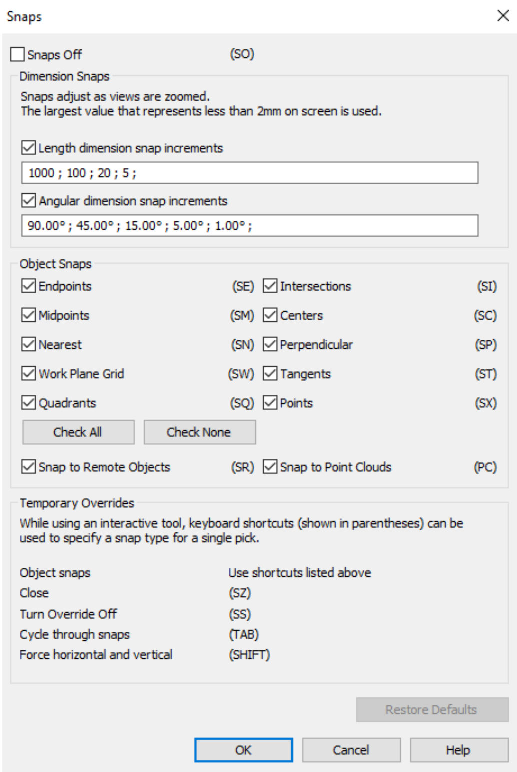


Figure 3-7 Snaps Settings

3.6. Starting the design

Starting by defining the number of stories (levels) that your building will have and giving the levels floor-to-floor heights.

Then creating the walls which are one of the basic building blocks of architecture, and are easily constructed with Revit. Walls are built from layers of materials that give the wall thickness; they aren't a mere collection of parallel lines. Each material has a user-definable representation for cut and projected geometry (Figure 3-9), which makes it possible for walls to be represented properly depending on the type of view the wall appears in. For example, when drawing walls in plan-view, the wall is shown as if it were being cut, with materials represented as abstract hatch patterns. Changing the viewing perspective of the same wall (from an elevation or in 3D view) as in Figure 3-8, materials are represented with a more realistic expression.

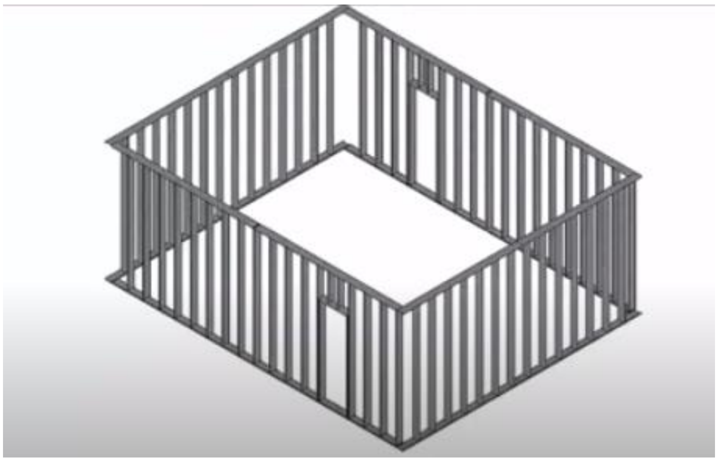


Figure 3-8 CFS Walls Representation in Autodesk Revit

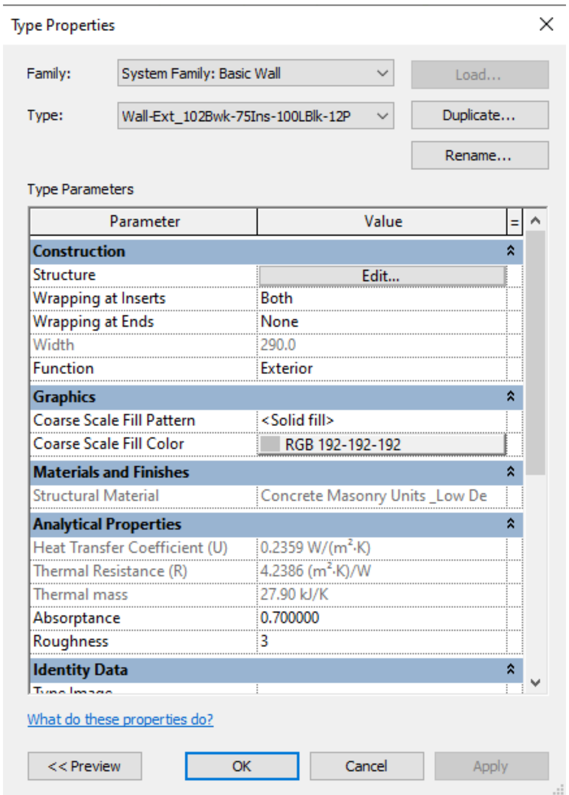


Figure 3-9 Wall Properties

The most important thing to understand about windows and doors is that they're hosted by walls. Without a host wall, doors and windows can't exist in your model. Figure 3-10 shows a window hosted by a wall.

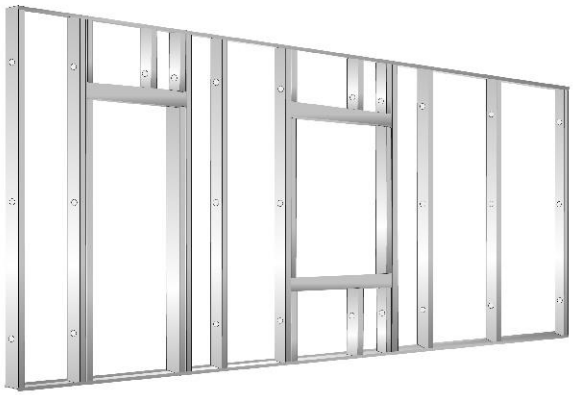


Figure 3-10 Door and Window hosted by a cold formed steel wall in Revit

Doors and Windows are like walls, they are created from layers of materials that give the opening properties (Figure 3-11).

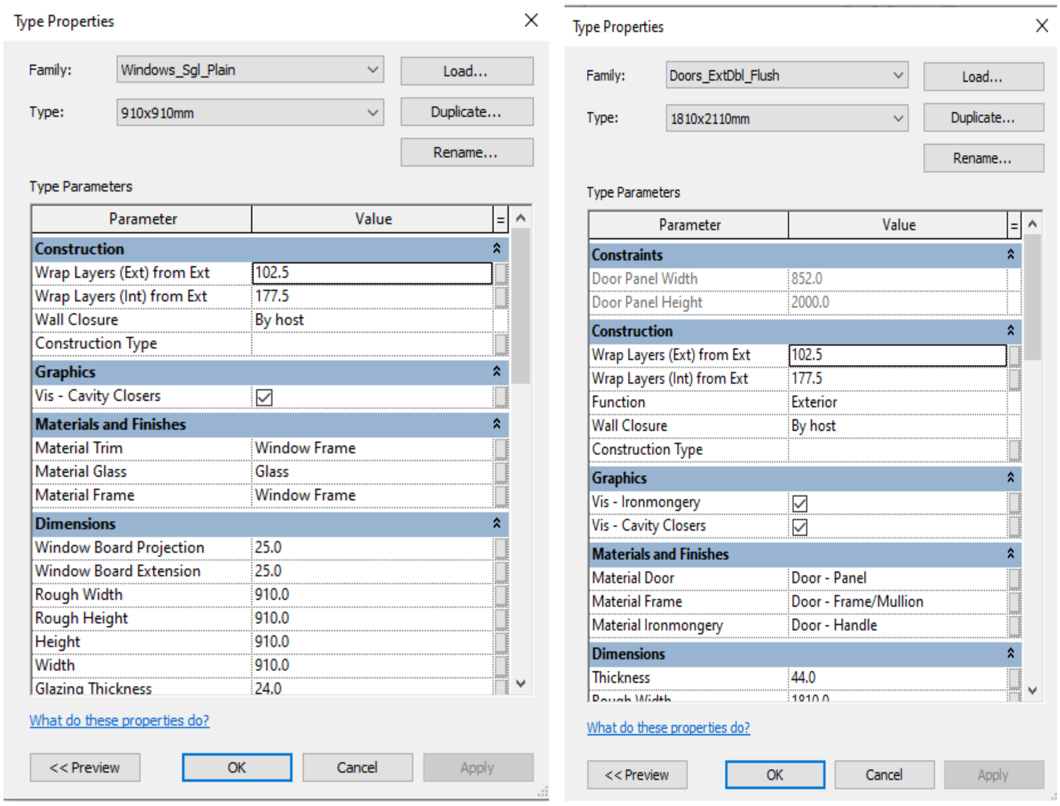


Figure 3-11 Type Parameter in Autodesk Revit

Then creating Floors, Roofs, and Ceilings, which are similar to walls in that they're built of layers of materials and are constrained to levels. The interface for creating and editing layers of construction is nearly identical to that of walls.

Floors and roofs also use the same material layer routing as walls, making connections between walls, floors, and roofs appear correctly (Figure 3-12).

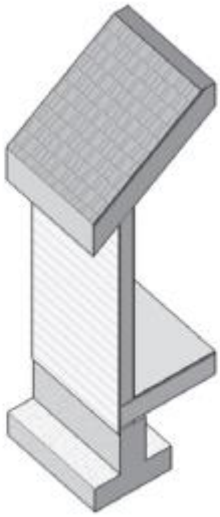


Figure 3-12 Wall joint with Roof and Floor

Finally creating stairs and railings, most buildings have stairs, and where there is a stair, it is possible to encounter a railing. Revit provides specially designed tools for the creation of stairs, ramps, and railings that allows user control over their basic constructive parts. With stairs, design rules for elements such as stringers, treads, and risers can also be set by the user; then Revit builds the 3D model according to the settings (Figure 3-13).

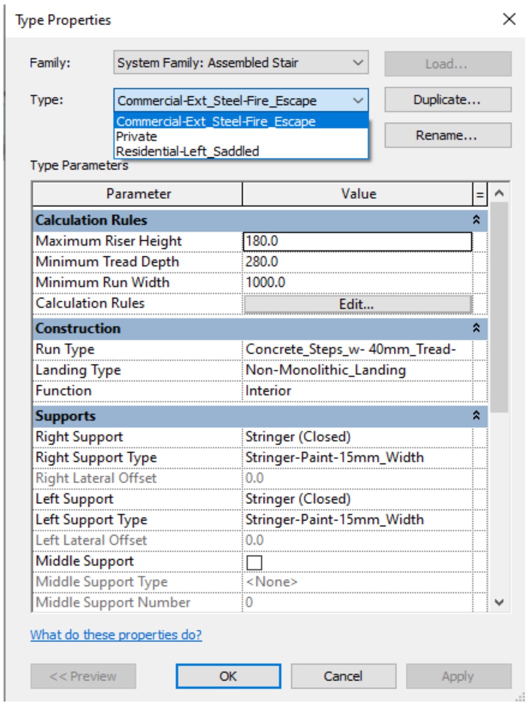


Figure 3-13 Stairs Parameters in Autodesk Revit

3.7. Converting 2D Drawings into a 3D BIM Model

Often when working on a project, 2D plans are already available, sections, and elevations that will be used as a base to create a 3D building information model. Revit offers the flexibility to incorporate legacy material in the model, and allows importing data from multiple file formats (DWG … etc). The development and adoption of intelligent software means that someday redrawing will no longer be a necessity. Revit offers the ways to maximize the reuse and referencing of existing data.

Revit objects can be created in three ways:

- Drawing: The default mode for all Revit tools that requires the user to draw objects is the Drawing mode. The shape of the object can be created using standard drawing options in this mode.
- Picking references (lines) out of which the object can be created: Instead of manually drawing, this option allows the user to create elements by picking references. It helps to draw and then convert any line of an imported drawing into an object.
- Picking a face

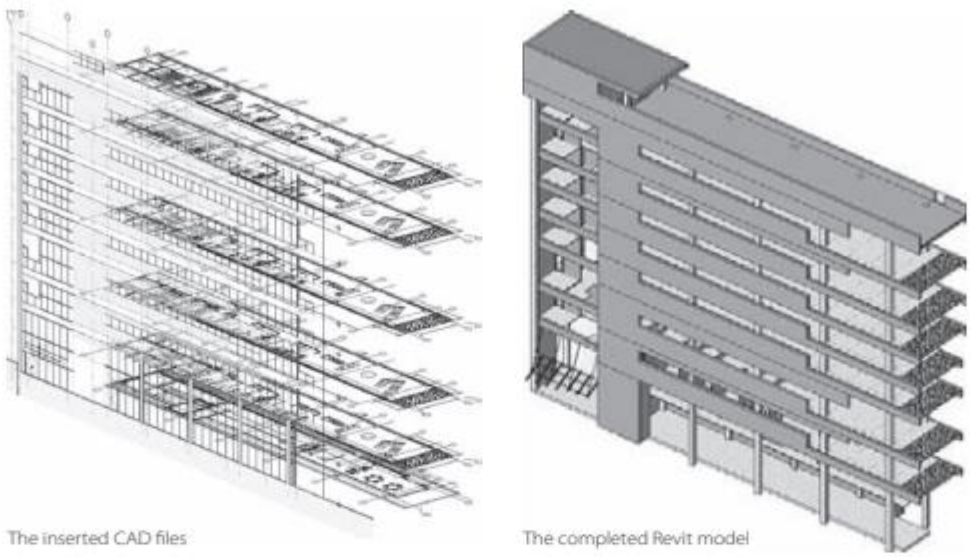


Figure 3-14 Converting 2D drawings into 3D BIM model

3.8. Exporting BIM Data

The construction process goes through many iterations and exchanges of information among different parties.

For cold formed steel frame system, the generation of the shop drawings is a long process and very important for the construction project.

Shop drawings can be defined as drawings and figures prepared specifically for the machines that print CFS elements, by a building product manufacturer using a specific software (Vertex BD).

These figures contain all the properties of each element of the structure (Figure 3-15).

PIECES LIST

LABEL	QTY	SIZE	LENGTH	USE
AC	2	3x.375PL	254 mm	HOLDDOWN-FI
CCN	2	150U50-54	2467 mm	HORIZONTAL BRACING
DHN	1	400D-54	2372 mm	STRAP
DMA	2	600D-68	203 mm	HEADER PLATE
SAB	4	600S162-54	918 mm	CRIPPLE
SAD	4	600S162-54	970 mm	CRIPPLE
SAL	2	600S162-54	1421 mm	HEADER
SBF	4	600S162-54	3681 mm	STUD
SBF	2	600S162-54	3681 mm	COLUMN
SCV	1	600S200-54	230 mm	BLOCK
SCY	1	600S200-54	241 mm	BLOCK
SEB	1	600S200-54	402 mm	BLOCK
SER	1	600S200-54	508 mm	BLOCK
SEW	1	600S200-54	565 mm	BLOCK
SFA	2	600S200-54	3681 mm	STUD
SPF	1	600T150-54	1418 mm	HEAD TRACK
SPF	2	600T150-54	1418 mm	HEADER BOTTOM TRACK
SPF	1	600T150-54	1418 mm	SILL
SPI	1	600T150-54	3581 mm	KING TRACK

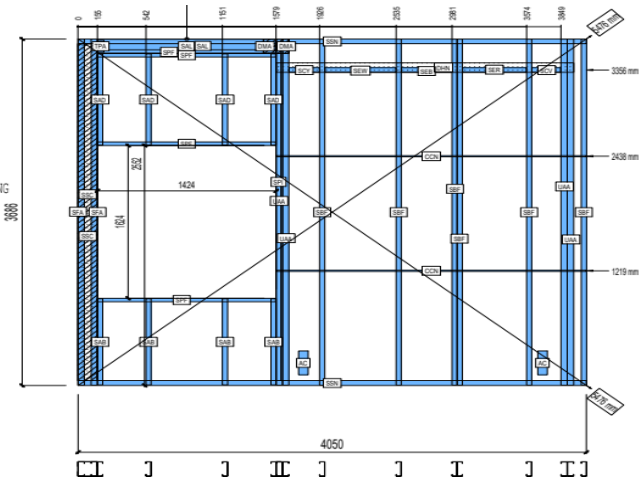


Figure 3-15 Shop Drawings

3.9. Work-sharing using Revit

The work sharing in Revit is established by the work set, which is a collection of building elements (floors, roofs, walls, windows, and so on) that can be edited by one team member at a time or by multiple team members.

Work-sharing is designed to accommodate any division of labour. There are no inherent restrictions on how work-sharing is used to accomplish work.

The Work-sharing tools are located on the Collaborate tab, figure:

types of work sets are created automatically:

- View work set: Each view in a project has a dedicated view work set. It contains the view's definition and any view-specific elements (text, dimensions, and so on).
- Family work set: For each loaded family in the project, an automatic work set is created.
- Project standards work set: This automatic work set covers project settings like materials, line styles, and so on.

3.10.Building models

- Model 1:

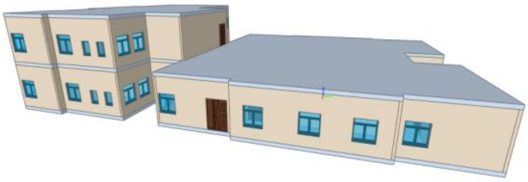


Figure 3-16 3D View

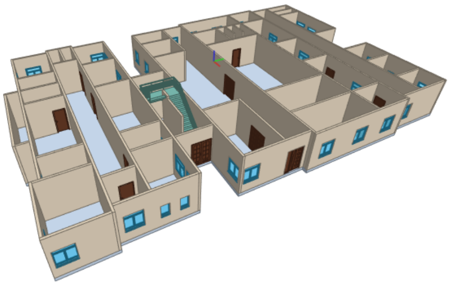


Figure 3-17 Floor Plan 3D view

- Model 2:

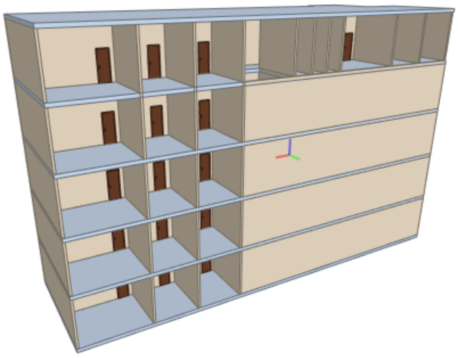


Figure 3-18 3D View

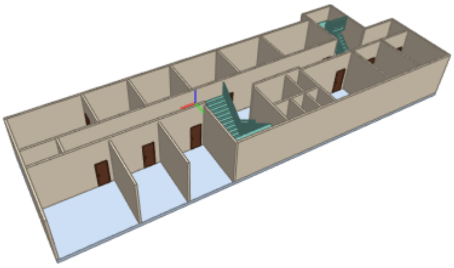


Figure 3-19 Floor Plan 3D view

- Model 3:

Figure 3-20 3D View

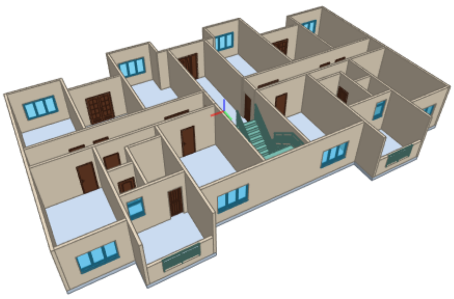


Figure 3-21 Floor Plan 3D view

3.11.Conclusion

The main advantage of Revit is not only specified in the 3D aspect but also in the combined database and bidirectional associativity. This means that everything is integrated and interrelated and a change will be reflected everywhere across the BIM platform.

The digital information contributed could include specifications, schedules, performance requirements, programmes, cost plans and drawings. Those drawings are created in 3D by different members of the project team in private "work-in-progress" areas. They are then put together into one 3D model to check that they co-ordinate, before being exported or shared with the wider project team.

Revit maintains digital libraries of CFS elements that can be incorporated into BIM models. The elements usually include performance attributes, such as fire ratings, sound tests, and material safety data sheets That present many advantages for all construction's schedules during all the construction's life: the estimation of the construction cost, the generation of the shop drawing …

For this study, more precise objective function of GA based on the strength of each element could be developed further.

Chapter Four

Automatic structural design of CFS structures using Genetic Algorithm

4.1. Introduction

In the past decade, there has been a rapid growth of the use of genetic algorithms in the various areas of engineering especially for optimization of complex problems with multi-objective functions.

A major reason for this interest is that genetic algorithms are powerful and broadly applicable in stochastic search and optimization techniques that really work for many problems that are very difficult to solve by conventional techniques.

In this chapter, a genetic algorithm for automatic structural design is adapted to Cold Formed Steel structural system. The structural features of this type of framing are first described. Then a set of specific rules are derived and implemented in the Genetic Algorithm.

4.2. Optimization

Optimization is the task of finding optimal solutions, which are solutions that have a better quality than others. We often seek for the global optimal solution, which is the best solution in the whole solution space. This can be a tedious task, as the solutions pace can suffer from constraints, strange fitness function conditions, unsteadiness, and a large number of local optima. If modelled in an appropriate kind of way, Genetic Algorithms are able to solve most optimization problems that occur in practice.

In this study, the algorithm has to find a distribution of structural shear wall panels in a CFS building that would simultaneously satisfy a set of constraints and optimize the design or performance criteria.

- Concepts of multi-objective optimization:

A multiple-objective optimization can be represented formally as:

$$\text{Max } \{ z_1 = f_1(\text{x}),\ z_2 = f_2(\text{x}),\ \ldots,\ z_q = f_q(\text{x})\} \qquad \textbf{Eq. 1}$$

$$\text{s.t. } g_i(\text{x}) \leq 0 \qquad \text{i} = 1, 2, \ldots \text{m}$$

Where x belongs to R^n is a vector of n decisions variables, $f_i(x)$ an objective function, and $g_i(x)$ inequality constraint m functions which form an area of feasible solutions.

In principle, in the case of the multiple-objective optimization problems, there does not necessarily exist a solution that is best with respect to all objectives because of incommensurability and conflict among objectives. A solution may be best in one objective but worst in another objectives. Therefore, there usually exist a set of solutions for the multiple-objective case which cannot simply be compared with each other. For such solutions, called nondominated solutions or Pareto [34] optimal solutions, no improvement in any objective function is possible without sacrificing at least one of the other objective functions.

The inherent characteristics of genetic algorithms demonstrate why genetic search may be well suited to multiple-objective optimization problems. The basic feature of genetic algorithms is multiple directional and global search through maintaining a population of potential solutions from generation to generation.

4.3. Genetic Algorithms

Genetic Algorithms are sub-class of evolutionary algorithms, GA are biologically-inspired algorithms for optimization. It is an explanation for the biological development of species with mating selection and survival of the fittest. [19]

Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection.

Figure 4-1 visualizes the continuous cycle of artificial evolution that is based on the principles of natural evolution. The evolutionary process begins with randomly or manually initialized solutions. The evolutionary cycle starts by recombining two or more solutions with the crossover operator. The outcome is mutated. The best solutions that have been generated this way a reselected for the following generation. Finally, the evolutionary cycle examines, if the termination condition has been met, else it continues the optimization process.

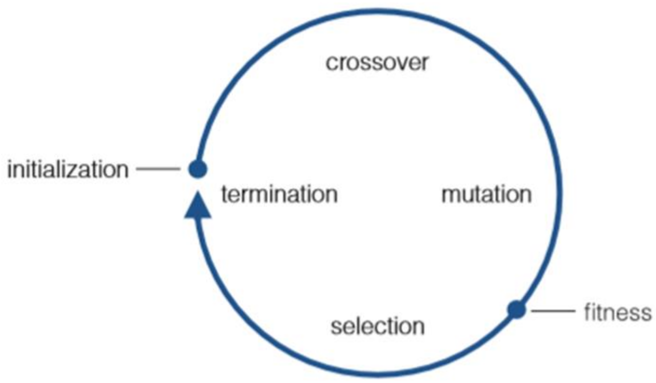


Figure 4-1 Genetic Algorithm cycle [19]

Definitions:

- Population:

In a Genetic Algorithm, each iteration, or generation, results in a series of possible hypotheses for best approximating a function, and the population refers to the complete set or pool of these generated hypotheses after a given iteration [26].

- Chromosome:

In an obvious nod to biology, a chromosome is a single hypothesis of which many make up a population [26].

- Gene:

A gene is a single bit within such a chromosome. In a GA, potential hypotheses are made up of chromosomes, which are, in turn, made up of genes. Practically, in a GA, chromosomes are generally represented as binary strings, a series of 1s and 0s, which denote inclusion or exclusion of particular items represented by position in the string [26].

- Generation:

In GAs, new sets of hypotheses are formed from previous sets of hypotheses, either by selecting some full chromosome (generally of high fitness) to move forward to a new generation unscathed (selection), by flipping a bit of an existing full chromosome and moving it forward to a new generation (mutation), or, most commonly, by breeding child chromosomes for the new generation by using an existing set's genes as parents.

A generation, then, is simply the full set of the results of a GA iteration.

- Evaluation of the solution:

Now to evaluate a solution, there are two things to consider:

  - constraints: these are some conditions that must be met. That is a solution is rejected if it does not meet these constraints.
  - fitness function: which is the target function of optimization. In the case of multi-objective optimization process, weights (scaling factors that are multiplied by the function value) are associated to each one of these values corresponding to their importance.

4.4. Formulation of the structural constraints and design rules for the CFS structure

The Cold formed Steel as illustrated in Figure 4-2 refers to light-frame construction where the vertical and horizontal structural elements are primarily formed by a system of repetitive framing member, where the Slab and walls are rigidly connected and form a monolithic system providing a structural redundancy which enhances the global stability of the building.

The vertical loads are supported by floor and Wall members which are typically vertical lipped channel "stud" members, which fit into unlipped channel "track" sections at the top and bottom into the foundations. Similar configurations are used for both floor joist and rafter assemblies.

The lateral forces, induced by the seismic or wind loads, are directly transmitted to the foundation through the Shear Wall.

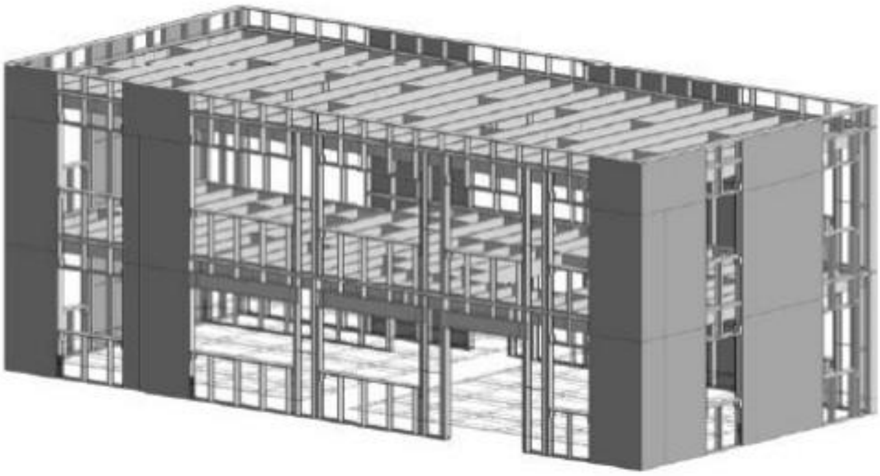


Figure 4-2 A 3D BIM Model of a CFS building

In general, a constraint is a condition, agency or force that impedes progress towards an objective or goal. There are a number of different types of constraint that can affect construction projects. Constraints should be identified, and described in as much detail as possible during the early stages of a project, so that awareness of them and their potential impact can be managed. For the purpose of this study, the constraints are limited to the architectural and structural aspects of the project.

A set of rules that specify the minimum acceptable level of safety for Cold Form Steel structure system is defined.

4.4.1. Vertical Loads

In this type of structures, vertical loads are distributed on slabs and transmitted into walls through joists. Noting that all walls are considered load bearing elements, in order to ensure structural stability and allowable slab bending, the joists' direction must be chosen according to multiple criteria. In this case, there is two major parameters that impacts the choice on how to place the joists: span and wall openings (Figure 4-3).

The concept of comparing the length of walls permitting loads transmission in the two directions will allow to determine which direction is optimal for the joist span.

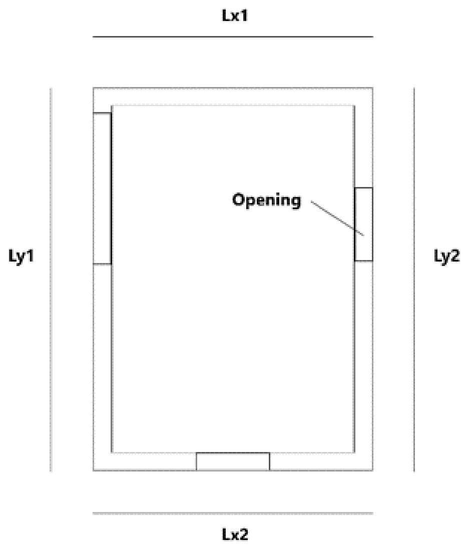


Figure 4-3 2D representation of a room with openings

First, the Algorithm calculates the ratio Lx / Ly and Ly/ Lx, if one of them is superior than:

- 2 if the maximum length of walls in X direction and Y direction is inferior than 5m.
- 1.5 if the maximum length of walls in X direction and Y direction is superior than 5m.

The algorithm will determine the bearing direction as parallel to the direction of the smallest lengths of walls (Figure 4-4).

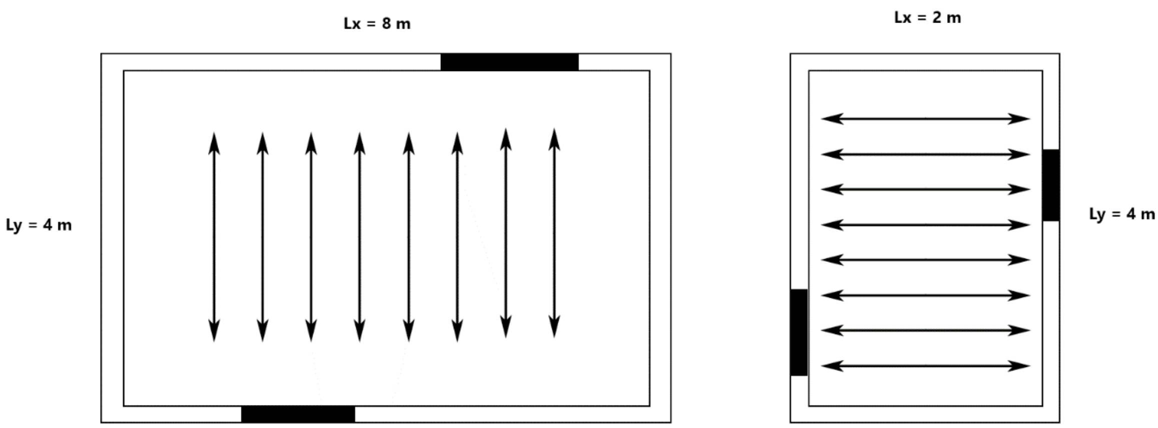


Figure 4-4 Joist Direction example 1

Then, if the two conditions are not respected, the optimal joist direction is assured by the direction that have less openings than the other. The algorithm will compare the lengths of the walls in the X direction without the openings, with the length of walls in the Y direction without openings. The optimal joist direction is assured by the direction that have less openings than the other (Figure 4-5).

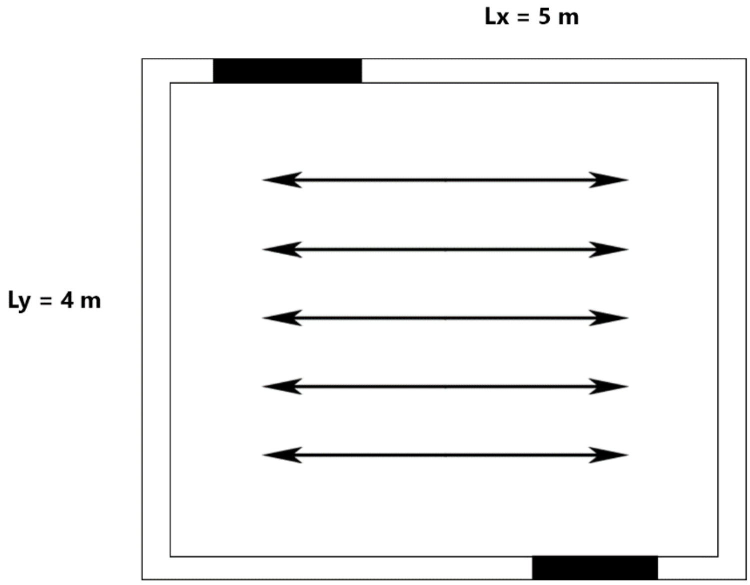


Figure 4-5 Joist Direction example 2

4.4.2. Shear Wall Design

As mentioned in the previous chapter, bearing walls in this type of structures are categorised in two, walls that only support vertical loads (bearing walls) and shear wall panels (SWP), the second type is used in order to resist to lateral loads resulting from earthquakes for example. Shear walls must comply to a set of rules and criteria to ensure stability towards lateral loads.

4.4.2.1. Length of Individual shear wall

The shear wall panels are composed of C-shaped framing members (chord studs, studs and tracks) attached to sheathing using screw fasteners. The minimal length of wall is the distance between two consequent studs which is equal to Lmin = 60cm (24 inches). [9]

L_{min} = max (60 cm, h/4) [9]

Also, the maximal height to width (h/w) ratio is 4:1, which implies that the minimal length must also be bigger than h/4; h is the story height.

L_{opt} = h/2 [37]

4.4.2.2. Total length of walls

In each direction, shear walls must be able to resist lateral loads. The minimal quantity of shear walls is determined according to their resistance and the supported lateral loads.

The lateral load is determined using the recommendations from the Algerian seismic code RPA99 (2003 Version).

The minimal quantity of walls that should be used in each direction is defined according to a pre-dimensioning technique. First, we calculate F, the lateral load applied to each storey using the equivalent static load method. Next, we determine the nominal strength of shear wall panels per unit length f. The minimum length of walls in each direction is equal to lateral load to nominal strength ratio.

$$L=F/f \qquad \textbf{Eq. 2}$$

F: lateral load (KN)

f: nominal strength of the wall per unit length (KN.m-1)

F = ADQW/R

A: Acceleration Coefficient

D: Dynamic Amplification Factor

Q: Quality Factor

W: Weight of the structure (Kg)

R: Behaviour Factor

4.4.2.3. Wall Distribution

During earthquakes, torsional vibrations represent a major danger to buildings. In order to reduce the building's torsional response, the SWPs are distributed in such a way to minimize the eccentricity e (distance between mass centre and stiffness centre).

The coordinate of the stiffness centre for a set of shear walls having the same material properties, storey height and thickness is given by:

$$x_s = \frac{\sum l_{yi} x_i}{\sum l_{yi}} \text{ and } y_s = \frac{\sum l_{xi} y_i}{\sum l_{xi}} \qquad \textbf{Eq. 3}$$

Where (xi, yi) are the co-ordinates of the centre of the shear wall i relative to axes x and y respectively; lxi and lyi being the length of a given shear wall i in the x and y directions, respectively; subscripts xi and yi vary from 1 to the total number of shear walls in x and y directions, respectively.

A general rule in earthquake resisting design is to increase the torsional stiffness that can be achieved by placing the SWPs the furthest possible from the centre of the building. This can be expressed by the torsional radius along the x (or y) direction of analysis as given by:

$$r_y^2 = \frac{\sum (x_i^2 l_{yi}^3 + y_i^2 l_{xi}^3)}{\sum l_{xi}^3} \qquad \textbf{Eq. 4}$$

Where y is the horizontal direction perpendicular to the direction x under consideration; (xi,yi) are the co-ordinates of the centre of the shear wall i relative to the stiffness centre; ry is the torsional radius of the shear walls of the considered floor; lxi and lyi being the length of a given shear wall i in the x and y directions, respectively; subscripts xi and yi vary from 1 to the total number of shear walls in x and y directions, respectively.

4.4.2.4. Load path continuity

A continuous load path involves connecting every piece of the building like the links of a strong chain. In this case, shear walls must be continuous down from the foundation up to the last part of the wall in order not to disrupt vertical loads transmission. Structural instability might be caused by a discontinuity of load path (Figure 4-6).

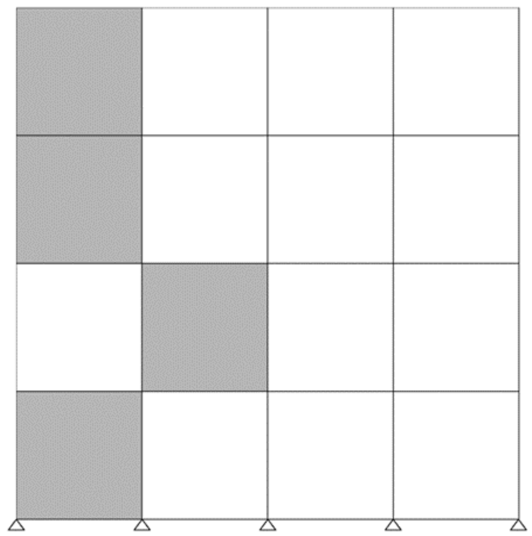


Figure 4-6 None continious Load Path Continuity

4.5. Procedure of identifying and generating an optimal structure using a GA

The geometry model of a given architectural layout on a BIM platform is exported using IFC format where the algorithm defines the structural elements of each floor: slabs, openings (windows, doors), walls.

The shear walls that will be generated are represented by a set of pairs of two-dimensional vectors where each pair of vectors represents a line segment denoting the start and end of a single SWP (Figure 4-7).

The slab is defined by its contour. The widths and heights can be taken directly from the model geometry given by the container-wall's dimensions.

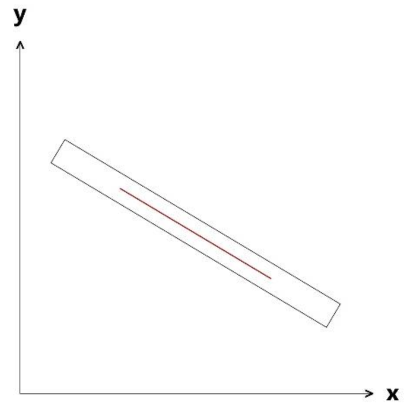


Figure 4-7 Wall projection

4.5.1. Genetic algorithm principle

Given a complete architectural geometry represented by the slabs and the walls layout at each floor, the algorithm has to find a distribution of structural SWP that would simultaneously satisfy a set of constraints and optimize the design or performance criteria.

At first step, a set of random potential solutions which satisfy the imposed constraints is generated and called initial population. The set will then evolve towards a population of solutions that matches better the criteria. The evolution consists of series of crossover between solutions followed by mutations, and keeping, amongst the newly produced solutions, those which fit better the performance criteria.

The GA flowchart shown in the next figure 4-8 illustrates the different steps of the Algorithm.

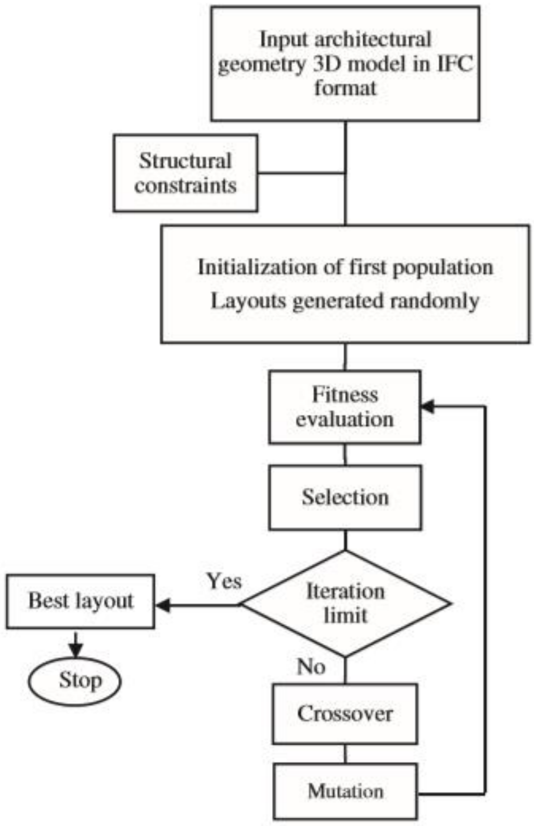


Figure 4-8 Genetic algorithm flow chart [36]

4.5.2. Implementation of the GA

For the present particular type of structural system (CFS structure), a solution generated by the GA needs to satisfy the following set of constraints:

- Minimum length of each shear wall
- Minimum length of all shear walls in one direction
- Architecture wall distribution (layout)
- Load path continuity

4.5.3. Random generation of walls configurations

The Shear walls are generated following a normal distribution N (μ, σ²) with the following parameters:

$$\mu = L_{opt} \qquad \textbf{Eq. 5}$$
$$\sigma^2 = L_{opt} - L_{min}$$

Each Shear wall is positioned randomly within the architecture walls layout given in the BIM model geometry following a positioning probability slightly biased towards the edge of the slab contour so that it accelerates the convergence to the optimal solution.

4.5.4. Crossover function

Crossover is an operator that allows the combination of the genetic material of two or more solutions [34] (Figure 4-9).

Crossover is the most significant phase in a genetic algorithm. For each pair of parents to be mated, a crossover point is chosen at random from within the genes.

A solution is generated from two existing configurations by selecting walls from the first solution and completing the remaining from the second; this will allow the new solution to inherit characteristics of both parents without violating the constraints listed above.

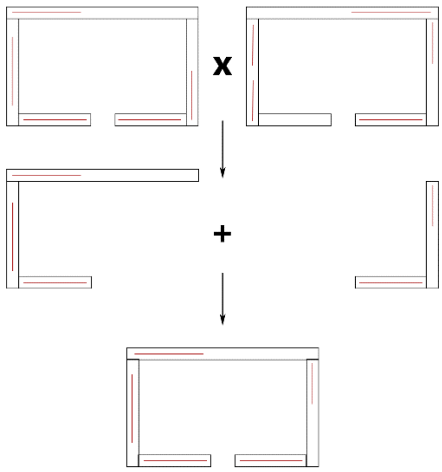


Figure 4-9 Crossover Operation

4.5.5. Mutation function

Mutation operators change a solution by disturbing them. Mutation is based on random changes [19].

The newly generated solution from the crossover has a probability of mutation, which is an empirical parameter given as input to the algorithm, through which one of the walls is slightly changed. Two types of mutations are considered:

- Adding shear wall length: it might be an extension to an existing shear wall if this one hasn't yet reached the maximum length allowed or a newly inserted shear wall (Figure 4-10).
- Reducing shear wall length: either an existing shear wall is shortened if it hasn't yet reached the minimum length allowed or it is removed completely (Figure 4-10).

The purpose of mutating solutions is to explore new possibilities and avoid the limitation set by the original characteristics generated randomly by the algorithm.

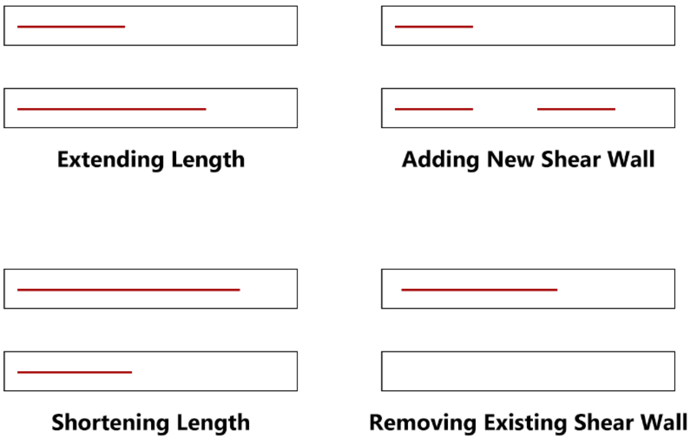


Figure 4-10 Mutation Operation

4.5.6. Formulation of objective functions

The fitness function determines how fit an individual is (the ability of an individual to compete with other individuals). It gives a fitness score to each individual. The probability that an individual will be selected for reproduction is based on its fitness score.

In order to move the population towards the optimal solution, a fitness function is required in order to evaluate how close the solution is to an optimal. First, for any given solution each criterion is evaluated independently, that is:

- Total length of shear walls L: must be bigger than the minimum quantity of walls needed for each direction (L_{tmin}).

$$\text{If } L<L_{tmin}\text{: score} = \left(\frac{L}{L_{tmin}}\right)^3 \text{, Else score} = 2- \left(\frac{L}{L_{tmin}}\right) \qquad \textbf{Eq. 6}$$

Where $L=\sum L_i$ is the total length of shear walls

Note that the score is cubed in the first case to penalize the case when having total length less than the optimum since it is also the minimum required

- The torsional radius needs be maximized in order to have an optimal wall distribution. In CFS structures, shear wall panels are ideally put in the external walls of the building, this parameter allows the algorithm to generate more external shear walls. the torsional radius is compared to Is (the radius of gyration of floor mass in plan)

$$R_x > I_s \text{ and } R_y > I_s \text{ [34]} \qquad \textbf{Eq. 7}$$

$$ScoreRx = \frac{Rx}{Is} \text{ and } ScoreRy = \frac{Ry}{Is}$$

- Floor Torsional eccentricity (Symmetry): The torsional eccentricities e_x and e_y, are normalized to 0 for a perfectly symmetric solution and 1 refers to a given limit eccentricity or an eccentricity equal to the maximum allowed by the regulations in plan dimension of the slab.

$$e_x < 0.3\, R_x \text{ and } e_y < 0.3\, R_y \text{ [34]} \qquad \textbf{Eq. 8}$$

$$ScoreEx = \frac{0.3\, R_x}{e_x} - 1 \text{ and } ScoreEy = \frac{0.3\, y}{e_y} - 1$$

- Torsional Radius to slab dimensions ratio: in order to achieve a better shear wall distribution in both directions, and avoid having more important SWP quantity in one direction than the other.

$$\frac{R_x}{L_x} = \frac{R_y}{L_y} \qquad \textbf{Eq. 9}$$

Two different values are defined in order to avoid errors during the optimization process

$$Score1 = 1 - \left(\frac{R_x}{R_y} - \frac{L_x}{L_y}\right) \text{ and } Score2 = 1 - \left(\frac{R_y}{R_x} - \frac{L_y}{L_x}\right) \qquad \textbf{Eq. 10}$$

4.5.7. Selection

The idea of evaluation phase is to select the fittest individuals and let them pass their genes to the next generation. The individuals are selected based on their fitness scores. Individuals with high fitness have more chance to be selected for reproduction.

Finally, an evaluation vector v of each criterion is generated. The fitness value of a solution is defined as: f_v = v. w.

Where w is a constant weight vector defined empirically, that is each criterion has a weight proportional to its importance in evaluating a solution.

4.5.8. Termination

The termination condition defines, when the main evolutionary loop terminates. Often, the Genetic Algorithm runs for a predefined number of generations. This can be reasonable in various experimental settings.

For this particular type of structural system, we opted to use 100 to 150 iterations in order to obtain an optimal solution for the considered examples.

4.6. Conclusion

In this chapter, a set of design rules for CFS was presented as constraints and conditions to a Genetic Algorithm able to automatically derive an optimal structure for a given architectural configuration in IFC format or BIM platform.

The concept of the GA is based on a multi-objective optimization process that randomly generates an initial population of potential structural configurations which comply with architectural constraints, matching a set of general structural guidelines and seismic design rules.

The initial population evolves through series of crossover between current solutions (parent) followed by mutations generating new solutions to be adopted, for the next iteration, when they improve the performance criteria.

Chapter Five

Performance of the GA: presentation and evaluation Of the Results

5.1. Introduction

For each architectural BIM model, an IFC model has been generated. It serves as input to the GA in order to perform the analysis and to provide as output a best layout after a predefined number of iterations. The obtained structures are evaluated using the targeted design criteria.

In this chapter, we present the resulting layouts, and assess their structural stability and resistance.

5.2. The architectural layouts

Three different architectural layouts are used in order to test the performance and the sensitivity of the GA. The architecture samples are selected according to the following parameters:

- The geometrical dimensions (surface, height)
- Locations of the openings (windows, doors)
- Layout of the inner and outer walls

The 3D architectural configurations are derived from realistic cold formed steel projects. They are adjusted using the software Autodesk Revit version 2020.

5.3. Determination of joists direction

The algorithm scans first the rooms of the building, and verifies if the architectural configuration is compliant to the constraints of CFS structures (limited to span and joist disposition).

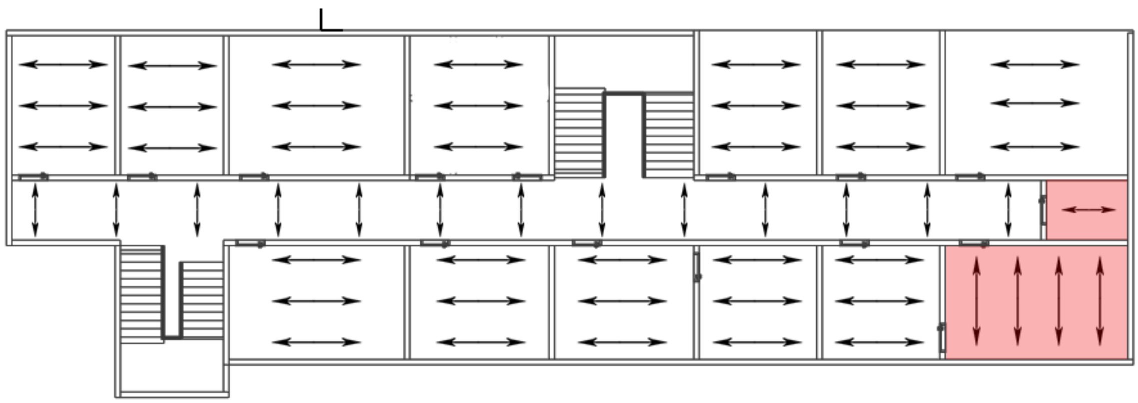


Figure 5-1 GA generated joists directions

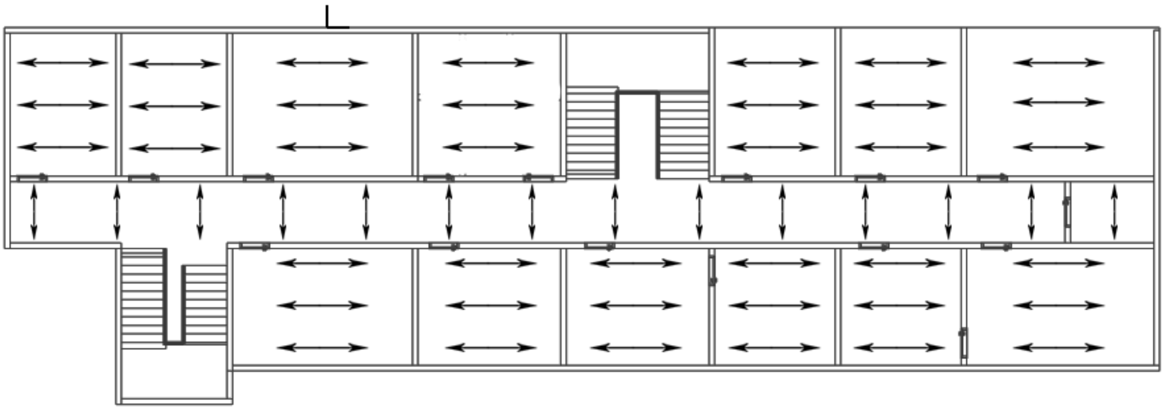


Figure 5-2 Conventional joists directions

The results are almost identical to the conventional joists directions plan, except for two specific spaces – as shown if figure 5-1. For the first case, it is caused by errors encountered while parsing the architectural configuration from IFC files. As for the second case, the algorithm generates the directions strictly according to a pre-defined condition (allowed span, openings…etc) and does not take in consideration construction-site conditions.

Therefore, we conclude that the algorithm takes into account the 2 effects that control the choice of direction while respecting the layout of the walls and openings to present results similar to that of the plans pre calculated by engineers.

5.3.1. Global stability performance of the generated structures

The output layouts of the GA respect totally the architecture interior partitions at all levels. The shear walls were positioned in agreement with all the openings (windows and doors). The load path condition of the walls has also been satisfied for all the configurations.

In order to evaluate the results generated by the algorithm, we decided to compare the results and the SWP plans – manually calculated by expert structural engineers –.

- Model 1: Two storeys building (R+1)

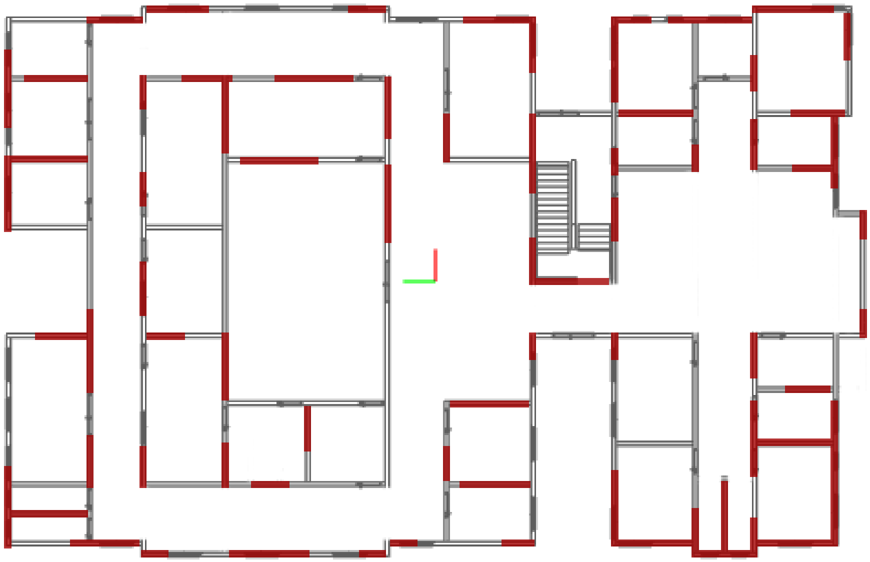


Figure 5-3 GA Generated SWP Plan

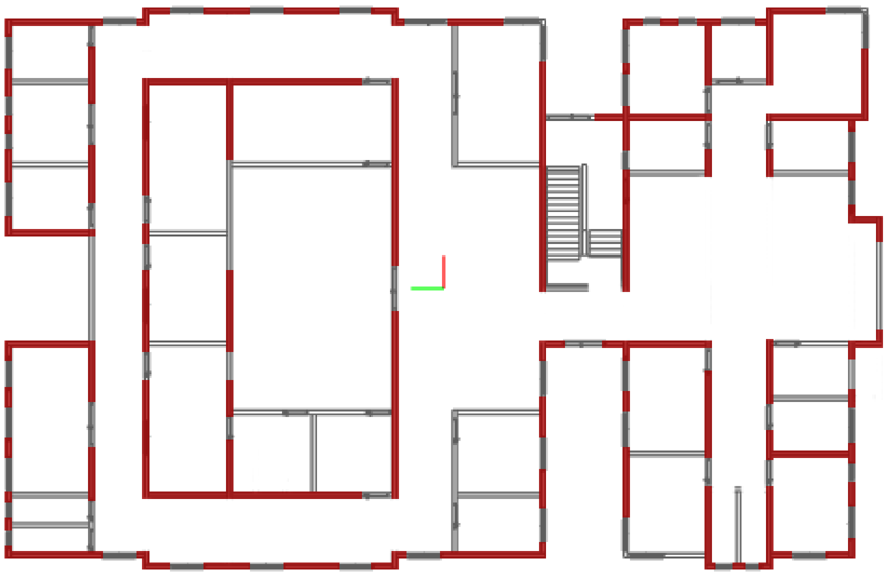


Figure 5-4 Conventional design SWP plan

- Model 2: Five storeys building (R+4)

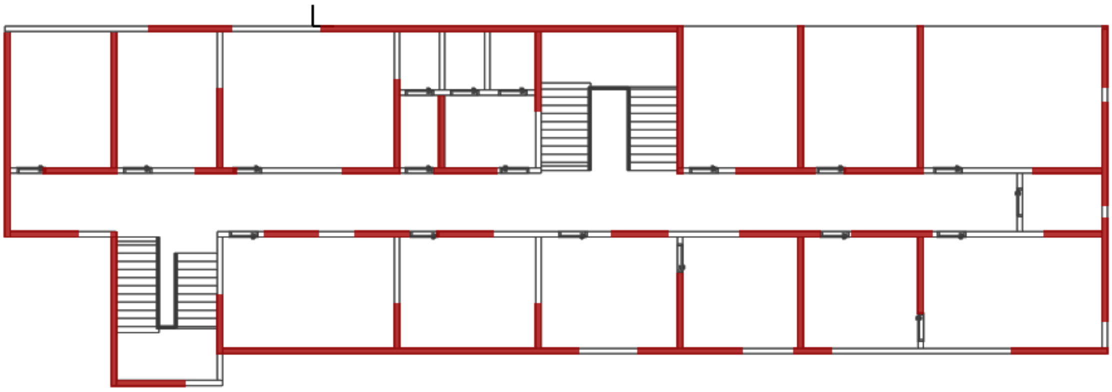


Figure 5-5 GA Generated SWP Plan

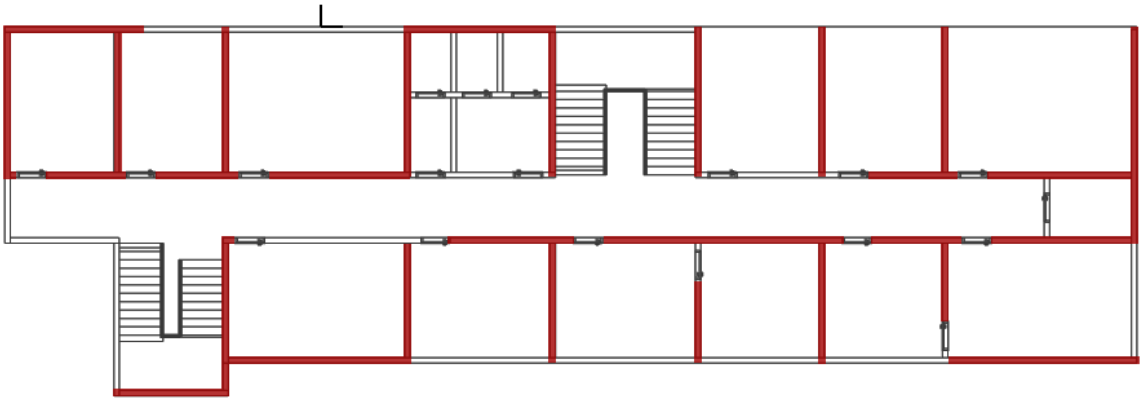


Figure 5-6 Conventional design SWP plan

- Model 3: Five storeys building R+4

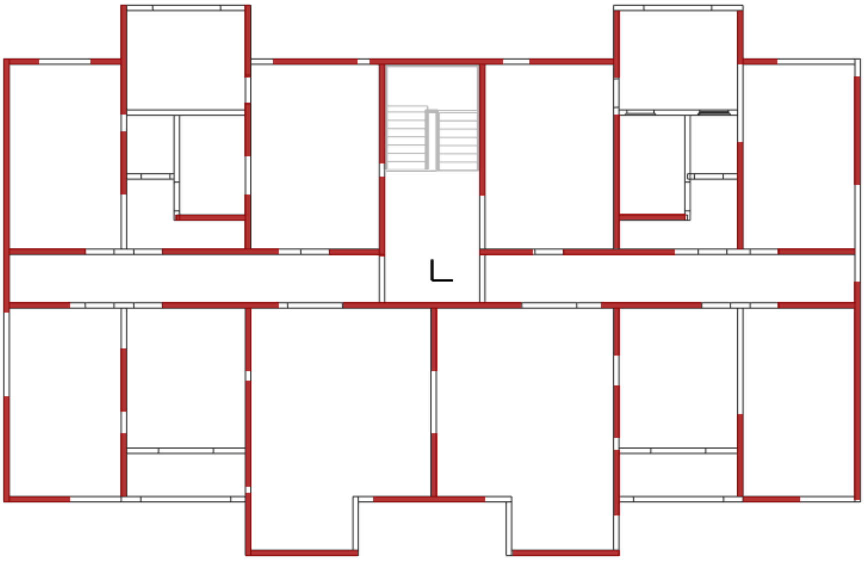


Figure 5-7 GA Generated SWP Plan

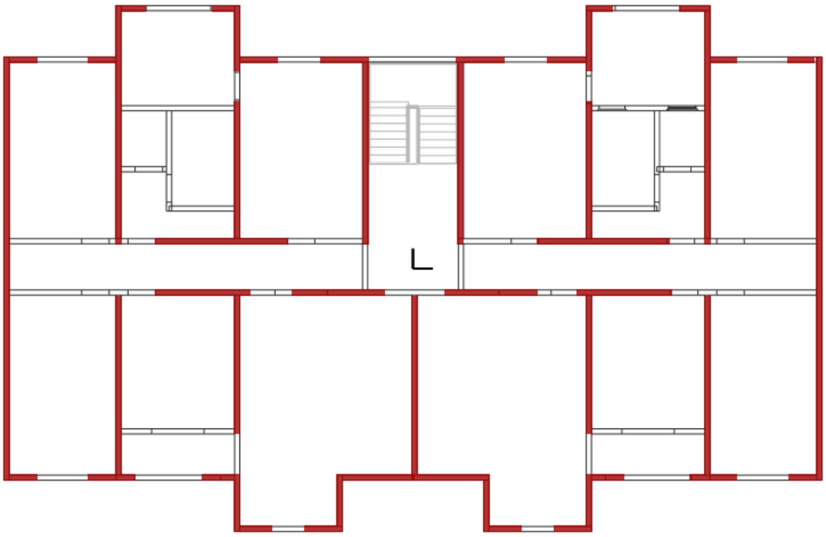


Figure 5-8 Conventional design SWP plan

- The generated SWP distribution plans of the three constructions are quite similar to reference plans, which justifies their structural stability. Although, some differences in shear walls length are noticed, the issue is that in the GA generated layout, some walls are shorter or divided into multiple walls, this is caused by the probability law used to generate new shear walls (Normal Distribution) and the defined maximum length of shear walls.
- We notice that the algorithm tends to assign a length close to the optimal length (L_{opt}) to the majority of generated shear walls, this ensures a better resistance and behaviour for individual walls.

5.3.2. Shear walls total length and distribution

For all the layouts generated by the GA having lengths over than the minimum length of 0.6 m with at least 20%. And less than the maximum length allowed of 3m with at least 7 %. However, most of their lengths are very close to Lopt predefined in the equation, which shows that the GA presents an efficient way to ensure the use of the optimal strength of SWP in each resulting layout.

The total length of the shear walls in each layout along each direction (X and Y) is at least 5.0% more than the minimal required total length of equation 2.

The shear walls are clearly shifted towards the periphery of the structure as a result of using torsional radius as an objective function. But, for the large buildings with have 1 or 2 levels the minimum quantity required of SWP is relatively small which in turn provokes some irregularity in the algorithm results.

The eccentricity of the generated layouts is very small, which is one of the most important condition for stability of CFS structures.

5.4. Effects of objective functions

The scaling factors values of the different parameters used to define the objective function and the constraints of the genetic algorithm are given in the next table. Best fit structures are obtained for the three architectural configurations using each combination of the scaled parameters.

Model	Scale factors			
	Eccentricity	Torsional Radius	SWP length	Radius to Dims ratio
1	1	1	1.5	1
2	0.5	1	1	1
3	0.5	1	1	1

Table 5-1 Scaling Factors for optimal results

5.4.1. Effect of eccentricity parameter

The eccentricity parameter is intended to control the structural symmetry of the floors of the building. To determine the effect and importance of the eccentricity parameter, the latter has been assigned three different values 1, 2 and 3 respectively, while all other weights were kept equal to unity. The resulting eccentricities of the floors of the optimized layouts for the buildings, obeyed to the variation of the eccentricity weight. Table 5-2 shows that the eccentricities along x and y directions are in the range of 0.9% to 4% for a weight of 1 and remains in a range of 0.1% to 0.3% for a scale factor weight of 1.5.

Eccentricity Scaling Factor	Model 1		Model 2		Model 3	
	X-Ecc ratio	Y-Ecc ratio	X-Ecc ratio	Y-Ecc ratio	X- Ecc ratio	Y- Ecc ratio
1	1.8 %	0.9 %	3 %	4 %	0.9 %	1.32 %
2	0.4 %	0.8 %	3.5 %	3%	0.25%	0.32 %
3	0.1 %	0.1 %	0.2 %	0.3%	0.1 %	0.19 %

Table 5-2 Eccentricity ratios relative to different scaling factors

5.4.2. Effect of the torsional radius parameter

The torsional radius parameter is intended to assure a good distribution of SWP and to ensure maximum SWP on the exterior walls. To show the effect and importance of this parameter, it has been assigned three different values 1, 2 and 3 respectively, while all other weights were kept equal to unity.

The results show that the SWP quantity in exterior walls increase according to the scaling factor's value as intended, however it causes an increase of the eccentricity as shown in table 5-3.

We note that for this test, the weight of the eccentricity objective function is fixed to 1.

Model	Radius Weight Factor	Peripheral Walls in %	Eccentricity	
			X- Ecc ratio	Y-Ecc ratio
1	1	18 %	1.8 %	0.9 %
	2	21 %	2.8 %	1.9 %
	3	24 %	4.3 %	3.5 %
2	1	33 %	3 %	4 %
	2	34 %	0.4 %	2 %
	3	43 %	4 %	7.4 %
3	1	41 %	1.3 %	2 %
	2	46 %	2.5 %	0.9 %
	3	58 %	3 %	1 %

Table 5-3 Variation of torsional radius scaling factor

5.4.3. Effect of radius to dimensions ratio parameter

The Radius to Dimensions ratio is a parameter that ensures a better SWP distribution in terms of the building's dimensions. Also, to avoid SWP concentration in only one direction.

It can be seen in figure 5-9 that the generated layout without taking account of the radius to dimension ratio shows an uneven distribution of SWP with less structural stability.

After few tests, we concluded that a scaling factor equal to 1 is the optimal value.

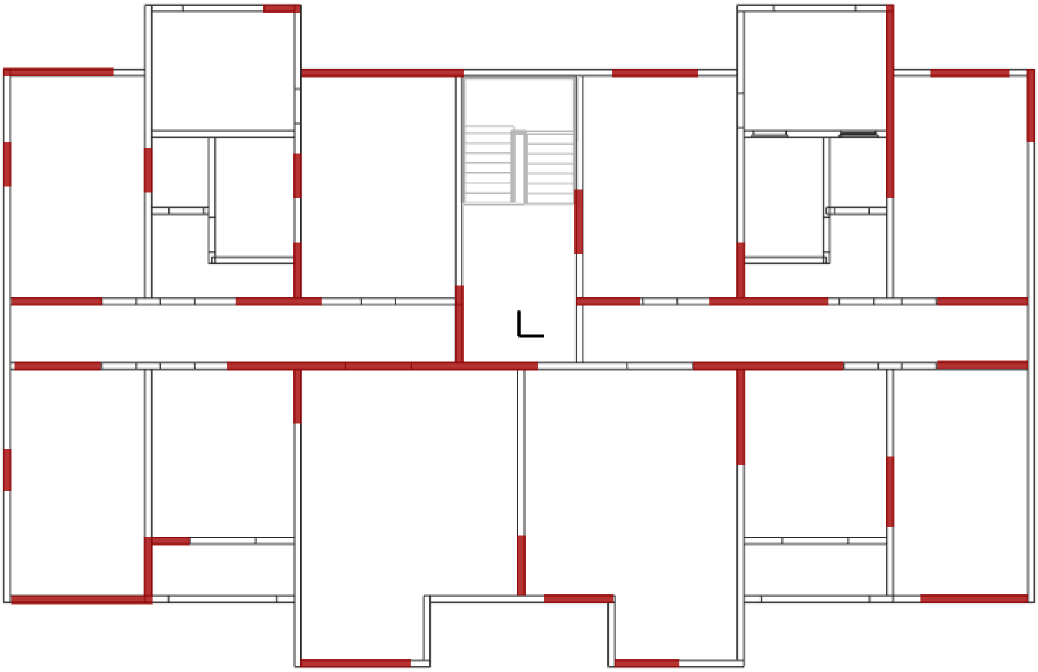


Figure 5-9 SWP layout with Ratio to Dim scaling factor set to 0

5.4.4. Effect of the minimum required SWP length parameter

The minimum required SWP length is a key parameter to ensure a good performance of the structure under a given level of a seismic loading. This parameter is crucial to the process, since without defining the minimum required length of the SWP, the resulting layouts will be either cluttered (full) of shear walls or having less than the required quantity. As show in the next example:

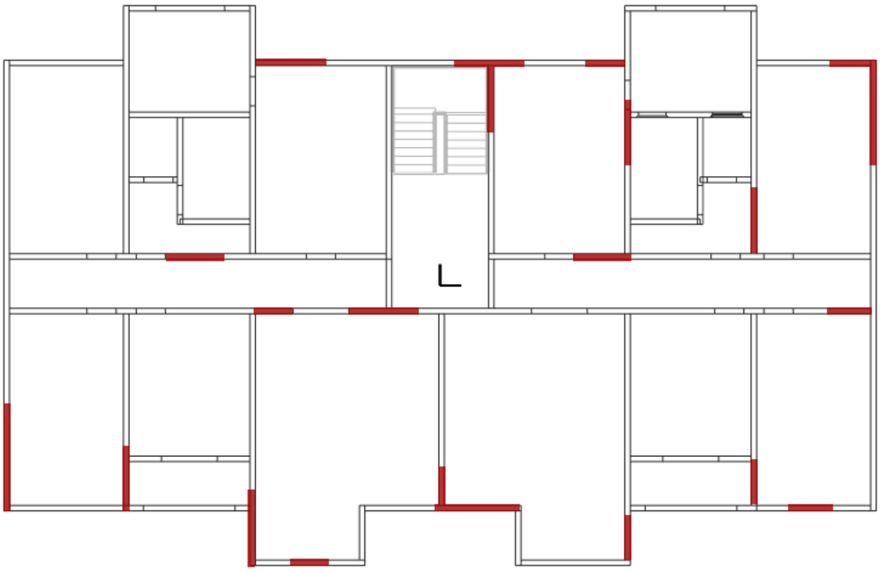


Figure 5-10 Example of resulting layout with minimum length parameter deactivated

5.5. Conclusion

After analysing the different results, and adjusting the algorithm, it is noted that:

- The selected objective functions gave satisfying results and their effect can be controlled through adjusting the scaling factors values.
- The algorithm has good overall performance and it can be used as a tool to help determine and optimize SWP layouts.
- The use of artificial intelligence tools can ease the process of building design, which results in a better productivity.
- Some openings (doors or windows) are ignored or not correctly parsed. This is due to the fact that the parsing library used is still in development.

Conclusion

The main objective of this study was to integrate a design system of CFS structures to a BIM platform and simulate the way that an engineer would proceed to design this light steel structural system starting from a given architectural configuration. An integration that enhance the productivity with the improvement of the knowledge sharing and interface between discipline involved in the whole construction process.

The automatic design procedure based on GA algorithm was adapted to CFS buildings. For given architectural model on a BIM platform using the IFC protocol, the algorithm defines the slab elements and the architectural walls layout on each floor, then set of random potential solutions which satisfy the imposed constraints is generated. The set will then evolve towards a population of solutions that matches better the criteria. The evolution consists of series of crossover between solutions followed by mutations, and keeping, amongst the newly produced solutions, those which fit better the performance criteria.

The results show that all the constraints of the GA are respected, the total length of the shear walls in each layout along each direction (X and Y) is more than the minimal required. The GA tends to adopt longer shear walls in order to approach the optimal length. The GA is able to detect perfectly the rooms' borders and propose an optimal joist direction according to the dimensions of the rooms and length of their openings.

The SWP of the resulting layouts are shifted towards the periphery of the structure and the eccentricity is clearly very small. By comparing the resulting layouts with the pre calculated plans, shows that the two plans are similar with some differences, which justify the stability of the layouts toward the lateral loads.

It turns out that the outcome layouts are very sensitives to the weights of the objective functions, a judicious choice allows a good SWP distribution. It was very challenging to fix the appropriate weight of each objective function without amplifying its effect and affecting the other parameters of the objective function.

An important implication of this research to the entire process of design and construction of CFS buildings is to help automatize the interface between disciplines especially architecture and structural engineering which can be easily implemented in a BIM environment.

Finally, the proposed approach is open to future enhancement of the algorithm to integrate more or updated code requirements related to the CFS structural system. As a perspective research work, this approach can be enhanced further using an artificial neural network to ensure the division of the slab of each level into rectangular rooms using some predefined criteria.

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Annexes

Annex A

Introduction

IFC, or "Industry Foundation Classes", is an international open standard (ISO 16739-1:2018), developed and maintained by BuildingSMART International, for building models and data that permits information to be shared and maintained throughout the life cycle of a construction project: design, analysis, specification, fabrication, construction, and occupancy.

What is Industry Foundation Classes (IFC)?

IFC, or Industry Foundation Classes, is a standardized open source file format that is optimized for building information modeling. Much like PDF or HTML, the specification for the code is open-source and freely available to the public for use and for developers to create their own tools to handle the data format. This means that all software vendors have equal access to the specifications and therefore, can create the necessary import and export technology. No single vendor controls this format or makes money from licensing this technology. The most important thing to remember is that IFC encodes both geometry and data. Additionally, there are certain aspects of IFC that make it ideal for an open BIM exchange. These include:

- Geometry: IFC geometry is robust and includes vectors, solids, surfaces, and so on.
- Data: IFC supports three main aspects of the data in a BIM model:
    - Semantics: the meaning or identity of a collection of geometry related to building objects, such as: a window within a wall. Relationships
    - speaks to how the geometry is related to each other such as a door inserted into a wall Properties
    - definition of materials that includes data such as cost or model number

Central to the concept of IFC is the idea of “semantic objects.” When the geometry of a model is identified as a building element and has “meaning” within the context of construction, it becomes a semantic object for a building information model. For this reason, IFC becomes an ideal file format to share a 3D model with associated data for the BIM process.

IFC specifies a representation of the contents of a BIM database in a plain text form suitable for exchange.

How is IFC file used?

Today, IFC is typically used to exchange information from one party to another for a specific business transaction. For example, an architect may provide an owner with a model of a new facility design, an owner may send that building model to a contractor to request a bid, and a contractor may provide the owner an as-built model with details describing installed equipment and manufacturer information. IFC can also be used as a means of archiving project information, whether incrementally during the design, procurement, and construction phases, or as an "as-built" collection of information for long-term preservation and operations purposes.

The desired IFC data can be encoded in various formats, such as XML, JSON, and STEP and transmitted over web services, imported/exported in files, or managed in centralized or linked databases.

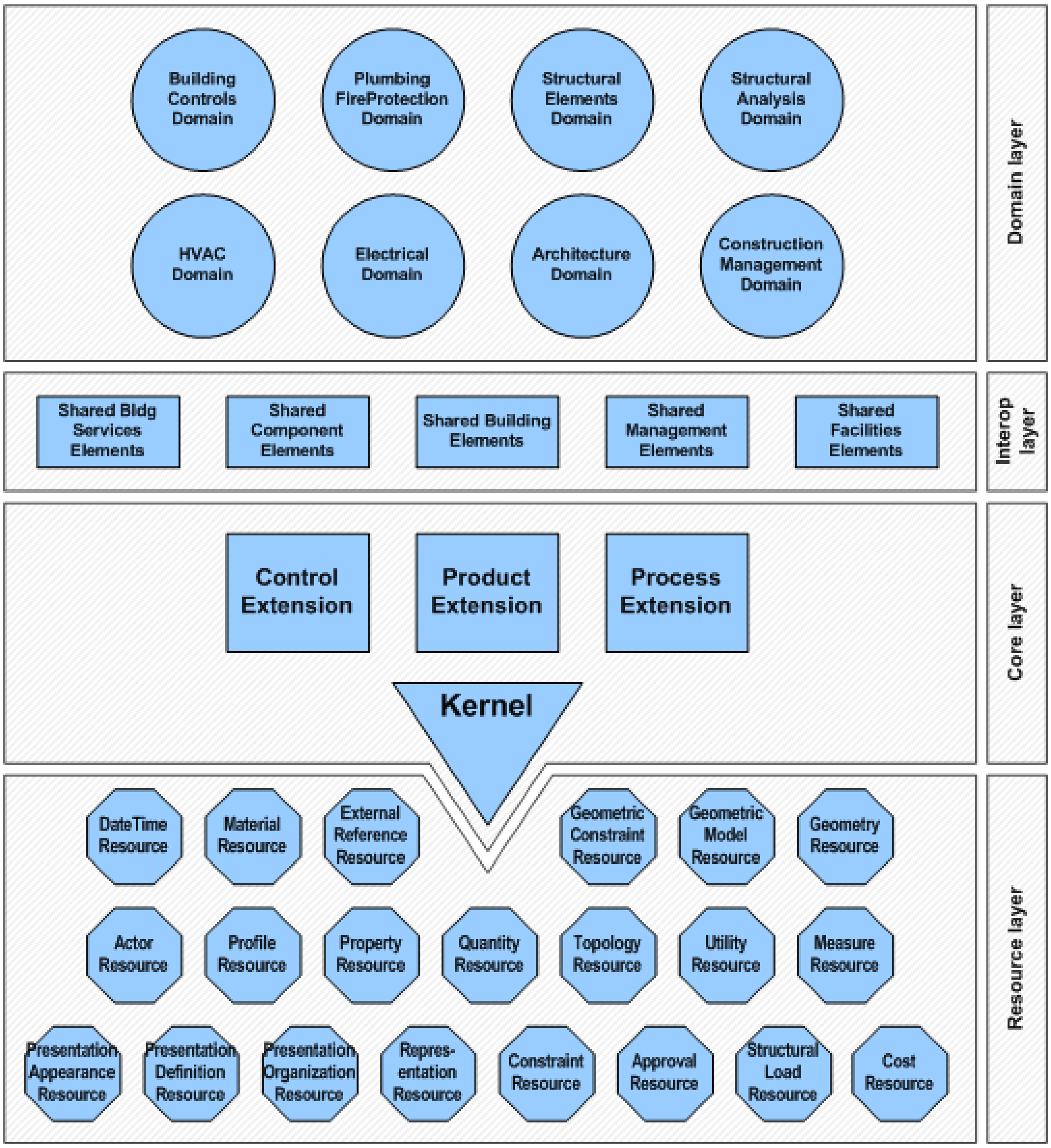
Software vendors of building information modeling tools - including model authoring, design, simulation and analysis, viewing and more - will provide interfaces to end users to export, import, and transmit data in some IFC format. It is up to users to decide what they want to share from their tools via IFC.

IFC Schema

The schema specification can describe how a facility or installation is used, how it is constructed, and how it is operated. IFC can define physical components of buildings, manufactured products, mechanical/electrical systems, as well as more abstract structural analysis models, energy analysis models, cost breakdowns, work schedules, and much, much more.

The introduction to the IFC4 specification describes the schema architecture for the IFC data model. The architecture has four layers, with each subschema belonging in one of the layers:

- Domain layer: The domains are: Building Controls; HVAC; Electrical; Plumbing/Fire Control; Structural Elements; Structural Analysis; Architecture; Construction Management.
- Interoperability layer: Contains schemas for shared elements in categories: Building Services Elements; Component Elements; Building Elements; Management Elements; Facilities Elements.
- Core layer: This layer has a kernel schema and three schemas for the general areas of Control, Product, and Process.
- Resource layer: The schemas in this layer define elements and attributes that describe low-level features used throughout, such as date and time; measurements; quantities; costs; geometric constraints; external references … etc.



Minimum contents for IFC Product Model

The IFC product model and specification set some specific minimum requirements for what the information content of file-based product model IFC data exchange should be. Regarding the Use Case, the required minimum IFC product model is specified in Tables. Separately, for the exchange of the 3D model and building product model exchange sub-cases.

Class	Properties
Project	Identification and owner history 3D coordinate system Project context and common measurement units
Site, Buildings and stores	Identification and owner's history
Building elements	Identification and owner history 3D-shape and location
Class	Properties

Project	Identification and owner history 3D coordinate system -Project context and common measurement units
Site, Buildings and stores	-Identification and owner’s history
Space	Space type 3D-shape and location