A Hybrid Decision Support System for Partition Wall Selection with an Application in Masonry Wall Systems

By

Samaneh Momenifar

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in Construction Engineering and Management

Department of Civil and Environmental Engineering

University of Alberta

Abstract: Masonry construction offers a range of benefits as it serves multiple purposes in a single system. It is cost-effective, long-lasting, and provides an aesthetically pleasing appearance. Moreover, its design flexibility and reasonable construction costs make it even more appealing. Masonry wall systems include several types. In this research, the focus is specifically directed towards masonry partition walls. Recent trends indicate a decreased preference for masonry construction. Literature and industry reports show several reasons behind this decline including: lack of masonry design knowledge among architects, labor-intensive execution, and intricate nature of masonry wall design and detailing. It is evident that the utilization of modern technological design advancements in this sector are not widespread. In addition to the general challenges identified in this field, masonry partition walls are being overdesigned. Also, there is no systematic selection method for wall type selection in partition wall design. This motivates the solution proposed in this study to develop a hybrid decision support system (DSS) for partition wall design. The proposed DSS includes two parts. The first part is a multi-criteria decision-making tool based on the choosing by advantage (CBA) method which facilitates the process of partition wall type selection, highlighting the advantages of masonry partition walls. Wall alternatives and wall selection criteria are determined based on the National Building Code of Canada and experts' opinion. As the second part of the DSS, a computational design tool is developed to facilitate the design process by automatically controlling the structural soundness of unreinforced masonry partition walls. It also aims at improving designers' comprehension of unreinforced masonry partition walls by automating the design process, ensuring compliance with structural requirements of Masonry Code, and offering clear visualization and simplified design iteration. The integration of design model into a Building Information Modeling (BIM) environment addresses the need to encourage the utilization of digital tools in masonry design. The proof of concept of the proposed model is conducted through the implementation of two different hypothetical case studies. Wall selection using the CBA method shows the significant impact of the developed DSS in clearly comparing wall options, highlighting the advantages of masonry systems, and guiding a well-informed decision considering all design requirements. The computational design model integrated in the BIM model streamlines the design process, enables architects to automatically check structural design requirements of masonry partition walls, while saving both time and cost. According to RSMeans cost database, 3-11% savings are achieved in constructing unreinforced masonry partition instead of reinforced walls. In conclusion, the proposed DSS can substantially improve both the partition wall design process and the adoption of masonry wall systems, with a notable potential for extension to other categories of masonry walls.

Acknowledgments

I wish to extend my heartfelt appreciation to my supervisor, Dr. Farook Hamzeh, for his unwavering support, expert guidance, and constant encouragement throughout this research endeavor. His vision and motivation have been instrumental in shaping my academic journey, and I am deeply grateful for his mentorship during my master's study. I also want to express my gratitude to the members of my thesis examination committee.

Furthermore, I am indebted to the Canada Masonry Design Center, specifically Dr. Bennett Banting and Monica Guzman, for providing the knowledge and context that were crucial for understanding my research. Their assistance and guidance along the way have been invaluable. Additionally, I express my thanks to the Masonry Research Group and the Natural Sciences and Engineering Research Council of Canada (NSERC) for their financial support, which has played a pivotal role in advancing my research endeavors. I must also acknowledge the indispensable support of my friends and family.

I want to offer my special thanks to my remarkable husband for nurturing my curiosity and boosting my confidence. His solid belief in me has been a constant source of motivation and strength throughout this journey.

Contents

List of Tables

List of Figures

List of Abbreviations

Abbreviation	Explanation
AEC	Architectural Engineering Construction
AHP	Analytical Hierarchy Process
BIM	Building Information Modeling
CBA	Choosing by Advantage
CMDC	Canada Masonry Design Center
CCMPA	Canadian Concrete Masonry Producers Association
CMHC	Canada Mortgage and Housing Corporation
CAD	Computer Aided Design
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
CSA	Canadian Standard Association
DSS	Decision Support System
DSR	Design science research
FRR	Fire Resistance Rate
MCDM	Multi Criteria Decision Making
MADM	Multi-Attribute Decision-Making
MAUT	Multi-Attribute Utility Theory
NBCC	National Building Code of Canada
NSERC	Natural Sciences and Engineering Research Council
SMART	Simple Multi-Attribute Rating Technique
STC	Sound Transmission Class
RM	Reinforced Masonry
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
URM	Unreinforced Masonry
WRC	Weighting, Rating, and Calculating

1 Chapter One: Introduction

1.1 Background

Masonry, a traditional construction material, holds unique characteristics that render it indispensable in the construction industry. It serves multiple purposes, providing structural support, fire protection, insulation, weather protection, and space division (Hendry & Khalaf, 2017). Additionally, masonry materials are renowned for their durability, requiring minimal maintenance and offering architectural flexibility. Modern masonry construction methods have improved productivity, thanks to larger units and off-site mortar preparation (Hendry, 2001). However, recent trends show a decline in masonry application. This building system is facing severe competition from other wall systems such as wood and glass (Jordan Kuntz, 2022).Modern architecture exhibits a complex relationship with masonry. The adoption of steel and concrete materials has led to a reduction of materiality in design, causing a somewhat hesitant association between modern architecture and masonry (Collins, 1998). Furthermore, there is a prevailing perception that architects are not fully exploring the potential of masonry, even though the masonry industry and research community have consistently evolved by introducing innovations such as sustainable and eco-friendly masonry unit types, integrated insulation (Subasic, 2022) ,advanced structural analysis methods, and more efficient construction processes (Beall, 2000; Beall & Jaffe, 2003). Heyman (1996) observed that the decline in the use of masonry as a building material has resulted in a decline in expertise and knowledge concerning masonry design, detailing, and construction, especially in the context of non-planar load-bearing masonry structures. Regarding technological advancement, research indicates that masonry designers currently have a limited set of digital tools available for depicting and exploring creative brickwork arrangements. Without such technology, architects face significant expenses in modeling and detailing buildings composed of numerous masonry components (Bettig & Shah, 2001). The need for application of advanced digital and computational tool in masonry design is being recognized by pioneer engineering firms. The advent of tools such as Masonry IQ is a proof for this phenomenon. These tools acknowledge the labor-intensive and manually intensive nature of masonry design process and seek to mitigate potential drawbacks that may discourage individuals from choosing masonry as a construction option (The Solution for Streamlined Masonry Design, 2020).

Narrowing down the scope of masonry wall systems to masonry partition walls, several research gaps have been identified in this area: First, there is a tendency to mistakenly apply design principles for masonry shear walls to partition walls within structural documentation. Overdesigning masonry partition walls with unnecessary reinforcement can be costly. Partition walls are primarily subjected to interior horizontal design pressure, not structural loads. They serve a different purpose than shear walls, particularly in low seismic zones, which they do not require minimum reinforcement (FORSE Consulting, 2019). This problem means the design principles of unreinforced masonry (URM) walls is not fully understood by designers. Second, masonry partition walls have many advantages compared to dry wall. For instance, masonry partition walls exhibit exceptional properties such as impressive fire resistance and sound transmission class ratings when compared to drywall alternatives (Government of Canada, 2022). This presents a great opportunity to facilitate the decision-making process of wall selection in partition wall design, ensuring that the benefits of each wall type are genuinely acknowledged. Lastly, selection of any building elements can be a challenging task for designers and an incorrect decision can lead to costly issues. It has been proved that the development of Decision Support Systems can mitigate human judgment errors (Alibaba & Özdeniz, 2004). There is a lack of a DSS to help designer in partition wall selection in the literature.

The reasons behind choosing partition walls as the scope of this research includes: the simplicity of partition wall systems in design, which involve fewer variables and makes it a logical fit for the scope of this research. In addition, partition walls hold significant importance in construction industry, representing approximately 10% of the total building cost of a townhouse in Canada (Canada Mortgage and Housing Corporation (CMHC), 2017).

This research succeeds on filling the identified gaps in partition wall design and masonry systems. A hybrid decision support system is developed to contribute to partition wall selection and design. The proposed solution applies multi criteria decision making method to enhance the wall selection process. Subsequently, a digital computational design tool has been created to automate structural design processes. Employing this computational tool empowers designers to make well-informed decisions about the selection of wall types, considering the structural demands of masonry walls. Additionally, it addresses the recognized gap the absence of technological advancements in masonry design, particularly in addressing the issue of overdesign in masonry partition walls. The outcomes of the developed DSS should lead to well-informed decisions regarding partition wall type and also having masonry partition walls which are designed structurally efficient and complained with masonry code requirements.

1.2 Problem Statement

The research problem lies in the absence of a systematic approach to partition wall selection in building design, resulting in an oversight of the advantages of each wall option based on specific design requirements. This leads to a failure in recognizing the best option tailored to the unique needs of the design. The identified issues also include problems related to overdesigned masonry walls and a recognized need for automation in the design of this wall type. This research identifies and addresses these issues by pioneering the development of a Decision Support System (DSS). The DSS, comprising a multi-criteria decision-making tool based on the CBA method and a computational design model, aims to systematically facilitate the selection and design process of partition wall types. Its implementation is expected to result in well-informed decisions by systematically evaluating design requirements and aiding in the efficient design of masonry walls, ensuring avoidance of unnecessary reinforcement when possible.

1.3 Research Objectives

The overarching objective of this research is to facilitate partition wall design process by selecting the best wall type and efficiently designing masonry partition walls. This objective involves the development of two main artefacts: the first one is a multi criteria decision making model based on CBA model and the second one a computational design model integrated in BIM environment

Objective 1: The first objective is to investigate the impact of a decision-making tool on the systematic selection of the most suitable partition wall option based on individual design requirements. The partition wall options under consideration include dry walls, constructed with steel and wood studs, and masonry. Despite the significant potential of masonry as a partition wall material, its frequent oversight prompts an exploration into the effectiveness of a decision-making tool in promoting its selection.

Objective 2: The second objective is to assess the influence of a computational design tool on the design of URM partition walls. This objective is motivated by three key considerations. Firstly, the construction of reinforced masonry partition walls poses significant challenges due to existing structures. Secondly, the tendency to incorporate unnecessary reinforcement in the design of such walls results from a lack of comprehensive understanding of the design principles among designers. Lastly, there is a need for wider adoption of digital tools in masonry wall design. Therefore, the second objective of this study aims to explore the impact of a computational design tool for URM partition walls on addressing these identified gaps and assess its overall contribution to the decision-making process in partition wall selection.

1.4 Research Scope

The research focuses specifically on partition walls, emphasizing a more limited scope when compared to the intricate variables associated with structural systems or external walls. The primary objective is to employ a decision support system in the selection of partition wall types, aiming to choose the most suitable option based on design requirements while acknowledging the unique strengths and characteristics of each wall type.

1.5 Research Methodology

Design science research methodology (DSR) is implemented in this research. Steps taken to implement this research are as follow:

1. Problem identification and motivation: The research begins with an extensive literature review on conducted research and industry practices in the field of masonry to identify the existing challenges faced in this industry.

2. Objectives of a solution: In the next step, the objective of a solution to contribute to solving the identified problem is developed. The intended solution here is a hybrid DSS which aims to facilitate the process of partition wall selection and URM partition wall design.

3. Design and development: In this step, the solution is developed. The solution development includes two parts; the first part is a decision-making tool based on CBA model. The steps for building this model is as follow:

- Literature review, meeting with industry experts and reviewing Codes requirements to determine partition wall selection criteria
- Wall alternatives are determined using NBCC and supplementary masonry wall options provided by Canadian masonry producers association (CCMPA)
- The CBA model is built using the factors and alternatives provided in the previous steps

As for the computational design tool, steps are as follow:

- Masonry structural Code is reviewed to specify design principles
- Industry common design practices are reviewed
- 2024 Masonry Code revision along with the CMDC simplified design tables are considered to develop the model
- Face validation of the developed solution is implemented by presenting the solution outline to the experts.

4. Demonstration: To validate the DSS's effectiveness, two case study projects are developed. The developed DSS is applied on each case study to select the partition wall type and efficiently design masonry walls.

5. Evaluation: The research assesses the effectiveness of the DSS by evaluating the efficacy of the developed DSS on the design facilitation of partition walls.

6. Communication: Throughout the research process, all aspects, including the problem, artifacts, value, originality, and effectiveness, are communicated with stakeholders to ensure a comprehensive understanding and alignment of objectives of this research with the industry' challenges.

1.5.1 Academic Contribution

This research significantly advances the academic field by introducing an unprecedented set of criteria for partition wall selection. It identifies the gaps in the design of this building element and proposes innovative solutions such as a hybrid DSS specifically designed for partition wall selection, filling previously unexplored areas in the understanding of partition wall design and selection processes. The research's emphasis on validation through case studies adds academic consistency, while its active engagement with industry experts ensures practical relevance and bridges the gap between academic research and real-world application.

1.5.2 Industrial Contribution

This research delivers practical tools and methodologies to enhance decision-making and automate design processes in the building industry, particularly through the utilization of advanced technologies such as computational design tools in BIM environment. The creation of a comprehensive database for partition wall options, a first in the field, and the educational potential of the DSS for efficient partition wall design are significant industry contributions. Moreover, experts suggest substantial commercialization potential for the DSS within the industry. The active engagement with industry experts during the design and implementation of the DSS, bridges the gap between academia and industry, ensuring that the research outcomes align with the practical needs and challenges of the construction sector.

1.6 Thesis Organization

This dissertation comprises five distinct chapters. The initial chapter serves to introduce the research's contextual background, define the problem statement, explain the research objectives and scope, and conclude in the research methodology. Subsequently, the resultant chapter expounds upon a comprehensive review of literature pertaining to masonry building systems, revisions in codes and building standards and decision support systems. The fourth chapter examines the proof of concept of the conceived DSS within the context of two tangible case studies. Ultimately, the final chapter encapsulates the culminating outcomes of the research, thus providing a conclusive synthesis.

2 Chapter Two: Literature Review

2.1 Introduction

A comprehensive literature review was conducted to gain a thorough understanding of masonry wall systems, decision support systems and partition wall alternatives. The aim was to identify and include all necessary factors for partition wall selection and accurately define the strengths and weaknesses of masonry. To facilitate this understanding, the literature review was organized into the following categories: Masonry wall general characteristics, Masonry wall application, Masonry wall advantages, Masonry wall architectural and structural design limitations, Masonry wall non-structural design limitations and Masonry construction. Then, unreinforced masonry design is studied since this study focuses on promoting the application of unreinforced masonry partition walls. Furthermore, since the purpose of this study is the creation of a DSS for partition walls in new building designs, the final section of this chapter undertakes a comprehensive review of existing literature related to DSSs, selection criteria, CBA method, and NBCC's requirements for partition walls.

2.2 Masonry wall general characteristics

Masonry refers to a construction method that involves joining numerous small modular units together using mortar to create a structure or structural elements. These modular units typically consist of clay bricks, concrete blocks, or cut stones. The primary masonry component is the wall, but masonry can also be employed to construct columns and beams when appropriately reinforced. Loadbearing masonry, which supports the structural load, is commonly constructed using clay bricks or concrete blocks. On the other hand, non-loadbearing masonry veneers are often made of clay bricks or cut stones (Hatzinikolas et al., 2015).

In specific scenarios, the relatively low tensile strength of masonry poses a restriction, especially when confronted with significant lateral forces. To overcome this limitation, reinforced masonry can be employed, particularly in buildings located in seismic areas and cases where non-load-bearing panels experience substantial wind loads. Walls with a cellular or T cross-section are particularly well-suited for large structures with a single cell. The use of such walls can be significantly enhanced by incorporating post-tensioning techniques (Hendry, 1998).

2.3 Masonry wall applications

Despite being overshadowed by steel and concrete for various purposes throughout the 20th century, masonry still holds significant value in **structural walls** of low and medium-rise structures, as well as in constructing **internal walls and building facades in buildings with steel or concrete structural frame** (Hendry, 2001). Masonry load-bearing walls have a long history of use in construction, dating back centuries. They have been used in many building types, from small, simple structures to grand monuments and public buildings (Cross, 1965). Brick construction for multi storey buildings was replaced by steel- and reinforced concrete-framed structures in the first part of the 20th century, but they were frequently covered with brick (Hendry et al., 2017a). The John Root-designed Monadnock Building in Chicago, which stands sixteen stories tall and has walls that are 1.82 meters thick at the base, was "*the final triumph of traditional masonry building*" in 1891 (Cross, 1965).

Masonry construction industry can be categorized into two main sectors: housing and non-housing. The non-housing sector encompasses industrial, commercial, and educational buildings, as well as administrative and recreational structures. Additionally, masonry construction is occasionally utilized in infrastructure projects, such as retaining walls (Hendry, 2001). In all these sectors, there is a notable demand for masonry when it comes to repairing and maintaining existing buildings (Sowden, 1990).

2.4 Masonry Wall Advantages

Masonry wall construction offers several advantages. Firstly, a single masonry element can serve multiple purposes, including providing structural support, fire protection, thermal insulation, sound insulation, weather protection, and dividing space. Masonry materials possess properties that are capable of fulfilling these functions. In some cases, supplementary materials may be needed for tasks such as thermal insulation or damp-proof courses. However, masonry materials alone are generally sufficient to meet these requirements (Hendry & Khalaf, 2017).

The second significant advantage of masonry wall construction is the durability of the materials used. With careful selection, these materials can remain functional for several decades, and even centuries, with minimal maintenance requirements. From an architectural standpoint, masonry provides a high level of flexibility in terms of plan design, spatial arrangement, and the external appearance of walls. There is a wide range of masonry materials available in various colors and textures, allowing for diverse aesthetic options. Complex wall configurations, including curved walls, can be constructed easily without the need for costly and inefficient formwork. Masonry construction offers the advantage of not requiring heavy and expensive machinery for its implementation. While skilled labor is necessary for achieving a high standard of construction, productivity has been improved through the use of larger units, enhanced materials handling, and off-site preparation of mortar (Hendry, 2001).

2.5 Masonry wall architectural and structural design limitations

Appropriateness of masonry wall construction for a specific application must be carefully considered, bearing in mind architectural considerations. For instance, if the masonry is not intended to bear structural loads, the weight of the masonry should be evaluated in relation to the supporting structure. In cases where load-bearing walls are required, the layout of the walls must align with overall stability requirements and minimize the risk of failure in the event of accidental damage. This implies that the building's function should necessitate an adequate number of walls to meet these requirements, such as in hotels or similar structures (Hendry, 2001).Two standard structural wall layouts are shown in figure 2-1 and 2-2.

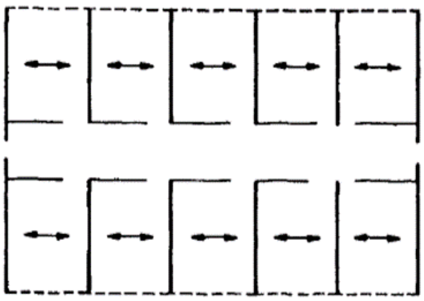


Figure 2-1: Simple cross wall structure(A.W.Hendry, 2004)

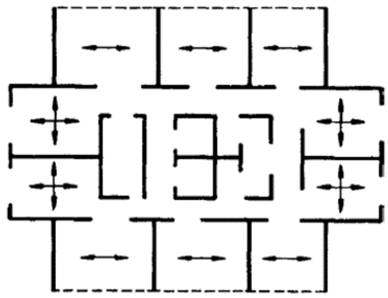


Figure 2-2: Complex wall arrangements (A.W.Hendry,2004)

Conversely, if a wide and open floor plan is desired, load-bearing masonry walls may not be suitable. (Hendry, 2001). The form and wall layout of a building are determined by functional requirements and site conditions, requiring collaboration between the engineer and architect. From a structural perspective, the chosen arrangement is typically not critical as long as a reasonable balance is maintained between walls oriented in the principal directions of the building (Hendry, 1998b). Construction imperfections like lack of verticality alignment further complicates the design. Creep effects and interacting floor slabs also impact the eccentricity (Hendry, 2001).

The sequential and complex construction process of masonry buildings causes inconsistent information flows in design and construction. Design management entails managing the flow of information and coordinating individuals and teams involved in the design process (Al Hattab & Hamzeh, 2018). The design workflow encompasses the exchange of information and deliverables among teams and individuals, and its complexity has heightened with advancements in design specifications, evolving end-user requirements, and technological progress. The production of large amounts of information and the pressure of deadlines and budgets increases the risk of design errors and conflicts. Poor design flow can lead to several types of waste, including excessive rework and revision cycles, design errors, reduced quality, increased costs, and schedule delays, ultimately decreasing the value generated for end-users (Ballard, 2002). According to (Momenifar et al., n.d.), the decline in the prevalence of masonry use can be categorized into three main groups: masonry design, masonry unit, and masonry construction. To address the design problems identified, the authors propose the introduction of intelligent BIM models specifically tailored for masonry design.

The structural code of practice for masonry encompasses all types of masonry, including brickwork, blockwork, and stone. It is important to recognize that the code assumes the structural design will be undertaken by a chartered civil or structural engineer, or another qualified individual with appropriate expertise. Similarly, the supervision of construction activities should be conducted by suitably qualified personnel, although they may not necessarily hold chartered engineer status. This ensures that the design and construction processes are handled by individuals with the necessary qualifications and knowledge to ensure the safety and integrity of the masonry structure (Hendry et al., 2017b).

2.6 Masonry wall non-structural design limitations

In addition to structural design requirements, there are some non-structural factors a designer should consider while designing a masonry wall, including: movement, moisture exclusion, durability, thermal and acoustic properties, and fire resistance (Hendry, 2001).

Movement in masonry materials can result from applied stress, moisture and temperature changes, chemical reactions, and foundation movements, potentially leading to cracking (Miranda Dias, 2002). Loading-induced movements can be significant in multistory buildings, and adjacent elements' movements can affect masonry walls. Thermal movements depend on material coefficients of expansion and temperature ranges, which can vary based on factors such as color, exposure, orientation, and climate. Dimensional changes occur in masonry units after manufacture and during service due to changes in moisture content. Provision should be made during the design stage to accommodate movements without causing unacceptable cracking, primarily through material selection and careful detailing (Hendry et al., 2017b).

Moisture exclusion is crucial in masonry wall design and requires careful material selection, detailing, and workmanship. Exposure conditions are specified in national codes, and architectural features such as overhangs and drips can help prevent water penetration, while large areas of glazing or impermeable cladding can increase the risk. Damp-proof courses, cavity trays, and complex details for steel or concrete clad in masonry are necessary to prevent moisture ingress (Hendry, 2001). Durability refers to a material or construction's ability to remain serviceable without excessive maintenance over a considerable period (Harding JR, 1986). Frost damage, resulting from freezing water in the material's pores, is a significant factor affecting durability. Salt crystallization, atmospheric pollution, biological agents, and metal components can also impact durability (Hendry, 2001).

Thermal and acoustic properties are important considerations in masonry wall design. Thermal insulation of buildings is an increasingly important factor in building design. Additional insulation may be required for conventional masonry walls, and the position of insulation (internal or external) affects thermal behavior (Ismaiel et al., 2021). Insufficient insulation and ventilation can lead to condensation in buildings, potentially causing harm to decorations and promoting the growth of mold (Becker, 1984).

Masonry materials are inherently incombustible and provide fire protection as specified in building regulations, but detailed design considerations are essential to ensure proper fire stops and prevent fire bypass (Oprite Bobmanuel, 2021).

2.7 Masonry construction

Traditional techniques for building masonry walls have remained mostly unaltered until recently, leading to concerns regarding the time-consuming nature of constructing masonry buildings and the challenge of finding skilled workers (Ramamurthy & Kunhanandan Nambiar, 2004). These concerns are partially due to the unappealing working conditions on construction sites. In recent years, numerous innovative types of masonry units have been created, focusing enhanced thermal properties, improved dimensional consistency, a wider range of sizes and types, new masonry unit types with sustainable and green construction and integrated insulation (Subasic, 2022). The introduction of larger and more precise units, along with the utilization of thin bed mortars that can be applied more quickly compared to traditional methods, has enabled noteworthy enhancements in productivity within masonry construction (Ramamurthy & Kunhanandan Nambiar, 2004). The feasibility of utilizing pre-fabricated brickwork columns instead of walls has been successfully demonstrated, addressing the challenges associated with this construction method, such as the requirement for costly and specialized equipment (Hendry, 2001).

In summary, masonry most important characteristics can be stated in the table 2-1:

Table 2-1: Summary of masonry characteristics

Category	**Summary**	**Reference**
Structural characteristics	• Low tensile strength, which can be overcome by using reinforced masonry in seismic areas or for wind load resistance • Cellular or T cross-sections are suitable for large structures • Still valuable for structural walls in low and medium-rise buildings, internal walls, and facades with steel or concrete frames	(Hendry, 1998b, 2001; Hendry & Khalaf, 2017)
Advantages	• Serves multiple purposes, including structural support, fire protection, insulation, weather protection, and space division. • Masonry materials are durable, requiring minimal maintenance and offering architectural flexibility • Masonry construction does not require heavy machinery, and productivity has improved with larger units and off-site mortar preparation	(Hendry, 2001; Hendry & Khalaf, 2017)
Design Considerations	• The appropriateness of masonry walls depends on architectural considerations and the need for load-bearing walls or open floor plans Structural design factors include compressive strength calculations, construction imperfections, and lateral resistance to wind and accidental damage	(Hendry, 1998b, 2001; Hendry & Khalaf, 2017)
Non-structural Considerations	• Non-structural factors in masonry wall design include movement, moisture exclusion, durability, thermal and acoustic properties, and fire resistance • Considerations should be made for loading-induced movements, thermal expansion, moisture ingress prevention,	(Harding JR, 1986; Hendry, 2001; Hendry et al., 2017b; Ismaiel et al., 2021; Miranda Dias, 2002; Oprite Bobmanuel, 2021)

	durability against environmental factors, insulation, and fire stops.	
Construction	• Traditional masonry techniques have been improved with innovative masonry units, larger and more precise units, and thin bed mortars. • Pre-fabricated brickwork columns and automated block laying systems have been introduced to enhance productivity in masonry construction.	(Hendry, 2001; Ramamurthy & K.B.Anand, 1999; Subasic, 2022)

2.8 Masonry structural design

In masonry structural design, a comprehensive consideration of various components is imperative. This encompasses masonry units, mortar, grout, and masonry reinforcement. Determination of masonry strength, encompassing compressive and flexural tensile strength, assumes paramount importance. Simultaneously, deformations including elastic strain, creep strain, shrinkage, expansion, and modular ratio must be exactly accounted for. The context of masonry structural design is underpinned by the limit states method, which ensures that various limiting states are not exceeded during the reasonable life of the structure. The design analysis for masonry also depends on the type of masonry member. For flexural members, the design considerations include flexure of reinforced masonry with single or double reinforced sections, shear analysis and design involving diagonal tension, masonry shear resistance, and shear reinforcement. For unreinforced flexural walls, the design should address their flexural resistance in both non-loadbearing and loadbearing walls. Factors like slenderness effect, arching action, wall panels, and composite walls are considered. Shear resistance should also be assessed for masonry walls (Hatzinikolas et al., 2015).

In summary, masonry structural design process include consideration of five main criteria as follows:

1. Masonry units: Concrete, clay, efflorescence and spalling units
2. Mortar and grout
3. Masonry reinforcement: Steel bars, joint reinforcement
4. Masonry strength: Compressive strength, flexural tensile strength
5. Masonry deformations: Elastic strain, creep strain, shrinkage and expansion and modular ratio

The secondary objective of this research is to enhance the adoption and utilization of masonry walls, focusing on a specific masonry wall type, namely masonry partition walls. This targeted approach enables us to address the realistic objectives of promoting the use of masonry walls and facilitating informed decision-making processes. Through consultations with industry experts, it became evident that masonry partition walls hold significant importance in the Canadian market, making them a pertinent choice for investigation and comparison with other wall systems (Canada Masonry Design Center, 2023). According to Canada Mortgage and Housing Corporation (CMHC), partition walls and doors contribute to 9% of total building cost of a townhouse (figure 2-3) (Canada Mortgage and Housing Corporation (CMHC), 2017). Also compared to other types of masonry walls, masonry partition walls are simpler in design making the process of comparison with other walls more straightforward and within the scope of this research. By investigating the specific design considerations and advantages of masonry partition walls, we can offer valuable insights and guidance to stakeholders, supporting their decision to opt for masonry as a viable and competitive wall solution. Also, masonry experts believe that facilitation of masonry partition wall uptake in the design of new building can potentially lead to considering masonry for other parts of the building, naming loadbearing elements.

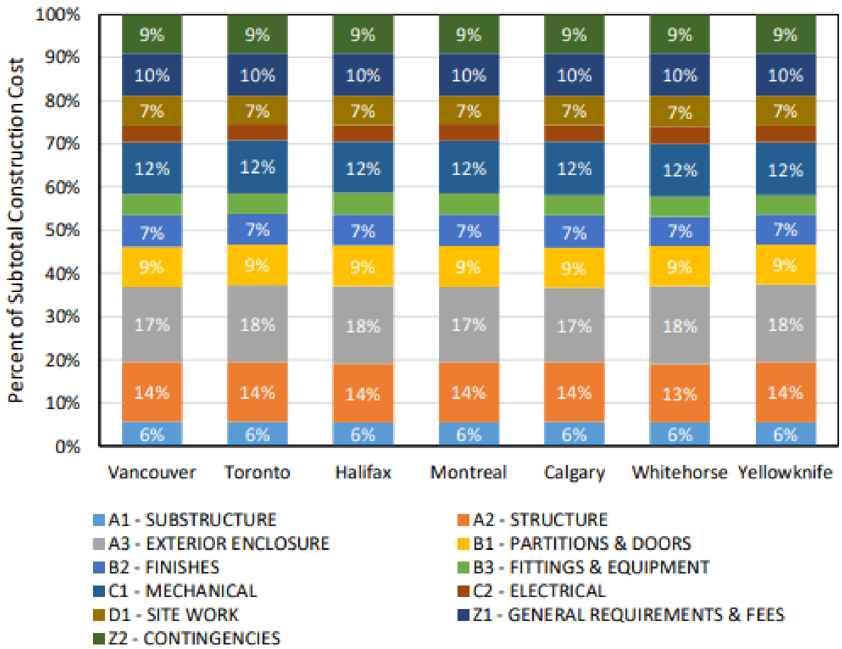


Figure 2-3- Cost contribution of different building parts of a townhouse in Canada(Canada Mortgage and Housing Corporation (CMHC), 2017)

2.8.1 Unreinforced Flexural Walls

In contemporary construction practices, reinforced masonry is the predominant method employed. However, it is essential to have a comprehensive understanding of the behavior of unreinforced masonry in order to fully comprehend and effectively utilize reinforced masonry. This understanding is essential in masonry partition wall design as such elements can be designed as unreinforced members and act as flexural walls due to existence of internal wind pressure.

When masonry walls experience transverse loading, such as wind pressure, they undergo out-of-plane bending. In the absence of significant axial compression, tensile stresses are introduced into the wall. If the wall is unreinforced, these tensile stresses are tolerated by the weakest component in tension, which is typically the bond between the mortar and masonry units. As a result, the effective area of this bond governs the calculation of flexural strength. Due to the inherent properties of masonry, which is significantly stronger in compression compared to tension (see values for tensile and compressive strength of masonry in figures 2-7 and 2-8), the compressive stress experienced under transverse loading is relatively low and likely to remain within the linear elastic range of the stress-strain relationship. In such cases, flexural stresses can be calculated using the well-established elastic expression that applies to linear elastic materials, equation 2-1 (Hatzinikolas et al., 2015).

$$f = \pm \frac{Mc}{I} = \pm \frac{M}{S} \qquad \text{(Equation 2-1)}$$

Where, $M =$ out-of-plane bending moment

$I =$ moment of inertia of the net section;

$c =$ distance of the extreme fibre of the section from the centroid = $t/2$ for uncracked sections, where t is the wall thickness; and

$S =$ section elastic modulus $= I/c$

The resulting flexural stresses in masonry walls are equal in magnitude but have opposite signs, with one being compressive and the other being tensile. It is essential for a proper design to ensure that neither stress surpasses the strength of the masonry material. Consequently, the elastic analysis establishes the following design criteria.

$$f_{compression} = -\frac{M}{S} \leq \emptyset_m f'_m \qquad \text{(Equation 2-2)}$$

$$f_{tension} = +\frac{M}{S} \leq \emptyset_m f_t \qquad \text{(Equation 2-3)}$$

Bending in unreinforced masonry walls can occur in one of two directions:

a) Vertical Span: In this case, the wall spans vertically, as depicted in Figure 2-4. The wall is laterally supported at the top and bottom, and the resulting stresses are perpendicular to the bed joints (horizontal). This can be observed from the failure mode of the wall.

b) Horizontal Span: Alternatively, the wall can span horizontally, as illustrated in Figure 2-5. In this scenario, the wall is laterally supported by vertical columns or masonry pilasters. The stresses induced in this case are parallel to the bed joints.

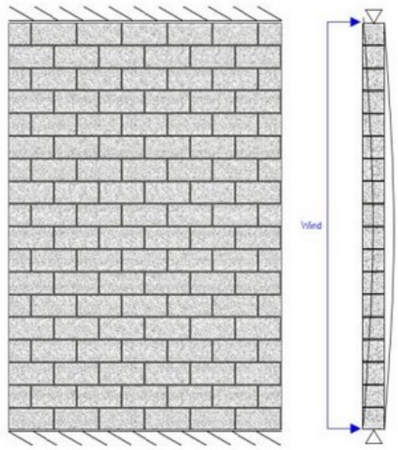


Figure 2-4: Vertical bending (Canada Masonry Design Center, 2017)

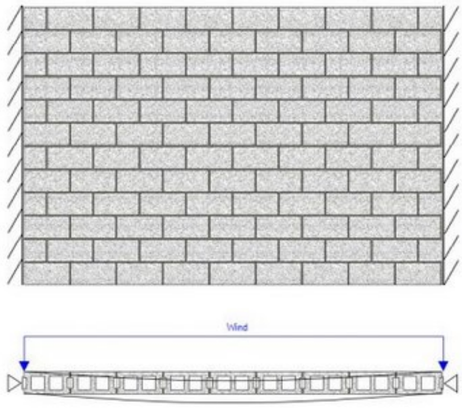


Figure 2-5: Horizontal Bending (Canada Masonry Design Center, 2017)

The ability of horizontal walls to bend is typically determined by the tensile strength of the masonry combination, f_t (with some exceptions noted), figure 2-5. On the other hand, vertically spanning walls have a continuous joint where a crack may appear without crossing the individual unit, figure 2-6b. As a result, the tensile strength of vertically spanning walls is lower than that of horizontally spanning walls. The CSA S304-14 in Table 5, table 4A in Appendix A, acknowledges this distinction by specifying separate values for tensile strength in the normal and parallel directions to the joint (Canada Masonry Design Center, 2017).

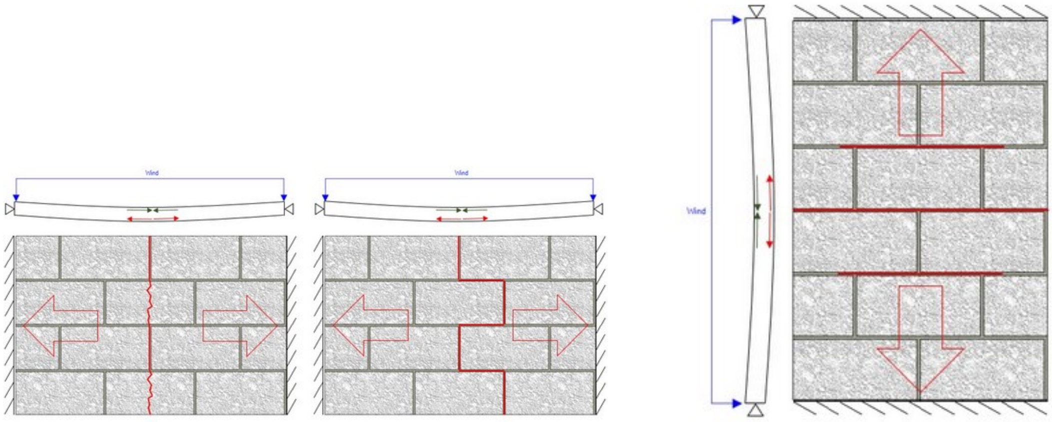


Figure 2-6: Crack development in a) horizontally spanning and b) vertically spanning walls(Canada Masonry Design Center, 2017)

CSA S304-14 acknowledges that the tensile strength is higher in case (a) compared to case (b). In Table 5 of S304, the flexural tensile strength values for clay and concrete units, with either type S or N mortar, are provided. The table includes values for both tensile strengths perpendicular and parallel to the bed joints. It is important to note that when calculating moments (M) in masonry structures, simple spans are typically assumed. This assumption is because of movement joints, which do not transfer moments, and are likely to be incorporated in the design (Canada Masonry Design Center, 2017).

2.8.2 Structural Code requirements for masonry partition wall

To further investigate masonry partition wall design, the Canadian Standards Association (CSA) is considered. The CSA standard refers the Canadian Standards Association (CSA), which is an organization responsible for creating and maintaining a wide range of standards across various industries in Canada. These standards are designed to ensure safety, reliability, and quality in products, services, and processes. In the context of masonry structural design, the CSA S304 plays a crucial role in establishing guidelines and requirements for the design, construction, and maintenance of masonry structures. The CSA S304 standard for masonry design provides a comprehensive framework that outlines the principles, methodologies, and criteria for designing safe and efficient masonry structures.

A structural code of practice or standard for masonry serves as a comprehensive reference for designing structures using this construction medium. It provides essential data and recommendations based on prevailing good practices at the time of its preparation. However, it is important to note that a code of practice is not a textbook and does not absolve the designer from the responsibility of fully understanding the materials and structural behavior inherent in their design. Therefore, to effectively and safely use a code of practice, engineers must carefully study its provisions and strive to grasp their underlying intentions. This task can be challenging since codes are often written in terms that may obscure the uncertainties of the drafters, and they are typically lacking commentaries that define the basis and limitations of the various clauses. Despite these challenges, it is crucial for engineers to make a diligent effort to comprehend and apply the provisions of the code in order to ensure sound and reliable structural designs (Hendry et al., 2017a).

CSA S304-14 defines masonry partition walls as "*an interior non-loadbearing wall that is one story or part of one story in height*" and demands masonry partition wall design to satisfy some requirements. A summary of all these requirements is presented in Table 2A of Appendix A. These requirements include several important criteria. First, all masonry walls, their components and assemblies must satisfy the fire resistance requirements of the National Building Code of Canada. Structural elements designed to support masonry must have a rigidity compatible with the stiffness of the masonry. For vertical support, recommended limits on vertical deflection apply, such as a span/480 or less, but not more than 20 mm, for elements supporting masonry other than veneer or reinforced masonry that meets deflection requirements. In the case of masonry partition walls and infill walls, it is permissible to surpass the deflection limit mentioned earlier, as long as there are adequately sized movement joints strategically positioned within the wall. These movement joints serve the purpose of preventing cracks or minimizing their width, and also ensure that there is no unintended stress imposed on adjacent masonry or non-masonry elements. The minimum thickness of a partition should conform to the values given in Table F.2 of CSA S304-14, table 6A in Appendix, (for partitions minimum slenderness ratio of 36 and thickness of 75 mm), unless lateral support is provided, in which case the height of the partition should not exceed 72 times its thickness, with horizontal intervals not exceeding 36 times the partition thickness. Reinforcement for non-loadbearing walls depends on the seismic hazard index, with a minimum total reinforcement ratio of 0.05% for indices between 0.35 and 0.75, and a minimum reinforcement ratio of 0.033% in each direction for indices equal to or greater than 0.75. The maximum spacing of vertical reinforcement should be less than the specified values based on the seismic hazard index, ranging from 12(t+10) mm or 2400 mm to 6(t+10) mm or 1200 mm.

Masonry partition walls can be designed based on part 16.2 of CSA S304-14 for unreinforced masonry elements. Such provisions are stated in the following:

"16.2 unreinforced masonry

16.2.1 General

Except as permitted in clauses 16.2.3 and clause 16.2.4, reinforced masonry shall be used where the seismic hazard index, $I_E F_a S_a(0.2)$, is greater than or equal 0.35 for loadbearing and lateral-load-resisting *masonry, and masonry enclosing elevator shafts and stairways. Unreinforced masonry may be used where the seismic hazard index, $I_E F_a S_a(0.2)$, is less than 0.35."*

This means if the seismic hazard index falls below 0.35, unreinforced masonry may be employed; in fact, no minimum reinforcement is required for partition walls designed for low seismic hazard areas (CSA Group- Canadian Standard Association, 2014). Considering the fact that several provinces in Canada, including Alberta, are located in low-seismic hazard areas (Government of Canada, 2020), designers can benefit from this requirement by designing unreinforced masonry partition walls and having a more economical design and less challenging construction.

2.8.3 Industry practice

As indicated by industry practitioners, there exists a tendency to mistakenly apply the design principles intended for masonry shear walls to partition walls within structural documentation. Within a set of design drawings, there might be a General Note stating that "*masonry walls should have #x vertical bars spaced at y" as a standard, unless otherwise specified*". However, it is unclear whether this note is necessary or applicable to non-structural partition walls. According to CSA S304-14, partition walls can be built without reinforcement and still extend to tall story heights if properly detailed. Consequently, including a General Note that requires reinforcement for all masonry walls, including shear walls, load-bearing walls, and partition walls, may result in an excessive use of reinforcement for non-loadbearing partition walls in the project (FORSE Consulting, 2019).

If detailed correctly, the only load that partition walls are to be designed for is an interior horizontal design pressure. Walls must solely endure loads stemming from their own weight and those explicitly authorized by regulations. Additional details regarding wind loads affecting interior walls and partitions are available in the "Structural Commentaries" section (User's Guide – NBCC Part 4 of Division B). As an industry practice standard, wind pressure numbers for partition wall design ranges from 0.25 to 0.75 Kpa.

Recognizing the existing problem of overdesigned masonry partition walls, Canada Masonry Design Center of Canada has provided some simplified design tables for masonry partition walls which are not published yet. Designers can choose the required wall thickness of masonry partition wall and get the maximum wall height without reinforcement. For instance, for the wind pressure of 0.25 Kpa and partition wall with 90 mm block, the wall can go as high as 2.5 m without reinforcement, considering the masonry wall with a compressive strength (f'_m) of 11.765 and tensile strength of 0.4 *Mpa*, hollow block and type S mortar. However, as the wall height increases or the wall thickness decreases, light reinforcement becomes necessary to resist the interior pressure (Canada Masonry Design Center, 2023).

In higher seismic design categories, minimum prescriptive reinforcing is required as per the applicable Seismic Design Category. Furthermore, as seismic requirements increase, the design of partition walls will likely be influenced by the seismic demands on non-structural components rather than the minimum load on the partition wall itself.

While masonry remains a popular choice for partition walls, it is important to be cautious of potential overdesign. Unreinforced masonry partition walls have faced considerable challenges in gaining acceptance within the industry, as conveyed by industry experts (Monica Guzman, 2023). This reluctance can be attributed to the longstanding perception of masonry as a sturdy material reinforced with strength-enhancing rebars. This history has fostered an inherent lack of confidence in utilizing masonry as an unreinforced element. Allocating a significant portion of a project's budget to partition walls can result from the inclusion of unnecessary heavy reinforcement. To mitigate the risk of cost overrun, it is beneficial to adopt effective design and detailing practices. It is crucial to recognize that partition walls serve a different purpose than shear walls. Shear walls actively contribute to the building's primary lateral force resistance system, while partition walls are not intended to bear any structural loads of any kind. Consequently, partition walls, particularly in low seismic zones, do not necessitate minimum reinforcement requirements. Additionally, optimizing the connection points at the top of partition walls by aligning them with pre-grouted cells can yield smarter outcomes. By incorporating such considerations into the design process, masonry partitions can offer all their advantages without any associated drawbacks (FORSE Consulting, 2019).

2.9 Technological advancements in masonry architectural design

In terms of architectural design, modern architecture has an ambivalent relationship with masonry. Using steel or concrete frames and curtain wall skins in construction has led to the dematerialization of design, while masonry construction is rooted in using materials. This change has created a hesitant relationship between modern architecture and masonry (Collins, 1998). In addition, there is a notion that architects are not pushing the boundaries of masonry, even though the masonry business and research community have consistently advanced with improvements. Such improvements aim for new masonry unit types with sustainable and green construction and integrated insulation (Subasic, 2022), structural analysis methodologies, and more effective building procedures (Beall, 2000; Beall & Jaffe, 2003). It has been noted by Heyman (1996) that the decline in masonry as a building material has led to a decrease in expertise and knowledge in masonry design, detailing, and construction, particularly in the use of non-planar forms of load-bearing masonry structures. Researchers claim that the perception of masonry as a conservative and risky building technique when aiming for innovative shapes, combined with a shortage of specialized knowledge and computational tools, limits its ability to compete with other building methods. Therefore, most new masonry buildings use traditional and conservative solutions (Gentry et al., 2009).

A phenomenon known as design fixation is happening in current masonry design due to lack of early feedback (Jansson & Smith, 1991; Purcell & Gero, 2006): The lack of early feedback during the conceptual design stage can result in uncertainty, leading architects to avoid unusual and potentially more innovative solutions and instead opt for simpler and more conventional solutions. This is more likely when the number of parts involved in a problem is high, such as in the case of a masonry wall, cladding system, or tiled roof. The tendency to follow conventional configurations is often justified by adhering to traditional construction wisdom (Cavieres et al., 2009), which can result in a missed opportunity for innovation and progress in the design and construction of masonry structures. To avoid this, it is important for architects to have access to the necessary knowledge resources and to receive early feedback during the conceptual design stage to help guide their decisions and minimize the risk of design fixation (Cavieres et al., 2011). One solution to this phenomenon can be fostering the application of digital design tools such as BIM.

Building Information Modeling (BIM) is expected to revolutionize the construction industry by introducing more standardization, consolidation, and integration in the construction process. In contrast to the traditional 2D CAD approach, which represents a model by objects and is constrained by the properties of architectural elements like walls, beams, and columns as well as the embedded consideration of materiality, the BIM approach to building design imposes more restrictions on the modelling process (Eastman, 2008). In the architectural design development phase, where a more developed architectural articulation of the structural connections, structural elements, member sizes, floor plates, etc. have been defined through numerous consultations with engineers, BIM is frequently thought to be more practical to use (Nixon Wonoto, 2017) . BIM will shift the construction process from being project-based and reliant on unique customer specifications to a more product-based approach, utilizing off-site manufacturing and prefabrication. This will lead to a reduction in the influence and responsibility of general contractors, who will have a limited role in on-site assembly. The integration of BIM technology with other disruptive technologies across the facilities' lifecycle will amplify its impact (Heigermoser & de Soto, 2022). BIM will enable the integration of computational and generative design solutions which can be useful in masonry design.

Research reveals masonry designers have a limited number of digital tools at their disposal to represent and investigate novel brickwork arrangements. The amount of work architects must spend into modelling and detailing a building with hundreds or maybe thousands of masonry components becomes expensive in the absence of such technologies (Bettig & Shah, 2001). This means current technical advancements are not being widely adopted into masonry design practice.

Some research focused on promoting the use of concrete masonry systems in contemporary design practice by incorporating masonry construction knowledge into the design process through state-of-art computational technologies. The goal is to improve the design and construction processes by enabling the creation, testing, and evaluation of a greater number of design alternatives from the start. A significant focus will be on the formal variability and geometric complexity of building envelopes. Masonry units offer a wide range of configurations and formal results, which can be intensively explored through parametric modeling, making the representation of complex geometries and assemblies easier and more realistic, leading to innovation in the design of masonry buildings. The methodology described is a simplified system that helps architects design complex masonry walls in the early stages of the design process. The system uses continuous updates in a computer aided design (CAD) and BIM environment to validate, shape, and bound architectural decisions. Its purpose is to provide architects with a tool to design walls that are both structurally feasible and constructible, giving them confidence in their design decisions (Gentry et al., 2009).

The literature reviewed here primarily focuses on masonry's structural aspects like external walls and cladding using brickwork. Notably, there's a gap in research concerning masonry as partition walls, although many gaps identified for other masonry aspects likely apply here too. This suggests a need for more attention to this less explored area in masonry studies.

2.10 Decision Support Systems

In architecture, choosing the right building elements from numerous options is a significant challenge. This selection process is influenced by various factors. Making the wrong choice can lead to significant issues related to cost, construction functionality, and aesthetics, which can be difficult to rectify (Alibaba & Özdeniz, 2004). In managerial decision-making, human judgment plays a pivotal role, primarily relying on deductive reasoning shaped by practical experience, information, and knowledge. To mitigate the potential impact of human errors, there is an opportunity to introduce computer-aided automation, Decision Support Systems (DSS), into the decision-making process (Faiz & Edirisinghe, 2009). The field of DSS serves as a means to emulate human reasoning and the decision-making process. Both DSS and human experts have the capacity to receive input from users, process this data, and propose solutions that closely align with those provided by human experts (Yehia et al., 2008). DSS can play a significant role in the assessment of various maintenance decisions, facilitating the selection of robust and cost-effective solutions in a logical and transparent manner (Zoeteman, 2001). Steven Alter's ground-breaking study from 1980 outlines three fundamental attributes inherent to Decision Support Systems. Firstly, DSS are tailor-made to streamline the decision-making process. Secondly, their role is to assist decision makers rather than replace them, promoting human involvement in decision-making. Lastly, DSS should possess the agility to swiftly adapt to the evolving requirements of decision makers (Alter, 1980). Different types of DSS can be categorized into various categories, each serving distinct decision-making purposes.

Data-Driven DSS: This type focuses on the analysis of extensive structured data, making it valuable for data-intensive decision processes.

Model-Driven DSS: These systems utilize accounting, financial, representational, and optimization models to aid decision makers by accessing and manipulating these models using data and parameters provided by them. Unlike data-driven DSS, they are not typically reliant on large databases.

Knowledge-Driven DSS: Also known as Management Expert Systems, these systems suggest or recommend actions to managers based on business rules and knowledge bases, functioning as computer-person systems equipped with specialized problem-solving expertise.

Document-Driven DSS: Evolving to assist managers in gathering, retrieving, categorizing, and managing unstructured documents, including web pages, this category of DSS integrates various technologies to provide comprehensive document retrieval and analysis solutions.

These DSS categories are complemented by Communication-Driven and Group DSS, Interorganizational DSS, Function-Specific or General-Purpose DSS, and Web-Based DSS, each tailored to specific decision support needs and methodologies (Power, 2002). Forgionne (2002) have illustrated a common DSS architecture in Figure 2-7.

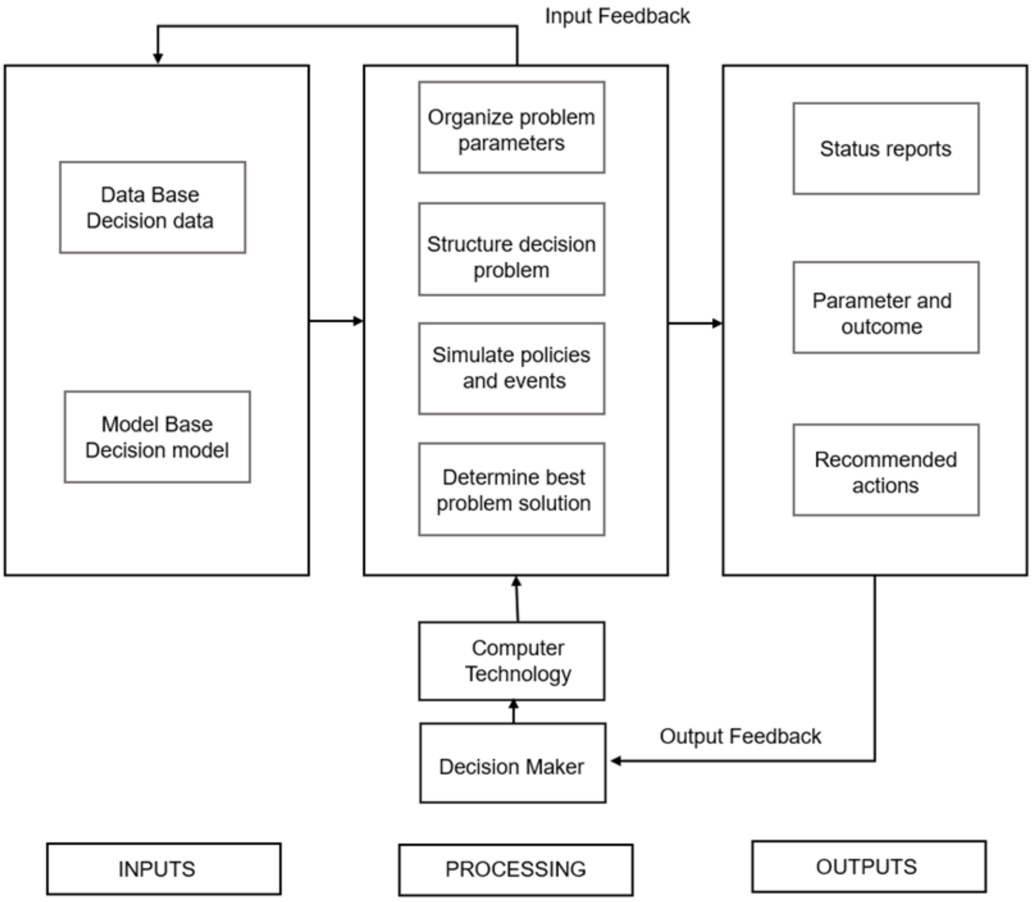


Figure 2-7: DSS common architecture (Forgionne et al., 2002)

Typically, decisions in engineering and management rely on data and information that are inherently characterized by vagueness, imprecision, and uncertainty (Devi et al., 2009). In commercial building design, group decision-making involving multiple internal stakeholders (such as the owner, architect, structural engineer, mechanical engineer, electrical engineer, and sometimes users) is a common practice. Throughout the various stages of the design process, numerous decisions are made, each with different levels of detail (Hartmann, 2011). However, the challenge lies in the inadequate management and understanding of the decision-making process within the architecture, engineering, and construction (AEC) industry. Professionals in the AEC field often lack the necessary education and training in utilizing multi-criteria decision-making (MCDM) methods, leading to decisions being made without a comprehensive understanding of all the technical aspects involved (Fischer & Adams, 2011).

Pass and Nelson (2013) report that the stakeholders involved in the design and construction process often employ different decision criteria when selecting building materials and designs. As a result, decision-makers' criteria can differ from one another, leading to potential inconsistencies. Sometimes, not all relevant aspects are considered during the final selection process. For example, experts stated that the selection of curtain wall systems relied on the designer's experience rather than a systematic scientific approach (Hamida & Alshibani, 2021).

In multi-attribute decision-making, a common tool is the decision matrix, depicted in Figure 2-8, which features m criteria and n alternatives. In this matrix, C1 to Cm represent the criteria, and A_1 to A_n represent the alternatives. Each row pertains to a specific criterion, while each column assesses an alternative's performance. The score a_{ij} signifies how well alternative A_j performs relative to criterion C_i. Traditionally, a higher score indicates superior performance (Fülöp, 2005).

$$
\begin{array}{cc|cccc|}
 & & x_1 & \cdot & \cdot & x_n \\
 & & \mathbf{A}_1 & \cdot & \cdot & \mathbf{A}_n \\
\hline
w_1 & \mathbf{C}_1 & a_{11} & \cdot & \cdot & a_{m1} \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
w_m & \mathbf{C}_m & a_{m1} & \cdot & \cdot & a_{mn} \\
\hline
\end{array}
$$

Figure 2-8: Decision Matrix (Fülöp, 2005)

In the realm of Multi-Attribute Decision-Making (MADM), various methods cater to different decision contexts and complexities. Elementary methods are marked by their simplicity and self-sufficiency, suitable for scenarios involving a single decision maker, limited alternatives, and criteria (Linkov et al., 2006). This category includes the Maximin and Maximax methods, Pros and Cons analysis, Conjunctive and Disjunctive methods, as well as the Lexicographic method (Baker et al., 2001).Maximin focuses on maximizing the weakest criterion's score, while Maximax selects alternatives based on their best attributes (Yoon & Hwang, 1995). Pros and Cons analysis offers a qualitative comparison of alternatives, requiring no mathematical skills (Baker et al., 2001). Conjunctive and Disjunctive methods operate as non-compensatory screening tools, and Decision Tree Analysis provides schematic representations of decision and outcome events (Linkov et al., 2006). The Lexicographic method prioritizes criteria by importance (Zavadskas et al., 2009). Additionally, Cost-Benefit Analysis (CBA) and Cost-Effectiveness Analysis (CEA) quantify costs and benefits in monetary terms but involve challenges related to subjective preferences and quantification of social and environmental factors (Williams, 2008).

Multi-Attribute Utility Theory (MAUT) employs utility functions to quantify decision-maker preferences and normalize performance values across diverse criteria into a dimensionless scale

(Marzouk, 2006). Simple Multi-Attribute Rating Technique (SMART) determines attribute weights through numerical ratings, favoring independence from action items but overlooking parameter interrelationships (Valiris et al., 2005). The Analytical Hierarchy Process (AHP) utilizes pair-wise comparisons to synthesize priority values in a hierarchical manner, providing objectivity and reliability in estimating weighting factors (Saaty, 1977). Outranking methods like ELECTRE and PROMETHEE address complex choice problems, offering preference rankings based on the degree of domination and the ability to handle uncertain or fuzzy information (Kiliç, 2012). ELECTRE focuses on preference concordance and discordance through pair-wise comparisons (Elbehairy et al., 2006), while PROMETHEE employs preference functions associated with each attribute (Brans & Vincke, 1985). Finally, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) identifies alternatives with the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Rashidi et al., 2017). Sensitivity Analysis evaluates the impact of input parameter changes on final rankings or values, particularly useful in scenarios involving uncertainties (Rashidi et al., 2018).

Recognizing the necessity to explore wall selection criteria for a comprehensive decision-making process, the subsequent section offers a literature review on this subject. It begins with a literature review encompassing selection criteria commonly employed by architects. It is clear that the existing literature predominantly centers on building envelope selection, with a relative scarcity of studies dedicated to internal elements such as partition walls.

2.10.1 Partition Wall Selection Criteria

Previous studies show that in the early design phases, building designers, and mostly architects, base material selection on a limited number of criteria naming aesthetics and costs (Singhaputtangkul et al., 2014; Zavadskas et al., 2008). Researchers stated that criteria used by different designers vary and they might not keep into consideration all important aspects until final decision-making stage (Passe & Nelson, 2013). It is expected that an inadequate set of decision-making criteria may result in poor selection of material or building envelop system as there are many examples of unsuccessful design models in the literature which did not achieve desired design result (Hassanain & Harkness, 1998; Smulski, 1999). We know that different building envelope such as wall, window, roof etc. have different impact on the building. Therefore, each building system needs its own criteria set and decision-making tool to be chosen appropriately. Overall there is extensive research on the criteria set for different building envelop selection.

Various criteria are identified in the literature for the selection of building envelope solutions. However, these studies tend to focus on specific criteria based on their research objectives. For instance, Horvat and Fazio (2020) assess a building envelope's performance based on factors like air-tightness, moisture management, thermal performance, energy performance, structural performance, acoustic performance, and fire resistance. Kaklauskas (2006) prioritize architectural appearance, energy usage, environmental impact, indoor climate, and costs when selecting windows for retrofitting buildings. Wang (2005) consider economic and environmental criteria, particularly cumulative energy consumption, and use a multi-objective genetic algorithm to find optimal solutions. Wang (2006) propose a methodology to optimize building shapes based on energy performance and construction costs. Zavadskas (2008) selects effective dwelling house walls based on durability, thermal transmittance, costs, weight, and labor requirements. Chua (2010) focuses on energy efficiency and cost savings as the main criteria for selecting building envelope systems. Granadeiro (2013) introduce a design indicator for residential buildings' energy performance, considering materials, shape, and window areas. Singhaputtangkul (2014) identify criteria for achieving sustainability and buildability in high-rise residential building envelope design. Passe and Nelson (2013) emphasize the significance of considering the thermal behavior of the building envelope, which accounts for a significant portion of residential energy consumption. Bojic (2001) evaluate the impact of thermal insulation positioning on cooling energy. Iwaro (2014) define sustainable performance criteria for building envelope assessment and design. Pulaski and Horman (2005) highlight the influence of constructability on project success and suggest incorporating construction expertise and difficulty in the selection process to enhance constructability. Based on the literature, the five main criteria for the selection of building envelope solutions can be identified in the table 2-2 (Martabid & Mourgues, 2015).

Table 2-2: Five main criteria based on the literature for building envelop selection (Martabid & Mourgues, 2015)

index	Criteria	Summary
1	Performance	This factor includes various aspects such as air-tightness, moisture management performance, thermal performance, energy performance, structural performance, acoustic performance, and fire resistance. Evaluating the performance ensures that the building envelope meets the necessary standards and requirements for functionality and occupant comfort.
2	Aesthetics	Aesthetics is an important criterion, considering factors such as the visual appeal, design integration, and overall aesthetic impact of the building envelope. This criterion focuses on achieving the desired look and style of the building.

3	Environmental Impact	This factor assesses factors such as energy consumption for heating, cooling, and appliances, as well as the overall impact on the environment. It considers energy efficiency, use of sustainable materials, and the reduction of greenhouse gas emissions.
4	Cost	Cost is a significant consideration for selecting a building envelope. This criterion involves evaluating the initial costs of materials, installation, and long-term maintenance expenses. Balancing the desired performance and aesthetics with the available budget is essential.
5	Sustainability	This criterion focuses on the long-term environmental, social, and economic sustainability of the building envelope. This includes factors such as energy efficiency, use of renewable materials, durability, and the ability to achieve sustainability goals and certifications.

It is important to note that these five criteria are not exhaustive and may vary depending on the specific project, research objectives, and context. Additionally, different studies may prioritize or emphasize certain criteria over others based on their research goals and perspectives (Martabid & Mourgues, 2015)

To determine the exact criteria of partition wall selection, an in-depth consultation with experts from Canada Masonry Design Center was performed. This consultation involved a review of all relevant criteria presented in the literature. Subsequently, this collaborative conversation led to the identification of five paramount criteria that are believed to be essential for inclusion in the multi-criteria decision-making model for partition walls, as delineated below (Canada Masonry Design Center, 2023):

Fire resistance, Sound resistance, Cost, Durability, Dead load, Aesthetics.

Considering different decision-making models, the authors have opted for the Choosing by Advantage (CBA) model. This selection is informed by prior research that demonstrates the superior efficacy of CBA when contrasted with conventional Multi-Criteria Decision-Making (MCDM) approaches like the Analytical Hierarchy Process (AHP) and Weighting, Rating, and Calculating (WRC) (Arroyo et al., 2014, 2015). Moreover, the attributes inherent to the CBA model align well with the need to enhance the effectiveness of comparing and selecting internal wall options. The subsequent section provides an exhaustive explication of this method, accompanied by its application as collected from the existing literature.

2.10.2 Choosing by Advantage Methodology

Choosing by Advantage (CBA) is a decision-making system to facilitate effective decision-making by comparing the advantages of different alternatives. It was developed by Suhr during his tenure at the US Forest Service (Suhr, 1999). The decision process can be characterized as an iterative procedure encompassing several steps: (1) identifying client needs, (2) establishing design goals, (3) generating or identifying alternatives, (4) gathering relevant data, (5) selecting an appropriate alternative, and (6) re-evaluating and refining the decision (Suhr, 1999). In this method, decisions are exclusively based on advantages to avoid duplication with disadvantages. Once the advantages are identified, stakeholders assess their relative importance through comparisons. When assigning weights, it is crucial to consider the specific significance of these advantages rather than general criteria, factors, or other data types (Suhr, 1999)[p. 80]. The decision-making process comprises seven steps, as depicted in Figure 2-9. An explanation of each parameter is presented in table 2-3.

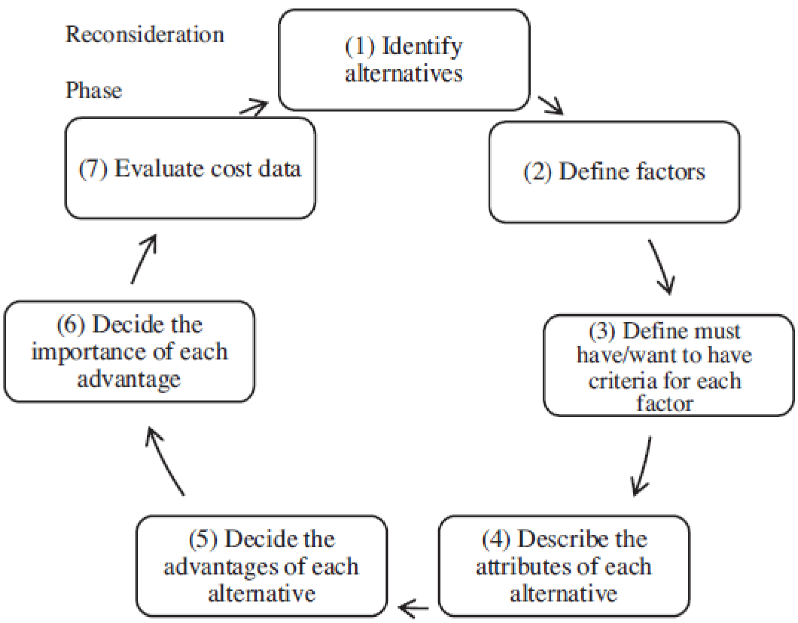


Figure 2-9: CBA steps (Arroyo et al., 2016)

In the CBA process, stakeholders go through several steps to make decisions about alternatives (Arroyo et al., 2016):

1. Alternatives Selection: Stakeholders choose alternatives that are expected to provide significant advantages compared to other options.
2. Factor Definition: Factors are defined to differentiate between alternatives. These factors serve the purpose of evaluating and comparing the options.

3. Criteria Agreement: Stakeholders agree on specific criteria within each factor. Criteria act as decision rules and express desired attributes (want criteria) or necessary requirements (must criteria). Alternatives that fail to meet must criteria are excluded from further consideration.
4. Alternative Attribute Summary: Stakeholders summarize the attributes of each alternative, highlighting their characteristics.
5. Advantage Evaluation: The least preferred attribute for each criterion is identified, and stakeholders assess the advantages of each alternative's attributes relative to the least preferred attribute.
6. Importance of Advantages (IofA) Determination: Stakeholders decide on the importance of each advantage. They select a paramount advantage, which is the most crucial advantage among all, and assign it a scale of Importance of Advantages (IofA). This scale is used to weigh other advantages, with the least-preferred attribute receiving a zero IofA relative to the paramount advantage.
7. Cost Evaluation and Selection: Stakeholders consider cost data and evaluate alternatives based on all the steps undertaken. Finally, they select from the available alternatives.

Table 2-3: CBA parameters Definition (Arroyo et al., 2016)

CBA definition	
Alternatives	Two or more construction methods, materials, building designs, or construction systems, from which one or a combination of them must be chosen
Factor	An element, part, or component of a decision. For assessing sustainability, factors should represent economic, social, and environmental aspects. It is important to note that CBA considers money (e.g., cost or price) after attributes of alternatives have been evaluated based on factors and criteria
Criterion	A decision rule, or a guideline. A ‘must’ criterion represents conditions each alternative has to satisfy or it will be discarded. A ‘want’ criterion represents preferences (of one or multiple decision makers) each alternative may satisfy to some degree
Attribute	A characteristic, quality, or consequence of one alternative
Advantage	A benefit, gain, improvement, or betterment. Specifically, an advantage is a beneficial difference between the attributes of two alternatives

These steps in the CBA process guide stakeholders in making decisions by considering advantages, criteria, and the importance of those advantages to ultimately select the most suitable alternative.

The challenge lies in the limited availability of literature offering guidance to practitioners on the selection of a suitable Multi-Criteria Decision-Making (MCDM) method within the context of partition wall selection. Addressing this gap in the literature, this research endeavors to contribute by assessing the efficacy of the CBA model. As the first step in CBA method, appropriate wall alternatives should be recognized. To do this, partition wall requirements as well as existing wall options based on National Building Code of Canada are reviewed in next section.

2.10.3 National Building Code of Canada

The National Building Code of Canada (NBCC) 2020, volume 2, is a set of technical regulations created by the Canadian Commission on Building and Fire Codes and published by the National Research Council of Canada. It provides minimum requirements for the design and construction, and modification of new and existing buildings, including changes in use and demolition. It is a comprehensive document that covers various aspects of building design and construction, including structural requirements, fire protection, plumbing, electrical systems, accessibility, and energy efficiency. The code is regularly updated to incorporate new technologies, research findings, and best practices in building design and construction. It undergoes a revision cycle every five years to address emerging issues and improve the standards for building safety and performance. It is important to note that while the NBC provides a common framework for building regulations in Canada, each province and territory has the authority to adopt and enforce its own building code based on the NBC or modify it to suit local requirements. Therefore, there may be some variations in building codes across different regions in Canada (Government of Canada, 2022).

National building code of Canada defines partition wall as: *"Partition means an interior wall 1 storey or part-storey in height that is not loadbearing"*, And discusses the requirements of interior walls in part 9. All the requirements are reviewed and presented in the table 1A in Appendix. A summary of these requirements is presented in table 2-4. In addition to these general requirements on partition wall elements, partition walls must comply with the fire and sound protection requirements of section 9 and 10 of part 9 in NBCC. Clauses 2.2.1.4 and 1.3.3.4 from NBCC presented here showcase fire protection requirements of different separators. It should be mentioned that NBCC provides user with the values of Fire resistance rating (FRR) and Sound transmission class (STC) of Different wall types in Table 9.10.3.1, which is represented as Table 3A in Appendix.

"2.2.1.4. Separation of Occupancies

1) Except as provided in Sentence (2), major occupancies shall be separated from adjoining major occupancies by fire separations having fire-resistance ratings conforming to Table 2.2.1.4.

2) If one major occupancy is located above another major occupancy, the fire-resistance rating of the floor assembly between the major occupancies shall be determined on the basis of the requirements of this Section for the lower major occupancy.

3) Occupancies other than major occupancies shall be separated from adjoining occupancies belonging to a different Group or Division by fire separations having fire-resistance ratings that conform to Table 2.2.1.4., but need not be more than 1 h.

1.3.3.4. Building Size Determination

Except as permitted by Sentences (2) and (3), major occupancies shall be separated from adjoining major occupancies by fire separations having fire-resistance ratings conforming to Table 3.1.3.1.

3.1.3.1. Separation of Major Occupancies

2) Except as permitted in Sentence (3), where portions of a building are completely separated by a vertical fire separation that has a fire-resistance rating of not less than 1 h and extends through all storeys and service spaces of the separated portions, each separated portion is permitted to be considered as a separate building for the purpose of determining building height, provided…"

From these clauses and tables 3.1.2.1, 2.2.1.4 and 3.1.3.1 of NBCC (presented in the Appendix as tables A7, A8 and A9, respectively), a **minimum fire protection of 1 hour is demanded by the NBCC**. This number can be higher according to the type of occupancy according to Table 3.1.3.1 (table A9 in Appendix) of NBCC. Therefore, fire protection resistance of wall is one of the most important factors while selecting partition wall in design of new buildings.

Table 2-4: Summary of partition wall requirements (Government of Canada, 2022)

Clause Number and Title	**Summary**
9.29.1.1. **Fire protection and Sound control**	Partition walls must conform to fire protection and sound control requirements in Sections 9.10 and 9.11
2.29.2. Waterproof Wall Finish	Waterproof finishes are required for shower stalls, bathtubs with showers, and bathtubs without showers to specified heights
2.29.3. Wood Furring **9.29.3.2. Fastening**	Wood furring used for attaching wall and ceiling finishes must meet the size and spacing requirements stated in Table 9.29.3.1 and be fastened with 51 mm nails.
9.29.4. Plastering **9.29.4.1. Application**	Application of plaster wall and ceiling finishes should follow CSA A82.30-M standards
9.29.5. Gypsum Board Finish (Taped Joints) **9.29.5.1. Application**	Gypsum board finishes with taped joints must adhere to specific application requirements and use gypsum products that conform to ASTM standards
9.29.5.3. Maximum Spacing of Supports	The maximum spacing of supports for gypsum board applied as a single layer is outlined in Table 9.29.5.3
9.29.5.4. Support of Insulation	Gypsum board supporting insulation must be at least 12.7 mm thick
9.29.5.5. Length of Fasteners **9.29.5.6. Nails** **9.29.5.8. Spacing of Nails** **9.29.5.9. Spacing of Screws**	For Length of Fasteners follow the specified depths in Table 9.29.5.5, unless …

9.29.5.10. Low Temperature Conditions	Heat must be provided to maintain a temperature not below 10°C for 48 hours before and after taping and finishing in cold weather conditions
9.29.6. Plywood Finish **9.29.6.1. Thickness**	Plywood finishes must meet minimum thickness requirements stated in Table 9.29.6.1, and grooved plywood has additional support requirements
9.29.6.3. Nails and Staples	Nails and Staples: For attaching plywood finishes, use nails that are at least 38 mm….should be spaced not more than 150 mm on edge supports and 300 mm ….
9.29.7. Hardboard Finish **9.29.7.1. Material Standard** **9.29.7.2. Thickness**	Material Standard (9.29.7.1): Hardboard must conform to the CAN/CGSB-11.3-M standard. Thickness (9.29.7.2): The thickness of hardboard should be: a) At least 3 mm when ….
9.29.8. Insulating Fibreboard Finish **9.29.8.1. Material Standard** **9.29.8.2. Thickness** **9.29.8.3. Nails** **9.29.8.4. Edge Support**	Material Standard (9.29.8.1): Insulating fibreboard must conform to the CAN/ULC-S706.1 standard…. Insulating fibreboard sheets should be at least 11.1 mm …
9.29.9. Particleboard, OSB or Waferboard Finish **9.29.9.1. Material Standard** **9.29.9.2. Minimum Thickness** **9.29.9.3. Nails** **9.29.9.4. Edge Support**	Particleboard finish must conform to ANSI A208.1, …. Minimum Thickness should conform to the thickness specified for plywood in Table 9.29.6.1, with a manufacturing tolerance of -0.4 mm. No minimum thickness is required ….
9.29.10. Wall Tile Finish **9.29.10.1. Tile Application** **9.29.10.2. Mortar Base** **9.29.10.3. Adhesives** **9.29.10.4. Moisture-Resistant Backing** **9.29.10.5. Joints between Tiles and Bathtub**	Tile Application (9.29.10.1): Ceramic tile should be set in a mortar base or applied with an adhesive. Plastic tile should be applied with an adhesive….

3 Chapter Three: Methodology

3.1 Introduction

In this chapter, I describe the research methodology, clarify the problem identification process, and explain upon the solution devised within this study. I investigate into a comprehensive examination of the analysis and principles underpinning the development of each component of the proposed solution, offering an in-depth discussion of our research approach and its subsequent implementation.

3.2 Design Science Research

Design science research (DSR) is the research method used in this study. DSR is a paradigm in problem solving. The goal of DSR is to produce required knowledge to achieve a desired objective (Peffers et al., 2007). According to March and Smith (1995), the primary objectives of DSR are twofold: the creation of practical solutions to real-world problems through the development of artifacts, and the evaluation of the effectiveness of these artifacts when put into use. On the other hand, Koskela (2008) argues that construction management aims to provide solutions to managerial challenges. He emphasizes that DSR is not merely focused on describing and explaining the existing state of the world but rather on generating innovative contributions that can bring about positive change in the world. In summary, DSR was chosen for this study due to its focus on creating and evaluating real-world solutions, its practical value, and its potential to contribute to the theoretical knowledge of the subject. The methodology incorporates three key cycles - relevance, rigor, and core design - which guide the research process, along with a framework for data evaluation and analysis.

According to Peffers (2007) DSR process consists of six steps as follows:

1. Problem identification and motivation: In this step a specific research problem is defined and the importance and value of a solution is highlighted.
2. Objectives of a solution: In this step the objective of a solution is inferred rationally from the problem specifications, which could be quantitative or qualitative.
3. Design and development: In this step an artifact is created based on its desired functionality.
4. Demonstration: in this step the efficacy of the artifact is demonstrated by its implementation in experiments, simulations, case study, etc.
5. Evaluation: In this step the effectiveness of the artifact in problem solving is measured by comparing the observed results with the objective of the solution.
6. Communication: all aspects of the problem including its importance, artifacts, its value and originality, and effectiveness are communicated with all the stakeholders.

The selection of DSR as the methodology for this study was driven by its ability to create and evaluate solutions for real-world problems, its practical applicability, and its potential to contribute to the theoretical understanding of the subject. Hevner (2007) outlines three key cycles within DSR that were relevant to this study. The first cycle, known as the relevance cycle, involves the development of a new artifact aimed at improving existing practices in a specific environment. Field testing plays a crucial role in this phase to ensure the practicality and effectiveness of the solution. The second cycle, called the rigor cycle, builds upon existing knowledge, skills, and artifacts within the application area to achieve innovation beyond what is already known. This cycle emphasizes the rigorous application of established principles to push the boundaries of the field. The core design cycle, which constitutes the third cycle, facilitates iterations in the design and assessment of the artifact until a satisfactory product is obtained. This iterative process allows for refinement and improvement of the solution. Figure 3-1 illustrates the methodology employed in the research, consisting of three main stages: identification of research problems and objectives, solution development, and evaluation and communication. Efforts taken in each phase is described in detail in the following sections. Then the developed solution is explained in two parts as for the CBA model and the computational model.

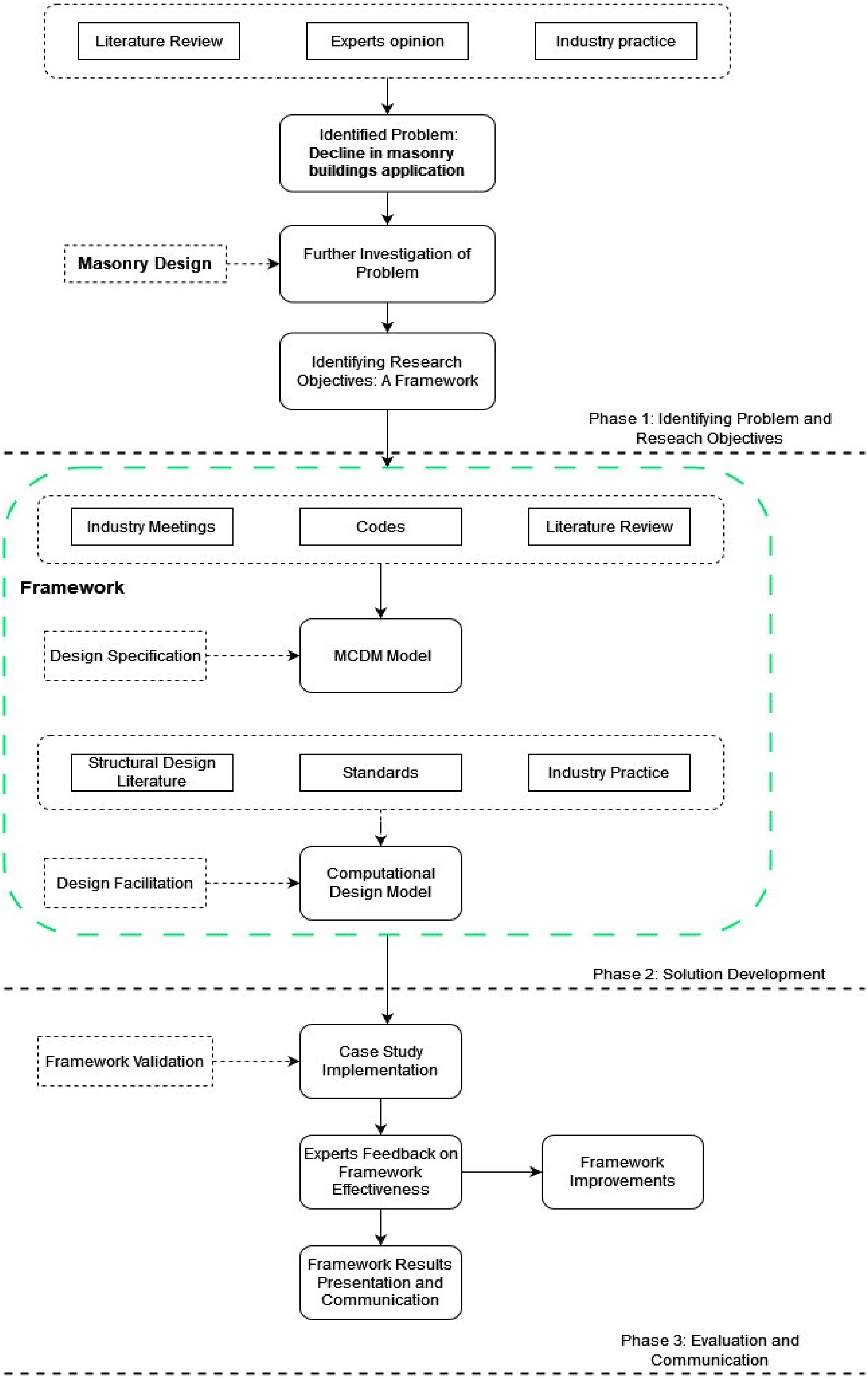


Figure 3-1: Overall Research Methodology

3.3 Problem identification and research objectives

The primary objective of this research is twofold: firstly, to assess the impact of a decision-making tool on the systematic selection of the most suitable partition wall option based on specific design requirements, encompassing dry walls constructed with steel and wood studs and masonry walls. Secondly, the study aims to evaluate the influence of a computational design tool on the design of URM partition walls, addressing challenges in construction and the incorporation of unnecessary reinforcement resulting from a lack of understanding of design principles among designers. The identified problem lies in the absence of a systematic approach to partition wall selection in building design and underscoring the need for a more widespread adoption of digital tools in masonry wall design. The research also aims to explore the impact of a computational design tool on the decision-making process for partition wall selection.

3.4 Solution development

A general overview of the proposed solution in this study is presented in figure 3-2. First step in building the proposed hybrid DSS is a document-driven DSS for facilitation of partition wall type selection which is divided in three sub steps:

- Comprehensive literature review on strength and weaknesses of masonry systems
- Partition wall requirements based on National Building Code of Canada; NBCC provides partition wall requirements as well as wall options with the related FRR and STC values.
- Consultations with industry practitioners to determine partition wall selection criteria.

Wall alternatives and wall selection criteria are determined by implementing these steps. Then, a multi criteria decision making model is built based on CBA method. The CBA model is supposed to help the designers with the determination of design specifications for the new design considering all viable wall alternatives, recognizing their advantages and selecting the best fit for the design.

Next is the development of a model-driven DSS which is a computational design model for automatically controlling the structural soundness of unreinforced masonry partition walls. To do this, steps below are taken:

- First a comprehensive review of structural design handbook is conducted to understand the design principles and analysis for masonry walls and masonry partition walls.
- Then Masonry Code (CSA S304-14) requirements are reviewed to ensure of applying the right design principles for masonry partition walls in Canada.

- Last step is to research current industry practice in masonry partition wall design for which both engineering consultation documents and Canada Masonry Design Center (CMDC) guides were considered.

The design principles and requirements for masonry partition walls are built upon the earlier steps. By taking industry advice into account, we have crafted an effective structural design algorithm. This algorithm ensures that partition walls are designed according to the Code, avoiding excessive design and costly reinforcement in masonry walls.

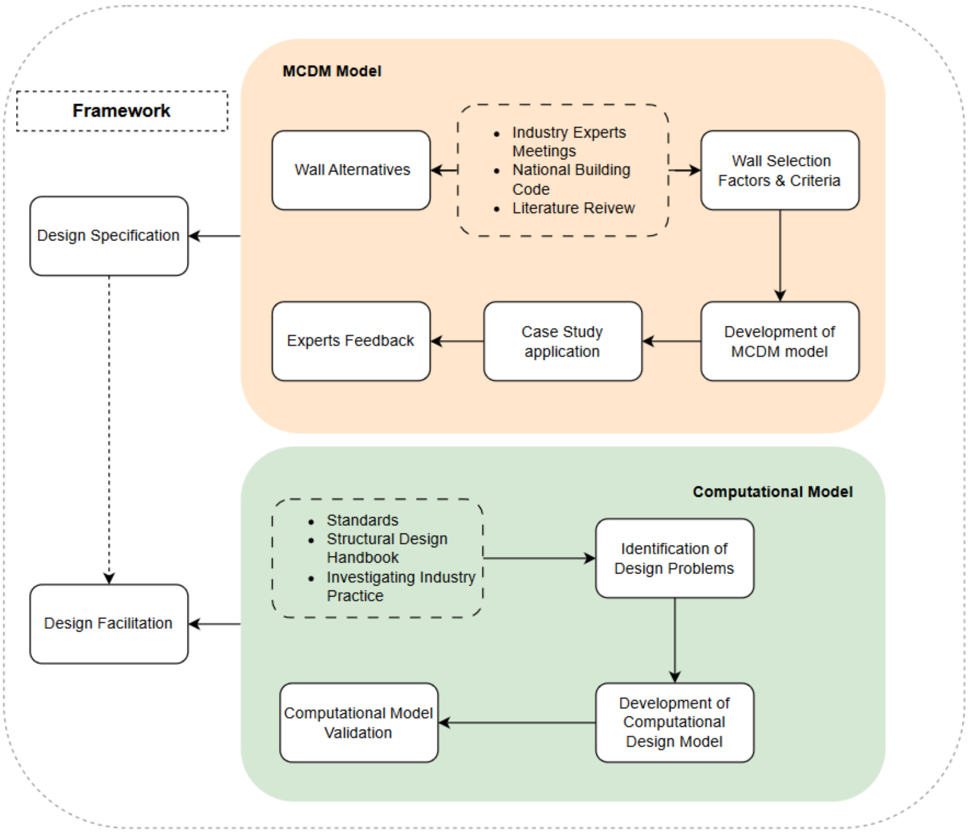


Figure 3-2: Proposed hybrid DSS as the solution

3.4.1 Face validation

With both the multi criteria decision making model and the computational design model in place, the proposed DSS is now complete and ready for implementation in case study projects. Prior to its implementation, I conducted a face validation procedure to ensure the accuracy of the steps involved. During a meeting with the experts from CMDC, I presented the developed DSS. The industry specialists validated the correctness of both the wall selection process and wall design. According to these experts, the systematic and logical approach embedded in the DSS is expected to be effective in facilitating partition wall selection and design.

3.5 CBA model

In the CBA, decisions are exclusively derived from the advantages, omitting any consideration of drawbacks, to prevent duplication. Once the benefits are identified, stakeholders must evaluate their significance through comparisons. The allocation of weights should be directly tied to the importance of these benefits, disregarding the significance of general criteria, factors, or other types of data (Suhr, 1999). The CBA concludes of seven steps. The process logically starts by determining alternatives. The selection of partition wall alternatives is based on information outlined in Table 9.10.3.1 of the NBCC. A summary of wall alternatives is represented in table 3-1. The wall alternative categories encompass steel and wood stud dry walls, as well as masonry walls. Each of these options features distinct configurations that result in varying Fire Resistance Rating (FRR) and Sound Transmission Class (STC) values. The total wall options from NBCC comprises 174 wall alternatives. Additionally, supplementary data from the CCMPA is used to incorporate further options, including masonry walls with 90mm, 240mm, and 290mm concrete blocks, table 3-2 (CCMPA, 2013). These additions broaden the spectrum of wall sections available for consideration. A comprehensive compilation of these various wall options, along with their specific details and corresponding FRR and STC values, is presented in Table A3 within the Appendix.

Table 3-1: Partition Wall Options based on NBCC

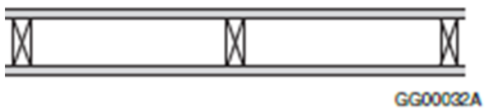
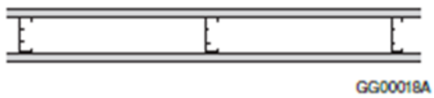
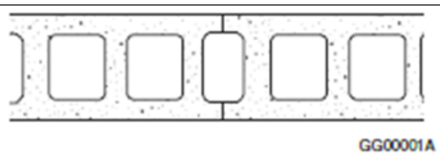
Wall Name	Fire resistance	Sound resistance	General detail
W	30 mins- 2 h	32-38	
S	45 mins- 2 h	35-54	
B	1 h- 3 h	46-71	

Table 3-2: Supplemental Wall options from CCMPA

Actual Dimension			Standard Configuration		
Width 90 mm	Length 390 mm	Height 190mm	Hollow	75% Solid	Solid
Fire Resistance Rating (Hours)	Normal Weight Light Weight		0.8 1.1	1.1 1.3	1.4 1.8
Sound Transmission Class	Type A, B concrete Type C, D concrete		43 40	45 42	47 45
Width 240 mm	Length 390 mm	Height 190mm	Hollow	75% Solid	Solid
Fire Resistance Rating (Hours)	Normal Weight Light Weight		2.4 3.5	4+ 4+	4+ 4+
Sound Transmission Class	Type A, B concrete Type C, D concrete		51 49	56 54	58 56
Width 290 mm	Length 390 mm	Height 190mm	Hollow	75% Solid	Solid
Fire Resistance Rating (Hours)	Normal Weight Light Weight		3.2 4+	4+ 4+	4+ 4+
Sound Transmission Class	Type A, B concrete Type C, D concrete		53 50	58 56	58 58

3.5.1 Selection of Wall Alternatives for CBA

The process of CBA will not be efficient with many numbers of wall alternatives. To enhance the efficiency of wall selection using CBA method, a reduction in the number of wall alternatives is recommended in the literature (Arroyo et al., 2018). To achieve this, an Excel database containing all potential wall alternatives with the respected values of FRR, STC, dead load, thickness and cost of each wall is constructed. At the initial stage of partition wall selection, the following questions are posed:

- What are the FRR and STC required in this design?
- What is the intended wall finishes and layers? For example, gypsum board, steel or wood stud and concrete?
- What is the maximum thickness of partition wall in this design?

This process is presented in figure 3-3. Each of these inquiries serves to progressively narrow down the range of wall alternatives. As a result, designers are left with a more refined set of options that align better with the design process, significantly enhancing the efficiency and promise of the decision-making process.

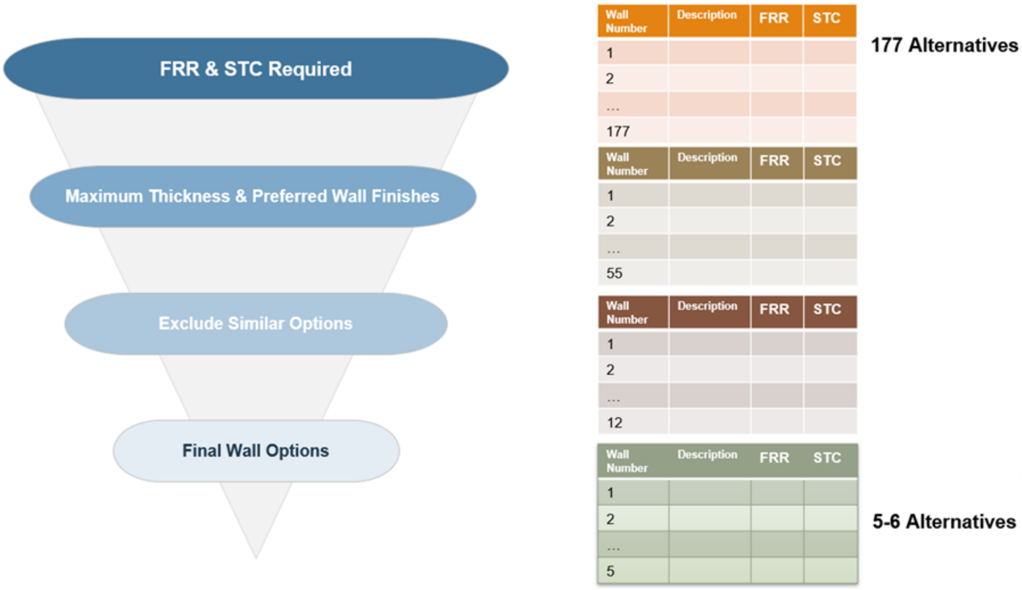


Figure 3-3: Narrowing Down Wall Alternatives

It is worth noting that the author received valuable input from an individual with an academic background in architectural design. In this section, the seven steps of the CBA process, which includes wall alternative selection, were executed based on the expert insights provided by this colleague who graciously dedicated time to collaborate with the author in developing and implementing the CBA model.

3.5.2 CBA steps

After determining final 5-6 wall alternatives from the database of 177 wall options, the wall selection process using CBA method is implemented. The steps taken in the CBA model is illustrated in figure 3-4.

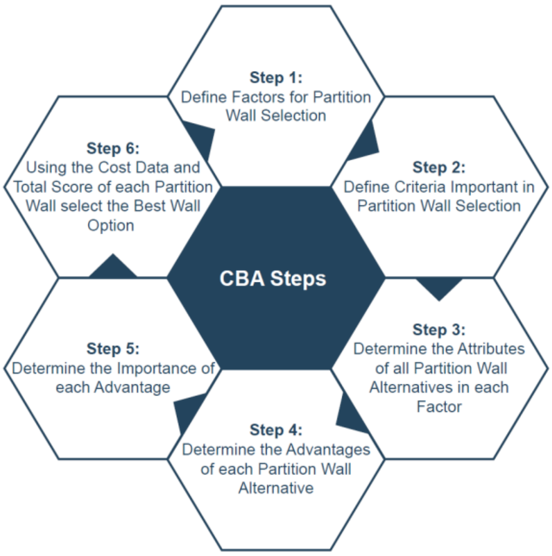


Figure 3-4: CBA Steps

Step 1:

Factors are established to distinguish between alternatives. As we discussed this in the literature review part 2.10.1, the partition wall selection factors are: Fire Rating, Sound Rating, Dead Load, Cost, Durability, and Aesthetics. The CBA table, looks like table 3-3. However, since cost factor is represented in the final step, it is excluded from the CBA table.

Table 3-3: CBA table

Factors	Alternative 1: W Dry wall with wood stud	Alternative 2: S Dry wall with steel stud	Alternative 3: B Masonry wall
Fire resistance			
Sound resistance			
Durability			
Dead load			
Aesthetics			

Step 2:

We reach a consensus on the criteria for each factor. These criteria serve as the basis for evaluating the attributes of alternatives. A criterion acts as a decision rule and can express either a preference (want criterion) or a necessity (must criterion). Alternatives that fail to meet a must criterion are excluded from consideration in the subsequent steps.

Step 3:

A summary of the attributes associated with each alternative is compiled in this step.

Step 4:

The least preferred attribute within each factor is determined and subsequently the assessment of advantage of each alternative's attribute in comparison to the least-preferred attribute is performed.

Step 5:

In this step, we focus on determining the Importance of each Advantage (IofA). This involves stakeholders clearly articulating their preferences for these IofAs. Initially, they are tasked with selecting the paramount advantage, which is defined as the most crucial advantage among all. Subsequently, the paramount advantage serves as the reference point for establishing an IofA scale. The least preferred attribute is consistently assigned a zero IofA value relative to itself, while the paramount advantage is designated as 100 IofAs. Using this scale, stakeholders proceed to assign weights to the other advantages. To facilitate this, we develop a table representing a score scale for all the advantages, which is presented in Table 3-4. The final task within this step involves calculating the IofA for each alternative by aggregating all the assigned IofAs.

Table 3-4: Scale of Scores for Advantages

Advantage	Score
Advantage 1	100
…	…
…	…
…	…
Advantage n	0

Step 6:

Accessing the cost data of all alternatives, the best wall option is selected in this step considering both the total score and the cost of each alternatives. Results are represented in graphs for better visualisation (Arroyo et al., 2016). Cost calculation is explained in the next section.

3.5.3 Cost Calculation

The calculation of costs associated with each partition wall types have been conducted using the RSMeans online database. Cost data within the RSMeans are represented based on partition wall type naming masonry wall and dry wall for both material and labor cost. Table 3-5 represents costs for dry wall and table 3-6 represents costs for masonry walls in both reinforced and non-reinforced types. There are 177 wall options in the developed database. While some of these walls precisely match RSMeans descriptions, others exhibit minor variations. For those lacking a direct RSMeans match, an approach involving interpretation and cost combination has been employed consistently. This has resulted in values for cost of wall options falling within an acceptable cost range aligned with market and industry standards.

Table 3-5: RSMeans Cost Data for Dry wall

No. of layers	water resistance	Gypsum Board Thickness(inch)	Fire Rated	Wood Stud	Steel Stud	Cost (CAD/m^2)
1		1/2	-		✓	52.83
1	✓	1/2	-	✓		58.86
1	✓	1/2	-		✓	53.48
2		1/2	1 1/2	✓		83.82
2		1/2	1 1/2		✓	74.03
2		5/8	2	✓		83.28
2		5/8	2		✓	75.43
1	✓	5/8	2	✓	✓	56.27
2	✓	5/8	2	✓		84.9

Table 3-6: RSMeans Cost Data for Masonry wall

Regular Unreinforced masonry Blocks, tooled joints, 2 sides, hollow blocks	
Block Dimensions	Cost (CAD/m^2)
8"x 16"x 4"	83.39
8"x 16"x 6"	94.15
8"x 16"x 8"	101.68
8"x 16"x 10"	110.83
8"x 16"x 12"	139.34
Regular Reinforced masonry Blocks, tooled joints, 2 sides, hollow blocks	
Block Dimensions	Cost (CAD/m^2)
8"x 16"x 4"	85.54
8"x 16"x 6"	96.84
8"x 16"x 8"	104.91
8"x 16"x 10"	121.59
8"x 16"x 12"	142.03

3.6 Computational Design Model

This study focuses on the development of a computational design model through a dynamo script which aims at assisting architects in efficiently designing masonry partition walls. By providing an efficient and automated structural design control of unreinforced masonry partition walls during the early stages of the design process by architects, it becomes possible to accurately assess costs and have a realistic comparison between various wall types, facilitating informed decision-making regarding wall selection. Through the implementation of this model, architects can assess masonry's structural requirements early on, allowing them to optimize wall configurations. The development of this model is motivated by several factors: firstly, the prevailing misconception among the public that masonry walls always require substantial reinforcement and grouting (FORSE Consulting, 2019); secondly, the limited knowledge of masonry design among architects (Gentry et al., 2009); and thirdly, the need for automation in masonry design, addressing the need for application of digital and advanced design tools in this industry.. As a result, this computational design model optimizes the design process, leading to time and cost savings through automated design procedures. This tool empowers architects to make informed decisions about wall type selection during the initial design phases.

The Dynamo script developed in this DSS checks the structural soundness of unreinforced masonry partition walls, offering applicability to any Revit model. In this context, Dynamo, seamlessly integrable with Revit, plays a pivotal role in shaping this model. Dynamo emerges as a potent and versatile resource for automation and computational design, redefining workflows, enabling the generation of intricate design solutions, and fostering data-informed decision-making. Its user-friendly platform empowers professionals across diverse domains, from architecture to engineering, enhancing both efficiency and creative possibilities.

3.6.1 Computational design algorithm

The dynamo script developed for structural control of unreinforced masonry wall can be implemented on any Revit model. It automatically performs the structural control of all unreinforced masonry partition walls, and renders the failed walls in red for the designer's convenience in interpretation. After showing the failed walls, the architect can change wall design, either the masonry block thickness or the wall height, and then run the model again to reach the acceptable design results. The algorithm for the script is shown in figure 3-5.

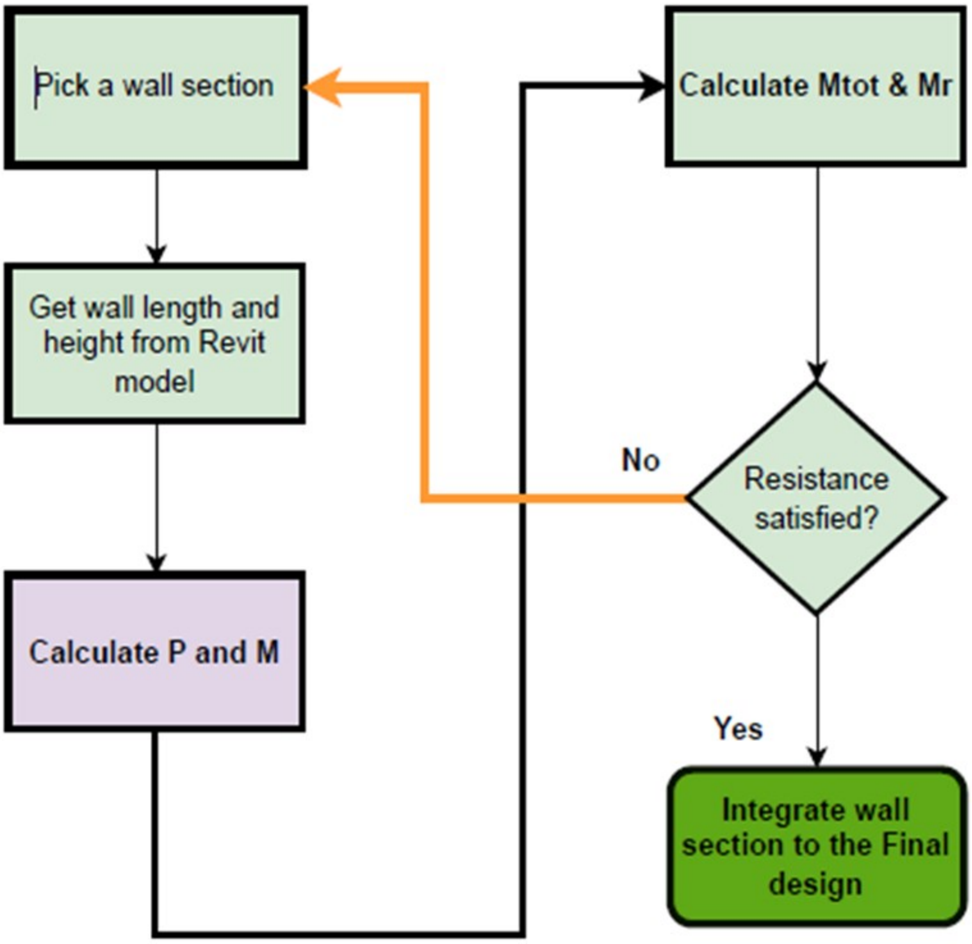


Figure 3-5: The Dynamo Script's algorithm

The steps taken within the model to perform the structural design control is as follows:

Step 1: Open the Revit file of the project, select intended partition walls and assign a masonry design wall type to the wall

Step 2: Run the Dynamo script within the Revit file

Step 3: Within the Script: masonry partition wall geometries are called from the Revit model, it should be noted that in case the slenderness ratio is bigger than 28, the script would skip the rest of calculation and will ask for design revision.

Step 4: Checking wall area, the existence of openings is determined and the maximum slenderness ratio is assigned.

Step 5: The primary moment $M_{fp} = \frac{ql^2}{8}$ which is due to internal pressure is calculated

Step 6: The additional moment M_{fApp} due to hangers and finishes is calculate:

$$M_{fApp} = \left(W_{Hangers} * \frac{t}{2}\right) + (W_{Finishings} * \frac{t}{2})$$

Step 7: Total moment

$M_{tot} = M_{fp} + M_{fApp}$ is calculated

Step 8: The moment resistance capacity of the wall section is calculated using wall section properties

Step 9: If both moment resistance and slenderness conditions are satisfied, design is approved as OK if not denied as Not Ok.

Step 10: The walls with Not Ok design result are rendered in Red in the Revit Model.

Step 11: Changing the wall section (selecting a masonry wall with higher block thickness) or reducing the wall height, as well as deleting the opening of the wall, the designer can repeat this process until all walls' design status is OK.

The iteration through the computational design model is very easy as the whole process only takes less than 5 seconds for processing 10 partition walls, making it easy to change the design repeatedly to see the impact of changing in wall thickness and height simultaneously or individually.

3.6.2 Dynamo Script Validation

The accuracy of the algorithm has been verified by comparing the design outcomes with simplified design tables received from the CMDC. These tables, prepared by certified structural engineers specializing in masonry design, offer a comprehensive and well-defined reference for analyzing masonry walls. The formulas incorporated in the dynamo script are based on the principles outlined in these tables. To ensure the reliability of the design outcomes, multiple design iterations were performed, and in each instance, the results closely aligned with the values provided in the tables. Subsequent section will provide a thorough explanation of the design assumptions that underpin the model.

3.6.3 Design assumptions

One main motive in developing this model is to benefit from low seismic hazard regions requirements by keeping masonry wall geometries applicable to unreinforced masonry walls requirements, hence making masonry wall competitive in price and ease of construction. The idea of computational design model development is to exclude the complicated parts of masonry walls, meaning reinforcement or even grouting, and the need for lateral supports such as pilasters. This is possible by benefiting from low seismic hazard regions requirements in aspect of minimum reinforcement. This means by appropriately designing ending conditions of the walls and considering moderate height and the right wall thickness, the goal of attaining an efficient masonry partition wall design is hopefully achieved. The fact that this model can be implemented in a BIM environment makes its application easy and accessible for architects. In the following the structural design assumptions considered in this model are presented.

3.6.3.1 Wall Span

A standard partition wall is treated as subject to one-way vertical bending with uncomplicated support conditions, making it amenable to design principles outlined in Chapter 6 of supplemental wall analysis (Canada Masonry Design Center, 2023).

3.6.3.2 Detailing

It is assumed that detailing confirms with the wall span assumption, not transferring any moment or other loads to the partition walls. Anchors are used to connect masonry partition walls to the floor and roof (Canada Masonry Design Center, 2023). In this study, anchors' design is not considered as part of the developed model.

3.6.3.3 Loading Condition

Masonry partition walls are non-loadbearing and non-structural elements. They are not supposed to carry roof or floor loads. However, they should be designed for a minimum internal pressure. This minimum internal pressure and the wall weight make the masonry wall to resist a combination of both axial and lateral loads (internal pressure caused by wind). Wind pressure is considered 0.25 kpa. Wind load factor according to Table 4.1.3.2-B of NBCC is 1.4. The choice of 0.25 kpa for wind pressures is guided by the NBCC Structural Commentary (I, 58.)10.6, which proposes this value as the recommended minimum thresholds for internal wind pressure. Partition walls experiencing interior pressure loads surpassing the suggested threshold are ineligible for design using the computational design tool developed in this study (Canada Masonry Design Center, 2023).

3.6.3.4 Seismic Design

The followings are summarized minimum seismic reinforcement requirements for nonloadbearing walls stated by CCMPA:

1. If the seismic hazard index, $I_E F_a S_a(0.2)$, is less than 0.35, there is no mandatory seismic reinforcement needed according to CSA S304-14.
2. If the seismic hazard index falls between 0.35 and 0.75, nonloadbearing walls must be reinforced in one or more directions using reinforcing steel.

3. If the seismic hazard index exceeds 0.75, nonloadbearing walls must be reinforced both horizontally and vertically with steel.

The developed model is specifically designed for implementation in regions characterized by low-seismic hazard areas. As indicated by requirement 1, in such areas where the seismic hazard index, $I_E F_a S_a(0.2)$, falls below the threshold of 0.35, there is no necessity for minimum reinforcement. This approach is motivated by the observation that several provinces in Canada, including Alberta, using masonry walls align with the classification of low seismic areas.

3.6.3.5 Design analysis

It is true that masonry partition walls are not load bearing and structural elements. But due to masonry inherent characteristics, such wall still needs structural analysis to make sure of having a proper design. As it was explained in the loading condition section, the main loading condition is a minimum internal pressure of 0.25 kpa. However, a pure bending condition is an idealized situation. In reality masonry walls resist a combination of both axial and lateral loads. This means a wall resists axial compression due to mass load of its components as well as bending due to wind. This can hypothetically range from axial load alone to pure bending. The compressive stress, f_m, can be calculated by dividing the factored concentric axial load, P_f, by the effective cross-sectional area, A_e.

$$f_m = \frac{P_f}{A_e}$$ Equation 3-1

The stress distribution in an unreinforced wall subjected to both axial load and bending can be analyzed by superimposing the stresses arising from axial load alone and the stresses resulting from pure bending. The design criteria for such cases are determined by (Hatzinikolas et al., 2015):

$$\frac{P_f}{A_e} + \frac{M_f}{S_x} \leq 0.6\emptyset_m f'_m$$ Equation 3-2

$$-\frac{P_f}{A_e} + \frac{M_f}{S_x} \leq \emptyset_m f_t$$ Equation 3-3

Considering what we discussed in the section related to unreinfoced flexural masonry design, the defining criteria here would be tensile resistance of masonry hence Equation 3-3. It sould be mentioned that the weight of hangers and wall finishes it also considered in the calculation of totoal moment posing to the masonry partition walls. Numbers for such weights are deriven from the maximum allowable values in the masonry code.

3.6.3.6 Slenderness effect

Clause 7.17 of the latest version of masonry code allows for the creation of basic, non-loadbearing, unfortified interior masonry partition walls without taking secondary effects into account (Canada Masonry Design Center, 2023).

It also indicates that Partition walls must adhere to the height-to-thickness (h/t) or length-to-thickness (ℓ/t) ratio limitations specified in Table 7.2 (Canada Masonry Design Center, 2023). This table limits the values of (h/t) or (ℓ/t) of partition walls to 28 and 22 for walls without openings and with large openings, respectively with the internal wind pressure value of 0.35 Kpa.

3.6.3.7 Window and door openings

Openings for windows and doors within partition walls are only allowed in vertically spanning walls constructed with units having an actual thickness of 140 mm or greater. These openings are subject to specific size restrictions, with a maximum height of 2200 mm and a maximum length of 1200 mm. For these openings, there must be at least 2000 mm of continuous masonry between adjacent openings horizontally, and there should be a minimum of 1000 mm of continuous masonry between an opening and the end of the wall. Failure to meet these criteria necessitates additional lateral support to comply with the provisions of Clause 7.17.5 of masonry code. Furthermore, partition walls with windows and doors must adhere to reduced height-to-thickness ratios as specified in the previous paragraph (Canada Masonry Design Center, 2023).

In the computational model, the maximum thickness ratio of each wall is determined depending on the existence or nonexistence of openings.

4 Chapter Four: Application on two hypothetical Case Studies

4.1 Introduction

This research implements “proof of concept" methodology to examine the efficacy of the developed DSS. The method "proof of concept" is commonly used in research descriptions, experimental studies, and the introduction of new technologies. Proof of concept refers to the substantiation derived from a preliminary project, undertaken to showcase the viability of a product concept, business proposal, or project scheme. To illustrate, within drug development, clinical trials are employed to ascertain the safety and efficacy of a new medication, thereby attaining proof of concept for its eventual implementation. The outcomes of a proof of concept initiative are compiled in a corresponding document, aiding stakeholders in comprehending the criteria for gauging the success of the proof of concept endeavor (William Malsam, 2023). Research shows how proof of concept research not only offers evidence of feasibility but also serves as a testament to overarching decision-making across practitioners, tools, techniques, and collaborative problem-solving among research groups (Kendig, 2016).

4.2 Implementation guidelines

The proposed Decision Support System (DSS) is proposed as the control interface of a software tool named MasonryPartition Pro. It is important to emphasize that this software interface is designed for academic purposes and is not ready for commercial use. Further work is required to have a commercial user interface design.

To put the developed model into action in the case studies, the author teamed up with an individual possessing an academic background in architectural design. This collaborative effort was essential. In this section, MasonryPartition Pro process, which encompass the selection of wall type and URM partition wall design, were carried out. These steps were executed based on the valuable insights provided by the collaborating colleague, who generously devoted their time to work alongside the author in the development and implementation of the CBA model.

MasonryPartition Pro encompasses three key phases: Input, Visualization, and Evaluation. The user interface is presented in figure 4-1.

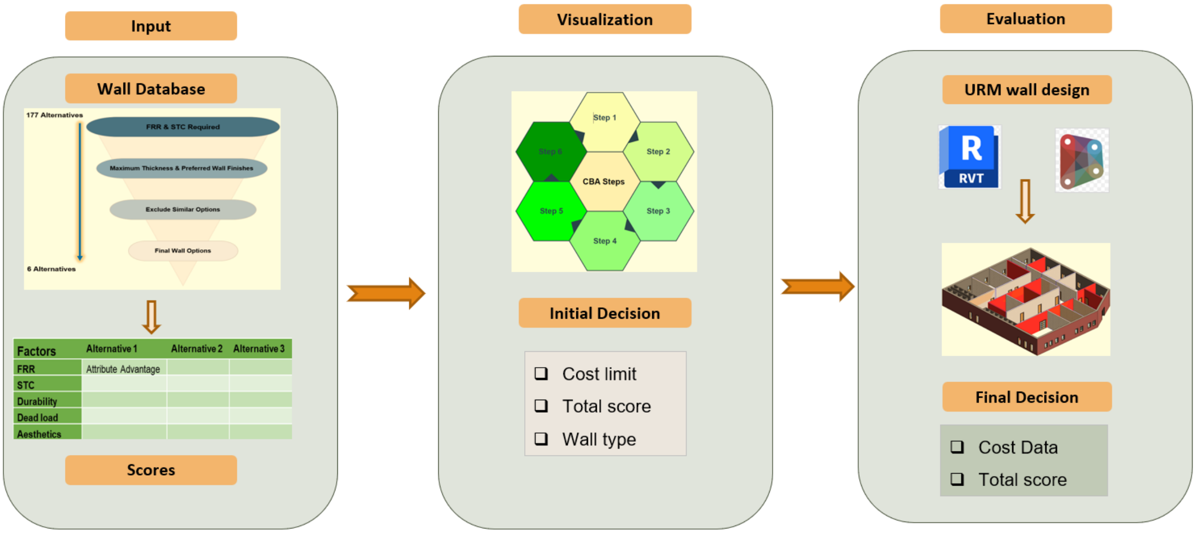


Figure 4-1: MasonryPartition Pro User Interface

4.2.1 Input

In the input phase, wall alternatives selection based on steps described in part 3.5.1 is completed. Design inputs such as FRR, STC, wall type, finishing and wall thickness enter the DSS to narrow down the 177 wall options. Then, the selected wall options enter the CBA model, and after implementing the CBA steps according to part 3.5.2, total scores of each alternative are calculated.

4.2.2 Visualization

The Visualization stage offers a visual representation of the CBA results. It presents the scores generated by the CBA model and includes cost-related data in graphical form. This aids stakeholders in making well-informed decisions, as they can weigh the total score against the cost of each option. It is at this point that initial decisions regarding partition walls are typically made, as the trade-offs associated with each option become evident.

4.2.3 Evaluation

Finally, during the Evaluation phase, the computational design model is applied to URM partition walls. This step explores the feasibility of employing URM walls. Through the use of a BIM platform, a clear visualization is provided, allowing for more informed decision-making. Designers gain insight into potential cost savings and a smoother construction process associated with URM partition walls. This information may lead to reconsideration of decisions made in the previous phase. Furthermore, multiple application of the design model in various design projects can shape designers' perceptions of URM wall design and enhance their understanding of the design principles.

In the next section the proposed MasonryPartition Pro user interface is applied to two hypothetical case studies. Steps taken to apply the model and the results on the effectiveness of the DSS on partition wall design are discussed in detail in this section.

4.3 Case studies introduction

To validate the developed DSS, two hypothetical case study projects have been constructed. These case studies consist of BIM models representing distinct building types: a warehouse and school. It is important to note that these case studies serve the purpose of visually illustrating the partition wall design process and are not comprehensive, certified designs created by professional architects. Rather, they are theoretical case studies as Revit models built to evaluate the effectiveness of the proposed DSS in streamlining partition wall design processes.

The two hypothetical case study projects include of BIM of a warehouse and a school. The selection of a warehouse and a school layout as the focal points for these case studies is deliberate. Warehouses, as expansive spaces dedicated to the storage, organization, and management of goods and materials, hold a pivotal role in supply chains. They offer various architectural designs, often characterized by their vast layouts and towering ceilings to accommodate substantial inventories. Given that the computational model's primary goal is to assess the structural integrity of unreinforced masonry partition wall designs, warehouses stand as an ideal case study due to their capacity to encompass a diverse array of partition wall selection and design possibilities.

Additionally, school layouts, typically comprising multiple classrooms and of moderate building height, are chosen to provide an illustrative example that showcases the outcomes of the DSS. Schools serve as a significant demonstration of the decision support system's effectiveness, particularly in areas where higher Sound Transmission Class (STC) values are required. For instance, spaces within schools such as gyms or music rooms necessitate elevated STC values in accordance with Alberta standards, making them a pertinent illustration of the DSS's capabilities (Alberta Infrastructure and Transportation, 2007).

4.4 Case Study 1

This section introduces a design model that illustrates the utilization of the proposed DSS through the representation of a standard warehouse layout. Warehouses are large, designated spaces used for the storage, organization, and management of goods and materials. They serve as pivotal hubs in supply chains, facilitating the storage of products before distribution, transportation, or sale. They usually come in various architectural designs, often characterized by their expansive layouts and high ceilings to accommodate a substantial volume of items. Since the computational model's objective is to assess the structural soundness of unreinforced masonry partition wall design, the geometry attributes of warehouses make them an ideal case study for this project, as they encompass a diverse array of partition wall selection and design possibilities. Figure 4-2 shows the plan layout of the warehouse.

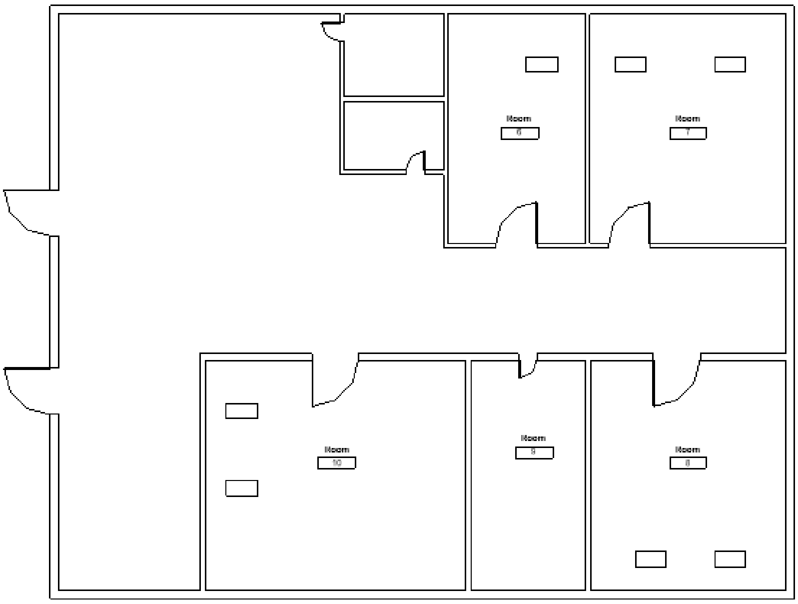


Figure 4-2: Case study 1 plan layout

4.4.1 Input

The process of partition wall design is dictated by non-structural parameters such as fire resistance rating or sound transmission class (Canada Masonry Design Center, 2023), hence wall selection starts with specifying the design requirements. Referring to the questions in part 3.5.1 of the previous chapter, we agreed on the following design information in this case study:

- All wall types are acceptable to enter the CBA process.
- The FRR range of 1 to 1 1\2 hour is considered for this building.
- The general number required by NBCC for STC is 50 to 55. The designers determine STC greater than 50 at this stage.
- The preferred wall finish is bare concrete masonry, due to aesthetic reasons and low maintenance cost which is suitable for a storage area.
- The remaining net area in each space in a warehouse is of paramount importance to provide more room for goods storage. Therefore, designers consider a maximum thickness of 250 mm for partition walls.

Continuing with the subsequent inquiries, the design alternatives have been refined. The process has been shown in figure 4-3.

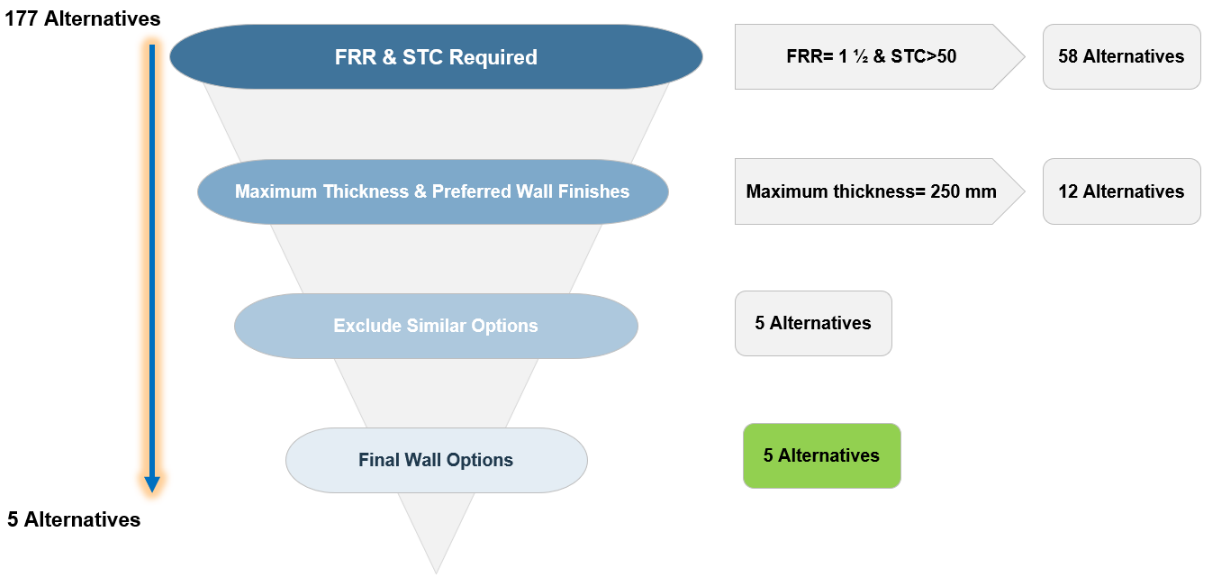


Figure 4-3: Narrowing Down Wall Alternatives in Case Study 1

This method results in a selection of 5 wall alternatives showcased in Table 4-1. With this groundwork established, the implementation of the CBA model becomes feasible.

Table 4-1: Final wall alternatives for Case study 1

Category	Wall number	Description	Thickness	Weight	FRR (min)	STC
Wood stud dry wall	W14f	W14 with: no absorptive material, 12.7 mm Type X gypsum board	242	37	60	51
Steel studs dry wall	S2a	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	242	41	60	50
Steel studs dry wall	S2c	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	232	35	60	50
Steel studs dry wall	S3c	S3 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	245	44	90	53
Hollow Concrete Block	B1b	190 mm bare concrete block	200	223	90	50

The selected wall alternatives for the CBA implementation for case study 1 are 5 wall options, 1 from dry wall with wooden stud category, 3 from dry wall with steel category and 1 from concrete walls. To be able to make an accurate comparison between wall options regarding wall aesthetics, wall detail presented in table 4-2, is considered.

Next step is to fill the CBA table: steps taken in this section are described in part 3.5.2 of the previous chapter. The required design information for implementation of the CBA model in this case study is as follow:

- The Values for FRR and STC for each wall are derived from the table 9.10.3.1-A of NBCC.
- Dead load of each wall in calculated based on presented detail in this table.
- The durability criterion is governed by the weakest material which means the main comparison here is between CMU blocks and gypsum board. It is clear that concrete material is more durable than gypsum board.
- Aesthetics is a subjective criterion ruled by the preference of stakeholders. Here the preference is given to concrete wall.

CBA process applied to this case study are presented in figure 4-4.

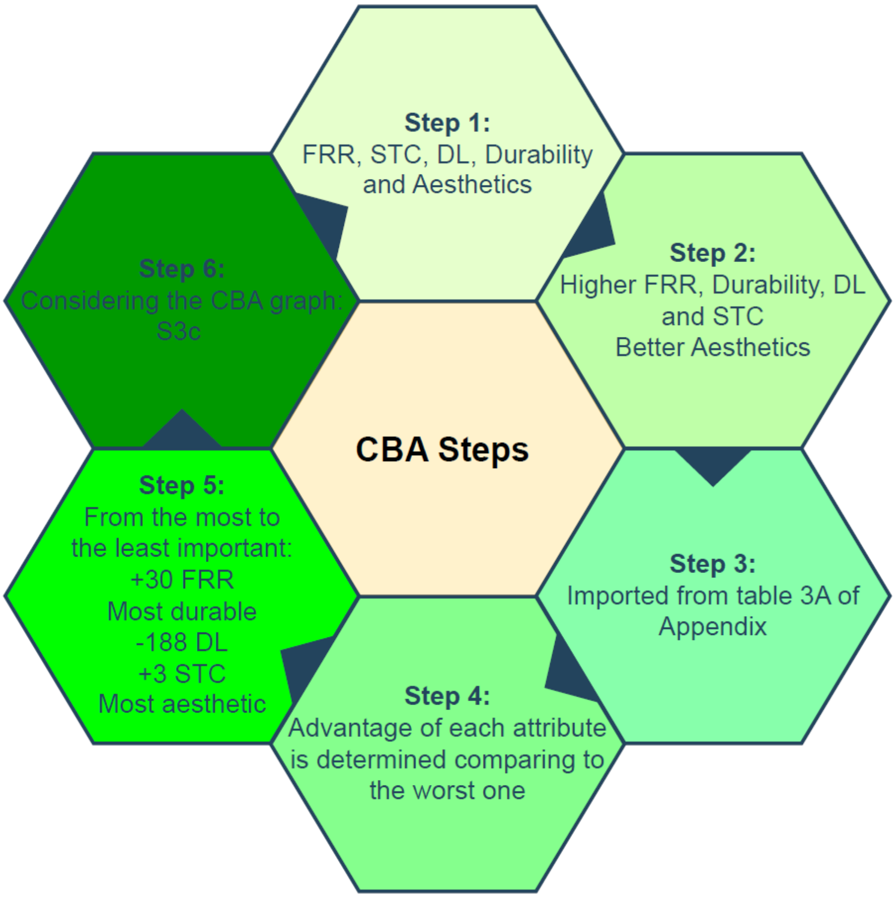


Figure 4-4: CBA Steps in Case Study 1

Step 5 in the graph 4-4 associates to the designer decision on the importance of each advantage. To do this, scores are given to the best advantages in each factor ranging from 100 to 0. This scale is presented in the table 4-2. To achieve this range of scores, stakeholders should compare each pare of advantages making clear that which advantage is the most important and which one is the least important in this case study. To reach this range of scores, the author made discussions on the design requirements of the case study with the volunteered expert.

Table 4-2: Scale of scores of advantages, Case study 1

Advantage	+30 FRR	Most Durable	-188 Dead Load	+3 STC	Most Aesthetic
Score	100	80	45	40	20

Continuing with filling the CBA table, the rest of advantages in each factor recieves the relative score by comparing each to the remaining advantages. Now all cells are filled and a total score for each alternative is presented by summing up all values in the associated column. Stakeholers can have a general decision for the selected wall based on the total score. In this case B1b with 200 score seems to be the winner wall. Table 4-3 shows the complete CBA model for the case study 1.

Table 4-3: CBA table for Case study 1

Factors	W14f		S2a		S2c		S3c		B1b	
Fire Resistance	60		60		60		90		90	
							30	100	30	100
Sound Resistance	51		50		50		53		50	
	1	30					3	40	0	
Durability	Gypsum Board Durability		Gypsum Board Durability		Gypsum Board Durability		Gypsum Board Durability		CMU Durability	
									Best	80
Dead load	37		41		35		44		223	
	186	42	182	40	188	45	179	35		
Aesthetics	Gypsum Board		Gypsum Board		Gypsum Board		Gypsum Board		CMU	
									Best	20
Total Score		**72**		**40**		**45**		**175**		**200**

4.4.2 Visualization

The final decision in the CBA model is made by comparing wall alternatvies with their relative total score and total cost in a digram presented in figure 4-5. Here we can see that while, parition wall B1b has the highest score it also has the highest cost of 105 CAD per square meter. While the next best optiton which is S3c with 175 total score (25 less score) is 23 CAD cheaper than the best options. In this stage, stakeholders may see that this much cost difference does not worth the 25 more score of the wall B1b and select wall S3c for this design. However, the digram below shows clearly that in case the stakeholders decide to save more on cost, the next best options would have a total score of 40 or 45 which means more than 100 less total score. This clear visulaziation shows the trad off happening in making the deceision of wall selection.

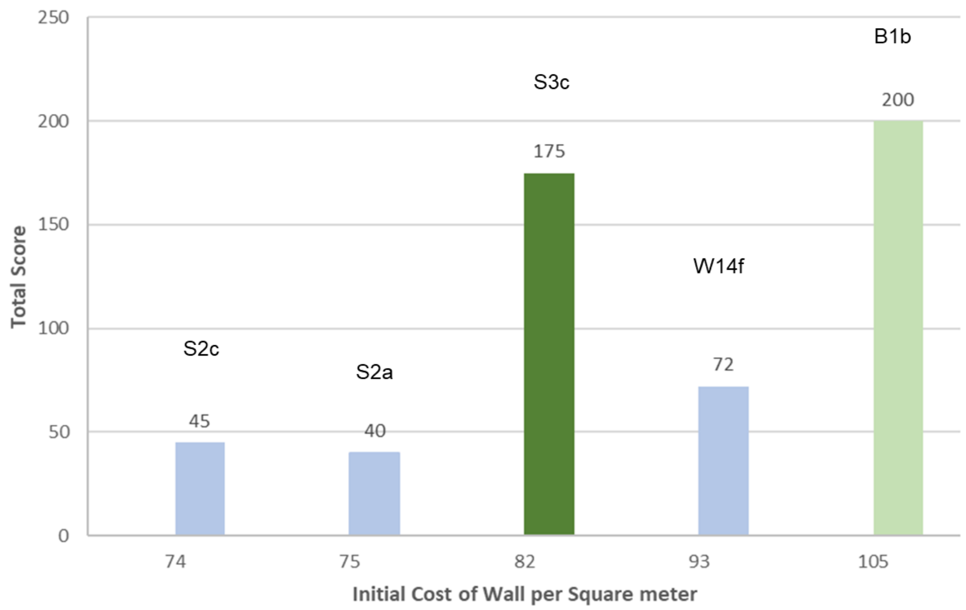
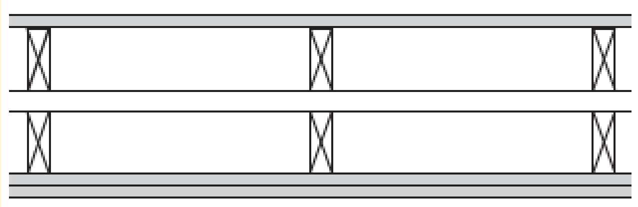
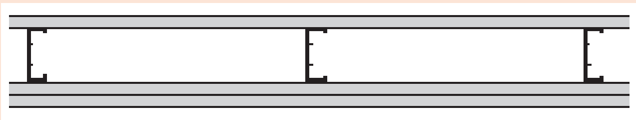
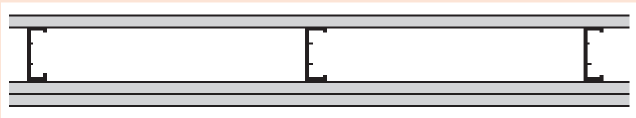
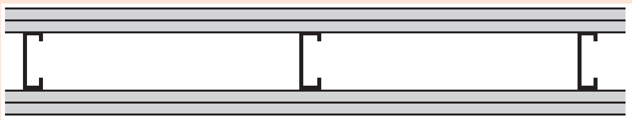
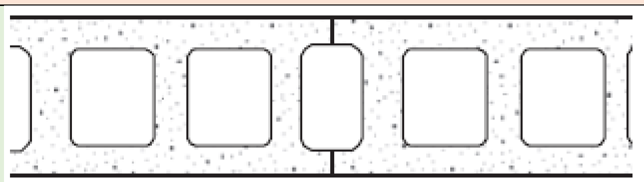


Figure 4-5: Cost-Score diagram of CBA, Case study 1

Cost data are based on RSMeans online free database. It was mentioned in part 3.5.3 of previous chapter that, some of wall options do not exactly match the wall details presented in the RSMeans cost database. For these options an approach involving interpretation and cost combination has been employed consistently. The calculated costs for the 5 wall options in this case study is presented in the table 4-4.

Table 4-4: Cost Data of Wall alternative in Case Study 1

Wall Name	Description	RSMeans Cost number for the most similar wall option	Wall Cost	Wall Detail
W14f	Two rows studs, 2 layers of 12.7 mm gypsum Type X board on one side, 1 layer of gypsum board on other side	83.82	93	
S2a	Steel studs, 65 mm thick absorptive material, 1 layer of 15.9 mm Type X gypsum board on one side, 2 layers on other side	75.43	75	
S2c	Steel studs, 65 mm thick absorptive material, 1 layer of 12.7 mm Type X gypsum board on one side, 2 layers on other side	74.03	74	
S3c	Steel studs, 65 mm thick absorptive material, 2 layer of 12.7 mm Type X gypsum board on each side	74.03	82	
B1b	190 mm bare concrete block	105	105	

The decision made in this stage by the volunteered expert is wall type **S3c,** to save 23 CAD in wall cost, compared to reinforced masonry wall B1b.

4.4.3 Evaluation

As for the final step in the implementation of MasonryPartition Pro, a Revit model of the case study 1 is constructed. The 3D model is presented in the figure 4-6. Using the developed dynamo script explained in section 3.6, we will examine the URM partition wall design of this case study to implement the final assessment of the decision made for the partition wall type. This model automatically performs the structural control of URM partition walls on the Revit file. The designer starts the process by assigning the intended masonry wall section to each partition wall. In this model, there are 11 partition walls with 6 meters heights. Since this is a high value for partition wall height, all walls are assigned sections 240 and 290. So, partition wall B1b mentioned in the CBA process with 190 mm thickness will nor t be assessed as it is assumed that URM design will fail. However, the feasibility of URM partition walls can be investigated for sections with higher thickness.

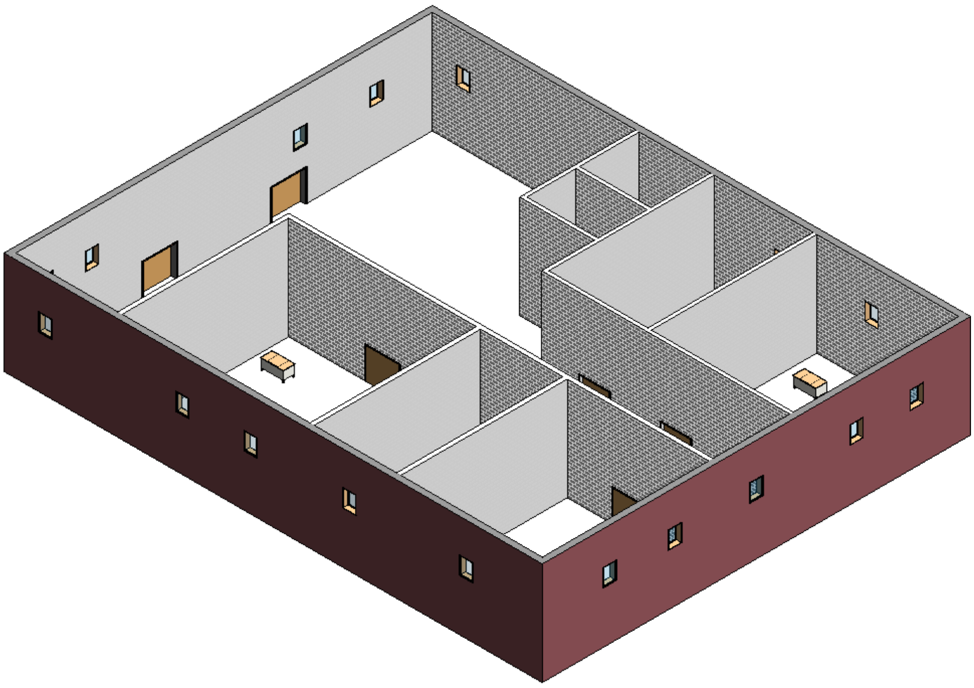


Figure 4-6: 3D model of the case study 1

Running the dynamo model on the case study 1 takes less than 5 seconds. Table 4-5 is the result of the first round of running the model. Walls with index number of 0, 3 and 4 failed. This means these walls cannot be constructed as URM partition walls with the specified thickness, height and opening. Figure 4-7 shows the 3D model of this case study in which the failed walls are rendered in red for effective visualization.

Table 4-5: Design results of URM partition walls for case study 1

index	h	l	t	h/t	Opening	Max Slenderness	Status
0	**6**	**17**	**240**	**25.00**	**Yes**	**22**	**Not OK**
1	6	11.6	240	25.00	No	28	OK
2	6	11.6	240	25.00	No	28	OK
3	**6**	**5.1**	**240**	**25.00**	**Yes**	**22**	**Not OK**
4	**6**	**8**	**240**	**25.00**	**Yes**	**22**	**Not OK**
5	6	11.7	290	20.69	No	28	OK
6	6	13.1	290	20.69	Yes	22	OK
7	6	11.7	290	20.69	Yes	22	OK
8	6	11.7	290	20.69	No	28	OK
9	6	5.9	290	20.69	No	28	OK
10	6	10	290	20.69	Yes	22	OK

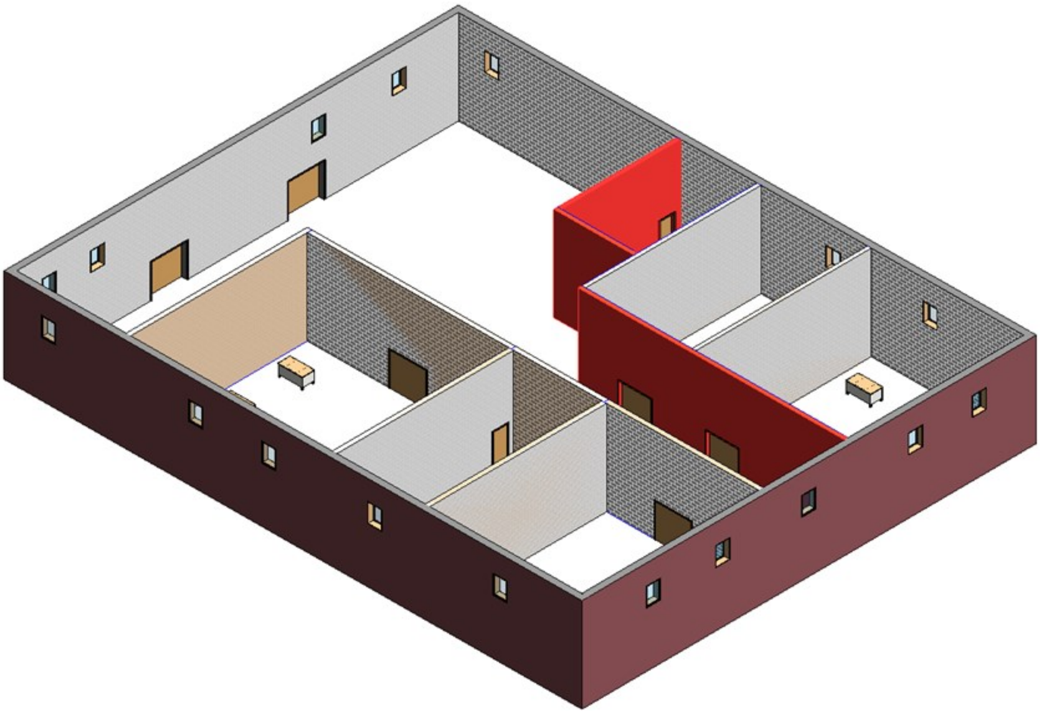


Figure 4-7: 3D representation of design model implementation of case study 1

The computational model can be implemented on the model in multiple design iterations easily. This feature serves perfectly in filling the educational purpose of the design model. Designers can have different variations of wall height, thickness and opening to reach a valid URM partition wall design. In addition, the application of model in the long run gives an in-depth understanding of URM design principles. Table 4-6 is the accepted design results of the case study 1 which shows by selecting different masonry sections for the failed walls, design results are approved.

Table 4-6: Accepted wall options for URM design in case study 1

index	h	l	t	h/t	Opening	Max Slenderness	Status
0	6	17	**290**	20.69	Yes	22	**OK**
1	6	11.6	240	25.00	No	28	OK
2	6	11.6	240	25.00	No	28	OK
3	6	5.1	**290**	25.00	Yes	22	**OK**
4	6	8	**290**	25.00	Yes	22	**OK**
5	6	11.7	290	20.69	No	28	OK
6	6	13.1	290	20.69	Yes	22	OK
7	6	11.7	290	20.69	Yes	22	OK
8	6	11.7	290	20.69	No	28	OK
9	6	5.9	290	20.69	No	28	OK
10	6	10	290	20.69	Yes	22	OK

Considering the table 4-6, designers understand that unreinforced masonry partition wall can be constructed in this projected with the thickness of 240- and 290-mm. Initial cost associated with URM walls are lower than reinforced ones. Construction of reinforced partition walls presents challenges due to the necessity of laying units, placing reinforcement, and pouring grout within the restricted space of an existing primary structure with limited clear height. Unlike some construction processes where reinforcement can be added from the top of a completed wall, in this case, the presence of open-ended units is typically required because reinforcement cannot be simply dropped into the cells from above (Canada Masonry Design Center, 2023). Making sure of the structural design soundness of URM partition walls for 240- and 290-mm masonry blocks will help the decision makers to reconsider their decision regarding wall selection. In this case study, the designer decided to change the selected wall type from S3c, dry wall with steel stud, to masonry wall.

4.5 Case Study 2

To have a comprehensive validation of the effectiveness of the developed DSS, a second case study entails generating a design model for a school layout in Revit. School layouts, characterized by multiple classrooms and moderate building height, provide an illustrative example to showcase the DSS's outcomes. Figure 4-8 displays the floor plan of the school layout.

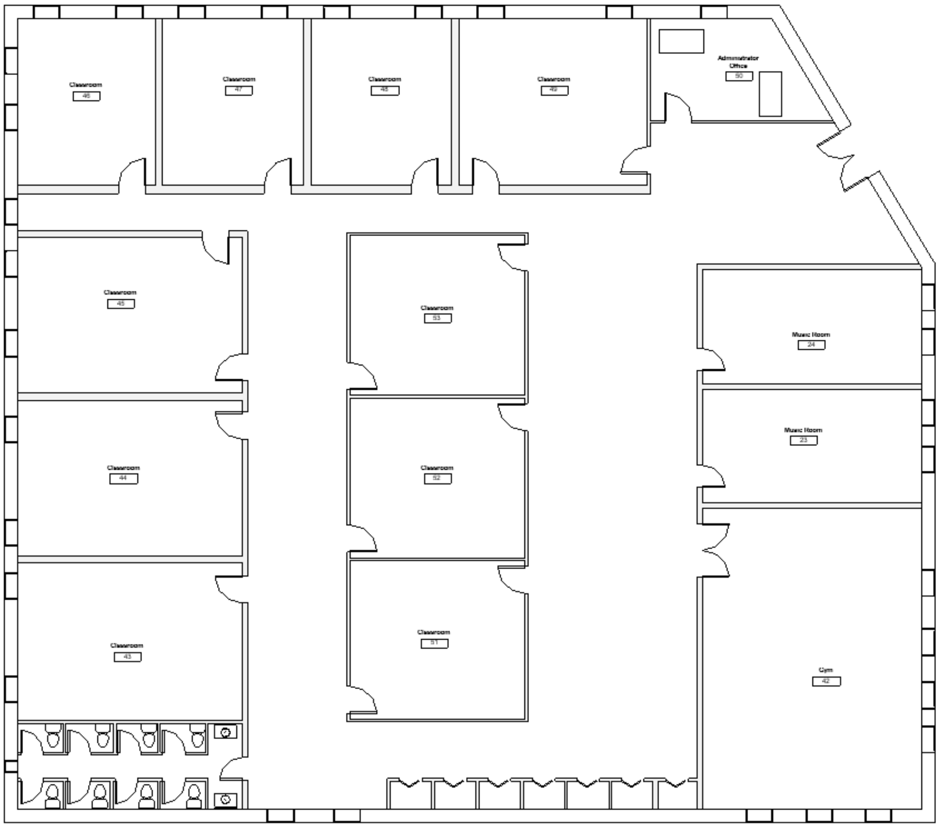


Figure 4-8: Case study 2 plan layout

4.5.1 Input

Similar to Case study 1, the process of partition wall design is dictated by non-structural parameters such as fire resistance rating or sound transmission class (Canada Masonry Design Center, 2023), hence wall selection starts with specifying the design requirements. Referring to the questions in part 3.5.1 of the previous chapter, we agreed on the following design information in this case study:

- All wall types are acceptable to enter the CBA process.
- The minimum FRR of 2 hours is required for partition walls.
- Sound transmission class of partition walls in a school is of high significance. The minimum acceptable STC value for schools is presented in the table 4-7 from Alberta infrastructure and transportation (Alberta Infrastructure and Transportation, 2007). The minimum acceptable value in this case study is set as 60.
- Both bare CMU (Concrete Masonry Unit) blocks and gypsum board (either type X or regular) are permissible choices.
- The designer opts for partition walls with a maximum thickness of 360 mm.

Table 4-7: Required STC for school areas(Alberta Infrastructure and Transportation, 2007)

Space	STC
Classrooms	50
Offices	45
Lunch Room	55
Music Room (Elem)	60
Music Room (Jr./Sr.)	65
Drama Rooms	55
Washrooms	55
Computer Labs	50
Libraries	50
Practice Room	60
Gymnasium	60

Continuing with the process of narrowing down wall options, the design alternatives have been refined (figure 4-9).

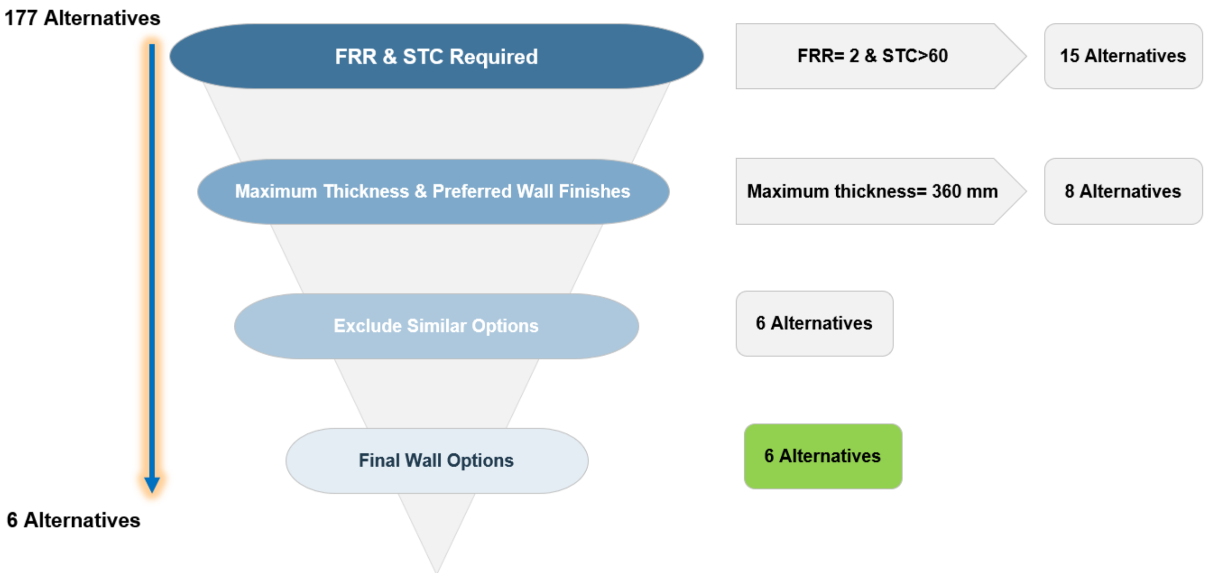


Figure 4-9: Narrowing Down Wall Alternatives in Case Study 2

The design alternatives have been refined, resulting in a selection of 6 wall alternatives showcased in Table 4-8. With this groundwork established, the implementation of the CBA model becomes feasible.

Table 4-8: Final wall options for Case study 2

Category	Wall Name	Description	Thickness	Weight	FRR (min)	STC
Wood stud dry wall	W10a	W10 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 15.9 mm Type X gypsum board	316	65	120	62
Wood stud dry wall	W15d	W15 with: 89 mm thick absorptive material on one side only, 15.9 mm Type X gypsum board	356	59	120	62
Hollow Concrete Block	B6c	B6 with 190 mm concrete block, 15.9 mm Type X gypsum board	308	251	180	60
Hollow Concrete Block	B7b	B7 with 12.7 mm Type X gypsum board	355	245	150	70
Hollow Concrete Block	B8a	B8 with 15.9 mm Type X gypsum board	360	252	180	71
Hollow Concrete Block	B8b	B8 with 12.7 mm Type X gypsum board	353	247	150	70

The selected wall alternatives for the CBA implementation in case study 2 are 6 wall options, 2 from dry wall category with wooden studs, 4 from concrete walls. To be able to make an accurate comparison between wall options regarding wall aesthetics, wall detail presented in table 4-11, is considered.

Next step is to fill the CBA table: steps taken in this section are described in part 3.5.2 of the previous chapter. The required design information for implementation of the CBA model in this case study is as follow: To evaluate durability and aesthetic descriptive attributes are employed. Specifying attributes for durability, dead load and aesthetic is similar to case study 1.

- The Values for FRR and STC for each wall are derived from the table 9.10.3.1-A of NBCC.
- Dead load of each wall in calculated based on presented detail in this table.

- In this case we can exclude durability as a factor since all the wall options include gypsum board. This is because the durability criterion is governed by the weakest material which is gypsum board.
- Aesthetics can also be excluded from the factors since all wall options are covered by gypsum board.

Proceeding with the CBA table similarly to what was described in case study 1, CBA process applied to this case study are presented in graph 4-10.

Figure 4-10: CBA Steps in Case Study 2

Step 5 in the graph 4-10 associates to the determination of each advantage importance. To do this, scores are given to the best advantages in each factor ranging from 100 to 0. This scale is presented in the table 4-9. To achieve this range of scores, stakeholders should compare each pare of advantages making clear that which advantage is the most important and which one is the least important in this case study. The highest advantage in this case study is given to the FRR due to the application of the building. According to the expert's opinion fire resistance of school areas is much more significant than other factors.

Table 4-9: Scale of scores of advantages, Case study 2

Advantage	+60 FRR R	+11 STC	-193 Dead Load
Score	100	80	60

Continuing with filling the CBA table, the rest of advantages in each factor receives the relative score by comparing each to the remaining advantages. Now all cells are filled and a total score for each alternative is presented by summing up all values in the associated column. Stakeholders can have an initial decision for the selected wall based on the total score. In this case B8a with 180 score seems to be the winner wall. Table 4-10 shows the complete CBA model for the case study 2.

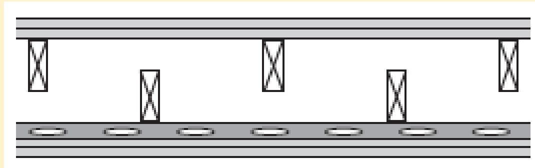
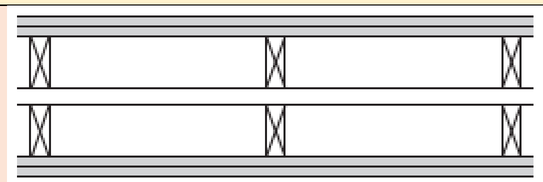
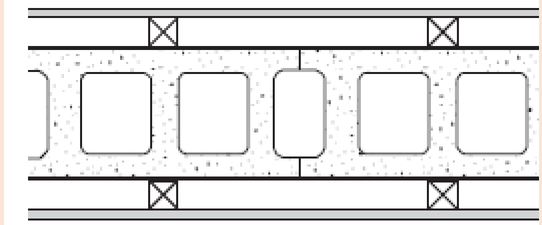
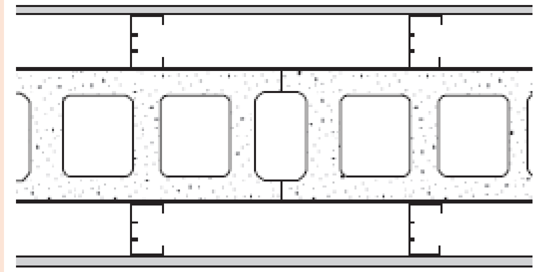
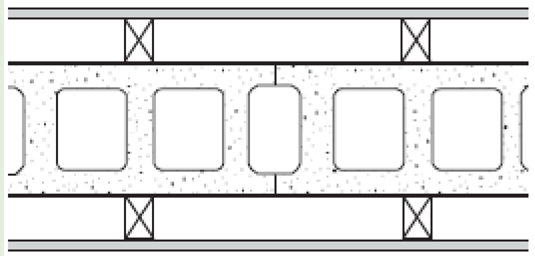
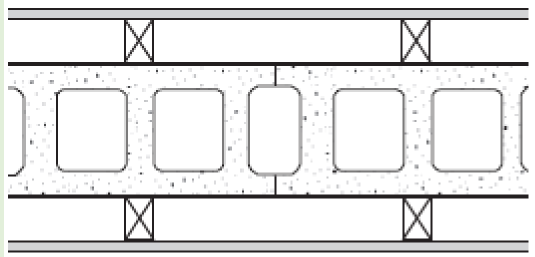
Table 4-10: CBA table for Case study 2

Factors	W10a		W15d		B6c		B7b		B8a		B8b	
Fire Resistance	120		120		180		150		180		150	
					60	**100**	30	80	60	100	30	80
Sound Resistance	62		62		60		70		71		70	
	2	30	2	30			10	75	11	**80**	10	75
Dead load	65		59		251		245		252		247	
	187	50	193	**60**	1	2	7	8			5	5
Total Score		**80**		**90**		**102**		**163**		**180**		**160**

4.5.2 Visualization

The final decision in the CBA model is made by comparing wall alternatives with their relative total score and total cost in a diagram presented in figure 4-11. As it was explained in the case study 1, cost data are based on RSMeans online free database. The calculated costs for the 6 wall options in this case study is presented in the table 4-11.

Table 4-11: Final wall details for Case study 2

Wall Name	Description	RSMeans Cost number for the most similar wall option	Wall Cost	Wall Detail
W10a	Wood studs, 89 mm absorptive material, resilient metal channels on one side, 2 layers of 15.9 mm Type X gypsum board on each side	83.82	97	
W15d	Wood stud, 89 mm absorptive material, 2 layers of 15.9 mm Type X gypsum board on each side	83.82	93	
B6c	190 mm concrete block, 15.9 mm Type X gypsum board	105	167	
B7b	190 mm concrete block, 12.7 mm Type X gypsum board	105	180	
B8a	190 mm concrete block, 15.9 mm Type X gypsum board	105	198	
B8b	190 mm concrete block, 12.7 mm Type X gypsum board	105	175	

So far, the wall section named B8a with total score of 180 is the best choice based on CBA table. Here we can see that while, parition wall B8a has the highest score, it also has the highest cost of 198 CAD per square meter. While the next best optiton which is B7b with 163 total score (17 less score) is 18

CAD cheaper than the best options. The next best option which is B8b has only 3 less scores compared to B7b and 5 CAD less cost.

The initial decision made in this stage is B8b, given the decent score and acceptable cost of this option.

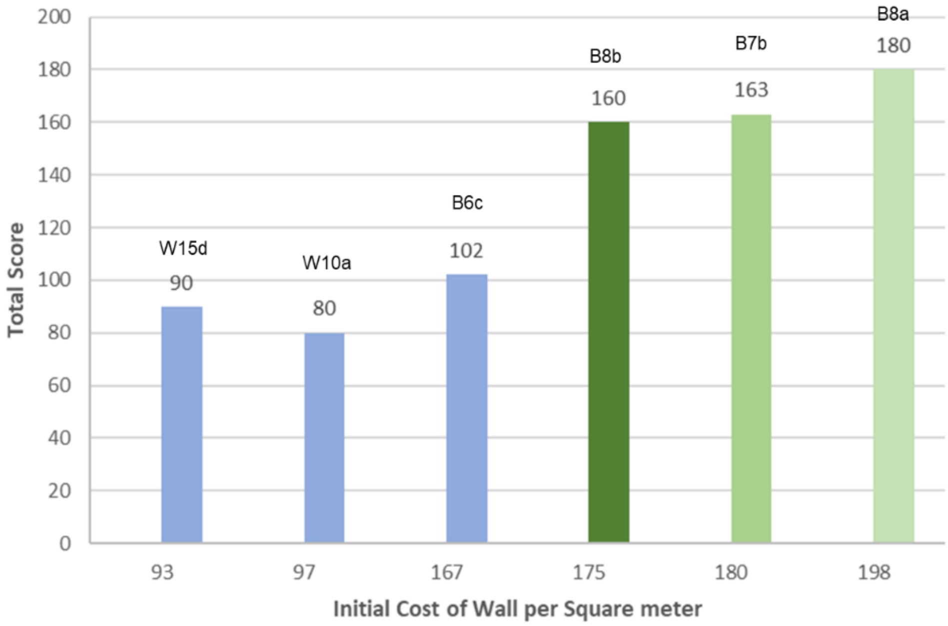


Figure 4-11: Cost-Score diagram of CBA, Case study 2

4.5.3 Evaluation

As for the final step in the implementation of MasonryPartition Pro, a Revit model of the case study 2 is constructed. The 3D model for the case study 2 is presented in the figure 4-12. Using the developed dynamo script explained in section 3.6, we will examine the URM partition wall design of this case study for the final assessment of the decision made for the partition wall type. In this model, there are 25 partition walls with 4.2-meter height which is a moderate wall height. A range of masonry sections of 140 to 290 thickness is assigned to walls.

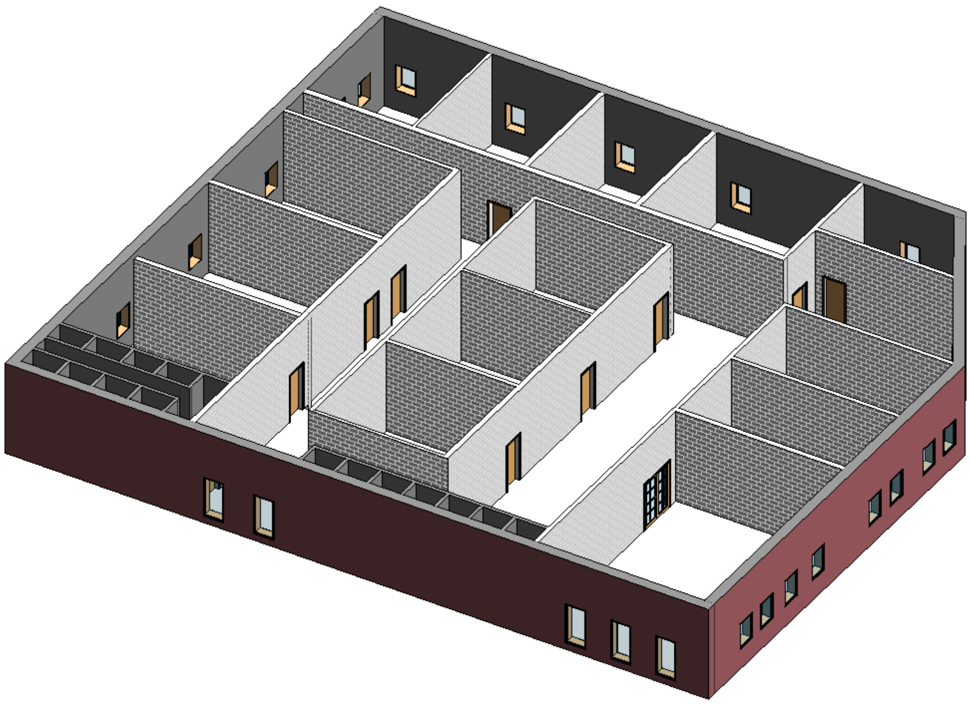


Figure 4-12: 3D model of Case study 2

Running the dynamo model on the case study 2 takes less than 10 seconds. Table 4-12 shows the result of the first round of running the model. We can see that walls with index number of 0-4 and 7-9 and 11 failed. This means these walls cannot be constructed as URM partition walls with the specified thickness, height and opening. Figure 4-13 shows the 3D model of the case study 2 after implementing the design model. Failed walls are rendered in red.

Table 4-12: Design results of masonry partition walls for the Case study 2

Index	h	l	t	Opening	Max Slenderness	Design Status
0	4.2	6	140	No	28	Not OK
1	4.2	6	140	No	28	Not OK
2	4.2	6	140	No	28	Not OK
3	4.2	6.46	190	Yes	22	Not OK
4	4.2	8.1	190	Yes	22	Not OK
5	4.2	7.75	190	No	28	OK
6	4.2	7.75	190	No	28	OK
7	4.2	6	190	Yes	22	Not OK
8	4.2	10.47	190	Yes	22	Not OK
9	4.2	7.89	190	Yes	22	Not OK
10	4.2	6	190	No	28	OK
11	4.2	16.45	190	Yes	22	Not OK
12	4.2	6	190	No	28	OK
13	4.2	7.89	240	No	28	OK

14	4.2	11	240	Yes	22	OK
15	4.2	7.89	240	No	28	OK
16	4.2	7.75	240	No	28	OK
17	4.2	6	240	No	28	OK
18	4.2	6	240	No	28	OK
19	4.2	8.67	240	Yes	22	OK
20	4.2	16.45	240	Yes	22	OK
21	4.2	5	290	Yes	22	OK
22	4.2	5	290	Yes	22	OK
23	4.2	5	290	Yes	22	OK
24	4.2	6.59	290	No	28	OK

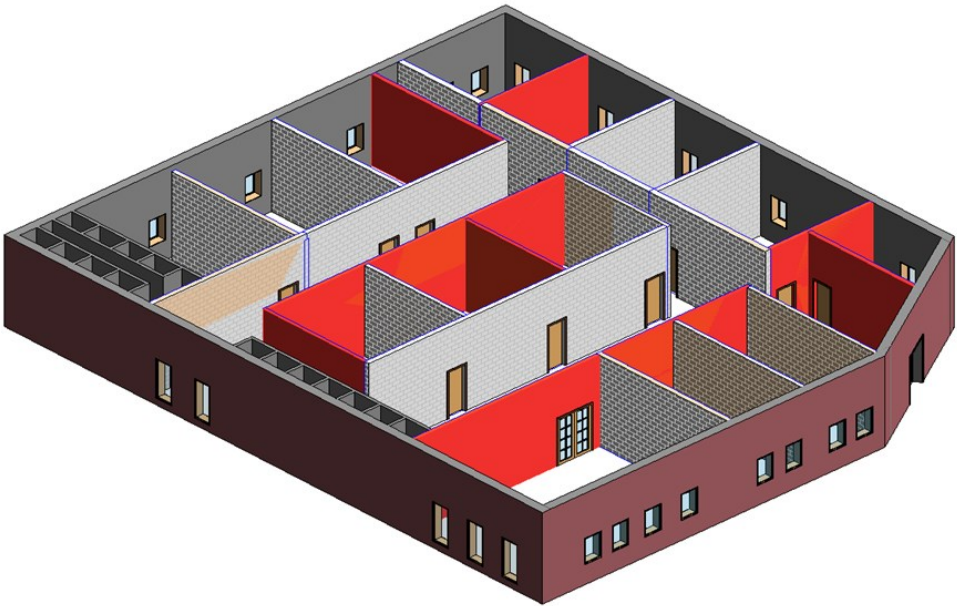


Figure 4-13: Failed walls in Case study 2

The computational model can be readily applied to the model through multiple design iterations, making it exceptionally suitable for fulfilling the educational objectives of the design model. In this case study, the Designer explores diverse options for wall height, thickness, and openings to arrive at a structurally sound URM partition wall design. Table 4-13 presents the validated design outcomes of case study 2, illustrating that different masonry sections which can yield approved design results for the previously failed walls.

Table 4-13: Accepted URM design for Case study 2

Index	h	l	t	Opening	Max Slenderness	Design Status
0	4.2	6	**190**	No	28	**OK**
1	4.2	6	**190**	No	28	**OK**
2	4.2	6	**190**	No	28	**OK**
3	4.2	6.46	**240**	Yes	22	**OK**
4	4.2	8.1	**240**	Yes	22	**OK**
5	4.2	7.75	190	No	28	OK
6	4.2	7.75	190	No	28	OK
7	4.2	6	**240**	Yes	22	**OK**
8	4.2	10.47	**240**	Yes	22	**OK**
9	4.2	7.89	**240**	Yes	22	**OK**
10	4.2	6	190	No	28	OK
11	4.2	16.45	**240**	Yes	22	**OK**
12	4.2	6	190	No	28	OK
13	4.2	7.89	240	No	28	OK
14	4.2	11	240	Yes	22	OK
15	4.2	7.89	240	No	28	OK
16	4.2	7.75	240	No	28	OK
17	4.2	6	240	No	28	OK
18	4.2	6	240	No	28	OK
19	4.2	8.67	240	Yes	22	OK
20	4.2	16.45	240	Yes	22	OK
21	4.2	5	290	Yes	22	OK
22	4.2	5	290	Yes	22	OK
23	4.2	5	290	Yes	22	OK
24	4.2	6.59	290	No	28	OK

According to the table 4-13, designers understand that unreinforced masonry partition wall can be constructed in this project with the thickness of 190- 290 mm. Initial cost associated with URM walls are lower than reinforced ones. Construction of unreinforced partition walls presents less challenges compared to the reinforced one walls. The results derived from the structural design model play a crucial role in convincing decision makers to embrace unreinforced masonry (URM) partition walls. These outcomes provide assurance and validation for the decision made in the CBA process to select a masonry wall as the partition wall for the design.

4.6 Results and Discussions

The successful development and implementation of the MasonryPartition Pro yielded significant insights in this research. Through the case studies, it was observed that the partition wall database greatly simplifies wall selection, aiding stakeholders in informed decision-making. The CBA model effectively demonstrates the advantages of masonry partition walls, while showcasing trade-offs related to cost constraints. Additionally, the computational model promotes the adoption of unreinforced masonry partition walls, maintaining simplicity and competitiveness in terms of affordability and construction ease, and its integration within the BIM environment enhances its usability and serves as an educational tool for designers to improve their understanding of URM design principles. Furthermore, a user interface for partition wall design software development is proposed in the figure 4-9. This software can simplify and enhance the process of partition wall selection and design by leading designers to selection of the best wall options considering all requirements, advantages and principles involved.

5 Chapter Five: Conclusions and Recommendations

5.1 Overview of the Study

This research addresses the lack of a systematic approach to partition wall type selection in building design, focusing on masonry partition walls and dry walls, two main types of partition walls based on NBCC. Masonry is a traditional construction material with unique properties, including structural strength, fire resistance, and durability. However, masonry is facing increasing competition from alternative building systems, primarily due to a complex relationship with modern architecture, limited utilization by architects, and a lack of integration of digital tools into masonry design practices. This research focuses on partition walls, which are essential building components representing about 10% of building costs. Overdesigning masonry partition walls, often due to a lack of design knowledge, is another identified problem in masonry design. In this study authors developed a hybrid DSS combining an MCDM model based on CBA and a computational design model to facilitate informed decision-making and streamline the design process for masonry partition walls. The primary objective of this DSS is to simplify partition wall selection, enhance informed decision-making, and promote the adoption of masonry wall systems. The CBA model, involves identifying advantages, selecting alternatives, establishing criteria, and evaluating attributes for factors naming fire rating, sound rating, dead load, cost, durability, and aesthetics. Stakeholders assign weights to the advantages of these criteria, which are presented in the form of total score for each alternative. Total score of each option and the initial cost are then represented in a graph, making the process of comparing walls and the trade off involved transparent and practical. The computational design model aims to facilitate architects in efficiently designing masonry partition walls. By providing an automated structural design control integrated in Revit, architects can accurately assess structural soundness of each URM partition wall. This model optimizes the design process, leading to time and cost savings and enabling architects to evaluate designs with varying geometries and properties. The goal is to promote the adoption of masonry wall systems by enhancing architects' understanding of URM design and facilitating the design process.

5.2 Conclusions

Upon the successful development and implementation of the hybrid Decision Support System (DSS), this study proceeds to validate the effectiveness of the proposed DSS through two distinct case studies, specifically focusing on partition wall selection and design processes. The outcomes of the research are divided to the CBA model and the design model in the following sections:

5.2.1 Results of the CBA model

The implementation of the decision-making tool for partition wall type selection has yielded several notable outcomes. Firstly, it has significantly simplified the decision-making process, providing a systematic framework for designers. The tool aids designers in better understanding the intricate design requirements by offering a systematic approach. Moreover, it facilitates the wall selection process by progressively narrowing down from 177 wall options, allowing for a more informed and focused decision. The tool also contributes to promoting the advantages of masonry walls, ensuring that their strengths are well-recognized during the decision-making process. A strategic aspect of the tool is its approach to leave the cost factor to the last step of the decision-making process. This sequential consideration ensures that decision-makers consider all critical factors before looking at the cost, ultimately leading to well-informed decisions based on a comprehensive evaluation.

The highlights of the overall results of the study are as follows:

5.2.2 Results of the computational design model

The implementation of the computational design model for masonry partition wall design has resulted in significant outcomes. Firstly, it actively promotes the adoption of unreinforced masonry partition walls, leveraging their structural efficiency and simplicity. The integration of the model into BIM environment enhances its accessibility and user-friendliness, transforming it into a powerful educational tool. The model's user-friendly interface allows for simple iterations on each design, making it more effective both in the design process and for educational purposes. Additionally, the model has demonstrated substantial cost savings based on RSMeans online cost database, with a reported 3-11% reduction in costs when utilizing unreinforced masonry compared to reinforced options. This cost-effectiveness adds practical value, making URM partition walls not only structurally efficient but also economically advantageous.

- Partition wall options database developed in this study can significantly facilitate the process of wall selection helping stakeholders in making well-informed decision.
- CBA model can greatly showcase the advantages of masonry partition walls and the trade off involved while not selecting the best wall options due to cost limits.
- The ease of constructing unreinforced masonry walls plays a pivotal role in promoting the adoption of masonry systems. The computational model developed in this study makes a significant contribution to this aspect by preserving the simplicity of design.

- Being integrated in BIM environment makes the design model easy and quick to run for designers, and also makes it a good educational tool to help designers fully grasp URM design principles.
- Showcasing the latest updates of CSA S304-14 (masonry Code design), and simplified design tables from CMDC in the design model is another strong feature of the model in educational purposes and helping these organizations to educate engineering community.
- Based on RSMeans online cost database, 3-11% cost saving is achieved when having unreinforced masonry partition walls instead of reinforced one, considering the basic reinforcement stated in this database and choosing the same thickness. Therefore, the developed model can contribute to a noticeable cost saving by designing URM.

5.3 Contributions of MasonryPartition Pro

The developed DSS is presented as a software user interface called MasonryPartition Pro. The results from implementation of this user interface are presented as academic and industry contributions.

5.3.1 Academic contributions of MasonryPartition Pro

MasonryPartition Pro has made significant academic contributions by introducing, for the first time in the literature, a comprehensive set of criteria specifically tailored for the selection of partition walls. While existing literature often provides criteria sets for various building elements, the oversight of partition walls prompted our research to fill this critical gap. Collaborating with the experts from CMDC and drawing insights from relevant literature, we identified a set of five criteria essential for evaluating and selecting partition walls. This pioneering effort adds depth to the academic understanding of partition wall design and selection processes, offering a valuable resource for researchers and practitioners alike.

5.3.2 Industry contributions of MasonryPartititon Pro

MasonryPartition Pro brings noteworthy contributions to the industry by serving as a driving force for the increased adoption of masonry systems. The user-friendly interface simplifies the design process, making it more accessible for practitioners and promoting the efficiency of masonry partition wall design and construction. Additionally, according to the experts, the commercialization potential of MasonryPartition Pro is substantial, offering a valuable tool for businesses seeking advanced solutions in partition wall design. Furthermore, the inclusion of a comprehensive database featuring 177 partition wall options, complete with all necessary information, enhances the practical utility of the software, providing a valuable resource for industry professionals to streamline decision-making and design processes of partition walls.

5.4 Implication of results on practice

The implications of MasonryPartition Pro's results on practice are substantial, revolutionizing the way designers approach partition wall design. Designers, armed with this tool, will systematically verify adherence to design requirements, gaining deeper insights into factors like the significance of the dead load in seismic design. A closer collaboration with the structural design team will follow, ensuring a holistic approach that considers structural intricacies. Moreover, designers will actively seek and consider input from various stakeholders, including owners, fostering a comprehensive decision-making process. By leveraging the iterative capabilities of the computational design tool, designers can engage in purposeful practice, refining their skills in URM partition wall design principles. Lastly, fostering comprehensive discussions with the construction team will become a norm, ensuring seamless communication of design intent, and minimizing potential discrepancies during the construction phase. This transformative approach promises to enhance efficiency and efficacy in partition wall design practices.

5.5 Limitations of this Research

This study primarily focuses on partition wall selection and design a of URM partition walls. Partition wall types used in the development of DSS are dry wall and masonry walls, based on NBCC part 9. Due to constraints in terms of time and available personnel, it was not feasible to comprehensively investigate a wide range of wall systems. Furthermore, the computational design tool developed for ensuring the structural integrity of unreinforced masonry partition walls is specifically tailored to address the wall's structural requirements, without considering end conditions and detailing. To ensure that the partition wall meets the specified structural analysis, connection accessories need to be designed. It is worth noting that URM design in masonry partition walls is mainly suitable for regions with low seismic hazard levels, such as Alberta. In areas with different seismic considerations, adjustments to the design are necessary to meet the minimum reinforcement requirements outlined in CSA S304-14. Despite these constraints, this research offers valuable insights and solutions to enhance partition wall design, the adoption of masonry partition walls, laying the groundwork for more specialized research in the future.

5.6 Recommendations for Future Works

Future research efforts should concentrate on expanding the model to other wall systems such as load bearing and external walls. This will help with the prompting masonry as a construction system, recognizing its inherent strength and versatility. One promising avenue for future exploration is the development of advanced digital design tools capable of designing structural masonry elements with unconventional configurations. These tools not only can facilitate the design process but also enhance designers' knowledge and enthusiasm for masonry design. The integration of digitalization can positively impact both the structural and architectural aspects of masonry design, opening up innovative possibilities. Additionally, future research should involve practical investigations aimed at understanding the challenges and expectations of the construction industry concerning masonry. Gathering real-world evidence on the industry's experiences and aspirations can offer valuable insights and potentially inspire new directions for masonry research, ultimately contributing to the continued improvement and wider adoption of masonry walls in the construction sector.

References

Alberta Infrastructure and Transportation. (2007). *Standards and Guidelines For School Facilities*.

Al Hattab, M., & Hamzeh, F. (2018). Simulating the dynamics of social agents and information flows in BIM-based design. *Automation in Construction*, *92*, 1–22.

Alibaba, H. Z., & Özdeniz, M. B. (2004). A building elements selection system for architects. *Building and Environment*, *39*(3), 307–316.

Alter, S. (1980). Decision support systems: current practice and continuing challenges. *(No Title)*.

Arroyo, P., Mourgues, C., Flager, F., & Correa, M. G. (2018). A new method for applying choosing by advantages (CBA) multicriteria decision to a large number of design alternatives. *Energy and Buildings*, *167*, 30–37.

Arroyo, P., Tommelein, I. D., & Ballard, G. (2014). Comparing weighting rating and calculating vs. choosing by advantages to make design choices. *Proceedings for the 22nd Annual Conference of the International Group for Lean Construction*, *1*(510), 1–12.

Arroyo, P., Tommelein, I. D., & Ballard, G. (2015). Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design. *Journal of Construction Engineering and Management*, *141*(1), 04014063.

Arroyo, P., Tommelein, I. D., Ballard, G., & Rumsey, P. (2016). Choosing by advantages: A case study for selecting an HVAC system for a net zero energy museum. *Energy and Buildings*, *111*, 26–36.

A.W.Hendry, B. P. S. and S. R. D. (2004). *Design of Masonry Structures* (Third). E & FN SPON An Imprint of Chapman & Hall London · Weinheim · New York · Tokyo · Melbourne · Madras.

Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J., & Sorenson, K. (2001). *Guidebook to decision-making methods* (Vol. 45). Westinghouse Savannah River Company Aiken, SC, USA.

Ballard, G. (2002). Managing work flow on design projects: a case study. *Engineering, Construction and Architectural Management*, *9*(3), 284–291.

Beall, C. (2000). New masonry products and materials. *Progress in Structural Engineering and Materials*, *2*(3), 296–303.

Beall, C., & Jaffe, R. (2003). *Concrete and Masonry Databook*. McGraw-Hill Professional Publishing.

Becker, R. (1984). Condensation and mould growth in dwellings—parametric and field study. *Building and Environment*, *19*(4), 243–250.

Bettig, B., & Shah, J. (2001). Derivation of a standard set of geometric constraints for parametric modeling and data exchange. *Computer-Aided Design*, *33*(1), 17–33.

Bojic, M., Yik, F., & Sat, P. (2001). Influence of thermal insulation position in building envelope on the space cooling of high-rise residential buildings in Hong Kong. *Energy and Buildings*, *33*(6), 569–581.

Brans, J.-P., & Vincke, P. (1985). Note—A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making). *Management Science*, *31*(6), 647–656.

Canada Masonry Design Center. (2017, January). *Using MASS to design walls that span horizontally*.

Canada Masonry Design Center. (2023). Meeting with CMDC. In *Meeting with Dr. Bennett Banting, director of CMDC*.

Canada Mortgage and Housing Corporation (CMHC). (2017). *HOUSING RESEARCH REPORT Cost of Delivering Housing in Canada*.

Cavieres, A., Gentry, R., & Al-Haddad, T. (2009). Rich Knowledge Parametric Tools for Concrete Masonry Design Automation of Preliminary Structural Analysis, Detailing and Specifications. *26th International Symposium on Automation and Robotics in Building, Information and Computational Technology*, 545–552.

Cavieres, A., Gentry, R., & Al-Haddad, T. (2011). Knowledge-based parametric tools for concrete masonry walls: Conceptual design and preliminary structural analysis. *Automation in Construction*, *20*(6), 716–728.

CCMPA. (2013). *Physical Properties*.

Chua, K. J., & Chou, S. K. (2010). Evaluating the performance of shading devices and glazing types to promote energy efficiency of residential buildings. *Building Simulation*, *3*, 181–194.

Collins, P. (1998). *Changing ideals in modern architecture, 1750-1950*. McGill-Queen's Press-MQUP.

Cross, J. C. (1965). Introduction to Contemporary Bearing Walls. *Proc. National Brick and Tile Bearing Conference*.

CSA Group- Canadian Standard Association. (2014). *CSA S304-14- Design of Masonry Structures*.

Devi, K., Yadav, S. P., & Kumar, S. (2009). Extension of fuzzy TOPSIS method based on vague sets. *International Journal of Cmputaional Cognition*, *7*(4).

Eastman, C. , T. P. , S. R. , & L. K. (2008). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors* (1st ed.).

Elbehairy, H., Elbeltagi, E., Hegazy, T., & Soudki, K. (2006). Comparison of two evolutionary algorithms for optimization of bridge deck repairs. *Computer-Aided Civil and Infrastructure Engineering*, *21*(8), 561–572.

Faiz, R. B., & Edirisinghe, E. A. (2009). Decision making for predictive maintenance in asset information management. *Interdisciplinary Journal of Information, Knowledge, and Management*, *4*, 23.

Fischer, M., & Adams, H. (2011). Engineering-based decisions in construction. *Journal of Construction Engineering and Management*, *137*(10), 751–754.

Forgionne, G. A., Gupta, J. N. D., & Mora, M. (2002). *Decision-Making Support Systems: Achievements and Challenges for the New Decade: Achievements and Challenges for the New Decade*.

FORSE Consulting, L. (2019). *Masonry Insight*.

Fülöp, J. (2005). Introduction to decision making methods. *BDEI-3 Workshop, Washington*, 1–15.

Gentry, T. R., Cavieres, A., & Al-Haddad, T. (2009). Parametric design, detailing and structural analysis of doubly-curved load-bearing block walls. *11th Canadian Masonry Symposium*.

Government of Canada. (2020). *2020 National Building Code of Canada seismic hazard maps*.

Government of Canada. (2022, March 28). *National Building Code of Canada 2020, Volume 2*.

Granadeiro, V., Correia, J. R., Leal, V. M. S., & Duarte, J. P. (2013). Envelope-related energy demand: A design indicator of energy performance for residential buildings in early design stages. *Energy and Buildings*, *61*, 215–223.

Hamida, H., & Alshibani, A. (2021). A multi-criteria decision-making model for selecting curtain wall systems in office buildings. *Journal of Engineering, Design and Technology*, *19*(4), 904–931.

Harding JR, S. RA. (1986). Brickwork durability. *BDA Design . Brick Development Association*, *Note 7*.

Hartmann, T. (2011). Goal and process alignment during the implementation of decision support systems by project teams. *Journal of Construction Engineering and Management*, *137*(12), 1134–1141.

Hassanain, M. A., & Harkness, E. L. (1998). Priorities in building envelope design. *Journal of Architectural Engineering*, *4*(2), 47–51.

Hatzinikolas, M., Korany, Y., & Brzev, S. (2015). *Masonry Design for Architects and Engineers*.

Heigermoser, D., & de Soto, B. G. (2022). Implementing Lean-BIM Duality: Balance between People, Process, and Technology. In *Lean Construction 4.0* (pp. 98–116). Routledge.

Hendry, A. W. (1998a). Reinforced and Prestressed Masonry. *Structural Masonry*, 181–209.

Hendry, A. W. (1998b). *Structural masonry*. Bloomsbury Publishing.

Hendry, A. W. (2001). Masonry walls: materials and construction. *Construction and Building Materials*, *15*(8), 323–330.

Hendry, A. W., & Khalaf, F. M. (2017). *Masonry wall construction*. CRC Press.

Hendry, A. W., Sinha, B. P., & Davies, S. R. (2017a). *Design of masonry structures*. CRC Press.

Hendry, A. W., Sinha, B. P., & Davies, S. R. (2017b). *Design of masonry structures*. CRC Press.

Hevner, A. R. (2007). A three cycle view of design science research. *Scandinavian Journal of Information Systems*, *19*(2), 4.

Heyman, J. (1996). The stone skeleton: structural engineering of masonry architecture. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, *3*(33), 133A.

Horvat, M., & Fazio, P. (2020). BEPAT–Building envelope performance assessment tool: Validation. In *Research in Building Physics and Building Engineering* (pp. 277–284). CRC Press.

Ismaiel, M., Chen, Y., Cruz-Noguez, C., & Hagel, M. (2021). Thermal resistance of masonry walls: a literature review on influence factors, evaluation, and improvement. *Journal of Building Physics*, *45*(4), 528–567. https://doi.org/10.1177/17442591211009549

Iwaro, J., Mwasha, A., Williams, R. G., & Zico, R. (2014). An Integrated Criteria Weighting Framework for the sustainable performance assessment and design of building envelope. *Renewable and Sustainable Energy Reviews*, *29*, 417–434.

Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*, *12*(1), 3–11.

Jordan Kuntz. (2022, October 17). *Industry challenges and wall share*. Masonry samposiom.

Kaklauskas, A., Zavadskas, E. K., Raslanas, S., Ginevicius, R., Komka, A., & Malinauskas, P. (2006). Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case. *Energy and Buildings*, *38*(5), 454–462.

Kendig, C. E. (2016). What is Proof of Concept Research and how does it Generate Epistemic and Ethical Categories for Future Scientific Practice? *Science and Engineering Ethics*, *22*(3), 735–753. https://doi.org/10.1007/s11948-015-9654-0

Kiliç, H. S. (2012). Supplier selection application based on a fuzzy multiple criteria decision making methodology. *AJIT-e: Academic Journal of Information Technology*, *3*(8), 7–18.

Koskela, L. (2008). *Which kind of science is construction management?*

Linkov, I., Satterstrom, F. K., Kiker, G., Batchelor, C., Bridges, T., & Ferguson, E. (2006). From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications. *Environment International*, *32*(8), 1072–1093.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266.

Martabid, J. E., & Mourgues, C. (2015). Criteria used for selecting envelope wall systems in Chilean residential projects. *Journal of Construction Engineering and Management*, *141*(12), 05015011.

Marzouk, M. (2006). Utility theory model for equipment selection. *Construction Innovation*, *6*(1), 21–32.

Miranda Dias, J. (2002). *Movement in Masonry Walls Caused by Temperature and Moisture Changes*.

Momenifar, S., Keyrouz, K., & Hamzeh, F. (n.d.). *IMPLEMENTATION OF LEAN THINKING TO IMPROVE MASONRY CONSTRUCTION AND DESIGN*.

Monica Guzman, M. Sc. , P. Eng. (2023, July 25). *Unreinforced masonry partition wall design*. Meetings with Masonry Design Center of Canada on Masonry partition wall design.

Nixon Wonoto, nixonwonoto@gmail. com. (2017). *Integrating Parametric Structural Analysis and Optimization in architectural schematic design phase*. Clemson University,.

Oprite Bobmanuel. (2021). *Improving The Fire Resistance Rating of Concrete Masonry Walls Through the Use of Insulations An Experimental and Numerical Study*. Carleton University.

Passe, U., & Nelson, R. (2013). Constructing energy efficiency: Rethinking and redesigning the architectural detail. *Journal of Architectural Engineering*, *19*(3), 193–203.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77.

Power, D. J. (2002). *Decision support systems: concepts and resources for managers*. Quorum Books.

Pulaski, M. H., & Horman, M. J. (2005). Organizing constructability knowledge for design. *Journal of Construction Engineering and Management*, *131*(8), 911–919.

Purcell, A. T., & Gero, J. S. (2006). *Design and Other Types of Fixation or Is Fixation Always Incompatible with Innovation?*

Ramamurthy, K., & K.B.Anand. (1999). Techniques for accelerating masonry construction. In *Int. Journal of Housing Science and its Applications* (Vol. 23, Issue 4).

Ramamurthy, K., & Kunhanandan Nambiar, E. K. (2004). Accelerated masonry construction review and future prospects. *Progress in Structural Engineering and Materials*, *6*(1), 1–9.

Rashidi, M., Ghodrat, M., Samali, B., Kendall, B., & Zhang, C. (2017). Remedial modelling of steel bridges through application of analytical hierarchy process (AHP). *Applied Sciences*, *7*(2), 168.

Rashidi, M., Samali, B., Azad, A., & Hatamian, H. (2018). Asset management of steel bridges. *Mechanics of Structures and Materials XXIV: Proceedings of the 24th Australian Conference on the Mechanics of Structures and Materials (ACMSM24, Perth, Australia, 6-9 December 2016)*, 216–221.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281.

Singhaputtangkul, N., Low, S. P., Teo, A. L., & Hwang, B.-G. (2014). Criteria for architects and engineers to achieve sustainability and buildability in building envelope designs. *Journal of Management in Engineering*, *30*(2), 236–245.

Smulski, S. (1999). Durability of energy-efficient wood-frame houses. *Forest Products Journal*, *49*(5), 8–15.

Sowden, A. M. (1990). *The maintenance of brick and stone masonry structures*. Taylor & Francis.

Subasic, C. (2022). A Survey of Innovations in Masonry Units Addressing Sustainability. *2022 Masonry Symposium: Advancing Masonry Technology*, 122–137.

Suhr, J. (1999). *The choosing by advantages decisionmaking system*. Greenwood Publishing Group.

The Solution for Streamlined Masonry Design. (2020). *Echelon Masonry + Masonry iQ*.

Valiris, G., Chytas, P., & Glykas, M. (2005). Making decisions using the balanced scorecard and the simple multi-attribute rating technique. *Performance Measurement and Metrics*, *6*(3), 159–171.

Wang, W., Zmeureanu, R., & Rivard, H. (2005). Applying multi-objective genetic algorithms in green building design optimization. *Building and Environment*, *40*(11), 1512–1525.

William Malsam. (2023, July). *What Is Proof of Concept (POC)? Examples for Business, Software & More*.

Williams, B. (2008). Methods explained: Cost-benefi t analysis. *Economic & Labour Market Review*, *2*, 67–70.

Yehia, S., Abudayyeh, O., Fazal, I., & Randolph, D. (2008). A decision support system for concrete bridge deck maintenance. *Advances in Engineering Software*, *39*(3), 202–210.

Yoon, K. P., & Hwang, C.-L. (1995). *Multiple attribute decision making: an introduction*. Sage publications.

Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Tamošaitiene, J. (2008). Selection of the effective dwelling house walls by applying attributes values determined at intervals. *Journal of Civil Engineering and Management*, *14*(2), 85–93.

Zavadskas, E. K., Ustinovičius, L., Turskis, Z., & Ševčenko, G. (2009). *Application of verbal methods to multi-attribute comparative analysis of investments risk alternatives in construction*.

Zoeteman, A. (2001). A life cycl costing based approach to design and maintenance of railway infrastructure. *Journal on Transport and Infrastructure Research*, *1*(4), 391–413.

Appendix

Table A14: A summary of Section 9.29. of NBCC on Interior Wall and Ceiling Finishes

Clause Number and Title	Code Specifications	Summary
9.29.1.1. **Fire protection and Sound control**	*A wall or ceiling finish shall also conform to the appropriate requirements in Sections 9.10. and 9.11., in addition to the requirements in this Section*	Partition walls must conform to fire protection and sound control requirements in Sections 9.10 and 9.11
2.29.2. Waterproof Wall Finish	*9.29.2.1. Where Required* *1) Waterproof finish shall be provided to a height of not less than* *a) 1.8 m above the floor in shower stalls,* *b) 1.2 m above the rims of bathtubs equipped with showers, and* *c) 400 mm above the rims of bathtubs not equipped with showers*	Waterproof finishes are required for shower stalls, bathtubs with showers, and bathtubs without showers to specified heights
2.29.3. Wood Furring **9.29.3.2. Fastening**	*9.29.3.1. Size and Spacing of Furring* *1) Wood furring for the attachment of wall and ceiling finishes shall conform to Table 9.29.3.1.* *1) Furring shall be fastened to the framing or to wood blocks with not less than 51 mm nails*	Wood furring used for attaching wall and ceiling finishes must meet the size and spacing requirements stated in Table 9.29.3.1 and be fastened with 51 mm nails.
9.29.4. Plastering **9.29.4.1. Application**	*1) Application of plaster wall and ceiling finishes, including installation of metal or gypsum lath, shall conform to CSA A82.30-M, "Interior Furring, Lathing and Gypsum Plastering."*	Application of plaster wall and ceiling finishes should follow CSA A82.30-M standards
9.29.5. Gypsum Board Finish (Taped Joints) **9.29.5.1. Application**	*1) The requirements for application of gypsum board in this Subsection apply to the single layer application of gypsum board to wood furring or framing using nails or screws.* *2) Except as provided in Sentence (3), gypsum board applications not described in this Subsection shall conform to CSA A82.31-M, "Gypsum Board Application."* *3) The application of gypsum board to flat insulating concrete form (ICF) walls shall conform to ASTM C840, "Standard Specification for Application and Finishing of Gypsum Board." (See Note A-9.29.5.1.(3).)* *9.29.5.2. Materials* *1) Gypsum products shall conform to* *a) ASTM C1178/C1178M, "Standard Specification for Coated Glass Mat Water-Resistant Gypsum Backing Panel," or* *b) ASTM C1396/C1396M, "Standard Specification for Gypsum Board," except that the flame-spread rating of gypsum board shall be determined in accordance with CAN/ULC-S102, "Standard Method of Test for Surface Burning Characteristics of Building Materials and Assemblies."*	Gypsum board finishes with taped joints must adhere to specific application requirements and use gypsum products that conform to ASTM standards
9.29.5.3. Maximum Spacing of Supports	*1) Maximum spacing of supports for gypsum board applied as a single layer shall conform to Table 9.29.5.3.*	The maximum spacing of supports for gypsum board applied as a single layer is outlined in Table 9.29.5.3

9.29.5.4. Support of Insulation	*1) Gypsum board supporting insulation shall be not less than 12.7 mm thick. 9.29.5.5.*	Gypsum board supporting insulation must be at least 12.7 mm thick
9.29.5.5. Length of Fasteners **9.29.5.6. Nails** **9.29.5.8. Spacing of Nails** **9.29.5.9. Spacing of Screws**	*1) The length of fasteners for gypsum board shall conform to Table 9.29.5.5., except that lesser depths of penetration are permitted for assemblies required to have a fire-resistance rating provided it can be shown, on the basis of fire tests, that such depths are adequate for the required rating.* *9.29.5.6. Nails* *1) Nails for fastening gypsum board to wood supports shall conform to* *a) ASTM F1667, "Standard Specification for Driven Fasteners: Nails, Spikes, and Staples," or* *b) CSA B111, "Wire Nails, Spikes and Staples."* *9.29.5.7. Screws* *1) Screws for fastening gypsum board to wood supports shall conform to ASTM C1002, "Standard Specification for Steel Self-Piercing Tapping Screws for the Application of Gypsum Panel Products or Metal Plaster Bases to Wood Studs or Steel Studs."* *9.29.5.8. Spacing of Nails* *1) For single-layer application on a ceiling, nails shall be spaced* *a) not more than 180 mm o.c. on ceiling supports, or* *b) every 300 mm o.c. along ceiling supports, in pairs about 50 mm apart.* *2) Where the ceiling sheets are supported by the wall sheets around the perimeter of the ceiling, this support may be considered as equivalent to nailing at this location.* *3) Except as required by Sentence (4), for single-layer application on walls, nails shall be spaced* *a) not more than 200 mm o.c. on vertical wall supports, or* *b) every 300 mm o.c. along vertical wall supports, in pairs about 50 mm apart.* *4) For single-layer application on walls, where gypsum board provides required bracing in braced wall panels, lateral support for studs, or fire protection, nails shall be spaced not more than 200 mm o.c. on* *a) vertical wall supports, and* *b) top and bottom plates. (See Article 9.23.10.2. and Section 9.10.)* *5) The uppermost nails on vertical wall supports shall be not more than 200 mm below the ceiling.* *6) Nails shall be located not less than 10 mm from the side or edge of the board.* *7) Nails shall be driven so that the heads do not puncture the paper.* *9.29.5.9. Spacing of Screws* *1) For single-layer application on a ceiling, screws shall be spaced not more than 300 mm o.c. on ceiling supports.*	For Length of Fasteners follow the specified depths in Table 9.29.5.5, unless fire tests prove otherwise for fire-rated assemblies. For Nails use nails that meet ASTM F1667 or CSA B111 standards for attaching gypsum board to wood supports. For screws use screws that meet ASTM C1002 specifications for attaching gypsum board to wood supports. For spacing of Nails: For single-layer wall application: Nails spaced not more than 200 mm on vertical wall supports or every 300 mm along supports, in pairs 50 mm apart. Additional requirements for bracing, lateral support, or fire protection apply. Spacing of Screws: For single-layer wall application: Screws spaced not more than 300 mm on vertical wall supports if >400 mm apart, or not more than 400 mm on supports if ≤400 mm apart. Additional requirements for bracing, lateral support, or fire protection apply.

	2) Where the ceiling sheets are supported by the wall sheets around the perimeter of the ceiling, this support may be considered as equivalent to screwing at this location. *3) Except as required by Sentence (4), for single-layer application on walls, screws shall be spaced* *a) not more than 300 mm o.c. on vertical wall supports where the supports are more than 400 mm o.c., or* *b) not more than 400 mm o.c. on vertical wall supports where the supports are not more than 400 mm o.c.* *4) Except as provided in Sentence (5), for single-layer application on walls, where gypsum board provides required bracing in braced wall panels, lateral support for studs, or fire protection, screws shall be spaced not more than 300 mm o.c. on* *a) vertical wall supports, and* *b) top and bottom plates.(See Article 9.23.10.2. and Section 9.10.)* *5) Where a fire-resistance rating is determined based on Table 9.10.3.1.-A, Sentence (4) need not apply for the purpose of fire protection.* *6) Screws shall be located not less than 10 mm from the edge of the board.* *7) Screws shall be driven so that the heads do not puncture the paper.*	
9.29.5.10. Low Temperature Conditions	*1) In cold weather, heat shall be provided to maintain a temperature not below 10°C for 48 h prior to taping and finishing and maintained for not less than 48 h thereafter.*	Heat must be provided to maintain a temperature not below 10°C for 48 hours before and after taping and finishing in cold weather conditions
9.29.6. Plywood Finish **9.29.6.1. Thickness**	*1) Except as provided in Sentences (2) and (3), the minimum thickness of plywood interior finish shall conform to Table 9.29.6.1.* *2) A manufacturing tolerance of −0.4 mm may be applied to the thicknesses listed in Table 9.29.6.1.* *3) No minimum thickness is required where plywood is applied over continuous backing.* *9.29.6.2. Grooved Plywood* *1) Except as permitted in Sentence (2), where plywood for interior finish is grooved, the grooves shall not extend through the face ply and into the plies below the face ply unless the groove is supported by framing or furring.* *2) If the grain of the face ply is at right angles to the supporting members, the groove is permitted to extend into plies below the face ply provided the thickness of the plywood exceeds the value shown in Table 9.29.6.1. by an amount equal to not less than the depth of penetration of the grooves into the plies below the face ply.*	Plywood finishes must meet minimum thickness requirements stated in Table 9.29.6.1, and grooved plywood has additional support requirements
9.29.6.3. Nails and Staples	*1) Except as provided in Sentence (2), nails for attaching plywood finishes shall not be less than 38 mm casing or finishing nails spaced not more than*	Nails and Staples: For attaching plywood finishes, use nails that are at least 38 mm casing or finishing nails.

	150 mm o.c. along edge supports and 300 mm o.c. along intermediate supports, except that staples providing equivalent lateral resistance may also be used. *2) Where plywood finish provides required bracing in braced wall panels, the plywood shall be fastened in accordance with the fastening requirements for sheathing stated in Sentence 9.23.3.5.(2).*	The nails should be spaced not more than 150 mm on edge supports and 300 mm on intermediate supports. Staples providing equivalent lateral resistance can also be used. Plywood Finish as Bracing: If the plywood finish provides the required bracing in braced wall panels, follow the fastening requirements for sheathing mentioned in Sentence 9.23.3.5.(2).
9.29.7. Hardboard Finish **9.29.7.1. Material Standard** **9.29.7.2. Thickness**	*1) Hardboard shall conform to CAN/CGSB-11.3-M, "Hardboard."* *1) Hardboard shall be not less than* *a) 3 mm thick where applied over continuous backing,* *b) 6 mm thick when applied over supports spaced not more than 400 mm o.c., and* *c) 9 mm thick when applied over supports spaced not more than 600 mm o.c.* *9.29.7.3. Nails* *1) Nails for fastening hardboard shall be casing or finishing nails not less than 38 mm long, spaced not more than 150 mm o.c. along edge supports and 300 mm o.c. along intermediate supports.* *9.29.7.4. Edge Support* *1) All hardboard edges shall be supported by furring, blocking or framing where the backing is not continuous.*	Material Standard (9.29.7.1):Hardboard must conform to the CAN/CGSB-11.3-M standard. Thickness (9.29.7.2):The thickness of hardboard should be: a) At least 3 mm when applied over continuous backing. b) At least 6 mm when applied over supports spaced not more than 400 mm apart. c) At least 9 mm when applied over supports spaced not more than 600 mm apart. Nails (9.29.7.3): Use casing or finishing nails that are at least 38 mm long for fastening hardboard. Nail spacing should be not more than 150 mm on edge supports and 300 mm on intermediate supports. Edge Support (9.29.7.4): Ensure that all edges of the hardboard are supported by furring, blocking, or framing when the backing is not continuous.
9.29.8. Insulating Fibreboard Finish **9.29.8.1. Material Standard** **9.29.8.2. Thickness** **9.29.8.3. Nails** **9.29.8.4. Edge Support**	*1) Insulating fibreboard shall conform to CAN/ULC-S706.1, "Standard for Wood Fibre Insulating Boards for Buildings."* *1) Insulating fibreboard sheets shall be not less than 11.1 mm thick on supports not more than 400 mm o.c.* *2) Insulating fibreboard tile shall be not less than 12.7 mm thick on supports spaced not more than 400 mm o.c.* *1) Nails for fastening fibreboard sheets shall be not less than 2.6 mm shank diameter casing or finishing nails of sufficient length to penetrate not less than 20 mm into the supports.* *2) Nails shall be spaced not more than 100 mm o.c. along edge supports and 200 mm o.c. along intermediate supports.* *1) All fibreboard edges shall be supported by blocking, furring or framing.*	Material Standard (9.29.8.1): Insulating fibreboard must conform to the CAN/ULC-S706.1 standard, which is the "Standard for Wood Fibre Insulating Boards for Buildings. "Thickness (9.29.8.2): Insulating fibreboard sheets should be at least 11.1 mm thick when applied on supports spaced not more than 400 mm apart. Insulating fibreboard tiles should be at least 12.7 mm thick when applied on supports spaced not more than 400 mm apart. Nails (9.29.8.3): Use casing or finishing nails with a shank diameter of at least 2.6 mm for fastening fibreboard sheets. The nails should be long enough to penetrate at least 20 mm into the supports. Nail spacing should not exceed 100 mm on edge supports and 200 mm on intermediate supports. Edge Support (9.29.8.4): Ensure that all edges of the fibreboard are

		supported by blocking, furring, or framing.
9.29.9. Particleboard, OSB or Waferboard Finish **9.29.9.1. Material Standard** **9.29.9.2. Minimum Thickness** **9.29.9.3. Nails** **9.29.9.4. Edge Support**	*1) Particleboard finish shall conform to ANSI A208.1, “Particleboard.”* *2) OSB or waferboard finish shall conform to* *a) CSA O325, “Construction sheathing,” or* *b) CSA O437.0, “OSB and Waferboard.”* *1) Except as provided in Sentences (2) and (3), the minimum thickness of O-2 grade OSB used as an interior finish shall conform to that shown for plywood in Table 9.29.6.1.* *2) Thicknesses listed in Table 9.29.6.1. shall permit a manufacturing tolerance of −0.4 mm.* *3) No minimum thickness is required where O-2 grade OSB is applied over continuous backing.* *4) OSB conforming to O-1 grade, waferboard conforming to R-1 grade and particleboard shall be* *a) not less than 6.35 mm thick on supports not more than 400 mm o.c.,* *b) not less than 9.5 mm thick on supports not more than 600 mm o.c., and* *c) not less than 6.35 mm thick on supports not more than 600 mm o.c. in walls where blocking is provided at mid-wall height.* *5) OSB conforming to CSA O325, “Construction sheathing,” shall meet the minimum panel mark of* *a) W16, on supports not more than 400 mm o.c.,* *b) W24, on supports not more than 600 mm o.c., and* *c) W16, on supports not more than 600 mm o.c. where blocking is provided at mid-wall height* *1) Except as provided in Sentence (2), nails for fastening particleboard, OSB or waferboard shall be not less than 38 mm casing or finishing nails spaced not more than 150 mm o.c. along edge supports and 300 mm o.c. along intermediate supports.* *2) Where OSB or waferboard provides required bracing in braced wall panels, the OSB or waferboard shall be fastened in accordance with the fastening requirements for sheathing stated in Sentence 9.23.3.5.(2).* *1) All particleboard, OSB or waferboard edges shall be supported by furring, blocking or framing.*	Material Standard (9.29.9.1): Particleboard finish must conform to ANSI A208.1, "Particleboard." OSB or waferboard finish must conform to either:a) CSA O325, "Construction sheathing," or b) CSA O437.0, "OSB and Waferboard." Minimum Thickness (9.29.9.2): The minimum thickness of O-2 grade OSB used as an interior finish should conform to the thickness specified for plywood in Table 9.29.6.1, with a manufacturing tolerance of -0.4 mm. No minimum thickness is required when O-2 grade OSB is applied over continuous backing. OSB conforming to O-1 grade, waferboard conforming to R-1 grade, and particleboard must meet the following thickness requirements: a) At least 6.35 mm thick on supports spaced not more than 400 mm apart. b) At least 9.5 mm thick on supports spaced not more than 600 mm apart. c) At least 6.35 mm thick on supports not more than 600 mm apart in walls where mid-wall height blocking is provided. OSB conforming to CSA O325 must meet specific minimum panel marks depending on the support spacing. Nails (9.29.9.3): Use casing or finishing nails that are at least 38 mm long for fastening particleboard, OSB, or waferboard. Nail spacing should not exceed 150 mm on edge supports and 300 mm on intermediate supports. If OSB or waferboard provides required bracing in braced wall panels, follow the fastening requirements for sheathing stated in Sentence 9.23.3.5.(2). Edge Support (9.29.9.4): Ensure that all edges of particleboard, OSB, or waferboard are supported by furring, blocking, or framing.
9.29.10. Wall Tile Finish **9.29.10.1. Tile Application** **9.29.10.2. Mortar Base** **9.29.10.3. Adhesives** **9.29.10.4. Moisture-Resistant Backing**	*1) Ceramic tile shall be set in a mortar base or applied with an adhesive.* *2) Plastic tile shall be applied with an adhesive.* *1) When ceramic tile is applied to a mortar base the cementitious material shall consist of one part Portland cement to not more than one-quarter part lime by volume.*	Tile Application (9.29.10.1): Ceramic tile should be set in a mortar base or applied with an adhesive. Plastic tile should be applied with an adhesive. Mortar Base (9.29.10.2): When ceramic tile is applied to a mortar base, the cementitious material should consist of one-part Portland

9.29.10.5. Joints between Tiles and Bathtub	*2) The cementitious material described in Sentence (1) shall be mixed with not less than 3 nor more than 5 parts of aggregate per part of cementitious material by volume.* *3) Mortar shall be applied over metal lath or masonry.* *4) Ceramic tile applied to a mortar base shall be thoroughly soaked and pressed into place forcing the mortar into the joints while the tile is wet.* *1) Adhesives to attach ceramic and plastic tile shall be applied to the finish coat or brown coat of plaster that has been steel-trowelled to an even surface or to gypsum board or to masonry provided the masonry has an even surface.* *1) Ceramic and plastic tile installed on walls around bathtubs or showers shall be applied over moisture-resistant backing.* *1) The joints between wall tiles and a bathtub shall be suitably caulked with material conforming to CAN/CGSB-19.22-M, "Mildew-Resistant Sealing Compound for Tubs and Tiles."*	cement to not more than one-quarter part lime by volume. The cementitious material should be mixed with 3 to 5 parts of aggregate per part of cementitious material by volume. Mortar should be applied over metal lath or masonry. Ceramic tile applied to a mortar base should be thoroughly soaked and pressed into place, ensuring that the mortar is forced into the joints while the tile is wet. Adhesives (9.29.10.3): Adhesives for ceramic and plastic tile should be applied to the finish coat or brown coat of plaster with a smooth, steel-troweled surface, or to gypsum board, or to masonry with an even surface. Moisture-Resistant Backing (9.29.10.4): Ceramic and plastic tile installed on walls around bathtubs or showers should be applied over moisture-resistant backing. Joints between Tiles and Bathtub (9.29.10.5): The joints between wall tiles and a bathtub should be caulked with a suitable material conforming to CAN/CGSB-19.22-M, which is the "Mildew-Resistant Sealing Compound for Tubs and Tiles."

Table A15: summary of CSA S304-14' requirements on masonry partition walls

Clause Number and Title	Code Specifications	Summary
16.2 unreinforced masonry **16.2.1 General**	*Except as permitted in clauses 16.2.3 and clause 16.2.4, reinforce masonry shall be used where the seismic hazard index, $I_EF_aS_a(0.2)$, is greater than or equal 0.35 for loadbearing and lateral-load-resisting masonry, and masonry enclosing elevator shafts and stairways. Unreinforced masonry may be used where the seismic hazard index, $I_EF_aS_a(0.2)$, is less than 0.35.*	Low seismic areas, such as Alberta, can have unreinforced masonry walls. In another word, in low seismic hazards area, no minimum reinforcement is required.
16.2.2 Combining unreinforced and reinforced shear walls	*Unreinforced shear walls shall not be combined with shear walls designed as reinforced shear walls in a SFRS where shear walls share the lateral load as a function of wall rigidity.*	In a SFRS (Seismic Force-Resisting System), it is not permissible to combine unreinforced shear walls with shear walls designed as reinforced shear walls, particularly when the lateral load is distributed based on wall rigidity.
4.7 Fire resistance	*Masonry structures, components, and assemblies shall satisfy the fire resistance requirements of the National Building Code of Canada*	Part 9 of NBC

4.8 Support of masonry **4.8.1 Rigidity requirements**	*A structural element designed to support masonry shall have a rigidity compatible with stiffness of the masonry. Notes: (2) For the vertical support of masonry, the following items apply: (d) Recommended limits on vertical deflection include:* *(i) span/480 or less, but not more than 20 mm, for elements supporting masonry other than masonry veneer, and other than reinforced masonry that satisfies the deflection requirement of clause 11.4.5 by acting compositely or non-compositely with the supporting element. For* ***masonry partition*** *walls and infill walls, this deflection limit may be exceeded, provided that* ***movement joints have sufficient width and are appropriately placed*** *in the wall to prevent cracking or to limit crack widths, and to prevent unintentional loading on other masonry and non-masonry elements*	Structural elements designed to support masonry must have a rigidity that matches the stiffness of the masonry. For vertical support, there are recommended limits on vertical deflection. These limits include span/480 or less (not exceeding 20 mm) for elements supporting masonry other than masonry veneer, unless reinforced masonry satisfies specific deflection requirements. However, masonry partition walls and infill walls may exceed this deflection limit if appropriate movement joints are included to prevent cracking and unintentional loading on other elements.
16.2.3 Partition Walls	*Where the seismic hazard index, $I_EF_aS_a(0.2)$, is equal to or greater than 0.35,* ***unreinforced masonry partitions may be designed*** *in accordance with clause 7 (Design of unreinforced walls & columns) provided that they* *(a) Have a mass less than or equal to 200 kg/m2;* *(b) Have a height less than or equal to 3 m and are laterally supported at the top and bottom; and* *(c) Are located where the seismic hazard index, $I_EF_aS_a(0.2)$, is less than 0.75.*	Unreinforced masonry partitions for areas with seismic hazard index greater than 0.35 and less than 0.75, can be designed if they meet the following conditions: • Mass ≤ 200 kg/m2 • Height ≤ 3 m with top and bottom lateral support • Located where seismic hazard index (IEFaSa(0.2)) < 0.75 and ≥ 0.35.
F.3.5 Partitions	*F.3.5.1 Except as provided in clause F.3.5.2, the minimum thickness of a partition shall conform to the value given in Table F.2.* *Note: Partitions likely to be subjected to internal differential wind pressure should be designed as exterior walls.* *F.3.5.2 Where lateral support of a partition is provided by walls or columns spaced at horizontal intervals not exceeding 36 times the partition thickness, the height of a partition shall not exceed 72 times its thickness.*	The minimum thickness of a partition should comply with the values specified in Table F.2, unless stated otherwise in clause F.3.5.2. Note: If a partition is expected to experience internal differential wind pressure, it should be designed as an exterior wall. If a partition receives lateral support from walls or columns spaced at intervals no greater than 36 times its thickness, the height of the partition must not exceed 72 times its thickness.
16.4.5.2Minimum reinforcement for nonloadbearing walls	*Except as permitted in clause 16.2.3, nonloadbearing walls shall be reinforced as follows:* *(a) Where the seismic hazard index, $I_EF_aS_a(0.2)$, is equal to or greater than 0.35, but less than 0.75, reinforcing steel in one or more directions shall*	

	have a minimum total reinforcement ratio of 0.05% of the gross cross-sectional area of the wall, taken perpendicular to the direction of reinforcement considered. The reinforcement may be placed in one direction, provided that it is located so as to adequately reinforce the wall against lateral loads and spans between lateral supports. *(b) Where the seismic hazard index, $I_EF_aS_a(0.2)$, is equal to or greater than 0.75, walls shall be reinforced horizontally and vertically with a minimum reinforcement ratio in each direction of 0.033% of the gross cross-sectional area of the wall taken perpendicular to the direction of the reinforcement considered. The sum of the horizontal and vertical reinforcement ratios shall be at lest 0.1%.* *(c) Note: The maximum spacing reinforcement of clause 16.5.2 apply to nonloadbearing and partition walls*	
16.5.2 Maximum spacing of vertical reinforcement	*The vertical seismic reinforcement at the maximum spacing shall be continuous and shall have a maximum spacing less than* *(a) The lesser of 12(t+10) mm or 2400 mm for seismic hazard index, $I_EF_aS_a(0.2)$, less than 0.75; or* *(b) The lesser of 6(t+10) mm or 1200 mm for seismic hazard index, $I_EF_aS_a(0.2)$, greater than or equal to 0.75.*	

Table A16: Partition wall options from Table 9.10.3.1-A of NBCC

Category	Type of Wall	Wall number	Description	Fire-Resistance Rating (min)	Typical Sound Transmission Class
Wood stud	W1				
Wood stud		W1a	W1 with: 89 mm thick absorptive material, 15.9 mm Type X gypsum board	60	36
Wood stud	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.,	W1b	W1 with: 89 mm thick absorptive material, 12.7 mm Type X gypsum board	45	34

Wood stud	with or without absorptive material	W1c	W1 with: 89 mm thick absorptive material, 12.7 mm regular gypsum board	30	32
Wood stud	1 layer of gypsum board on each side	W1d	W1 with: no absorptive material, 15.9 mm Type X gypsum board	60	32
Wood stud		W1e	W1 with: no absorptive material, 12.7 mm Type X gypsum board	45	32
Wood stud	W2				
Wood stud	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W2a	W2 with: 89 mm thick absorptive material, 15.9 mm Type X gypsum board	120	38
Wood stud	with or without absorptive material	W2b	W2 with: 89 mm thick absorptive material, 12.7 mm Type X gypsum board	90	38
Wood stud	2 layers of gypsum board on each side	W2c	W2 with: 89 mm thick absorptive material, 12.7 mm regular gypsum board	60	36
Wood stud		W2d	W2 with: no absorptive material, 15.9 mm Type X gypsum board	120	36
Wood stud		W2e	W2 with: no absorptive material, 12.7 mm Type X gypsum board	90	35
Wood stud		W2f	W2 with: no absorptive material, 12.7 mm regular gypsum board	60	34
Wood stud	W3				
Wood stud	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W3a	W3 with: studs spaced 400 mm o.c., 15.9 mm Type X gypsum board	60	45
Wood stud	89 mm thick absorptive material(6)	W3b	W3 with: studs spaced 600 mm o.c., 15.9 mm Type X gypsum board	120	48
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W3c	W3 with: studs spaced 400 mm or 600 mm o.c., 12.7 mm Type X gypsum board	45	43
Wood stud	1 layer of gypsum board on each side				
Wood stud	W4				
Wood stud	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W4a	W4 with: studs spaced 400 mm o.c., 15.9 mm Type X gypsum board	60	51

Wood stud	89 mm thick absorptive material(6)	W4b	W4 with: studs spaced 600 mm o.c., 15.9 mm Type X gypsum board	60	54
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W4c	W4 with: studs spaced 400 mm o.c., 12.7 mm Type X gypsum board	60	49
Wood stud	2 layers of gypsum board on resilient metal channel side	W4d	W4 with: studs spaced 600 mm o.c., 12.7 mm Type X gypsum board	60	53
Wood stud	1 layer of gypsum board on other side				
Wood stud	W5				
Wood stud	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W5a	W5 with: studs spaced 400 mm o.c., 15.9 mm Type X gypsum board	60	51
Wood stud	89 mm thick absorptive material	W5b	W4 with: studs spaced 600 mm o.c., 15.9 mm Type X gypsum board	60	54
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W5c	W5 with: studs spaced 400 mm o.c., 12.7 mm Type X gypsum board	60	49
Wood stud	1 layer of gypsum board on resilient metal channel side	W5d	W4 with: studs spaced 600 mm o.c., 12.7 mm Type X gypsum board	60	53
Wood stud	2 layers of gypsum board on other side				
Wood stud	W6				
Wood stud	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W6a	W6 with: studs spaced 400 mm or 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 400 mm o.c., 15.9 mm Type X gypsum board	120	55
Wood stud	with or without absorptive material	W6b	W6 with: studs spaced 400 mm or 600 mm o.c. with blocking at mid-height, 89 mm thick rock or slag fibre insulation, resilient metal channels spaced 400 mm or 600 mm o.c., 15.9 mm Type X gypsum board	120	

Wood stud	resilient metal channels on one side	W6c	W6 with: studs spaced 400 mm o.c. with blocking at mid-height, 89 mm thick dry-blown cellulose fibre insulation, resilient metal channels spaced 400 mm or 600 mm o.c., 15.9 mm Type X gypsum board	120	
Wood stud	2 layers of gypsum board on each side	W6d	W6 with: studs spaced 400 mm or 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 600 mm o.c., 15.9 mm Type X gypsum board	120	58
Wood stud		W6e	W6 with: studs spaced 400 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 400 mm o.c., 12.7 mm Type X gypsum board	90	53
Wood stud		W6f	W6 with: studs spaced 400 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 600 mm o.c., 12.7 mm Type X gypsum board	90	55
Wood stud		W6g	W6 with: studs spaced 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 400 mm o.c., 12.7 mm Type X gypsum board	90	55
Wood stud		W6h	W6 with: studs spaced 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 600 mm o.c., 12.7 mm Type X gypsum board	90	58
Wood stud		W6i	W6 with: studs spaced 400 mm or 600 mm o.c., no absorptive material, resilient metal channels spaced 400 mm or 600 mm o.c., 15.9 mm Type X gypsum board	120	47

Wood stud		W6j	W6 with: studs spaced 400 mm or 600 mm o.c., no absorptive material, resilient metal channels spaced 400 mm or 600 mm o.c., 12.7 mm Type X gypsum board	90	46
Wood stud	W7				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W7a	W7 with: 15.9 mm Type X gypsum board	60	47
Wood stud	89 mm thick absorptive material on one side or 65 mm thick on each side	W7b	W7 with: 12.7 mm Type X gypsum board	60	45
Wood stud	1 layer of gypsum board on each side	W7c	W7 with: 12.7 mm regular gypsum board	30	42
Wood stud	W8				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W8a	W8 with: 15.9 mm Type X gypsum board	90	52
Wood stud	89 mm thick absorptive material on one side or 65 mm thick on each side	W8b	W8 with: 12.7 mm Type X gypsum board	60	50
Wood stud	2 layers of gypsum board on one side				
Wood stud	1 layer of gypsum board on other side				
Wood stud	W9				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W9a	W9 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 15.9 mm Type X gypsum board	120	56
Wood stud	with or without absorptive material	W9b	W9 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 12.7 mm Type X gypsum board	90	55

Wood stud	2 layers of gypsum board on each side	W9c	W9 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 12.7 mm regular gypsum board	60	53
Wood stud		W9d	W9 with: no absorptive material, 15.9 mm Type X gypsum board	120	48
Wood stud	W10				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W10a	W10 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 15.9 mm Type X gypsum board	120	62
Wood stud	with or without absorptive material	W10b	W10 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 12.7 mm Type X gypsum board	90	60
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W10c	W10 with: no absorptive material, 15.9 mm Type X gypsum board	120	50
Wood stud	2 layers of gypsum board on each side	W10d	W10 with: no absorptive material, 12.7 mm Type X gypsum board	90	48
Wood stud	W11				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W11a	W11 with: 15.9 mm Type X gypsum board	60	56
Wood stud	89 mm thick absorptive material on one side or 65 mm thick on each side	W11b	W11 with: 12.7 mm Type X gypsum board	60	54
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.				
Wood stud	2 layers of gypsum board on resilient channel side				
Wood stud	1 layer of gypsum borad on other side				
Wood stud	W12				

Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W12a	W12 with: 15.9 mm Type X gypsum board	60	56
Wood stud	89 mm thick absorptive material on one side or 65 mm thick on each side	W12b	W12 with: 12.7 mm Type X gypsum board	60	54
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.				
Wood stud	1 layer of gypsum board on resilient metal channel side				
Wood stud	2 layers of gypsum borad on other side				
Wood stud	W13				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W13a	W13 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	60	57
Wood stud	with or without absorptive material	W13b	W13 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	45	57
Wood stud	1 layer of gypsum board on each side	W13c	W13 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	60	54
Wood stud		W13d	W13 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	45	53
Wood stud		W13e	W13 with: no absorptive material, 15.9 mm Type X gypsum board	60	45
Wood stud		W13f	W13 with: no absorptive material, 12.7 mm Type X gypsum board	45	45
Wood stud	W14				

Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W14a	W14 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	60	61
Wood stud	with or without absorptive material	W14b	W14 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	60	61
Wood stud	2 layers of gypsum board on one side	W14c	W14 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	60	57
Wood stud	a layer of gypsum board on other side	W14d	W14 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	60	57
Wood stud		W14e	W14 with: no absorptive material, 15.9 mm Type X gypsum board	60	51
Wood stud		W14f	W14 with: no absorptive material, 12.7 mm Type X gypsum board	60	51
Wood stud	W15				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W15a	W15 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	120	66
Wood stud	with or without absorptive material	W15b	W15 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	90	65
Wood stud	2 layers of gypsum board on each side	W15c	W15 with: 89 mm thick absorptive material on each side, 12.7 mm regular gypsum board	60	61
Wood stud		W15d	W15 with: 89 mm thick absorptive material on one side only, 15.9 mm Type X gypsum board	120	62
Wood stud		W15e	W15 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	90	62

Wood stud		W15f	W15 with: 89 mm thick absorptive material on one side only, 12.7 mm regular gypsum board	60	57
Wood stud		W15g	W15 with: no absorptive material, 15.9 mm Type X gypsum board	120	56
Wood stud		W15h	W15 with: no absorptive material, 12.7 mm Type X gypsum board	90	55
Wood stud		W15i	W15 with: no absorptive material, 12.7 mm regular gypsum board	60	51
Wood stud	W16				
Wood stud	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W16a	W16 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	120	66
Wood stud	resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W16b	W16 with: stud spaced 400 mm o.c. with blocking at mid-height, 89 mm thick rock or slag fibre insulation on each side, resilient metal channels on one side spaced 400 mm o.c., 15.9 mm Type X gypsum board	120	
Wood stud	with or without absorptive material	W16c	W16 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	90	65
Wood stud	2 layers of gypsum borad on each side	W16d	W16 with: 89 mm thick absorptive material on one side only, 15.9 mm Type X gypsum board	120	62
Wood stud		W16e	W16 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	90	60
Wood stud		W16f	W16 with: no absorptive material, 12.7 mm Type X gypsum board	90	55
Steel studs	S1				

Steel studs	31 mm × 64 mm steel studs spaced 400 mm or 600 mm o.c.	S1a	S1 with: studs spaced 600 mm o.c., 65 mm thick absorptive material, 15.9 mm Type X gypsum board	45	43
Steel studs	with or without absorptive material	S1b	S1 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	45	39
Steel studs	2 layers of gypsum board on each side	S1c	S1 with: studs spaced 400 mm or 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	45	35
Steel studs	S2				
Steel studs	31 mm × 64 mm steel studs spaced 400 mm or 600 mm o.c.	S2a	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	60	50
Steel studs	with or without absorptive material	S2b	S2 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	60	44
Steel studs	1 layer of gypsum board on one side	S2c	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	60	50
Steel studs	2 layers of gypsum board on other side	S2d	S2 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	60	42
Steel studs		S2e	S2 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	60	41
Steel studs		S2f	S2 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	60	37
Steel studs		S2g	S2 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	60	40
Steel studs		S2h	S2 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	60	35

Steel studs	S3				
Steel studs	31 mm × 64 mm steel studs spaced 400 mm or 600 mm o.c.	S3a	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	120	54
Steel studs	with or without absorptive material	S3b	S3 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	120	51
Steel studs	2 layers of gypsum board on each side	S3c	S3 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	90	53
Steel studs		S3d	S3 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	90	47
Steel studs		S3e	S3 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm regular gypsum board	60	49
Steel studs		S3f	S3 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 12.7 mm regular gypsum board	60	41
Steel studs		S3g	S3 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	120	45
Steel studs		S3h	S3 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	120	42
Steel studs		S3i	S3 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	90	44
Steel studs		S3j	S3 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	90	39
Steel studs		S3k	S3 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	60	40

Steel studs		S3l	S3 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	60	37
Steel studs	S4				
Steel studs	31 mm × 92 mm steel studs spaced 400 mm or 600 mm o.c.	S4a	S4 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	45	48
Steel studs	with or without absorptive material	S4b	S4 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	45	47
Steel studs	1 layer of gypsum board on each side	S4c	S4 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	45	38
Steel studs		S4d	S4 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	45	38
Steel studs	S5				
Steel studs	31 mm × 92 mm steel studs spaced 400 mm or 600 mm o.c.	S5a	S5 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	60	53
Steel studs	with or without absorptive material	S5b	S5 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	60	52
Steel studs	1 layer of gypsum board on one side	S5c	S5 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	60	51
Steel studs	2 layers of gypsum board on other side	S5d	S5 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	60	50
Steel studs		S5e	S5 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	60	43

Steel studs		S5f	S5 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	60	42
Steel studs		S5g	S5 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	60	41
Steel studs		S5h	S5 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	60	40
Steel studs	S6				
Steel studs	31 mm × 92 mm steel studs spaced 400 mm or 600 mm o.c.	S6a	S6 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	120	56
Steel studs	with or without absorptive material	S6b	S6 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	120	55
Steel studs	2 layers of gypsum board on each side	S6c	S6 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	90	55
Steel studs		S6d	S6 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	90	54
Steel studs		S6e	S6 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 12.7 mm regular gypsum board	60	50
Steel studs		S6f	S6 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 12.7 mm regular gypsum board	60	48
Steel studs		S6g	S6 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	120	47
Steel studs		S6h	S6 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	120	45

Steel studs		S6i	S6 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	90	45
Steel studs		S6j	S6 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	90	44
Steel studs		S6k	S6 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	60	41
Steel studs		S6l	S6 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	60	39
Steel studs	S7				
Steel studs	31 mm × 152 mm steel studs spaced 400 mm or 600 mm o.c.	S7a	S7 with:150 mm thick absorptive material, 15.9 mm Type X gypsum board	45	51
Steel studs	with or without absorptive material	S7b	S7 with: no absorptive material, 15.9 mm Type X gypsum board	45	41
Steel studs	1 layer of gypsum board on each side				
Steel studs	S8				
Steel studs	31 mm × 152 mm steel studs spaced 400 mm or 600 mm o.c.	S8a	S8 with:150 mm thick absorptive material, 15.9 mm Type X gypsum board	60	55
Steel studs	with or without absorptive material	S8b	S8 with:150 mm thick absorptive material, 12.7 mm Type X gypsum board	60	54
Steel studs	1 layer of gypsum board on one side	S8c	S8 with:no absorptive material, 15.9 mm Type X gypsum board	60	45
Steel studs	2 layers of gypsum board on other side	S8d	S8 with:no absorptive material, 12.7 mm Type X gypsum board	60	44
Steel studs	S9				
Steel studs	31 mm × 152 mm steel studs spaced 400 mm or 600 mm o.c.	S9a	S9 with:150 mm thick absorptive material, 15.9 mm Type X gypsum board	120	59

Steel studs	with or without absorptive material	S9b	S9 with:150 mm thick absorptive material, 12.7 mm Type X gypsum board	90	57
Steel studs	2 layers of gypsum board on each side	S9c	S9 with:150 mm thick absorptive material, 12.7 mm regular gypsum board	60	53
Steel studs		S9d	S9 with:no absorptive material, 15.9 mm Type X gypsum board	120	49
Steel studs		S9e	S9 with:no absorptive material, 12.7 mm Type X gypsum board	90	47
Steel studs		S9f	S9 with:no absorptive material, 12.7 mm regular gypsum board	60	43
Hollow Concrete Block	B1				
Hollow Concrete Block	140 mm or 190 mm concrete block				
Hollow Concrete Block		B1a	140 mm bare concrete block	60	48
Hollow Concrete Block		B1b	190 mm bare concrete block	90	50
Hollow Concrete Block	B2				
Hollow Concrete Block	140 mm or 190 mm concrete block	B2a	B2 with 140 mm concrete block, 12.7 mm gypsum-sand plaster	120	50
Hollow Concrete Block	no absorptive material	B2b	B2 with 140 mm concrete block, 12.7 mm Type X gypsum board or 15.9 mm Type X gypsum board	120	47
Hollow Concrete Block	1-layer gypsum-sand plaster or gypsum board on each side	B2c	B2 with 140 mm concrete block, 12.7 mm regular gypsum board	90	46
Hollow Concrete Block		B2d	B2 with 190 mm concrete block, 12.7 mm gypsum-sand plaster	150	51
Hollow Concrete Block		B2e	B2 with 190 mm concrete block, 15.9 mm Type X gypsum board	180	50
Hollow Concrete Block		B2f	B2 with 190 mm concrete block, 12.7 mm Type X gypsum board	150	49

Hollow Concrete Block		B2g	B2 with 190 mm concrete block, 12.7 mm regular gypsum board	120	48
Hollow Concrete Block	B3				
Hollow Concrete Block	140 mm or 190 mm concrete block	B3a	B3 with 140 mm concrete block, 12.7 mm or 15.9 mm Type X gypsum Board	120	51
Hollow Concrete Block	resilient metal channels on one side spaced at 400 mm or 600 mm o.c.	B3b	B3 with 140 mm concrete block, 12.7 mm regular gypsum board	90	48
Hollow Concrete Block	absorptive material filling resilient metal channel space	B3c	B3 with 190 mm concrete block, 15.9 mm Type X gypsum board	180	54
Hollow Concrete Block	1-layer gypsum board on each side	B3d	B3 with 190 mm concrete block, 12.7 mm Type X gypsum board	150	53
Hollow Concrete Block		B3e	B3 with 190 mm concrete block, 12.7 mm regular gypsum board	120	51
Hollow Concrete Block	B4				
Hollow Concrete Block	140 mm or 190 mm concrete block	B4a	B4 with 140 mm concrete block, 12.7 mm Type X gypsum Board	120	47
Hollow Concrete Block	resilient metal channels on each side spaced at 400 mm or 600 mm o.c.	B4b	B4 with 140 mm concrete block, 12.7 mm regular gypsum board	90	42
Hollow Concrete Block	with or without absorptive material	B4c	B4 with 190 mm concrete block, 15.9 mm Type X gypsum board	180	50
Hollow Concrete Block	1 layer gypsum board on each side	B4d	B4 with 190 mm concrete block, 12.7 mm Type X gypsum board	150	49
Hollow Concrete Block		B4e	B4 with 190 mm concrete block, 12.7 mm regular gypsum board	120	45
Hollow Concrete Block	B5				
Hollow Concrete Block	190 mm concrete block	B5a	B5 with 15.9 mm Type X gypsum Board	180	54
Hollow Concrete Block	38 mm × 38 mm horizontal or vertical wood strapping on one side spaced at 600 mm o.c.	B5b	B5 with 12.7 mm Type X gypsum board	150	53

Hollow Concrete Block	with or without absorptive material	B5c	B5 with 12.7 mm regular gypsum board	120	51
Hollow Concrete Block	1 layer gypsum board on each side				
Hollow Concrete Block	B6				
Hollow Concrete Block	140 mm or 190 mm concrete block	B6a	B6 with 140 mm concrete block, 12.7 mm or 15.9 mm Type X gypsum board	120	57
Hollow Concrete Block	38 mm × 38 mm horizontal or vertical wood strapping on each side spaced at 600 mm o.c.	B6b	B6 with 140 mm concrete block, 12.7 mm regular gypsum board	90	56
Hollow Concrete Block	absorptive material filling strapping space on each side	B6c	B6 with 190 mm concrete block, 15.9 mm Type X gypsum board	180	60
Hollow Concrete Block	1 layer gypsum board on each side	B6d	B6 with 190 mm concrete block, 12.7 mm Type X gypsum board	150	59
Hollow Concrete Block		B6e	B6 with 190 mm concrete block, 12.7 mm regular gypsum board	120	57
Hollow Concrete Block	B7				
Hollow Concrete Block	190 mm concrete block	B7a	B7 with 15.9 mm Type X gypsum board	180	71
Hollow Concrete Block	65 mm steel studs each side spaced at 600 mm o.c.	B7b	B7 with 12.7 mm Type X gypsum board	150	70
Hollow Concrete Block	absorptive material filling stud space on each side	B7c	B7 with 12.7 mm regular gypsum board	120	69
Hollow Concrete Block	1 layer gypsum board on each side				
Hollow Concrete Block	B8				
Hollow Concrete Block	190 mm concrete block	B8a	B8 with 15.9 mm Type X gypsum board	180	71
Hollow Concrete Block	38 mm × 64 mm wood studs on each side spaced at 600 mm o.c.	B8b	B8 with 12.7 mm Type X gypsum board	150	70
Hollow Concrete Block	absorptive material filling stud space on each side(6)	B8c	B8 with 12.7 mm regular gypsum board	120	69
Hollow Concrete Block	1 layer gypsum board on each side				

Hollow Concrete Block	B9				
Hollow Concrete Block	190 mm concrete block	B9a	B9 with 15.9 mm Type X gypsum board	180	65
Hollow Concrete Block	50 mm metal Z-bars on each side spaced at 600 mm o.c. (or 38 mm × 38 mm horizontal or vertical wood strapping plus resilient metal channels)	B9b	B9 with 12.7 mm Type X gypsum board	150	64
Hollow Concrete Block	absorptive material filling Z-bar space on each side	B9c	B9 with 12.7 mm regular gypsum board	120	63
Hollow Concrete Block	1-layer gypsum board on each side				
Hollow Concrete Block	B10				
Hollow Concrete Block	190 mm concrete block	B10a	B9 with 15.9 mm Type X gypsum board	180	56
Hollow Concrete Block	resilient metal channels on one side spaced at 600 mm o.c.	B10b	B10 with 12.7 mm Type X gypsum board	150	55
Hollow Concrete Block	absorptive material filling resilient metal channel space	B10c	B10 with 12.7 mm regular gypsum board	120	54
Hollow Concrete Block	2 layers gypsum board on one side only				
Hollow Concrete Block		B11	90 mm concrete block	48	43
Hollow Concrete Block		B12	240 mm concrete block	144	51
Hollow Concrete Block		B13	290 mm concrete block	192	53

Table A17: Partition wall database developed for the DSS model

Category	Type of Wall	Wall number	Description	Thickness (mm)	Weight (Kg)	FRR (min)	STC	Cost (CAD/ m²)
Wood stud	W1							
		W1a	W1 with: 89 mm thick absorptive material, 15.9 mm Type X gypsum board	298.8	33.45	60	36	56
	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.,	W1b	W1 with: 89 mm thick absorptive material, 12.7 mm Type X gypsum board	292.4	29.05	45	34	59
	with or without absorptive material	W1c	W1 with: 89 mm thick absorptive material, 12.7 mm regular gypsum board	292.4	29.05	30	32	47
	1 layer of gypsum board on each side	W1d	W1 with: no absorptive material, 15.9 mm Type X gypsum board	120.8	27.85	60	32	45
		W1e	W1 with: no absorptive material, 12.7 mm Type X gypsum board	114.4	23.45	45	32	42
	W2							
	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W2a	W2 with: 89 mm thick absorptive material, 15.9 mm Type X gypsum board	330.6	57.45	120	38	83
	with or without absorptive material	W2b	W2 with: 89 mm thick absorptive material, 12.7 mm Type X gypsum board	317.8	48.65	90	38	84
	2 layers of gypsum board on each side	W2c	W2 with: 89 mm thick absorptive material, 12.7 mm regular gypsum board	317.8	48.65	60	36	67
		W2d	W2 with: no absorptive material, 15.9 mm Type X gypsum board	152.6	51.85	120	36	67
		W2e	W2 with: no absorptive material, 12.7 mm Type X gypsum board	139.8	43.05	90	35	74
		W2f	W2 with: no absorptive material, 12.7 mm regular gypsum board	139.8	43.05	60	34	59
	W3							
	38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W3a	W3 with: studs spaced 400 mm o.c., 15.9 mm Type X gypsum board	328.8	39.84	60	45	60

89 mm thick absorptive material(6)	W3b	W3 with: studs spaced 600 mm o.c., 15.9 mm Type X gypsum board	328.8	38.5464	120	48	54
resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W3c	W3 with: studs spaced 400 mm or 600 mm o.c., 12.7 mm Type X gypsum board	322.4	35.44	45	43	62
1 layer of gypsum board on each side							
W4							
38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W4a	W4 with: studs spaced 400 mm o.c., 15.9 mm Type X gypsum board	344.7	51.84	60	51	75
89 mm thick absorptive material(6)	W4b	W4 with: studs spaced 600 mm o.c., 15.9 mm Type X gypsum board	344.7	50.5464	60	54	75
resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W4c	W4 with: studs spaced 400 mm o.c., 12.7 mm Type X gypsum board	335.1	45.24	60	49	60
2 layers of gypsum board on resilient metal channel side	W4d	W4 with: studs spaced 600 mm o.c., 12.7 mm Type X gypsum board	335.1	43.9464	60	53	60
1 layer of gypsum board on other side							
W5							
38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W5a	W5 with: studs spaced 400 mm o.c., 15.9 mm Type X gypsum board	344.7	51.84	60	51	75
89 mm thick absorptive material	W5b	W4 with: studs spaced 600 mm o.c., 15.9 mm Type X gypsum board	344.7	50.5464	60	54	75
resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W5c	W5 with: studs spaced 400 mm o.c., 12.7 mm Type X gypsum board	335.1	45.24	60	49	60
1 layer of gypsum board on resilient metal channel side	W5d	W4 with: studs spaced 600 mm o.c., 12.7 mm Type X gypsum board	335.1	43.9464	60	53	60
2 layers of gypsum board on other side							
W6							
38 mm × 89 mm studs spaced 400 mm or 600 mm o.c.	W6a	W6 with: studs spaced 400 mm or 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 400 mm o.c., 15.9 mm Type X gypsum board	360.6	63.84	120	55	87

	with or without absorptive material	W6b	W6 with: studs spaced 400 mm or 600 mm o.c. with blocking at mid-height, 89 mm thick rock or slag fibre insulation, resilient metal channels spaced 400 mm or 600 mm o.c., 15.9 mm Type X gypsum board	360.6	63.84	120		87
	resilient metal channels on one side	W6c	W6 with: studs spaced 400 mm o.c. with blocking at mid-height, 89 mm thick dry-blown cellulose fibre insulation, resilient metal channels spaced 400 mm or 600 mm o.c., 15.9 mm Type X gypsum board	360.6	63.84	120		71
	2 layers of gypsum board on each side	W6d	W6 with: studs spaced 400 mm or 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 600 mm o.c., 15.9 mm Type X gypsum board	360.6	63.84	120	58	70
		W6e	W6 with: studs spaced 400 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 400 mm o.c., 12.7 mm Type X gypsum board	347.8	55.04	90	53	78
		W6f	W6 with: studs spaced 400 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 600 mm o.c., 12.7 mm Type X gypsum board	347.8	55.04	90	55	63
		W6g	W6 with: studs spaced 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 400 mm o.c., 12.7 mm Type X gypsum board	347.8	55.04	90	55	71
		W6h	W6 with: studs spaced 600 mm o.c., 89 mm thick absorptive material, resilient metal channels spaced 600 mm o.c., 12.7 mm Type X gypsum board	347.8	53.7464	90	58	70

	W6i	W6 with: studs spaced 400 mm or 600 mm o.c., no absorptive material, resilient metal channels spaced 400 mm or 600 mm o.c., 15.9 mm Type X gypsum board	182.6	58.24	120	47	78
	W6j	W6 with: studs spaced 400 mm or 600 mm o.c., no absorptive material, resilient metal channels spaced 400 mm or 600 mm o.c., 12.7 mm Type X gypsum board	169.8	49.44	90	46	63
W7							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W7a	W7 with: 15.9 mm Type X gypsum board	254.3	34.5	60	47	65
89 mm thick absorptive material on one side or 65 mm thick on each side	W7b	W7 with: 12.7 mm Type X gypsum board	247.9	30.1	60	45	62
1 layer of gypsum board on each side	W7c	W7 with: 12.7 mm regular gypsum board	247.9	30.1	30	42	56
W8							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W8a	W8 with: 15.9 mm Type X gypsum board	270.2	46.5	90	52	71
89 mm thick absorptive material on one side or 65 mm thick on each side	W8b	W8 with: 12.7 mm Type X gypsum board	260.6	39.9	60	50	68
2 layers of gypsum board on one side							
1 layer of gypsum board on other side							
W9							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W9a	W9 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 15.9 mm Type X gypsum board	286.1	58.5	120	56	78

with or without absorptive material	W9b	W9 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 12.7 mm Type X gypsum board	273.3	49.7	90	55	75
2 layers of gypsum board on each side	W9c	W9 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 12.7 mm regular gypsum board	273.3	49.7	60	53	67
	W9d	W9 with: no absorptive material, 15.9 mm Type X gypsum board	197.1	55.7	120	48	70
W10							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W10a	W10 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 15.9 mm Type X gypsum board	316	65	120	62	82
with or without absorptive material	W10b	W10 with: 89 mm thick absorptive material on one side or 65 mm thick on each side, 12.7 mm Type X gypsum board	303.3	56.09	90	60	78
resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W10c	W10 with: no absorptive material, 15.9 mm Type X gypsum board	227.1	62.09	120	50	71
2 layers of gypsum board on each side	W10d	W10 with: no absorptive material, 12.7 mm Type X gypsum board	214.3	53.29	90	48	74
W11							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W11a	W11 with: 15.9 mm Type X gypsum board	300.2	52.89	60	56	78
89 mm thick absorptive material on one side or 65 mm thick on each side	W11b	W11 with: 12.7 mm Type X gypsum board	290.6	46.29	60	54	74
resilient metal channels on one side spaced 400 mm or 600 mm o.c.							
2 layers of gypsum board on resilient channel side							
1 layer of gypsum borad on other side							

W12							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. staggered on common 38 mm X 140 mm plate	W12a	W12 with: 15.9 mm Type X gypsum board	300.2	52.89	60	56	78
89 mm thick absorptive material on one side or 65 mm thick on each side	W12b	W12 with: 12.7 mm Type X gypsum board	290.6	46.29	60	54	74
resilient metal channels on one side spaced 400 mm or 600 mm o.c.							
1 layer of gypsum board on resilient metal channel side							
2 layers of gypsum borad on other side							
W13							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W13a	W13 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	412.8	37.3	60	57	68
with or without absorptive material	W13b	W13 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	406.4	32.9	45	57	65
1 layer of gypsum board on each side	W13c	W13 with: 89 mm thick absorptive material on one side only, 15.9 mm Type X gypsum board	323.8	34.5	60	54	54
	W13d	W13 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	317.4	30.1	45	53	52
	W13e	W13 with: no absorptive material, 15.9 mm Type X gypsum board	234.8	31.7	60	45	49
	W13f	W13 with: no absorptive material, 12.7 mm Type X gypsum board	228.4	27.3	45	45	47
W14							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W14a	W14 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	428.7	49.3	60	61	68

with or without absorptive material	W14b	W14 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	419.1	42.7	60	61	68
2 layers of gypsum board on one side	W14c	W14 with: 89 mm thick absorptive material on one side, 15.9 mm Type X gypsum board	339.7	46.5	60	57	65
a layer of gypsum board on other side	W14d	W14 with: 89 mm thick absorptive material on one side, 12.7 mm Type X gypsum board	330.1	39.9	60	57	64
	W14e	W14 with: no absorptive material, 15.9 mm Type X gypsum board	250.7	43.7	60	51	63
	W14f	W14 with: no absorptive material, 12.7 mm Type X gypsum board	241.1	37.1	60	51	62
W15							
two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W15a	W15 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	445	61	120	66	83
with or without absorptive material	W15b	W15 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	431.8	52.5	90	65	75
2 layers of gypsum board on each side	W15c	W15 with: 89 mm thick absorptive material on each side, 12.7 mm regular gypsum board	431.8	52.5	60	61	73
	W15d	W15 with: 89 mm thick absorptive material on one side only, 15.9 mm Type X gypsum board	356	59	120	62	81
	W15e	W15 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	342.8	49.7	90	62	72
	W15f	W15 with: 89 mm thick absorptive material on one side only, 12.7 mm regular gypsum board	342.8	49.7	60	57	70
	W15g	W15 with: no absorptive material, 15.9 mm Type X gypsum board	266.6	55.7	120	56	79

		W15h	W15 with: no absorptive material, 12.7 mm Type X gypsum board	253.8	46.9	90	55	77
		W15i	W15 with: no absorptive material, 12.7 mm regular gypsum board	253.8	46.9	60	51	76
	W16							
	two rows 38 mm × 89 mm studs each spaced 400 mm or 600 mm o.c. on separate 38 mm X 89 mm plates set 25 mm apart	W16a	W16 with: 89 mm thick absorptive material on each side, 15.9 mm Type X gypsum board	475	68	120	66	78
	resilient metal channels on one side spaced 400 mm or 600 mm o.c.	W16b	W16 with: stud spaced 400 mm o.c. with blocking at mid-height, 89 mm thick rock or slag fibre insulation on each side, resilient metal channels on one side spaced 400 mm o.c., 15.9 mm Type X gypsum board	474.6	67.69	120		75
	with or without absorptive material	W16c	W16 with: 89 mm thick absorptive material on each side, 12.7 mm Type X gypsum board	461.8	58.89	90	65	63
	2 layers of gypsum borad on each side	W16d	W16 with: 89 mm thick absorptive material on one side only, 15.9 mm Type X gypsum board	386	65	120	62	61
		W16e	W16 with: 89 mm thick absorptive material on one side only, 12.7 mm Type X gypsum board	372.8	56.09	90	60	57
		W16f	W16 with: no absorptive material, 12.7 mm Type X gypsum board	283.8	53.29	90	55	55
Steel stud	S1							
	31 mm × 64 mm steel studs spaced 400 mm or 600 mm o.c.	S1a	S1 with: studs spaced 600 mm o.c., 65 mm thick absorptive material, 15.9 mm Type X gypsum board	225.8	29.1175	45	43	56
	with or without absorptive material	S1b	S1 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	225.8	29.6425	45	39	58

2 layers of gypsum board on each side	S1c	S1 with: studs spaced 400 mm or 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	95.8	25.5625	45	35	54
S2							
31 mm × 64 mm steel studs spaced 400 mm or 600 mm o.c.	S2a	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	241.7	41.1175	60	50	62
with or without absorptive material	S2b	S2 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	241.7	41.6425	60	44	64
1 layer of gypsum board on one side	S2c	S2 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	232.1	34.5175	60	50	60
2 layers of gypsum board on other side	S2d	S2 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	232.1	35.0425	60	42	59
	S2e	S2 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	111.7	37.0375	60	41	57
	S2f	S2 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	111.7	37.5625	60	37	61
	S2g	S2 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	102.1	30.4375	60	40	56
	S2h	S2 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	102.1	30.9625	60	35	58
S3							
31 mm × 64 mm steel studs spaced 400 mm or 600 mm o.c.	S3a	S3 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	257.6	53.1175	120	54	68
with or without absorptive material	S3b	S3 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 15.9 mm Type X gypsum board	257.6	53.6425	120	51	71

2 layers of gypsum board on each side	S3c	S3 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	244.8	44.3175	90	53	66
	S3d	S3 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 12.7 mm Type X gypsum board	244.8	44.8425	90	47	65
	S3e	S3 with: studs spaced 600 mm o.c.,65 mm thick absorptive material, 12.7 mm regular gypsum board	244.8	44.3175	60	49	62
	S3f	S3 with: studs spaced 400 mm o.c.,65 mm thick absorptive material, 12.7 mm regular gypsum board	244.8	44.8425	60	41	67
	S3g	S3 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	127.6	49.0375	120	45	61
	S3h	S3 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	127.6	49.5625	120	42	63
	S3i	S3 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	114.8	40.2375	90	44	66
	S3j	S3 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	114.8	40.7625	90	39	67
	S3k	S3 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	114.8	40.2375	60	40	63
	S3l	S3 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	114.8	40.7625	60	37	65
S4							
31 mm × 92 mm steel studs spaced 400 mm or 600 mm o.c.	S4a	S4 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	301.8	30.762	45	48	62

with or without absorptive material	S4b	S4 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	301.8	31.35	45	47	64
1 layer of gypsum board on each side	S4c	S4 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	123.8	25.162	45	38	60
	S4d	S4 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	123.8	25.75	45	38	57
S5							
31 mm × 92 mm steel studs spaced 400 mm or 600 mm o.c.	S5a	S5 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	317.7	42.762	60	53	68
with or without absorptive material	S5b	S5 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	317.7	43.35	60	52	71
1 layer of gypsum board on one side	S5c	S5 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	308.1	36.162	60	51	66
2 layers of gypsum board on other side	S5d	S5 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	308.1	36.75	60	50	65
	S5e	S5 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	139.7	37.162	60	43	62
	S5f	S5 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	139.7	37.75	60	42	67
	S5g	S5 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	130.1	30.562	60	41	61
	S5h	S5 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	130.1	31.15	60	40	63
S6							

31 mm × 92 mm steel studs spaced 400 mm or 600 mm o.c.	S6a	S6 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	333.6	54.762	120	56	75
with or without absorptive material	S6b	S6 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 15.9 mm Type X gypsum board	333.6	55.35	120	55	78
2 layers of gypsum board on each side	S6c	S6 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	320.8	45.962	90	55	72
	S6d	S6 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 12.7 mm Type X gypsum board	320.8	46.55	90	54	71
	S6e	S6 with: studs spaced 600 mm o.c.,89 mm thick absorptive material, 12.7 mm regular gypsum board	320.8	45.962	60	50	68
	S6f	S6 with: studs spaced 400 mm o.c.,89 mm thick absorptive material, 12.7 mm regular gypsum board	320.8	46.55	60	48	74
	S6g	S6 with: studs spaced 600 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	155.6	49.162	120	47	68
	S6h	S6 with: studs spaced 400 mm o.c.,no absorptive material, 15.9 mm Type X gypsum board	155.6	49.75	120	45	70
	S6i	S6 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	142.8	40.362	90	45	72
	S6j	S6 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm Type X gypsum board	142.8	40.95	90	44	74
	S6k	S6 with: studs spaced 600 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	142.8	40.362	60	41	69

		S6l	S6 with: studs spaced 400 mm o.c.,no absorptive material, 12.7 mm regular gypsum board	142.8	40.95	60	39	71
	S7							
	31 mm × 152 mm steel studs spaced 400 mm or 600 mm o.c.	S7a	S7 with:150 mm thick absorptive material, 15.9 mm Type X gypsum board	483.8	35.675	45	51	68
	with or without absorptive material	S7b	S7 with: no absorptive material, 15.9 mm Type X gypsum board	183.8	26.075	45	41	71
	1 layer of gypsum board on each side							
	S8							
	31 mm × 152 mm steel studs spaced 400 mm or 600 mm o.c.	S8a	S8 with:150 mm thick absorptive material, 15.9 mm Type X gypsum board	499.7	47.675	60	55	78
	with or without absorptive material	S8b	S8 with:150 mm thick absorptive material, 12.7 mm Type X gypsum board	490.1	41.075	60	54	67
	1 layer of gypsum board on one side	S8c	S8 with:no absorptive material, 15.9 mm Type X gypsum board	199.7	38.075	60	45	76
	2 layers of gypsum board on other side	S8d	S8 with:no absorptive material, 12.7 mm Type X gypsum board	190.1	31.475	60	44	65
	S9							
	31 mm × 152 mm steel studs spaced 400 mm or 600 mm o.c.	S9a	S9 with:150 mm thick absorptive material, 15.9 mm Type X gypsum board	515.6	59.675	120	59	82
	with or without absorptive material	S9b	S9 with:150 mm thick absorptive material, 12.7 mm Type X gypsum board	502.8	50.875	90	57	85
	2 layers of gypsum board on each side	S9c	S9 with:150 mm thick absorptive material, 12.7 mm regular gypsum board	502.8	50.875	60	53	79
		S9d	S9 with:no absorptive material, 15.9 mm Type X gypsum board	215.6	50.075	120	49	78
		S9e	S9 with:no absorptive material, 12.7 mm Type X gypsum board	202.8	41.275	90	47	75
		S9f	S9 with:no absorptive material, 12.7 mm regular gypsum board	202.8	41.275	60	43	82

Hollow concrete block	B1							
	140 mm or 190 mm concrete block							
		B1a	140 mm bare concrete block	150	170	60	48	97
		B1b	190 mm bare concrete block	200	223	90	50	105
	B2							
	140 mm or 190 mm concrete block	B2a	B2 with 140 mm concrete block, 12.7 mm gypsum-sand plaster	175.4	189.6	120	50	136
	no absorptive material	B2b	B2 with 140 mm concrete block, 12.7 mm Type X gypsum board or 15.9 mm Type X gypsum board	181.8	194	120	47	137
	1-layer gypsum-sand plaster or gypsum board on each side	B2c	B2 with 140 mm concrete block, 12.7 mm regular gypsum board	175.4	189.6	90	46	135
		B2d	B2 with 190 mm concrete block, 12.7 mm gypsum-sand plaster	225.4	242.6	150	51	144
		B2e	B2 with 190 mm concrete block, 15.9 mm Type X gypsum board	231.8	247	180	50	154
		B2f	B2 with 190 mm concrete block, 12.7 mm Type X gypsum board	225.4	242.6	150	49	145
		B2g	B2 with 190 mm concrete block, 12.7 mm regular gypsum board	225.4	242.6	120	48	143
	B3							
	140 mm or 190 mm concrete block	B3a	B3 with 140 mm concrete block, 12.7 mm or 15.9 mm Type X gypsum Board	211.8	200.39	120	51	140
	resilient metal channels on one side spaced at 400 mm or 600 mm o.c.	B3b	B3 with 140 mm concrete block, 12.7 mm regular gypsum board	205.4	195.99	90	48	141
	absorptive material filling resilient metal channel space	B3c	B3 with 190 mm concrete block, 15.9 mm Type X gypsum board	261.8	253.39	180	54	139
	1-layer gypsum board on each side	B3d	B3 with 190 mm concrete block, 12.7 mm Type X gypsum board	255.4	248.99	150	53	148

	B3e	B3 with 190 mm concrete block, 12.7 mm regular gypsum board	255.4	248.99	120	51	157
B4							
140 mm or 190 mm concrete block	B4a	B4 with 140 mm concrete block, 12.7 mm Type X gypsum Board or 15.9 Type X	241.8	206.78	120	47	144
resilient metal channels on each side spaced at 400 mm or 600 mm o.c.	B4b	B4 with 140 mm concrete block, 12.7 mm regular gypsum board	235.4	202.38	90	42	144
with or without absorptive material	B4c	B4 with 190 mm concrete block, 15.9 mm Type X gypsum board	291.8	259.78	180	50	142
1 layer gypsum board on each side	B4d	B4 with 190 mm concrete block, 12.7 mm Type X gypsum board	285.4	255.38	150	49	152
	B4e	B4 with 190 mm concrete block, 12.7 mm regular gypsum board	285.4	255.38	120	45	161
B5							
190 mm concrete block	B5a	B5 with 15.9 mm Type X gypsum Board	269.8	249.075	180	54	146
38 mm × 38 mm horizontal or vertical wood strapping on one side spaced at 600 mm o.c.	B5b	B5 with 12.7 mm Type X gypsum board	263.4	244.675	150	53	147
with or without absorptive material	B5c	B5 with 12.7 mm regular gypsum board	263.4	244.675	120	51	145
1 layer gypsum board on each side							
B6							
140 mm or 190 mm concrete block	B6a	B6 with 140 mm concrete block, 12.7 mm or 15.9 mm Type X gypsum board	257.8	198.15	120	57	161
38 mm × 38 mm horizontal or vertical wood strapping on each side spaced at 600 mm o.c.	B6b	B6 with 140 mm concrete block, 12.7 mm regular gypsum board	251.4	193.75	90	56	162
absorptive material filling strapping space on each side	B6c	B6 with 190 mm concrete block, 15.9 mm Type X gypsum board	308	251	180	60	167

1 layer gypsum board on each side	B6d	B6 with 190 mm concrete block, 12.7 mm Type X gypsum board	301.4	246.75	150	59	168
	B6e	B6 with 190 mm concrete block, 12.7 mm regular gypsum board	301.4	246.75	120	57	166
B7							
190 mm concrete block	B7a	B7 with 15.9 mm Type X gypsum board	362	249	180	71	185
65 mm steel studs each side spaced at 600 mm o.c.	B7b	B7 with 12.7 mm Type X gypsum board	355	245	150	70	180
absorptive material filling stud space on each side	B7c	B7 with 12.7 mm regular gypsum board	355	245	120	69	175
1 layer gypsum board on each side							
B8							
190 mm concrete block	B8a	B8 with 15.9 mm Type X gypsum board	360	252	180	71	198
38 mm × 64 mm wood studs on each side spaced at 600 mm o.c.	B8b	B8 with 12.7 mm Type X gypsum board	353	247	150	70	175
absorptive material filling stud space on each side(6)	B8c	B8 with 12.7 mm regular gypsum board	353	247	120	69	172
1 layer gypsum board on each side							
B9							
190 mm concrete block	B9a	B9 with 15.9 mm Type X gypsum board	368	264	180	65	176
50 mm metal Z-bars on each side spaced at 600 mm o.c. (or 38 mm × 38 mm horizontal or vertical wood strapping plus resilient metal channels)	B9b	B9 with 12.7 mm Type X gypsum board	361	260	150	64	177
absorptive material filling Z-bar space on each side	B9c	B9 with 12.7 mm regular gypsum board	361	260	120	63	182
1-layer gypsum board on each side							

	B10							
	190 mm concrete block	B10a	B9 with 15.9 mm Type X gypsum board	261.8	253.39	180	56	161
	resilient metal channels on one side spaced at 600 mm o.c.	B10b	B10 with 12.7 mm Type X gypsum board	255.4	248.99	150	55	162
	absorptive material filling resilient metal channel space	B10c	B10 with 12.7 mm regular gypsum board	255.4	248.99	120	54	167
	2 layers gypsum board on one side only							
		B11	90 mm concrete block	100	138	48	43	86
		B12	240 mm concrete block	250	267	144	51	122
		B13	290 mm concrete block	300	310	192	53	142

Table A18- Specified flexural tensile strength from CSA S304-14

Table 5
Specified flexural tensile strength, f_t
(See Clauses 2.3.2, 5.2.1, 5.2.2, 7.12.3.1, 10.14.2, 11.3.4.3, 11.4.3.2, and 15.4.)

	Normal to bed joints (vertical span), MPa		Parallel to bed joints* (horizontal span), MPa	
	Mortar type		Mortar type	
Unit type	S	N	S	N
Clay brick, solid	0.65	0.50	1.3	1.0
Clay brick, hollow	0.30	0.20	0.55	0.35
Concrete brick and block	0.40	0.30	0.80	0.55
Calcium silicate brick	0.30	0.25	0.55	0.45
Grouted hollow block and brick	0.65	0.50	0.85	0.55

**These values apply only to masonry constructed of fifty percent running bond.*

Notes:

(1) *The stresses in this table do not apply to free-standing cantilever walls (no support at the top or sides). In such cases the strength shall be limited to 0.1 MPa.*

(2) *The stresses listed in the table will not be achieved for all types and combinations of masonry unit and mortar. For example, reductions of strength can occur with masonry units having very low or high initial rates of water absorption, masonry units with water-repellant additives or coatings, or mortars with excessive amounts of entrained air (> 15%).*

(3) *For partially grouted hollow units, a weighted value of flexural tensile strength may be used to account for the fraction of the wall section along the length or height that is grouted.*

(4) *For grouted semi-solid units, the values for "Concrete brick and block" shall be used.*

Table A19: Compressive Strength of Concrete blocks from CSA S304-14

Table 4
Specified compressive strength normal to the bed joint, f'_m, for concrete block masonry, MPa
(See Clauses 5.1.3.3, 5.1.3.5.2, and D.6.1.)

	Type S mortar		Type N mortar	
Specified compressive strength of unit (average net area)*, MPa	Ungrouted hollow units	Solid† units or grouted hollow units	Ungrouted hollow units	Solid† units or grouted hollow units
30 or more**	17.5	13.5	12	9
20	13	10	10	7.5
15	10	7.5	8	6
10	6.5	5	6	4.5

*Linear interpolation may be used
** For concrete block units with a specified compressive strength greater than 30 MPa, Clause 5.1.2 may be used to determine an f'_m that could exceed the values given in this table.
†For semi-solid concrete block units, the effective cross-sectional area shall be used in combination with the f'_m values for solid units.

Notes:
(1) *Requirements for concrete block masonry units are included in CSA A165.1 and A165.3.*
(2) *Grouted concrete block masonry walls may use the specified strength for hollow concrete block masonry, provided that the effective cross-sectional area is based on the mortar bedded area (The mortar bedded area is normally greater than the minimum faceshell area and can be found in industry literature.). Because grouting cannot reduce section capacity, the grout area may be ignored, in which case the compressive strength value for ungrouted masonry may be used (see Clause 5.1.3.5.2, Note (2)).*
(3) *For partially grouted walls, a weighted value of f'_m may be used to account for the percent of the wall length that is grout filled. Alternatively, the grouted and ungrouted parts of the wall may be treated separately, provided that compatibility of deformations is included.*
(4) *The compressive strength of grout depends on its consistency when poured, on the size of the void it fills, and on the absorptive capacity of the masonry unit it contacts. A fluid grout is required for placement, and excess water is required to ensure a sufficient amount is present to "replace" that lost through absorption and to ensure complete hydration. These requirements generally necessitate a high-slump grout, in the order of 200 to 275 mm, with a high water-to-cement ratio. The designer, when testing the compressive strength of grout prepared in accordance with the proportion specifications and cast in non-absorbent cylinder moulds, should expect average 28 d minimum strengths around 10 to 12 MPa. Such grout strength levels are accepted by this Standard and lead to satisfactory structural performance.*

Table A20: Allowable slenderness ratio and thickness for masonry walls from CSA S304-14

Table F.2
Allowable slenderness ratio and minimum thickness of masonry walls
(See Clauses F.2.1.3.1, F.3.2.1, F.3.3.1, F.3.5.1, F.4.2.5, and F.5.2.)

Type of masonry	Allowable slenderness ratio of unsupported height or length to masonry thickness*	Minimum thickness masonry, mm
Loadbearing walls:		
Cavity wall†‡	20	90 (per wythe)
Solid masonry of hollow or solid units	20	190
Solid masonry of rubble stone	14	290
Nonloadbearing walls:		
Exterior cavity walls†‡	20	90 (per wythe)
Exterior solid masonry of solid units	20	140
Exterior solid masonry of hollow units grouted fully solid	20	140
Exterior solid masonry of hollow units	20	190
Partitions	36	75

Values for exterior walls shall be reduced according to Clause F.8.2.
†See Clause F.2.1.2 for effective thickness of cavity walls.
‡Except for Clause F.5.4.

Table A21

Table 3.1.2.1.
Major Occupancy Classification
Forming Part of Sentences 3.1.2.1.(1) and 3.1.2.2.(1)

Group	Division	Description of *Major Occupancies*
A	1	*Assembly occupancies* intended for the production and viewing of the performing arts
A	2	*Assembly occupancies* not elsewhere classified in Group A
A	3	*Assembly occupancies* of the arena type
A	4	*Assembly occupancies* in which occupants are gathered in the open air
B	1	*Detention occupancies*
B	2	*Treatment occupancies*
B	3	*Care occupancies*
C	—	*Residential occupancies*
D	—	*Business and personal services occupancies*
E	—	*Mercantile occupancies*
F	1	*High-hazard industrial occupancies*
F	2	*Medium-hazard industrial occupancies*
F	3	*Low-hazard industrial occupancies*

Table A22

Table 2.2.1.4.
Major Occupancy Fire Separations(1)
Forming Part of Sentences 2.2.1.4.(1) and (3)

Major Occupancy	Minimum *Fire-Resistance Rating* of *Fire Separation*, h			
	Adjoining *Major Occupancy*			
	G-1	G-2	G-3	G-4
A-1	(2)	(3)	(3)	(2)
A-2	(2)	1	1	(2)
A-3	(2)	(3)	(3)	(2)
A-4	(2)	1	1	(2)
B	(2)	(3)	(3)	(2)
C	(2)	1	1	(2)
D	1	–	–	–
E	1	–	–	–
F-1	–	2	2	–

Table A23

Table 3.1.3.1.
Major Occupancy Fire Separations[1]
Forming Part of Sentence 3.1.3.1.(1)

Major Occupancy	Minimum *Fire-Resistance Rating* of *Fire Separation*, h												
	Adjoining *Major Occupancy*												
	A-1	A-2	A-3	A-4	B-1	B-2	B-3	C	D	E	F-1	F-2	F-3
A-1	—	1	1	1	2	2	2	1	1	2	(2)	2	1
A-2	1	—	1	1	2	2	2	1(3)	1(4)	2	(2)	2	1
A-3	1	1	—	1	2	2	2	1	1	2	(2)	2	1
A-4	1	1	1	—	2	2	2	1	1	2	(2)	2	1
B-1	2	2	2	2	—	2	2	2	2	2	(2)	2	2
B-2	2	2	2	2	2	—	1	2	2	2	(2)	2	2
B-3	2	2	2	2	2	1	—	1	2	2	(2)	2	2
C	1	1(3)	1	1	2	2	1	—	1	2(5)	(2)	2(6)	1(7)
D	1	1(4)	1	1	2	2	2	1	—	—(8)	3	—(8)	—(8)
E	2	2	2	2	2	2	2	2(5)	—(8)	—	3	—	—
F-1	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	3	3	—	2	2
F-2	2	2	2	2	2	2	2	2(6)	—(8)	—	2	—	—
F-3	1	1	1	1	2	2	2	1(7)	—(8)	—	2	—	—