THESIS

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Master Course

DESIGN OF A MULTI-HINGED GATE-OPENING MECHANISM

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INSTITUTE OF TECHNOLOGY MECHANICAL ENGINEERING (MSC)
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THESIS

worksheet for

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(MSc) student

Entitled:

Design of a Multi-Hinged Gate-Opening Mechanism

Task description:

Designing a bi-folding gate mechanism specifically for a 4-meter-long gate consisting of panels joined properly and operating under a motor. Designing in the sophisticated Autodesk Inventor Program and Simulating the mechanism in Adams-view student edition software. Analyzing the results from the simulation and representing the parameters using Python programming language plots.

Department: Mechanical Engineering

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Approved **Received**

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As an independent consultant of the author of this thesis, I hereby declare that the student took part in the planned consultations.

Gödöllő, 03 May 2023.

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1 Introduction

Understanding the relationship between the geometry and motions of the pieces of a machine or mechanism requires the use of the theory of machines and mechanisms. and the forces which produce these motions. Designing, solving, or even understanding a modern machine is often a very complex and hard task. There are multiple different branches of mechanical science but in this topic, there are two main aspects of the study of mechanical systems, design, and analysis. Design is the process of prescribing the sizes, shapes, material compositions, and arrangements of the parts so that the resulting machine will perform the prescribed task [9]. On the other hand, the largest collection of scientific methods at the designer's disposal is analysis.

Above all, the analysis branch which deals with motions, time, and forces is called mechanics and is made up of two main parts, statics, and dynamics. Statics deals with the analysis of stationary systems, furthermore, the branch that concerns movement is called dynamics. Obviously, there are more brunches, so that can be seen in Figure 1 where is summarized different types of systems, or disciplines.

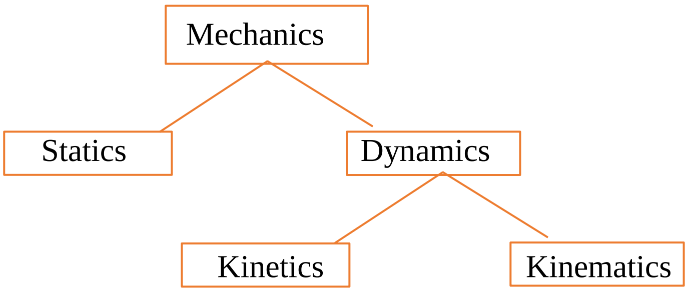

Figure 1 Disciplines in mechanics [9]

In truth, all of the processes have the aim to get the proper result for building some construction or having some results from the proper simulation. The history of construction is as old as the history of humanity. The evolution of construction, from mud huts and massive stone blocks to mega roadways and cathedrals, is a reflection of humanity's already mastery of technology and resources. The history of construction is complicated and extensive.

Obviously, there are countless definitions, categories, and chapters that describe the meaning of various constructions. The majority of constructions are made up of several parts, and each of them has unique properties or characteristics.

The goal of this thesis is to focus on gate construction because it is a crucial component of practically every mechanical system. The doors help in protecting, regulate, and facilitate quick access to a variety of properties.

The significance of protecting the safety and security of people and property cannot be overstated in today's rapidly, modern society. The number of burglary, theft and vandalism incidents has increased almost daily, and every two minutes, we learn about damage or loss brought on by security errors. These factors make it essential that security measures be implemented, both to monitor and safeguard assets and to help reduce the likelihood of such threats.

Physical security is one of many categories into which security measures can be divided. The huge role of physical security plays the gates, and that's why they are a significant component.

There are several different types of mechanical or automatic doors that are available today on the market, and all of them have different purposes, and each of these gates has distinctive qualities that influence its use.

There are five gate designs that are commonly used in modern security gate usage:

- Swinging Gates
- Sliding Gates
- Vertical Lift Gates
- Vertical Pivot Gates
- Bi-Folding Gates

Swinging Gate – The most commonly used type of gate, especially as gates for residential properties, the reason is that these gates are very easy to install and operate. One end of the gate usually can extend to 90 degrees or 180 degrees fully open, and that depends on how it is installed. It is strongly advised that property owners improve by installing gate access control systems and automating swing gates. Instead of sliding a door out of the way horizontally, automatic swinging doors move a door along a hinge [15][16].Depending on the direction of traffic, these doors for businesses can open either inside or outward (Figure 2).

Figure 2 Swinging Gate [17]

Sliding Gate - A motorized track and frequently two sets of sliding panel doors make up sliding automatic doors. The appearance of a gate is one thing that people consider when choosing their security gate. The modern design of sliding gates adds value and appeal to a property, which is why many businesses and homes choose them. Slide gates provide superior security measures in addition to their visual appeal. They also allow smoother operation and with less trouble compared to the traditional swing gates. These panels will silently move out of the way when someone steps on the sensor plate. They are frequently the most well-liked because of their slick design and unhindered entry, which is perfect for managing entering and outgoing customers at the same time. They can maximize door space and handle heavier traffic because their panels move out of the way (Figure 3).[17]

Figure 3 Sliding Gate [18]

Vertical Lift Gate – The vertical lift gate can be opened by moving up, as opposed to sliding to the side or swinging outward. When there is not enough room for a swing gate installation or a moving slide gate, vertical lift gates are ideal. Often, commercial or industrial spaces use these gates also the gate is appropriate for major traffic areas like airports, ports, transportation hubs, and docks as well as high-security settings like jails and detention centers.[20] (Figure 4).

Figure 4 Vertical Lift Gate [20]

Vertical Pivot Gate – The gate opens by pivoting 90 degrees at the bottom corner, allowing entry. The industrial environment is where this design works best. Although, not very popular, Vertical Pivot Gates provide a number of unique features and security advantages (Figure 5).

Figure 5 Vertical Pivot Gate [21]

Folding Gate - The folding model of automatic door swings and slides into a small folded position as another option. When there is little room surrounding the opening, folding doors are the best option because they demand less interior construction ceiling space. The folding doors are made to require less maintenance. Lifting hinges raise the door off the ground as the doors slide open, reducing wear. They have additional advantages when compared to overhead sectional doors. Additionally, there are smaller elements that might be damaged on folding doors. They are also more flexible and manual operation is easier. Both outward and inward opening options are available for the doors. Also, because of their weight, overhead sectional doors are sometimes fitted with plastic windows, which can be twisted and reflect light in such a way that it is impossible to see through them from a distance. Over time, the plastic may also turn darker. Although they frequently have glass panes, folding doors offer superior insulation and visibility (Figure 6).

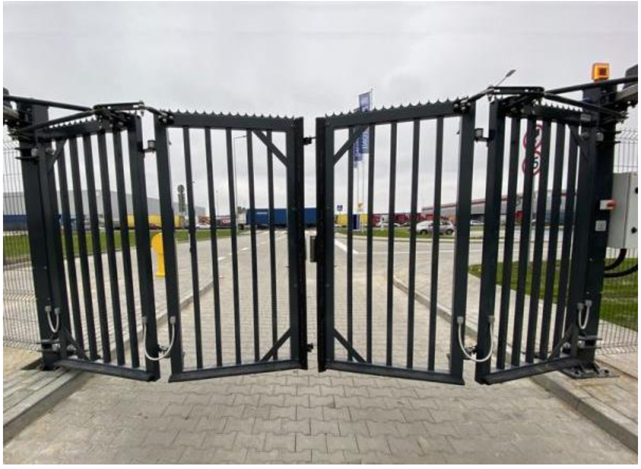

Figure 6 Folding Gate [21][21]

The objective of this project is to evaluate the solution for a given gate, with given dimensions. A multi hinged mechanism should be designed and a proper simulation model performed. The aim is to design a gate construction that is a space-saving solution for opening.

There are the project goals:

- ✓ Explaining what is designing as a process, why practically every engineering discipline places a high value on that field, and what are the designing most important phases;
- ✓ Describing the advantages of the Bi-Folding gate, understanding what is the aim of the folding gate and how it is working;
- ✓ Illustrating the various varieties of bi-folding gates, depending on what type of material or dimensions the gate is;
- ✓ Representing the parts and elements that are consisting of one Bi-Folding gate, showing how they look like, as well as their connection;
- ✓ Investigating the manufacturers of various types of gates,
- ✓ A brief explanation of the installation and maintenance procedures for the gates.
- ✓ A list of application areas where the gates can be used;
- ✓ According to the given dimensions for the physical gate finding the available solution on the market;
- ✓ Calculations for the gate,following the applicable standards and regulations;
- ✓ Desribing the method of data collection process;
- ✓ Representing the Gate dimensions, material properties and calculations for necessary parameters;
- ✓ Create a CAD model that illustrates the functionality of the drive system concept and provides a calculation model of the chosen drive system;
- ✓ Representation of a Bi-Folding gate Simulation.
- ✓ Analyzing the results parameters and their values from the Simulation
- ✓ Representing the results in the plots.

2 Literature Review

2.1 Designing process

Theoretically, the process from idea to finished product is very long. This process always contains more aspects like time, labor and money. In this long process the designing stage has very important role, it is a tool that is converting the requirements into functional ideas and plans. It's possible that design makes a message easier to understand so that individuals can communicate more effectively. While science can provide us with data and statistics, design can be utilized to explain complex concepts to non-scientists. Also, the design information should be collected from many different sources, and the main process has six phases, which can be shown in Figure 7. However, these phases are overlapping constantly [12].

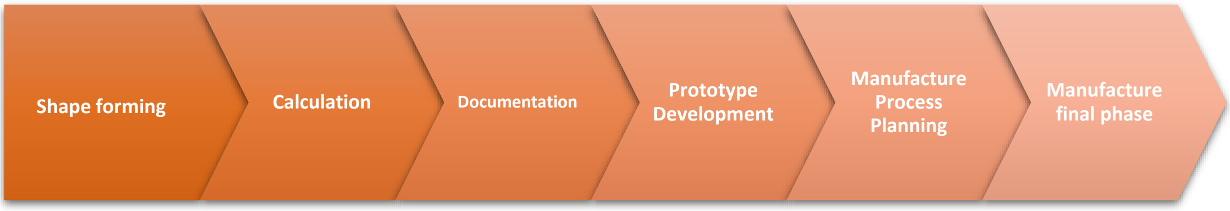

Figure 7 Design phases [12]

Shape forming – The first step is very important because there is the need of identifying the problem and adding the necessary information for further problem-solving steps. In order to define the shape there are some questions that should be answered:

What problem should be fixed?

Who has this problem?

Can everyone benefit equally from the solution?

What specifications apply to this project?

What financial and other restrictions are there on each other?

What is the long-term purpose?

Calculation – Once the problem is identified, the following phase begins. Any engineering discipline will associate word calculation with formulas and equations that should produce a specific number or range of digits. This phase depends on the product, obviously, different products or constructions require different calculations, but mechanical engineering calculations primarily focus on forces, moments, motions, loads, fatigue, tension, and other such factors.

Documentation – A collection of documents and resources called design documentation covers every part of your product design. Users, product features, project deadlines, all crucial implementation information, and design choices that have been approved by participants should all be included in the documentation.

Prototype Development – Without hurrying the process, spending the little time prototyping the idea is also an important step. While doing the prototype that does not mean that the product is bringing to the market. It should not require a full branding package or all the bells and conveniences. It is allowed to be used not expensive components and reusable pieces for the physical object. That rely on rough prototypes like storyboards or imperfectly finished products where the process is manually completed.

Manufacture Process Planning - A component of product lifecycle management, manufacturing process planning enables engineers to author, simulate, and manage manufacturing information while working together to match manufacturing plans with product design. Planning for the manufacturing process involves operation sequencing, planning for the machining process, planning for the assembly process, planning for the assembly line, and communicating plans across the organization and extended enterprise.

Manufacture final phase - As the designing process nears its conclusion, all previous processes have been completed, resulting in the information, calculations, and drawings needed to begin manufacturing and complete the product.[10]

Design is a process that begins with an explicit statement of the design's goals and ends with the observation of behavior to verify that the design is valid and achieves its goals. Moreover, using sophisticated software is a sizeable percentage of the designing process. Currently, it is practically impossible to get started and complete any product design without using any program. [22]

Computer-aided design (CAD) and computer-aided engineering (CAE) software can be used to build and analyze more complicated mechanical components and system designs. Computer-aided design (CAD) is the use of computer-based software to aid in design modeling, design analysis, design review, and design documentation [4]. The majority of CAD programs allow the creation of 3D views, which helps them to identify potential issues and optimize the design before it is manufactured. Making ensuring that everyone is on the same page and improving teamwork can both benefit from this. CAD software allows multiple engineers to work on the same design simultaneously, and to share and communicate their ideas and designs with others easily. This can help to improve collaboration and ensure that everyone is on the same page. CAD software allows engineers to create detailed documentation and record-keeping of the design process, including all modifications and iterations. This can help to ensure that the design meets all required standards and regulations, and can be used as a reference in the future.[4]

A general computer-based method called finite element analysis assesses the consequences of disturbances one at a time (mechanical stress, vibration, temperature, etc.). Direct communication between FEA applications and CAD software [7]. With CAD software, engineers may produce accurate, precise, and detailed designs that are simple to operate and modify. This guarantees that the design complies with the necessary requirements and standards.

There are an unlimited number of advantages of CAD/CAE software, but in Figure 8 are listed just a few of them:

Figure 8 Benefits of CAD softwares

Overall, CAD software is an essential tool for engineering design, as it allows engineers to create accurate, efficient, and detailed designs, and to optimize and improve the design before it is manufactured. Engineering professionals can use CAD software to see and simulate their ideas in three dimensions, which helps them spot possible problems.[7]

2.2 Categorization of Bi-folding Gates

2.2.1 Types of Bi-folding gates

Bifold gates, commonly referred to as folding gates, fold in half to provide a little storage space. Here are listed the most common different types of bi-folding gates:

- Bi-folding swing gate: This type of bifold gate is made up of two gate panels that swing open in a bifold manner, like a pair of saloon doors. They can be manually operated or automatically.
- Bi-folding sliding gate: This type of bifold gate consists of two gate panels that slide open and closed, much like a sliding glass door. These gates are usually automated and are a popular choice for driveways with limited space.
- Bi-folding speed gate: This type of bifold gate is designed for high-speed operation, with the two gate panels folding open and closing quickly. They are commonly used in areas with heavy traffic flow, such as parking garages or toll booths.
  Bi-folding cantilever gate: This type of bifold gate operates without a track or bottom rail, making it ideal for areas with uneven ground. In commercial and industrial environments, it is often applied.[23]

The specific type of bifold gate that can be chosen depends on the needs and the space available for installation. In this thesis, the gate will be used for a living house. The sliding bi-fold gate is probably the most popular type of bi-folding gate for homes. This style of gate normally comprises two or more hinged panels that fold up against one another when the gate is opened. It is made to glide open and closed horizontally down a track. Due to the fact that they don't need as much space as a conventional swinging gate would in order to swing open, sliding bi-fold gates are well known for their space-saving design. They can also be automated for more security and comfort. Other types of bi-fold gates, such as accordion-style or concertina-style gates, are less common for residential use. [25]

2.2.2 Bi-folding gate categorized by the material

By the kind of material bi-folding gates can be grouped:

- Aluminum Bi-Folding Gates: These gates are lightweight, durable, and corrosion-resistant. They are also easy to maintain and come in a variety of styles and finishes.
- Steel Bi-Folding Gates: Steel gates are strong, durable, and provide excellent security. They can also be customized with various design elements, such as ornamental features.

- Wood Bi-Folding Gates: These gates are aesthetically pleasing and offer a classic look. However, they require more maintenance than metal gates and are not as durable.
- Glass Bi-Folding Gates: These gates are modern and elegant, providing a sleek look to the property. They are ideal for areas that require high visibility, such as commercial properties.
- PVC Bi-Folding Gates: These gates are lightweight, durable, and low-maintenance. They are a cost-effective option for those on a budget, but they may not be as sturdy as metal gates.
- Composite Bi-Folding Gates: These gates are made from a combination of materials, such as wood, plastic, and metal. They offer the benefits of each material, such as durability, low maintenance, and aesthetic appeal.

These are just some of the common types of bi-folding gates categorized by material. Each material has its own benefits and drawbacks, so it's important to choose the good one. The choice of material will depend on factors such as budget, maintenance requirements, durability, aesthetics, and the intended use of the gate. In this case, the material that is chosen is Steel.[26][25]

2.2.3 Size and Configuration

The size of bi-folding gates can vary depending on several factors, such as the intended use, the space available, and the materials used to construct the gate. Of course, there must be some proper range, minimum and maximum, that can be seen in Table 1.
The number of panels depends on the width of the gate and the desired panel size. Bi-folding gates typically have an even number of concertina-folding panels that open and close the gate. Two panels may be suitable for smaller gate openings, but four or more panels may be necessary for bigger gates. Normally, the panels are of the same size, but they can also be of varying sizes to match particular design requirements. [26]

Table 1 Sizes for Bi-folding gates [26][22]

General minimum and maximum dimensions for bi-fold door panels		
Max height	60-70 inch	1.5-1.8 m
Min height	120-145 inch	3-3.7 m
Max width	16 inches (odd number of doors) 28 inches (even number of doors)	0.4(odd number of doors) 0.8(even number of doors)
Min width	420–780 inches	10-20 m

2.3 Elements

The elements of a sliding bi-folding gate typically include a lot of particulars:

- Gate panels: These are the individual sections that make up the gate and are connected by hinges.
- Hinges: These are the mechanisms that connect the gate panels together and allow them to fold.
- Track system: A track system is used to guide the gate panels along a specific path when opening and closing.
- Wheels: The wheels are attached to the bottom of the gate panels and run along the track system, enabling smooth and easy movement.
- Locking mechanism: A locking mechanism is used to secure the gate panels in place when closed.
- Control system: A control system is used to operate the gate, typically via a remote control, keypad, or other types of the access control system.
- Motor: A motor is often used to power the gate, providing the force necessary to open and close it.

In addition to these elements, a sliding bi-folding gate may also include:

- Telescopic system: A telescopic system allows the gate panels to slide and fold in a compact manner, minimizing the space required for the gate to operate.
- Top guide rollers: Top guide rollers help to keep the gate panels aligned and moving smoothly along the track system.[26]

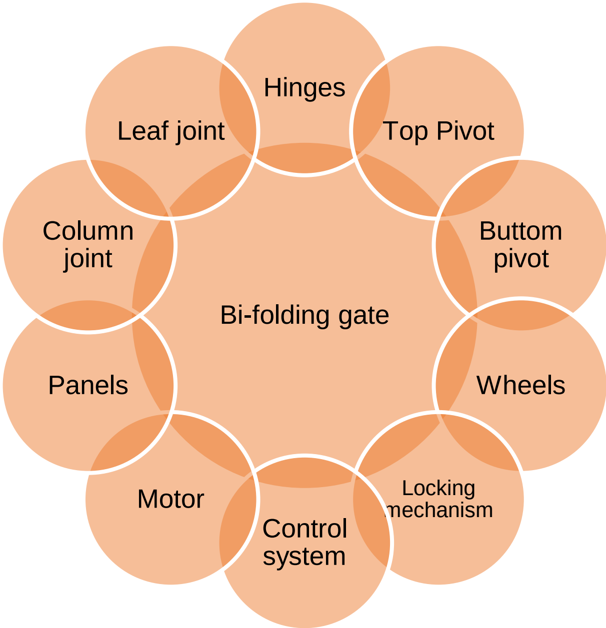

Figure 9 Elements of Bi-folding gate[26]

2.3.1 Panels

In a bi-folding gate mechanism, panels refer to the individual sections or leaves of the gate that fold and unfold to open and close the gate. Bi-folding gates are typically made up of two or more panels (Figure 10) that are hinged together, with the panels folding inwards or outwards as the gate is opened or closed.

Depending on the size and style of the gate, the mechanism for a bi-folding gate may have different numbers of panels. A smaller gate, for instance, might only have two panels, whereas a larger gate might have four or more. To fit the opening, the panels may be either of two sizes: equal or different.

The functionality and operation of a bi-folding gate mechanism are strongly influenced by the panels. These are the discrete parts of the gate that fold and unfold to let people or vehicles pass.[26]

Figure 10 Panels for Bi-folding gate [26]

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2.3.2 Hinges

The door panels are supported by hinges, which also enable them to pivot and fold as necessary. These are a few examples of the various types of hinges frequently used for sliding bi-folding doors: thigh hinges, hinges with ball bearings hinge pivots. In general, the selection of a sliding bi-folding door hinge will rely on a number of variables, such as the weight and size of the door panels, the door's style, and the particular application. In Figure 11 one basic hinge can be seen.

Figure 11 Hinge for bi-folding door [28]

2.3.3 Column joint

In a building or other construction, a column joint is a structural component that connects two or more panels or beams. It is designed to transfer the load from one column to another or from a column to a beam in order to sustain and balance the structure.
Column joints can be classified based on their type of connection, such as welded connections, bolted connections, or pinned connections. The type of connection used depends on various factors, including the load capacity, the type of structure, and the design requirements.
Column joints are essential to the structure's overall safety and stability. For the building to be strong and long-lasting, the column joints must be designed, made, and installed correctly. A well-designed and properly installed column joint can withstand the forces and stresses that are placed on it, and ensure that the building or structure remains stable and secure. The example of column joint is represented in Figure 12.[29]

Figure 12 Column joint for bi-folding gate [29]

2.3.4 Leaf joint

A leaf joint is a type of joint used in the construction of bi-folding gates. It is typically used where two gate panels meet and allows them to pivot open and closed together, while still maintaining structural stability.

The leaf joint is made to provide for smooth movement as the panels are opened and closed as well as support and strength for the gate. Usually constructed from a hard material like steel or aluminum, it is made to withstand the weight and pressure of the gate panels.

The leaf joint serves to ensure that the gate panels stay in alignment as they are opened and closed in addition to offering support. Misaligned panels can make the gate difficult to operate and can also detract from its overall appearance, thus this is crucial for both esthetic and functional reasons. Overall, a bi-folding gate's leaf joint which is in Figure 13 is an essential part that affects both the function and aesthetic of the gate.[30]

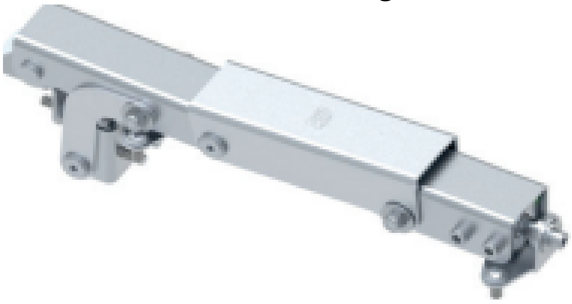

Figure 13 Leaf joint for Bi-Folding Gate [30]

2.3.5 Top pivot

A bi-folding gate's top pivot (Figure 14) is a piece of hardware used to support and pivot the gate's upper section as it opens and closes. Normally, the top pivot is placed at the top of the gate, either on the header above the gate or on the vertical support. A bi-folding gate's top pivot is a piece of hardware used to support and pivot the gate's upper section as it opens and closes. Normally, the top pivot is placed at the top of the gate, either on the header above the gate or on the vertical support. Overall a bi-folding gate's top pivot is essential to its functionality and durability, thus it's important to choose a top pivot of superior quality that can withstand the weight and stress of the gate over time.

Figure 14 Top pivot (supporter) for Bi-folding gate [31]

2.3.6 Button pivot

Bi-folding gates and doors typically use a form of hardware called a button pivot (Figure 15). The gate can be folded in half for convenient storage or opening when this device is fitted normally at the pivot point where two folding parts of the gate meet.

When the gate is opened or closed, the button pivot acts as a hinge, allowing the gate to smoothly revolve around its pivot point. It is made to be strong and endure the pressure of the gate's weight and movement.

In addition to serving as a hinge, the button pivot also aids in maintaining the alignment and stability of the gate parts when they are closed. This aids in avoiding any gaps or misalignments that can compromise the gate's stability or security.

Figure 15 Button pivot(supporter) for Bi-Folding Gate [31]

2.4 Calculations for Bi-Folding Gate

Before starting the design for the Bi-folding gate there are a lot of aspects that should be researched, concluded, and understood. As it is mentioned earlier, one folding gate has several panels. The number of panels depends on the space that should be covered. These panels are connected by durable and tight hinges with a rack and pinion mechanism. The rack and pinions are the elements that are allowing the synchronous opening and closing gate mechanism. When there isn't enough room for a gate to fold to both sides or just one, a solution that uses just two leaves on each side can be put. These leaves fold back out of the way in one direction to provide the greatest amount of vehicular entry required.
The bi-fold design overcomes the issue while only taking up half the space when the driveway has an upward inclination that a typical swing gate would bottom out on. Lifting or rising hinges may be required to assist in lifting the gate, depending on the slope. In Figure 16 and Figure 17 can be seen how the gate is moving from a closed to an open position.

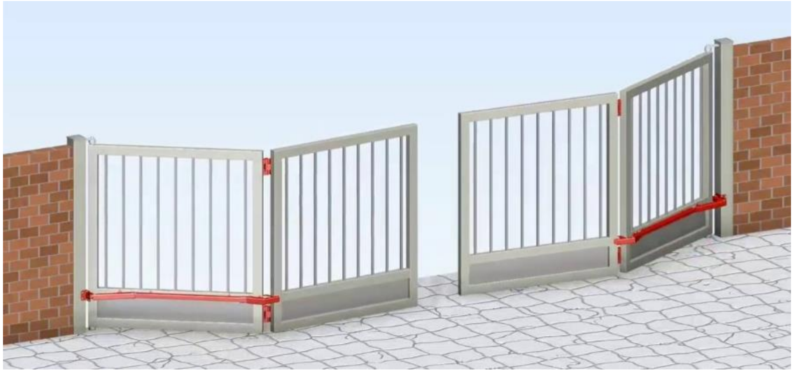

Figure 16 Bi-folding gate moving from the closed position [27]

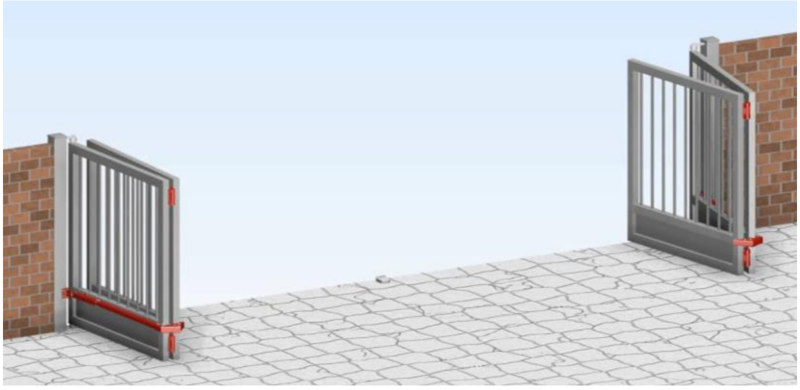

Figure 17 Bi-folding gate open position [26]

In the figures, the gate is represented by four panels, in which two endings are connected to the wall on each side. In order to explain the movement of this construction the panels can be substituted with links. Considering the fact that two halves of the gate are precisely equal, the calculation can be done just for one half of the gate, because the same calculation will be valuable for the other one. Fortunately, although all real machine parts are flexible to some degree, machines are usually designed from relatively rigid materials, keeping part deflections to a minimum. [2][9] The word link acts as a machine part or a component of a mechanism. Therefore, the links or the mechanisms are connected by joints or pairs. In such a way links connected with joints are creating a kinematic chain. The connections are needed in order to transmit the motion from the driver, or input, to the driven, follower, or output. In Figure 18 in AutoCAD is represented the bi-folding gate in three positions: starting, middle and final one.

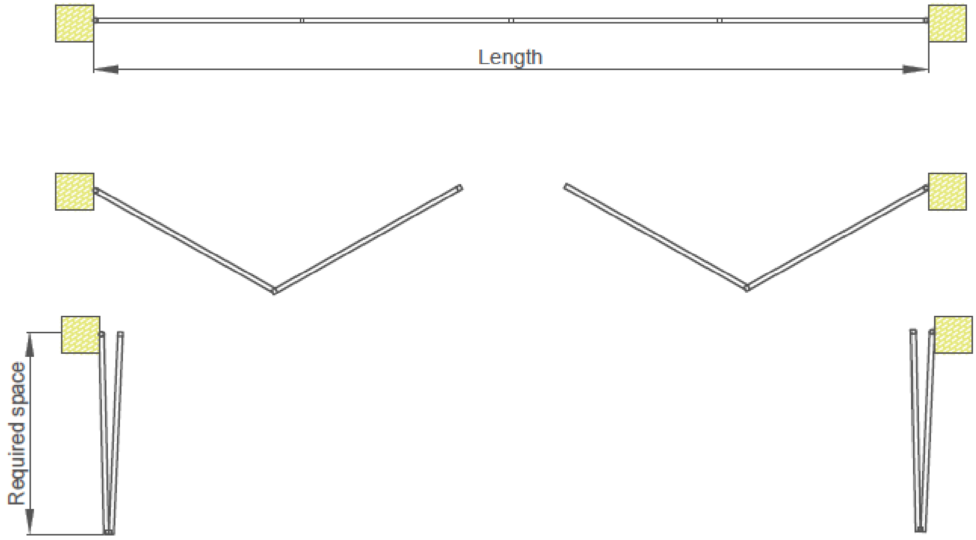

Figure 18 Bi-folding gate (AutoCAD)

In order to get the proper calculation for the motor power that is required for movement, the panels are represented to beams and the hinges to joints as in Figure 19.

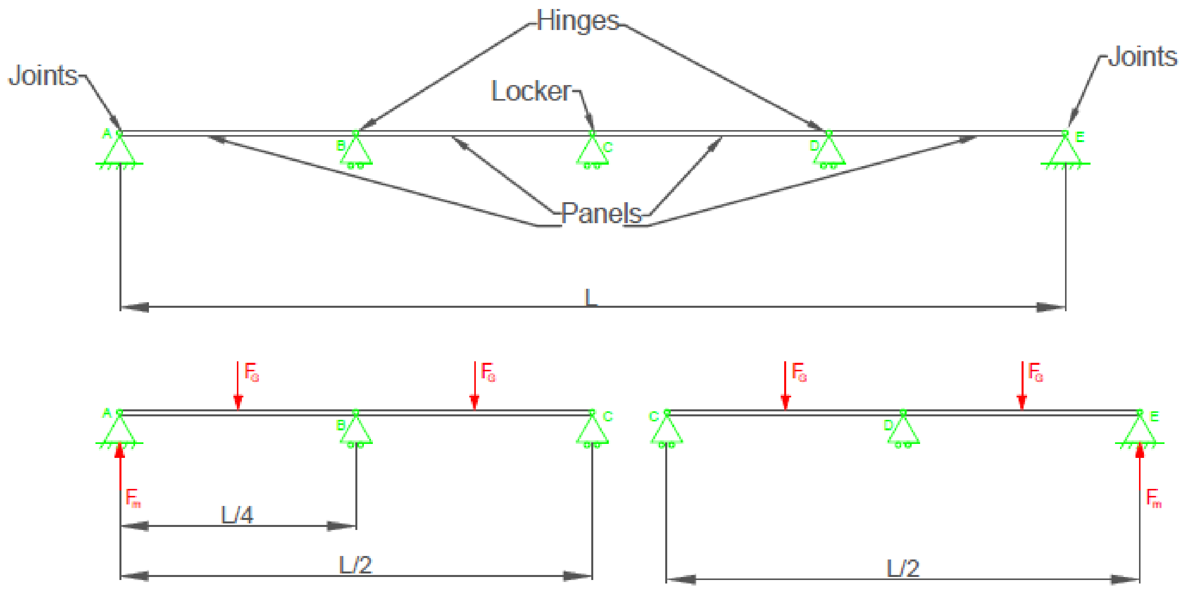

Figure 19 Static Diagram of a Bi-folding Gate (AutoCAD)

2.4.1 Weight calculation

A gate experiences many forces when it is being opened or closed. The weight of the gate and the force provided by the motor moving it are the two primarily forces acting on it. That can be also seen in Figure 19 on the bottom part, on the static diagram. Each panel has some force of a mass (**F_G**), so obviously that means if there are four panels there will be four forces of mass.

When it comes to calculating the mass of a bi-folding gate, which is necessary to calculate the weight, there are several factors that need to be considered such as the dimensions of the gate, the material it is made of, and of course there are some additional features such as decorative elements or automation systems.

To calculate the mass of the gate, the first step is to determine the total surface area of the gate. This can be done by measuring the height and width of each section of the gate and multiplying these dimensions together. Once the surface area for each section is calculated, they can be added together to get the total surface area of the gate.

Total surface area of the gate:

$$A = (H_1 * W_1) + (H_2 * W_2)\ [m^2] \qquad (1)$$

Where:

H_1 [m] - the height of the first section of the gate;

W_1 [m] - width of the first section of the gate;

H_2 [m] - the height of the second section of the gate;

W_2 [m] - width of the second section of the gate;

Next step, is to determine the volume of the gate. In order to get the volume the component that is needed is thickness of the gate material. This can be done by measuring the depth of the gate at its thickest point. After the thickness determining, the volume of the gate can be calculated by multiplying the total surface area by the thickness.

Volume of the gate:

$$V = A * D\ [m^3] \qquad (2)$$

Where:

D [m] - is the thickness of the gate material.

Additionally, the mass of the gate panels can be calculated by multiplying the volume by the density of the material it is made of. The density of the material will vary depending on the type of material used, for example, the density of wood is different from that of metal.[6]

Mass of the gate panels:

$$M_1 = V * \rho\ [kg] \qquad (3)$$

Where:

ρ [$\frac{kg}{m^3}$] - is the density of the gate material.

Here are some common densities for different gate materials:

Wood: 500-800 $\frac{kg}{m^3}$

Aluminum: 2700 $\frac{kg}{m^3}$

Steel: 7850 $\frac{kg}{m^3}$

Since the mass of the panels is calculated, in order to get the total mass for the gate there should be added the mass of the additional hardware system that is included in the mechanism.

Total mass of the gate:

$$M = M_1 + M_2 \,[kg] \qquad (4)$$

Where:

M_1 [kg] – is the gate panels mass;

M_2 [kg] – is the gate hardware mass;

Finally, the weight of a gate can be calculated by multiplying the total mass by the gravity acceleration, which has the constant value.

Weight of a gate:

$$F_G = M * g \,[N] \qquad (5)$$

Where:

g = 9.81 $[\frac{m}{s^2}]$ – is Gravity's acceleration.

In the calculation for the weight of a gate or actually the force that is needed in order to move the gate there is one more factor that need to be consider, that factor is friction. If the gate is for example sliding and there is contact between the panels and sliding paths, the force can be calculated by multiplying the weight of a gate by coefficient of friction. The coefficient of friction may vary depending on the materials used for the gate and tracks and other environmental factors. that actually depends on the material.[8]

Force required to move the gate:

$$F = F_G * \mu \,[N] \qquad (6)$$

Where:

μ [-] - the friction coefficient

2.4.2 Torque required

To calculate the required torque that is needed for a motor selection to operate a bi-folding gate, the factors that need to be taken into consideration are, the weight of the gate, the dimensions of the gate, and other environmental factors[13].

The twisting force that the motor uses to move the gate is referred to as motor torque. When choosing a motor for the gate mechanism, the amount of torque the motor is capable of producing is crucial.

Torque required:

$$T = F * r \,[N * m] \qquad (7)$$

Where:

r [m] - is the distance from the center of the motor shaft to the point where the force is applied.

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2.4.3 Angular velocity

Angular velocity is a measure of how quickly an object is rotating about its axis. In the context of a bi-folding gate mechanism, angular velocity is important because it determines how quickly the gate opens and closes, which affects the overall operation of the mechanism. Angular velocity is calculated as the change in the angle of rotation over a given period of time. [13]

Angular velocity:

$$\omega = \frac{\Delta\theta}{\Delta t} \; [\frac{rad}{s}] \qquad (8)$$

Where:

$\Delta\theta$ [rad] - change in the angle of rotation;

Δt [s] – change in time.

2.4.4 Required Power for the motor

The power required for the motor is the amount of energy that the motor must output in order to move the gate at the desired speed. Usually, this power is expressed in watts or horsepower.[13]

The formula for calculating the power required for the motor can be expressed as:

$$P = T * \omega \; [W] \;\; or \;\; [kW] \qquad (9)$$

2.4.5 Efficiency of the motor

Efficiency is the ratio of the output power to the input power of a system. In the case of a bi-folding gate mechanism with a motor, the efficiency of the motor is the ratio of the mechanical power output of the motor (in this case, the power output required to open and close the gate) to the electrical power input to the motor.

To calculate the efficiency of the motor, both the mechanical power output of the motor and the electrical power input to the motor are needed. The mechanical power output of the motor can be calculated as the torque output of the motor multiplied by the angular velocity of the motor shaft. That value for the efficiency should be lower or equal to 1, and multiplied with 100% will give the percentage value.

Efficiency of the motor:

$$\eta = \frac{P_{out}}{P_{in}} * 100\% \qquad (10)$$

Where:

P_{out} [W] - Mechanical power output

P_{in} [W] - Electrical power input

Electrical power input is the amount of electrical power that a device or system consumes to operate. It is the rate at which electrical energy is delivered to the device or system to power it. Electrical power input is calculated by multiplying the voltage applied to the device or system by the current flowing through it.[13]

Electrical power input:

$$P_{in} = U * I \; [W] \quad (11)$$

Where:

U [V] – voltage applied to the device or system;

I [A] – flowing current

2.5 Installation and maintenance

Any mechanical system must be installed and maintained correctly in order to function effectively and safely. This is crucial for bi-folding gates since they are complex machines that include many moving components that need precise alignment in order to work properly. Bi-folding gates that have been improperly installed or maintained may present major safety risks, such as panels that may fall or broken automation. Therefore, it is important to have an in-depth knowledge of the bi-folding gate setup and maintenance procedures to guarantee their long-term security and reliability. This chapter will explore the importance of proper installation and maintenance practices for bi-folding gates, and provide guidelines for ensuring their safe and effective operation. [27]

In Figure 20 are the typical steps involved in the installation of a bi-folding gate:

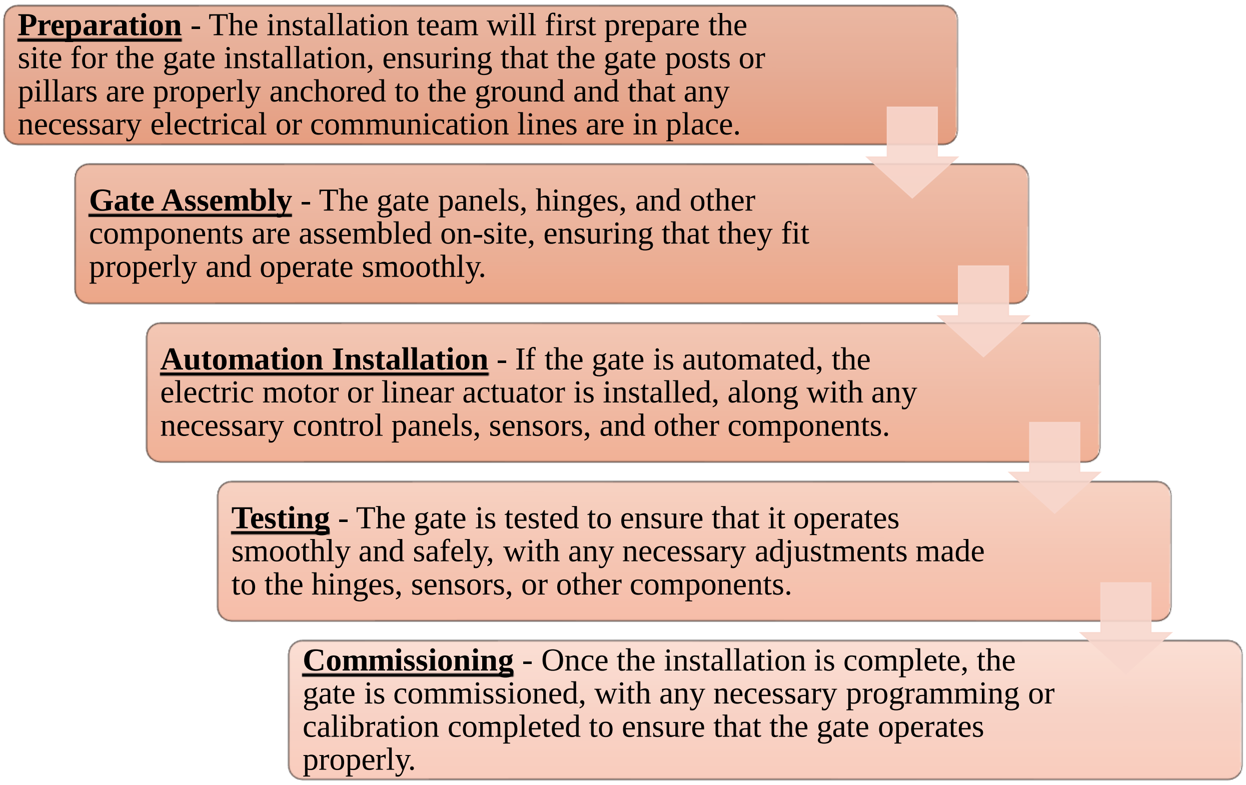

Figure 20 Installation process of a folding gate [27]

As for maintenance, in Figure 21 are some steps that are typically taken to ensure the ongoing reliability and safety of a bi-folding gate:

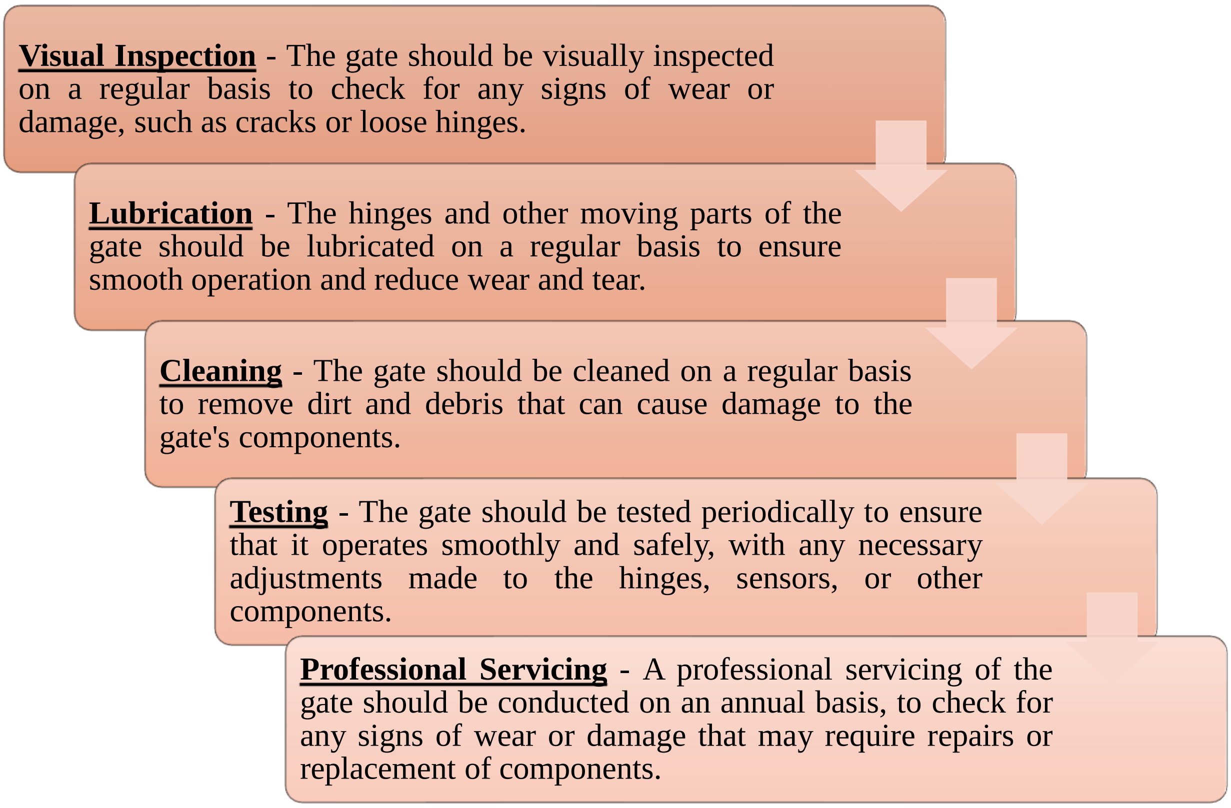

Figure 21 Maintenance process of a folding gate [27]

2.6 Benefits of a Bi-folding Gate

Bi-folding gates offer several benefits compared to traditional swing gates or sliding gates. Here are some of the key benefits of bi-folding gates:

- Space-saving design: Bi-folding gates are designed to fold in half, taking up less space than traditional swing gates or sliding gates. This makes them ideal for locations where space is limited, such as narrow driveways or properties with limited clearance.
- Aesthetic appeal: Bi-folding gates are available in a wide range of materials, finishes, and designs, making them a popular choice for homeowners and commercial property owners who want a gate that is both functional and aesthetically pleasing.
- Security: Bi-folding gates offer a high level of security, thanks to their sturdy construction and locking mechanisms. They are a popular choice for residential, commercial, and industrial applications where security is a top priority.
- Convenience: Bi-folding gates can be automated, allowing them to be opened and closed with the push of a button. This makes them a popular choice for homeowners and commercial property owners who want a gate that is easy to use and convenient.
- Less maintenance: For the rollers to pass through, many gates have tracks that go into the ground. These tracks are still used by some folding gates, but they are not always required. Despite being useful, tracks are prone to collecting dirt, leaves, and other debris as they are used frequently.
- Fast and very quite: Comparing traditional swinging or sliding gates to folding gates, the latter typically open between 3 and 7 seconds faster.[28]

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3 Data Collection

3.1 Types of Data Collection

The systematic process of accurately obtaining data from multiple sources to offer insights and solutions, such as testing a hypothesis or assessing a result, is known as data collecting. The basic goal of data collecting is to collect reliable data that can be examined and utilized as evidence or to support choices.

Overall there are two forms of data collection: quantitative and qualitative. Quantitative data is gathered using statistics and data, such as measurements and percentages. The gathering of qualitative data includes descriptions, explanations, and opinions.

The two main types of data collection methods are primary and secondary. Information is collected directly using primary data gathering techniques, making them source data. Information is obtained from existing repositories through secondary data-gathering gathering techniques. It might come from outside sources or from the results of the analysis. [32]

Quantitative variables might be continuous or discontinuous. A type of numerical information known as discrete data is made up of whole, concrete numbers with predetermined, established values that can be counted. Complex numbers and shifting data values taken over a certain amount of time are included in continuous data.[33] In Figure 22 can be seen all types of data collection methods.

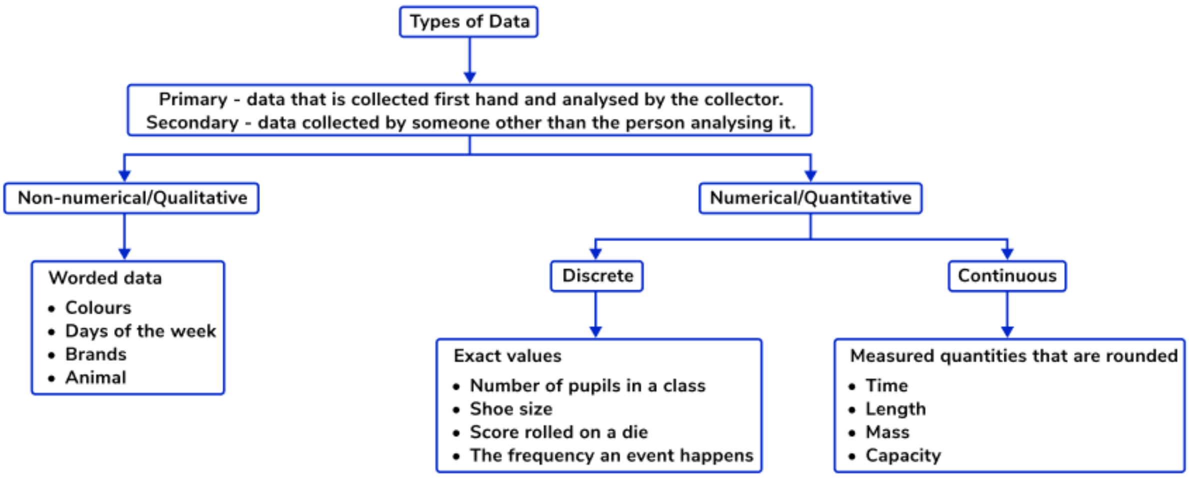

Figure 22 Types of Data Collection Methods [35]

In this thesis it is previously mentioned that the aim is to design a bi-folding gate, and after the designing to get the results for certain parameters. The thesis involves measuring the space required for a bi-folding gate and supervising the dimensions with the help of the thesis's mentor. In this case, using the primary and quantitative data collection method to gather information and support the research is appropriate. Also, the data collected is continuous.

3.2 Gate Dimensions

The measurements of the designing gate are provided by this thesis's supervisor in order to complete the design and make the thesis relevant and complete. Collecting door dimensions is actually collecting data on the dimensions of the door, including the height, width, and thickness of the door panels, as well as the overall size of the door opening.
In Figure 23 can be summarized the necessary dimensions for the model.

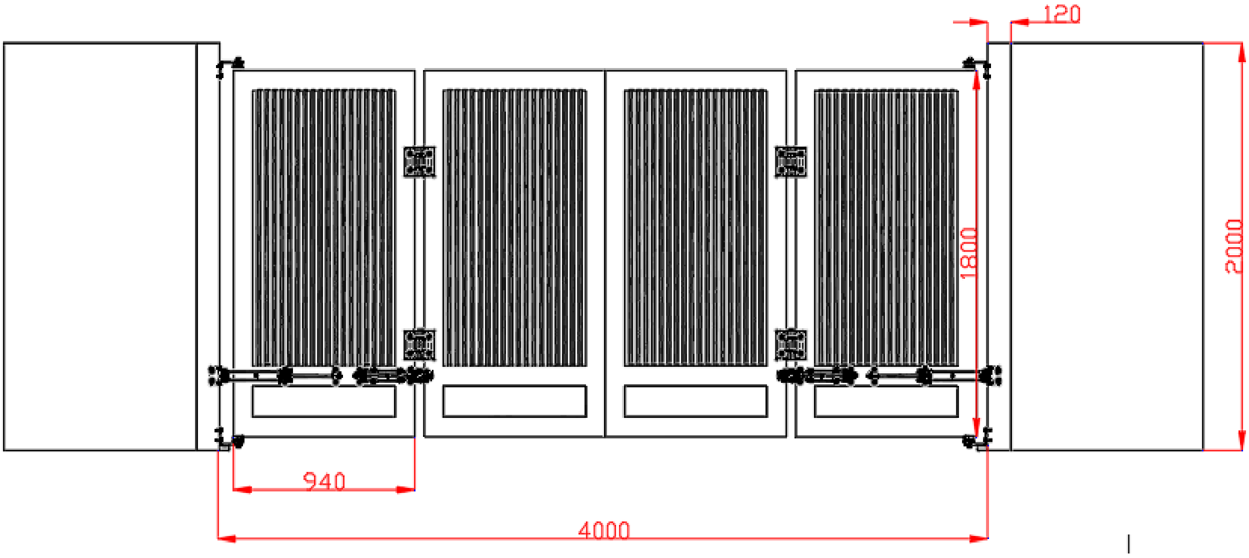

Figure 23 2D Design of a Bi-Folding Gate – Length/Width and Height Dimensions

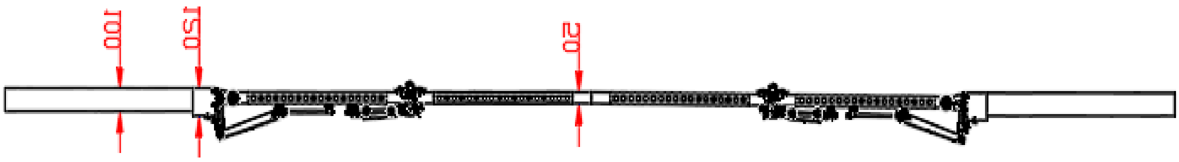

Figure 24 2D Design of a Bi-Folding Gate – Thickness Dimensions

Overall size of the gate opening mechanism, according the measurement is:

$$L_{total} = 4000 \text{ [mm]}$$

The length of one single panel is:

$$L = 940 \text{ [mm]}$$

The overall height of the gate mechanism, or the height from the ground till the top point of a wall, according the measurement, is:

$$H_{total} = 2000 \text{ [mm]}$$

The height of one single panel is:

$$H = 1800 \text{ [mm]}$$

The thickness of a wall is:

$$t_{wall} = 100 \text{ [mm]}$$

The thickness of a bean that is connected properly with the gate is:

$$t_{beam} = 120 \text{ [mm]}$$

The thickness of a gate panels is:

$$t = 50 \text{ [mm]}$$

As a conclusion, the overall space that should be cover with Bi-folding gate mechanism is:

$$L_{total} \text{ x } H_{total} = 4000 \text{ x } 2000 \text{ [mm]}$$

Additionally, the mechanism is consisting 4 panels, which are with dimensions:

$$L \text{ x } H \text{ x } t = 940 \text{ x } 1800 \text{ x } 50 \text{ [mm]}$$

3.3 Material properties

The choice of material is an essential aspect of designing any mechanical system, including a bi-folding gate mechanism. Stainless steel is a popular material for constructing mechanical systems because of its unique properties, including corrosion resistance, high strength, and excellent ductility.

In designing a bi-folding gate mechanism, it's essential to consider the specific requirements of the system and how the chosen material will meet those requirements. For instance, the material should be strong enough to handle the forces and stresses involved in operating the gate, while also being lightweight enough to allow for smooth movement.

In *Table 2* the properties of the material that is used for the gate panels can be seen:

Table 2 Stainless Steel Properties source - Autodesk Inventor

Properties	**Value**
Informations	
material	Stainless steel 18/8
Type	metal
description	Semi-polished
Basic Thermal	
Thermal Conductivity	2.167E-04 btu/(in·sec·°F)
Specific heat	0.114 btu/(lb·°F)
Thermal exp. coefficient	5.778E-06 inv °F
Mechanical	
Young’s Modulus	2.799E+07 psi
Poisson’s Ratio	0.29
Shear Modulus	1.247E+07 psi
Density	0.289 pound per cubic inch
Strength	
Yield Strength	3.626E+04 psi
Tensile Strength	7.832E+04 psi

In addition to strength and weight considerations, it's also essential to consider the mechanical properties of stainless steel, such as its coefficient of thermal expansion and its elastic modulus. These properties will impact how the material behaves under different environmental conditions, such as changes in temperature or load.

Other factors to consider when working with stainless steel include its susceptibility to stress corrosion cracking, its weldability, and the appropriate surface finish for the specific application. Proper surface treatment, such as passivation or electropolishing, can improve the corrosion resistance of stainless steel and extend its service life.[37]

3.4 Gate calculations

3.4.1 Weight calculation

In accordance with chapter 2.4.1 the gate calculation can be started with examining the mass of a gate. The first step includes simply summarizing the areas that make up the panel using the formula (1). In Figure 25 the panel dimensions and areas can be seen.

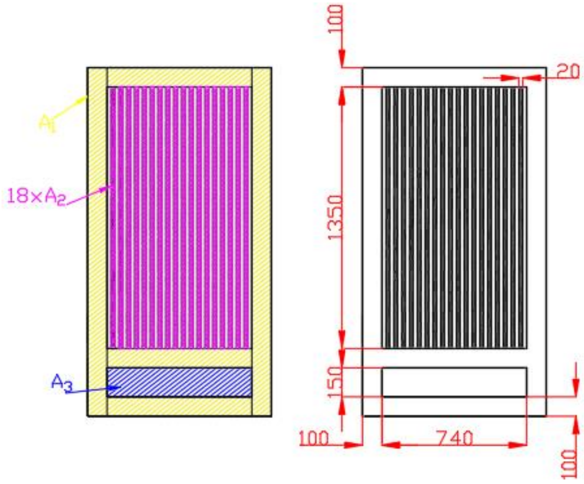

Figure 25 Panel dimensions and areas

$$A = A_1 + A_2 + A_3 \ [m^2]$$

Where:

A_1 - area for the frame of the panel

A_2 - area for the panel grid, that consists 18 cylinders

A_3 – area in the basis of the panel that has thickness t_3 = 15 mm

$$A_1 = (1.8 * 0.1 * 2) + (0.74 * 0.1 * 3)$$

$$A_1 = (0.36) + (0.222)$$

$$A_1 = 0.582 \ [m^2]$$

$$A_2 = \left(\frac{(0.02)^2 * \pi}{4}\right)$$

$$A_2 = 0.000314 \ [m^2]$$

$$A_3 = (0.74 * 0.15)$$

$$A_3 = 0.111 \ [m^2]$$

The next step is calculating the volume by using the formula (2).

$$V = V_1 + V_2 + V_3 \ [m^3]$$

$$V_1 = (A_1 * D_1)$$

$$V_1 = (0.582 * 0.05)$$

$$V_1 = 0.0291 \ [m^3]$$

$$V_2 = (A_2 * 0.135)$$

$$V_2 = (0.000314 * 0.135)$$

$$V_2 = 0.0000424 \ [m^3]$$

$$V_3 = (A_3 * D_3)$$

$$V_3 = (0.111 * 0.02)$$

$$V_3 = 0.00222 \ [m^3]$$

The total volume is:

$$V = 0.0291 + 0.0000424 + 0.00222$$

$$V = 0.0313[m^3]$$

Additionally, the mass of the panel can be calculated with formula (3):

$$M_1 = V * \rho \ [kg]$$

To convert the density from pound per cubic inch into kilogram per cubic meter:

$$\rho = \rho * 27679.9 \ \frac{kg}{m^3}$$

$$\rho = 0.289 * 27679.9$$

$$\rho = 7999.52 \ \frac{kg}{m^3} \quad \text{or} \quad \rho = 8000 \frac{kg}{m^3}$$

$$M_1 = 0.0313 * 8000$$

$$M_1 = 250.4 \ [kg]$$

Because it is previously mentioned that the mechanism will be consisting two panels and hardware kit that is using for the movement, the formula for total mass is (4):

$$M = 2 * M_1 + M_2 \ [kg]$$

The mass for the hardware kit is available from the manufacturer web site [26]

$$M_2 = 13.6 \ [kg]$$

$$M = 2 * 250.4 + 13.6$$

$$M = 514.4 \ [kg]$$

The final step, the total weight for one half of the gate can be calculated by using the formula (5):

$$F_G = M * g \ [N]$$

$$g = 9.81 \ [\frac{m}{s^2}]$$

$$F_G = 514.4 \ * \ 9.81$$

$$F_G = 5046.264 \ [N] \quad \text{or} \quad F_G = 5.046264 \ [kN]$$

Although, it must be mentioned that because there is no connection between the ground and the panel, the estimation part with the friction can be skipped, so the final force will be equal to total weight of the mechanism.

$$F = F_G = 5.046264 \ [kN]$$

3.4.2 Reaction Forces

Assuming that the gate is in static equilibrium, which means the sum of all forces and torques acting on the gate is zero, will allow to begin calculating the reaction forces at the pivot points. In other words, the forces and torques are all balanced and the gate is not moving. Assume that both the gate and the two panels are horizontal with the gate completely extended. The center of mass, which is located at the middle of the gate's top and bottom edges, is where the weight of the gate acts in this situation when it acts vertically downward.

The principle of force equilibrium and the principle of moments can be used to determine the reaction forces at the pivot points. According to the principles, if an object is in equilibrium, the sum of its moments and forces around any given location equals zero.[14]

The force equilibrium equations:

$$\sum F_x = 0 \qquad \sum F_y = 0 \qquad \sum F_z = 0$$

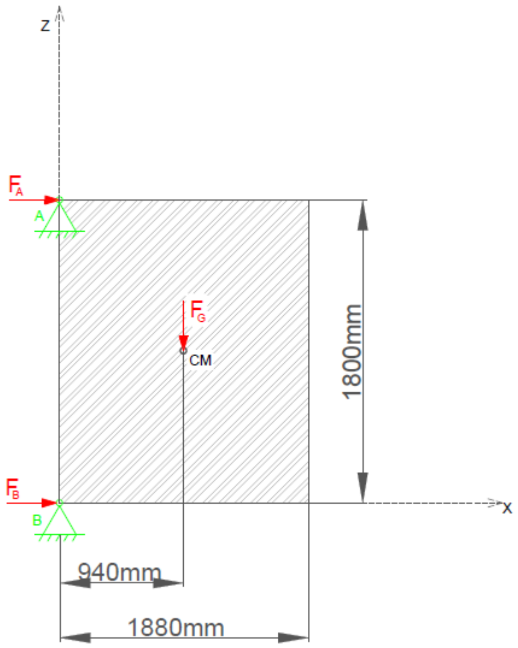

Figure 26 Reaction forces diagram (AutoCAD)

From the Figure 26 can be assumed that in x direction there are reaction forces, so:

$$\sum F_x = F_A + F_B = 0$$

$$F_A = -F_B$$

The moment equilibrium equation:

$$\sum M = 0$$

where M is the total of the moments around a specific point or axis. When one of the pivot points is used in this situation, the equation becomes:

$$\sum M_A = 0$$

$$\sum M_A = F_{Bx} * 1.8 - F_G * 0.94 = 0$$

$$F_B = \frac{F_G * 0.94}{1.8}$$

$$F_B = \frac{5046.264 * 0.94}{1.8}$$

$$F_B = 2635.27\ [N]$$

From the previous calculations:

$$F_A = -\ 2635.27[N]$$

After the reaction forces are calculated that are acting on the pivot joints, the friction forces should be calculated:

$$F_{fr.} = \mu * F_N [N]$$

Where:

μ [-] - is coefficient for the friction

$F_N [N]$ – Normal force that is acting on the pivot joint

The friction coefficient depends on the surfaces' textures and conditions, as well as the materials with which they come into contact. The amount that characterizes the frictional force between two surfaces in contact is a dimensionless quantity. Coefficients of friction come in two flavors: static and kinetic. The frictional force needed to start motion between two stationary surfaces in contact is described by the static coefficient of friction. The frictional force between two surfaces that are moving in relation to one another is described by the kinetic coefficient of friction. For this calculation is chosen a proper coefficient for steel-steel contact surface, furthermore the properties can be seen in *Table 3*.

Table 3 Friction coefficient properties [38]

Material and material combinations		Surface conditions	Static Friction coefficient	Dynamic Friction coefficient
Steel	Steel	Clean and Dry	0.5 - 0.8	0.42

Because the mechanism is having a motion, the coefficient is:

$$\mu = 0.42$$

The friction forces for the pivot joints are:

$$F_{Afr.} = 0.42 * (-2635.27)$$

$$F_{Afr.} = -1106.8\ [N]$$

$$F_{Bfr.} = 0.42 * 2635.27$$

$$F_{Bfr.} = 1106.8\ [N]$$

3.4.3 Required Torque

The required torque is needed in order to get the value of the motor power, which can be calculated with the formula (7).

$$T = F_{fr.} * r\ [N * m]$$

The torque in the mechanism depends on the both pivots, in that case the total torque will be a sum of the individual torques for each joint. In *Figure 27* can be seen the radiuses for each joint, furthermore with these radiuses and the previously calculated friction forces the torques can be estimated.

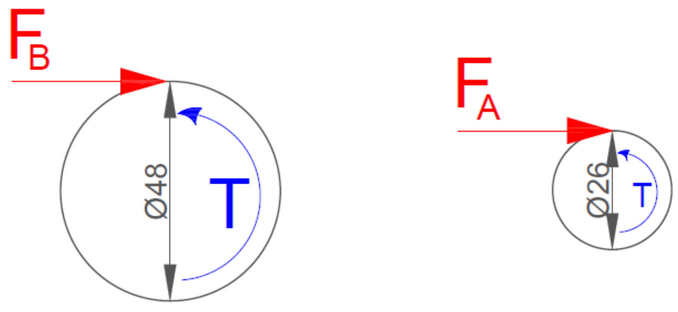

Figure 27 Applied torque for the pivot joints (AutoCAD)

The A pivot joint or actually the top pivot torque is:

$$T_A = F_{Afr.} * r_A\ [N * m]$$

$$T_A = -1106.8 * \frac{0.026}{2}$$

$$T_A = -14.3884\ [N * m]$$

The B pivot joint or actually the bottom pivot torque is:

$$T_B = F_{Bfr.} * r_B\ [N * m]$$

$$T_B = 1106.8 * \frac{0.048}{2}$$

$$T_B = 26.5632\ [N * m]$$

The total torque will be:

$$T = T_A + T_B [N * m]$$

$$T = -14.3884 + 26.5632$$

$$T = 12.1748 \ [N * m]$$

3.4.4 Angular velocity

As in to estimate, for angular velocity there is formula (8):

$$\omega = \frac{\Delta\theta}{\Delta t} \ [\frac{rad}{s}]$$

Where the change in the angel rotation, for this mechanism is equal to:

$$\Delta\theta = 90°$$

Because the velocity is related to the time, there is … in which for different time is calculated the proper angular velocity.

Table 4 Angular velocity depending on time

Time [s]	Angular velocity [rad/s]
10	9
15	6
18	5
20	4.5

In the next calculations it will be taken t = 20 s, or

$$\omega = 4.5 \ [\frac{rad}{s}]$$

3.4.5 Motor Power

The required power for the motor that should be chosen, after the calculation can be estimated with formula (9):

$$P = T * \omega \ [W] \quad or \quad [kW]$$

$$P = 12.1748 * 4.5$$

$$P = 54.7866 \ [W]$$

3.5 Motor Selection

Motors play a crucial role in the operation of bi-folding gates, as they provide the necessary power to move the gate panels smoothly and safely. Motorized bi-folding gates are available in various types, including hydraulic, electromechanical, and pneumatic motors. Each type of motor has its own advantages and disadvantages, depending on the specific needs and requirements of the gate installation. Electromechanical motors are a more affordable option that offers precise control and quiet operation.

When choosing a motor for a bi-folding gate, it's essential to consider factors such as the weight and size of the gate, the expected frequency of use, and the available power sources. By selecting the right motor for the gate installation, property owners can ensure that their bi-folding gates operate smoothly, efficiently, and safely.

Bi-folding gates frequently use linear motors because of their great speed, accuracy, and stability. Linear motors are more effective and faster than standard rotary motors because they directly produce linear motion rather than converting rotational motion into it. A smooth and accurate functioning is made possible by the exact control that linear motors provide over the movement of the gate panels. They are a great option for bi-folding gates since they need a lot of power to quickly move heavy gate panels and they also have a high-power density, which means they can supply a lot of power in a little space. [5] [11]

In order to choose the right linear motor for the calculated bi-folding gate, first it must be summarized the acting mass force:

$$F = F_G = 5046.264 \ [N]$$

The motor that is chosen is **Optical Feedback Linear Actuator** (Figure 29) and its specifications can be seen in *Table 5*. The proper Mounting Bracket is in Figure 28.

Table 5 Actuator Specifications [39]

Model	**FA-OS-400-12-(X)**
Dynamic Force	400 lb
Static Force	800 lb
Speed ("/S)	.30
Gear Ratio	19:1
Feedback	Optical Sensor
Feedback Voltage	5V
Synchronous Capability	Yes, the 200 lb. & 400lb., with our Sync Control Board or a Microcontroller
Duty Cycle	25%
IP Rating	IP61
Screw Type	ACME
Sound Rating	20 dB over Ambient
Input	12v DC
Max Draw	5 A
Clevis End	1/4" diameter
Operational Temperature	-26°C/65°C (-15°F/150°)
Limit Switch	Built-in, non-adjustable (factory preset)
Safety Certifications	CE
Wire Length	2.5 feet
Wire Gauge	Motor wires 18. Sensor wires 20

Figure 28 MB1-P Mounting Bracket for Actuator [40]

Figure 29 Optical Feedback Linear Actuators [39]

4 Analysis

4.1 3D CAD Model

In the very beginning it is mentioned that the aim of this thesis is to design a bi-folding gate by the given dimensions. Starting the 3D CAD modeling topic for a gate design thesis requires a solid understanding of the gate's function and the desired aesthetic. The 3D CAD modeling process begins with creating a detailed and accurate digital representation of the gate's components and assembly. This includes determining the appropriate dimensions, materials, and tolerances to ensure the gate functions as intended.

For that purpose is used the Autodesk Inventor software. Autodesk Inventor is a professional 3D CAD software developed by Autodesk, Inc. that is commonly used for designing and modeling mechanical parts, products, and assemblies. It provides a comprehensive set of tools for designing and engineering complex mechanical systems, including parametric modeling, assembly modeling, sheet metal design, and stress analysis.

The first step in designing a bi-folding gate is to determine the panel configuration that will meet the specific requirements. Consider the width of the gate opening, the weight of the panels, and any other factors that may affect the design.

Once is determined the panel configuration, starts the selection phase of the necessary hardware for connecting the panels to the beam. This includes hinges, pivot points, bolts, and joints that will allow the gate to smoothly and securely fold and unfold.

It's important to ensure that the gate is properly supported and balanced so that it can be operated safely and efficiently. For this part, it is created a beam that is grounded and makes the gate stable.

The model can be seen in Figure 30, Figure 31, and Figure 32. However, later on, each part will be represented separately.

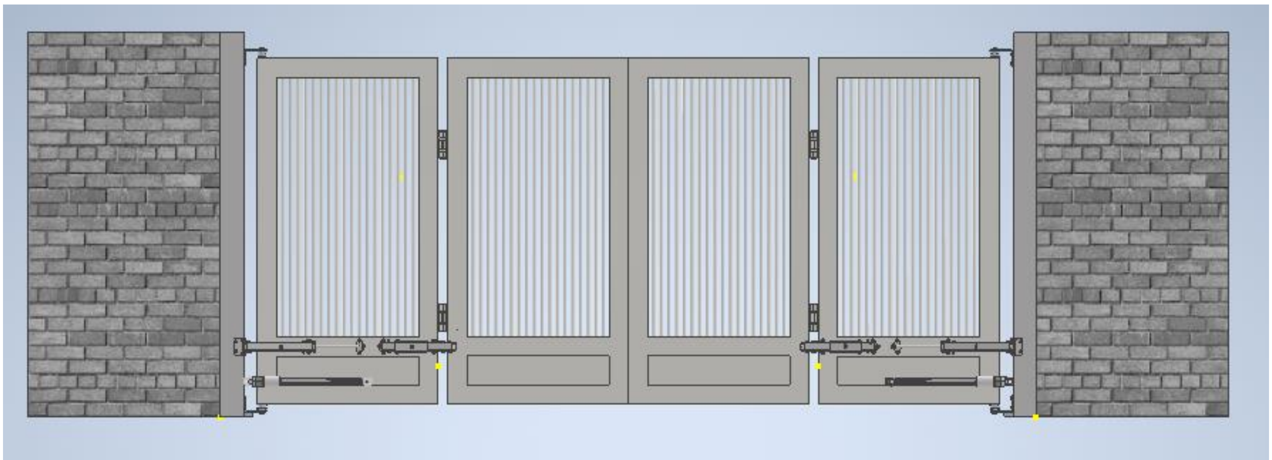

Figure 30 Model of a Bi-Folding Gate (Autodesk Inventor) – Front view

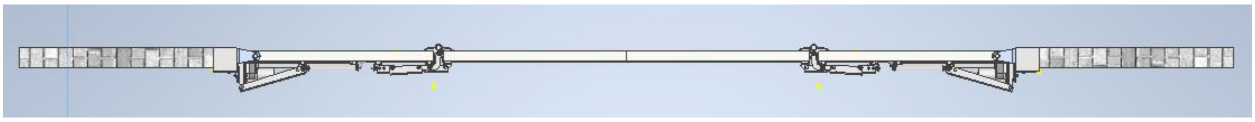

Figure 31 Model of a Bi-Folding Gate (Autodesk Inventor) – top view

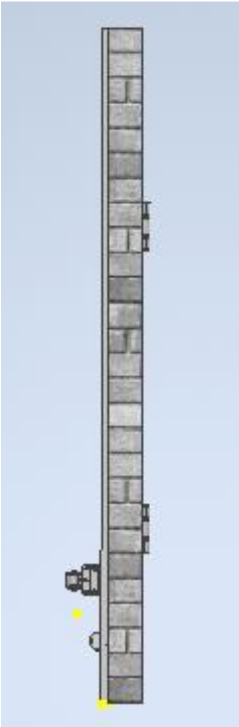

Figure 32 Model of a Bi-Folding Gate (Autodesk Inventor) – side view

In the context of a bi-folding gate mechanism, a "panel" refers to one of the individual sections that make up the entire gate. (Figure 33)

Figure 33 Panel for the model (Autodesk Inventor)

The panel for the model has a rectangular shape, made up from stainless steel and connected:

- on the one side with the beam throughout the bottom (Figure 34) and top pivot (Figure 35).
- on the other side throughout the hinges with the other panel.

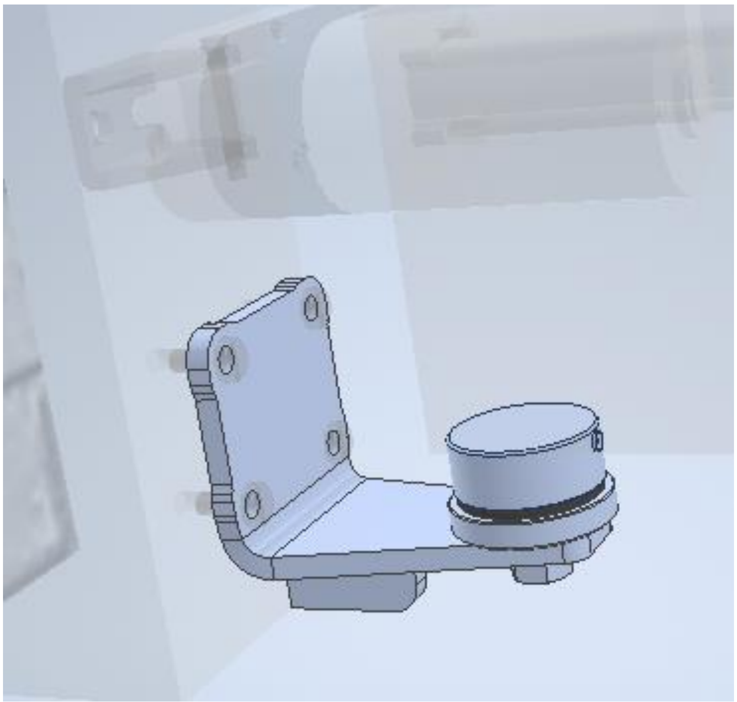

Figure 34 Bottom pivot joint for the model (Autodesk Inventor)

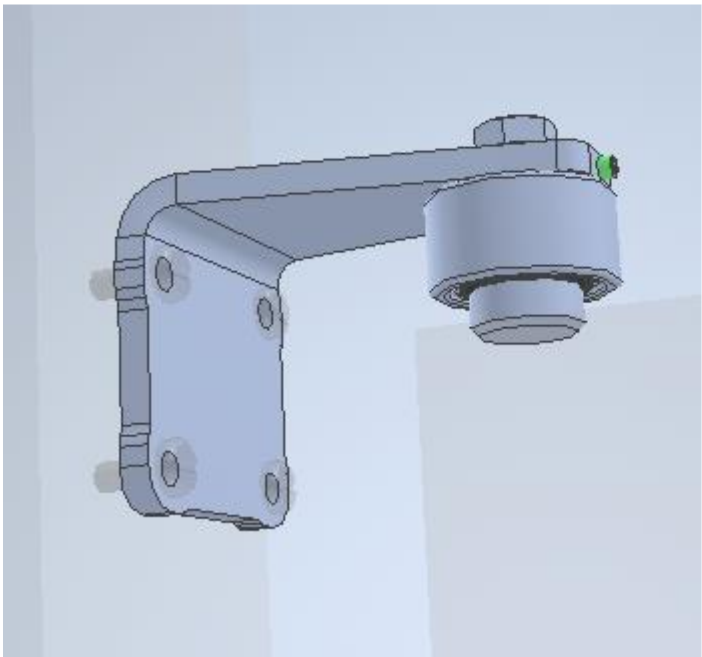

Figure 35 Top pivot joint for the model (Autodesk Inventor)

Each gate has pivot joints at the top and bottom that allow for smooth rotation during opening and closing. This junction is made up of a bracket that is attached to the frame and a pin that is put into the gate panel. The gate rotates 90 degrees, so that mean that these joint are having the motion of 90 degrees.

The two hinges located in the middle of the gates are responsible for keeping the panels together when the machine is working. Each hinge is made up of two plates that are attached to each gate panel and connected by a pin. The hinge has also a rotational motion, around the y-axis, thus each plate is rotating 90 degrees. The hinge can be seen in Figure 36 and Figure 37.

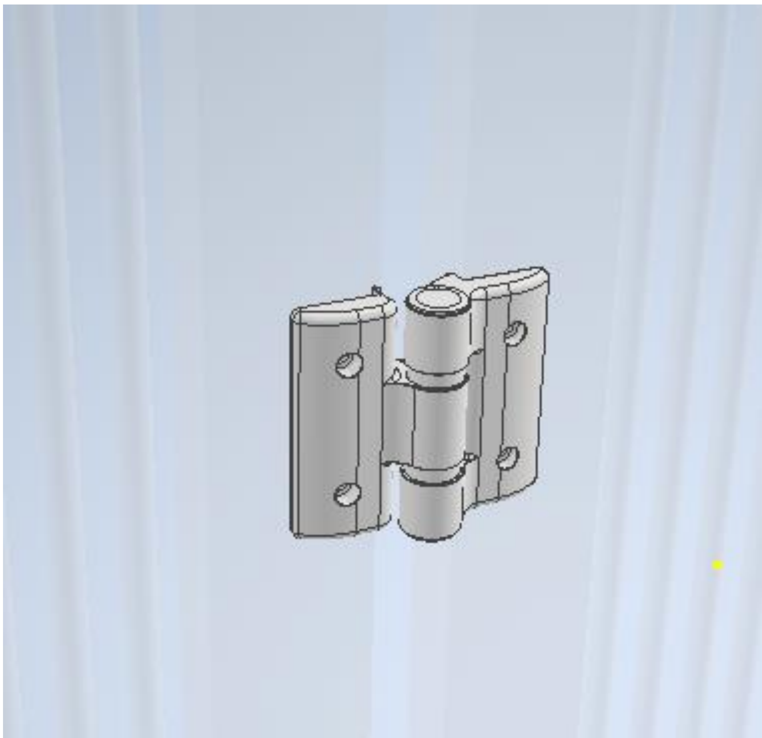

Figure 36 Hinge for the model (Autodesk Inventor)

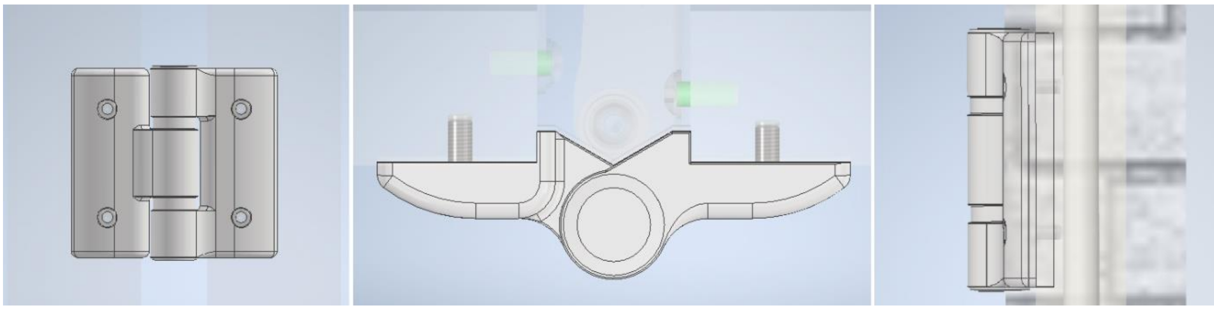

Figure 37 Different view of a Hinge (Autodesk Inventor)

The column and leaf joints are connected to the gate frame which includes the hinges for the folding panels. The pivots and hinges that link the two panels of a bi-folding gate design are definitely important. However, the gate's overall functionality and stability are further affected by the column and leaf joints, which are also essential parts.

When the gate is in the closed position, the leaf joint (Figure 40) is positioned parallel to the column joint (Figure 38). As the gate is opened, the pivot points at the top and bottom of the gate allow the gate panels to rotate outward, away from each other, and the column joints begin to push the leaf joints outward, causing the gate panels to fold.

As the gate continues to open, the leaf joints move away from the column joints, and the panels fold in a concertina-like motion until they are fully open. When the gate is being closed, the leaf joints move towards the column joints, and the panels unfold until they are fully closed.

The different views of a joints can be seen in Figure 39 and Figure 41.

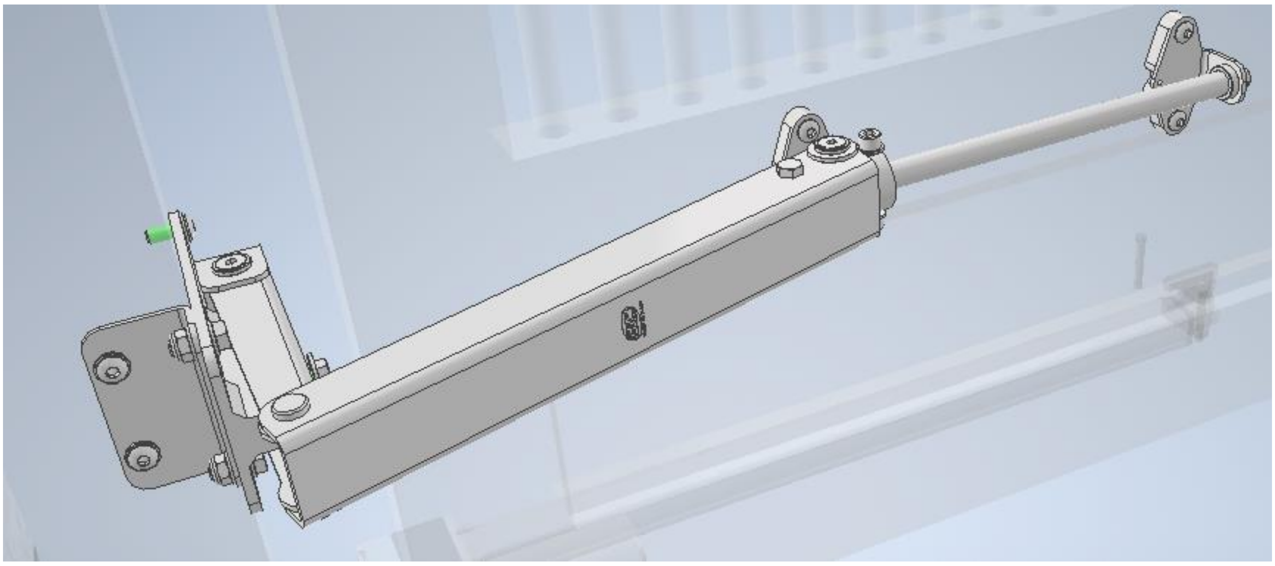

Figure 38 Column joint for the model (Autodesk Inventor)

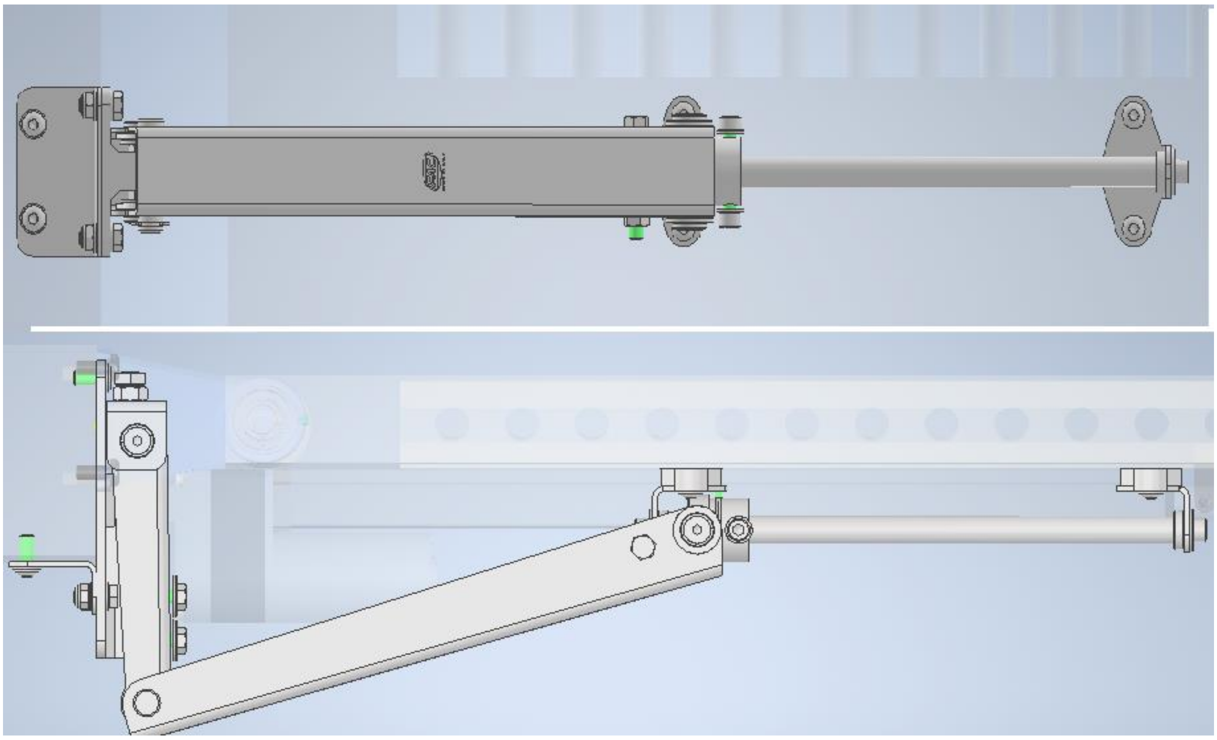

Figure 39 Different views of a Column joint (Autodesk Inventor)

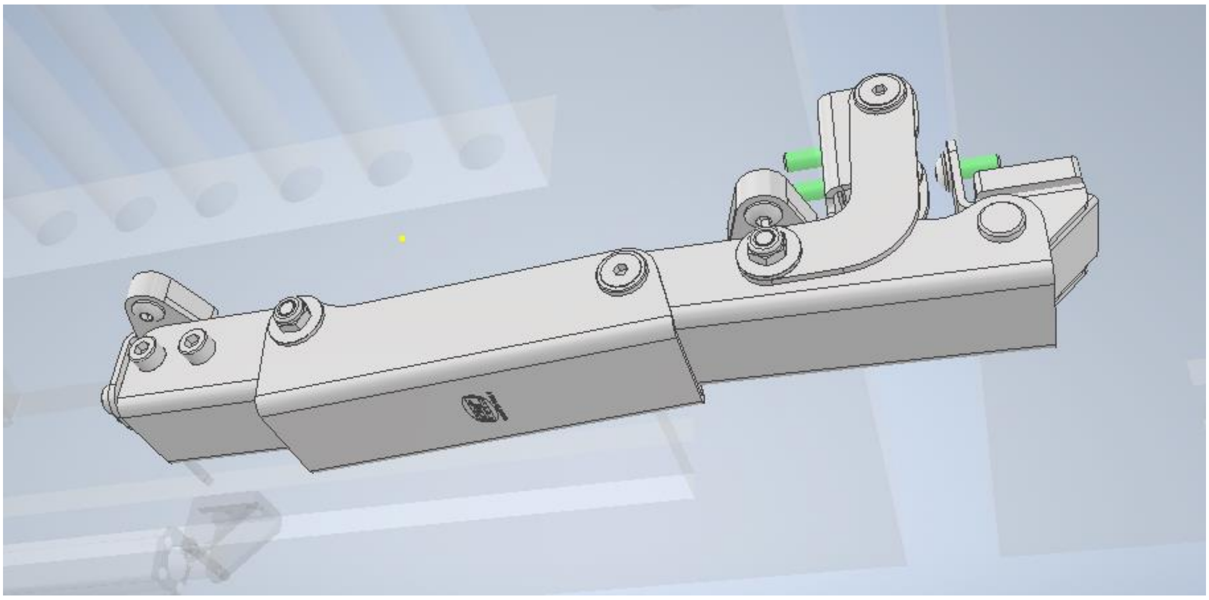

Figure 40 Leaf joint for the model (Autodesk Inventor)

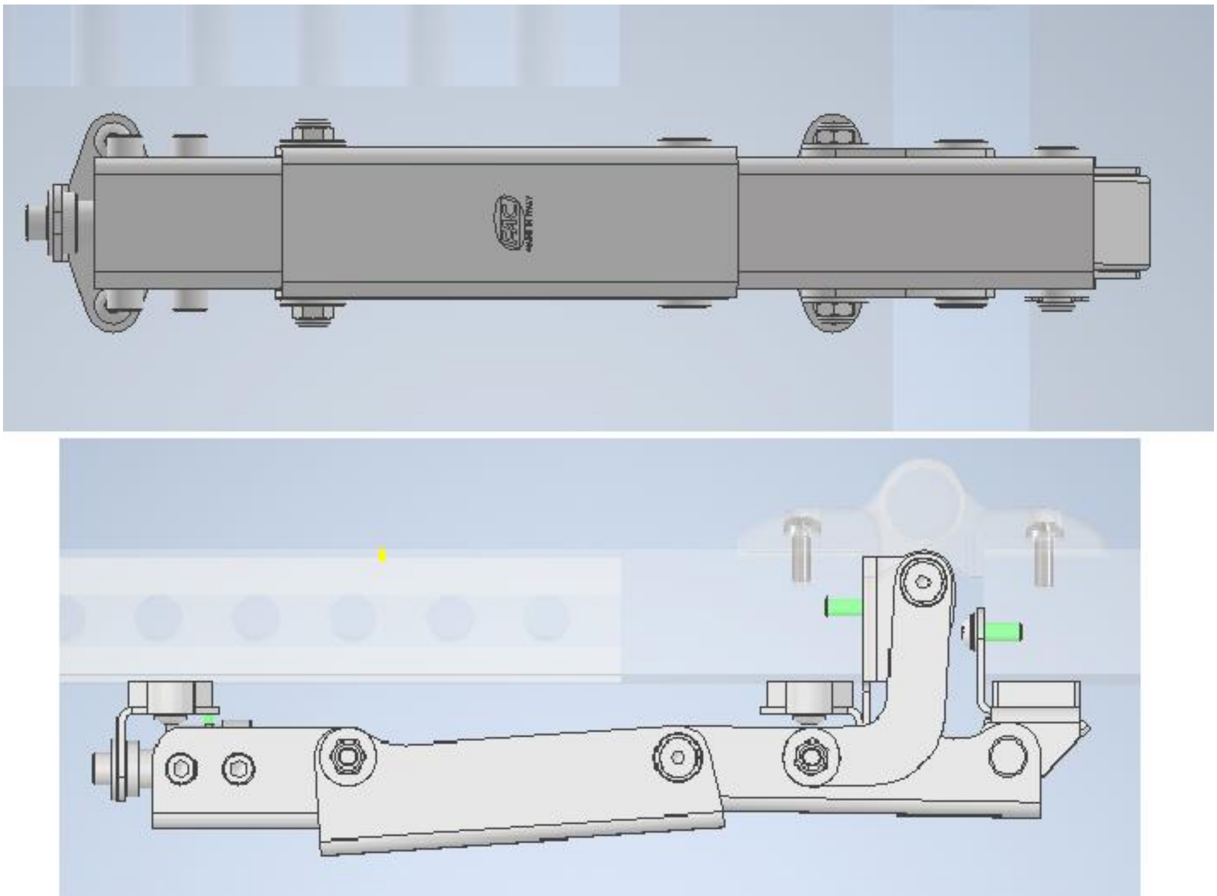

Figure 41 Different views of a Leaf joint (Autodesk Inventor)

For the model, as it is previously mention, the linear actuator is chosen, which can be seen in Figure 42. The motor is connected to the panel through the special joints for that purpose (Figure 43). There are used two joints, one at the starting point on the beam, and the other at the ending point of the actuator. Also, the starting point of the actuator has wires, and the power source should be connected to the actuator wiring.

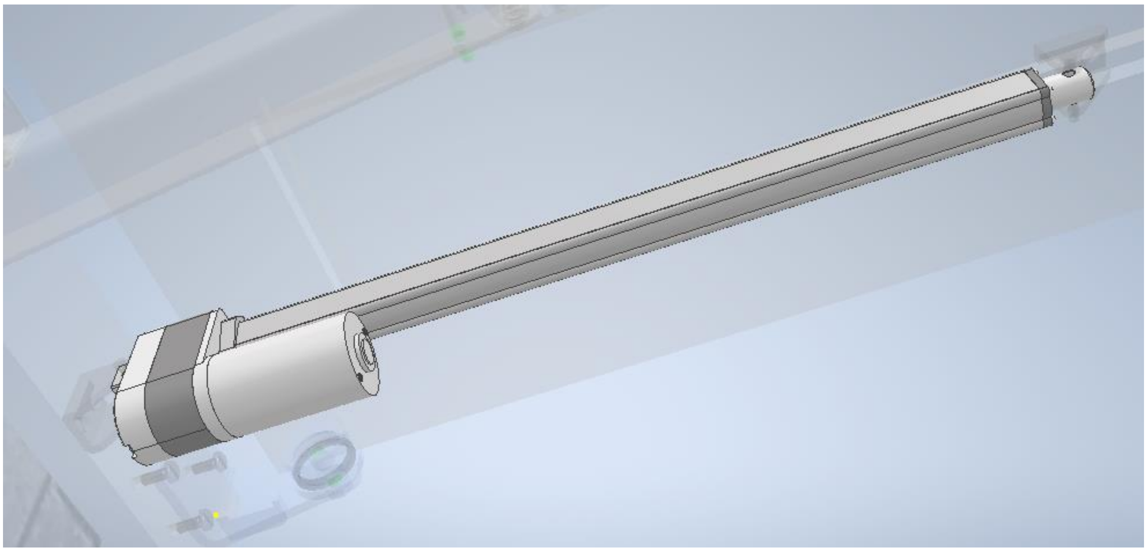

Figure 42 Motor for the model (Autodesk Inventor)

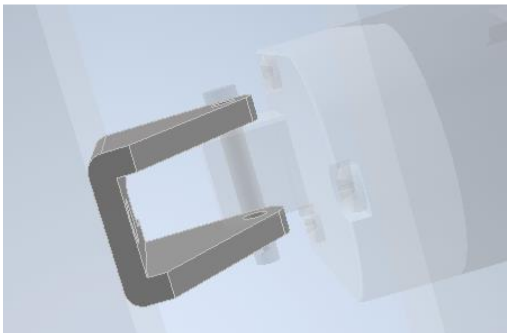

Figure 43 Joint for the motor (Autodesk Inventor)

The additional pictures from the model can be seen in Figure 44, Figure 45, Figure 46, and Figure 47.

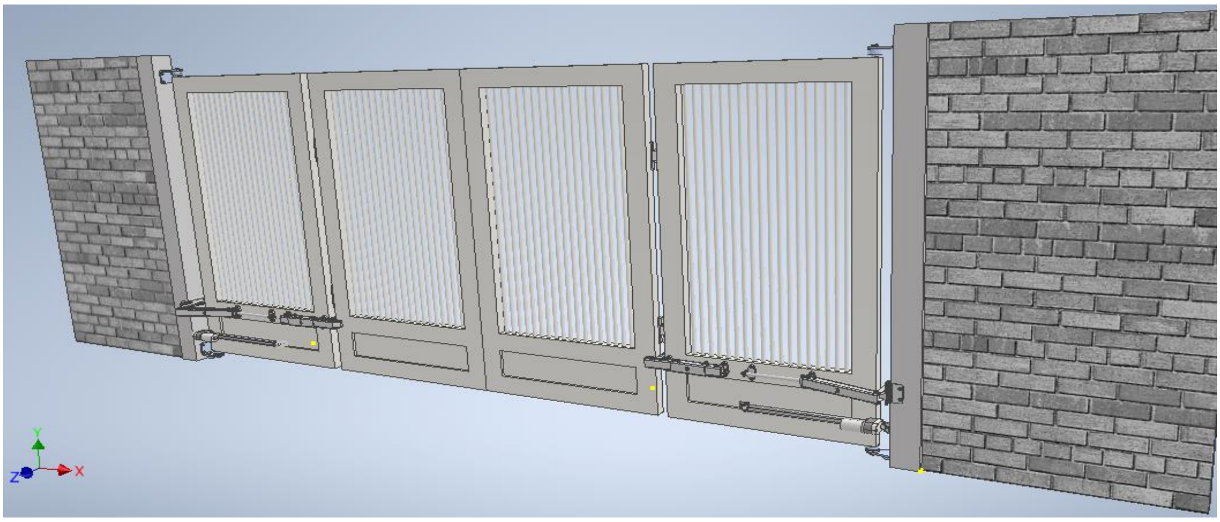

Figure 44 Additional model picture 1 (Autodesk Inventor)

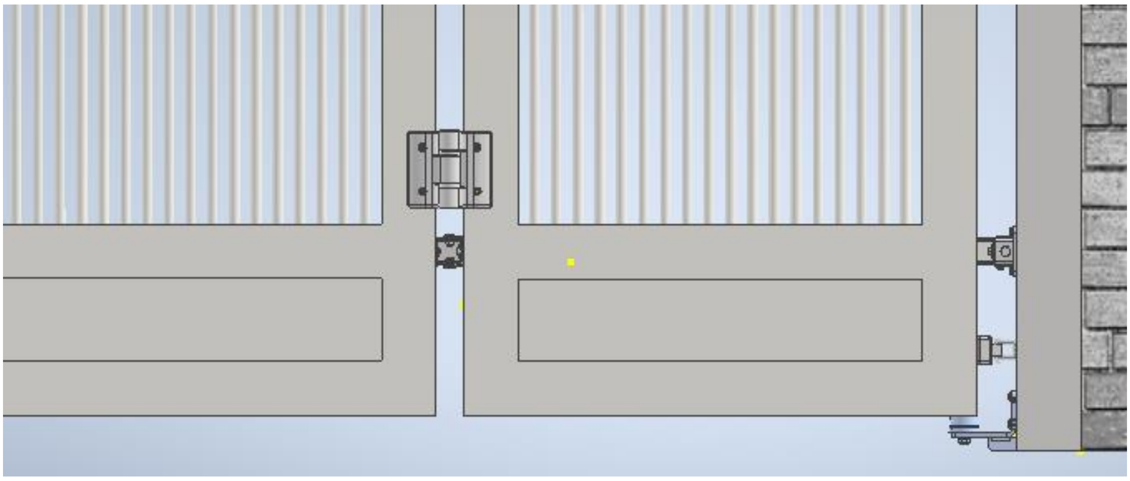

Figure 45 Additional model picture 2 (Autodesk Inventor)

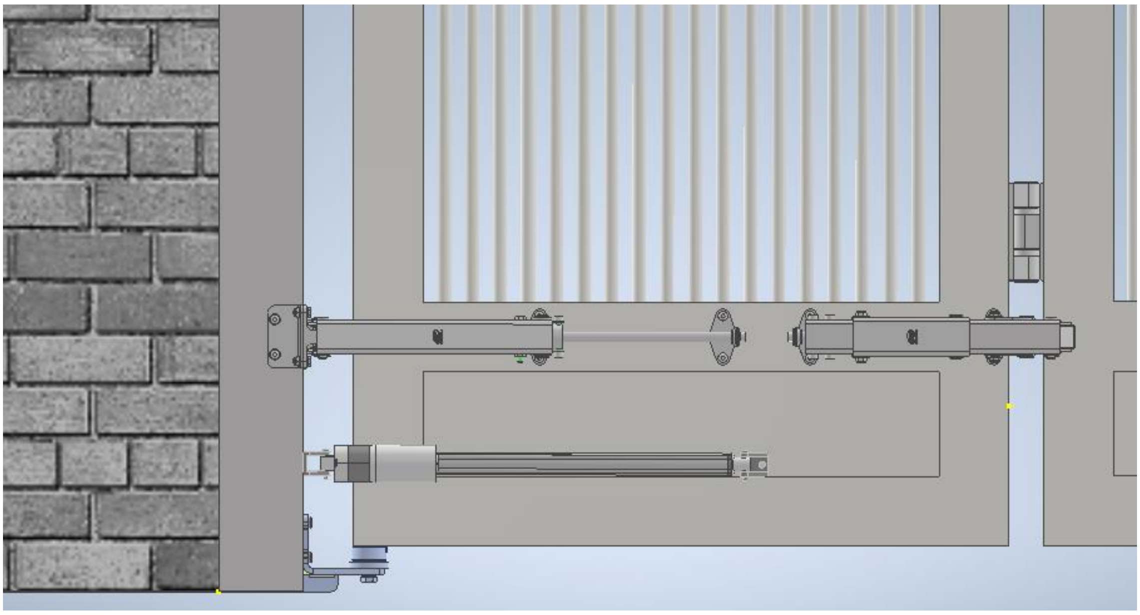

Figure 46 Additional model picture 3 (Autodesk Inventor)

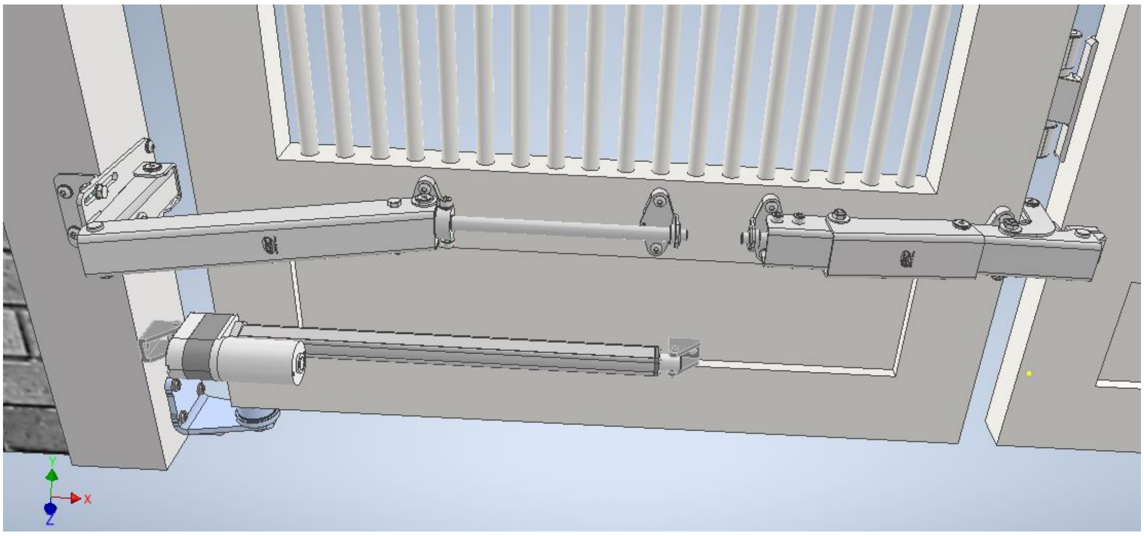

Figure 47 Additional model picture 4 (Autodesk Inventor)

4.2 Simulation

The bi-folding gate model used in the thesis focuses significantly on simulation since it enables testing and performance validation of the gate design prior to actual construction. Adams View has been selected as the program to be applied for the gate model.

Adams is a common program for modeling mechanical systems like bi-folding gates. It is used for multibody dynamics simulation. Adams creates the building of a thorough virtual prototype of the gate, complete with all of its parts and interactions, and it imitates the gate's behavior under various operating circumstances. This can assist in locating potential problems, improving the design, and finally making sure the gate functions as expected in practical situations.

The first stage in representing a bi-folding gate in Adams is to design and model each component of the gate individually, giving consideration to each component's mass, size, and other relevant information. In order for the simulation to run successfully, these parameters must also be computed and checked beforehand. The bodies used for the panels are rectangular, made of stainless steel, and have dimensions of 1.8x0.94x0.05 m. Each one weighs 250.4 kg.

The following step is to identify the joint elements as well as the joints between the pieces, which are commonly hinge and pivot joints where the gate panels fold. Basic link bodies with dimensions of 0.1x0.05x0.02 m is used for the joints. The supporter beam and link joints are fixed, while all the other joints are revolving joints. A revolute joint is a kind of joint that allows rotation around a fixed axis, in this case, it rotates around the z-axis in accordance with the design coordinate system.

The motions added between the parts are taking that angle in the right direction since, according to the report of earlier calculations, each panel is taking a 90-degree angle.

The simulation can then be performed to follow the gate's behavior under different situations. In order to improve the performance of the gate, the results from the simulation can finally be analyzed.

The model that is simulated is represented in Figure 48.

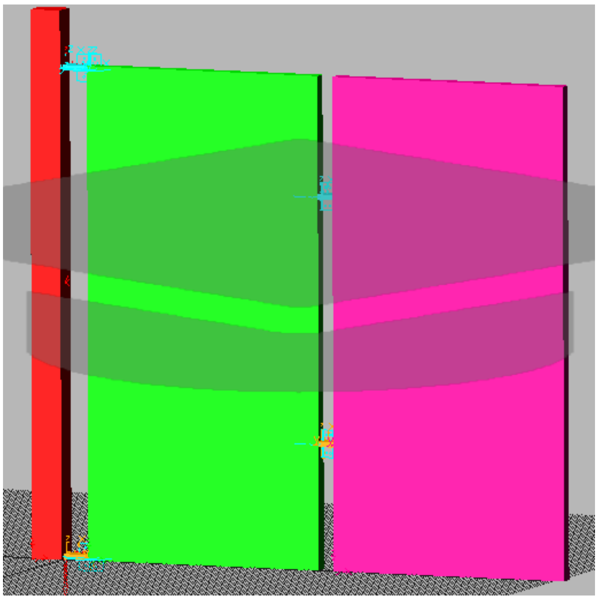

Figure 48 Bi-folding gate model simulation (Adams View-Student Edition)

Typically, in Figure 49 and Figure 50 can be seen simulation images of gate opening show or actually a series of shots of the gate motion in various opening positions.

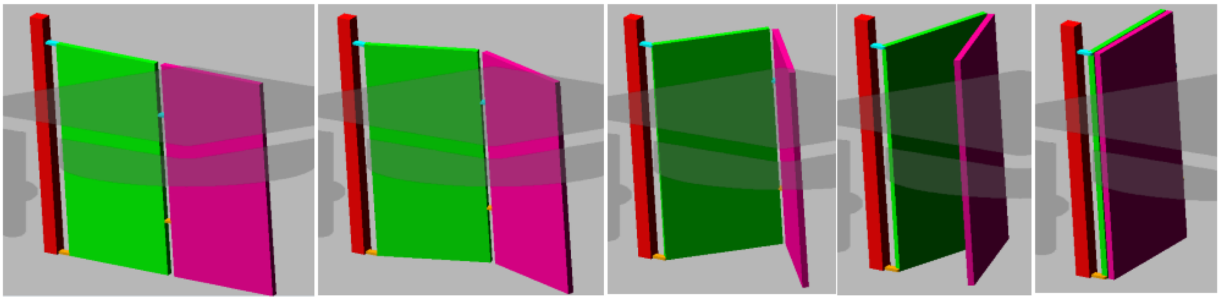

Figure 49 Bi-folding gate opening simulation (Adams View-Student Edition)

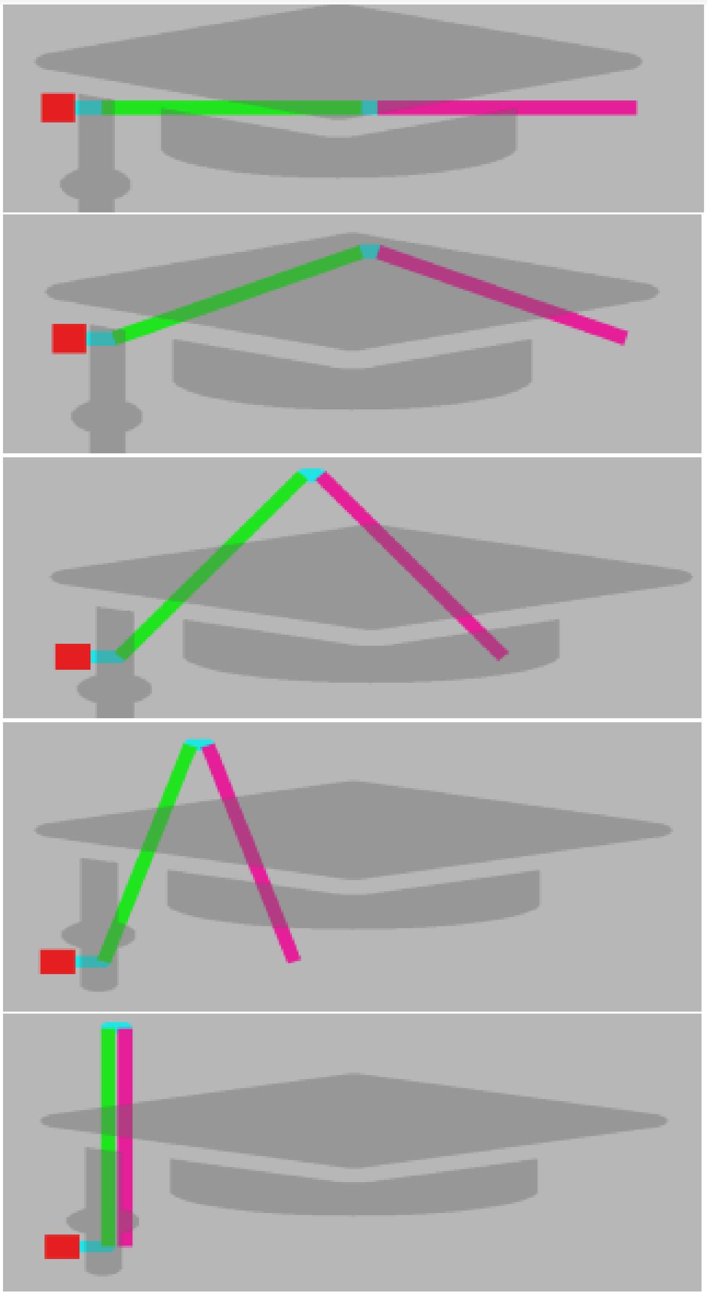

Figure 50 Bi-folding gate opening simulation - Top view (Adams View-Student Edition)

5 Results and Conclusions

The bi-folding gate opening mechanism is a complex system requiring precise engineering and design to ensure smooth operation. The pivot joint, which is located at the top and bottom edge of the gate, is one of the crucial parts of this system. The torque applied to the pivot joints while it is in use is one of the crucial elements that affect how well it performs. It is essential to make sure the joint can handle the forces and stresses involved in the movement of the gate since the torque is a measurement of the twisting force that operates on the joint. To simulate the gate's motion and determine the torque acting on the pivot joint, the appropriate simulation techniques are used. In the *Figure 51* can be seen the results for the torque.

The diagram represents the torque values of the top and bottom pivot joints of the bi-folding gate opening mechanism over a 20-second time period. The y-axis shows the torque values in N*mm, while the x-axis represents the time in seconds.

The two lines on the graph represent the torque values for the top and bottom pivot joints. The lines show the torque values as the gate is opening, and the maximum torque value reached is 120000 Nmm or 120 Nm.

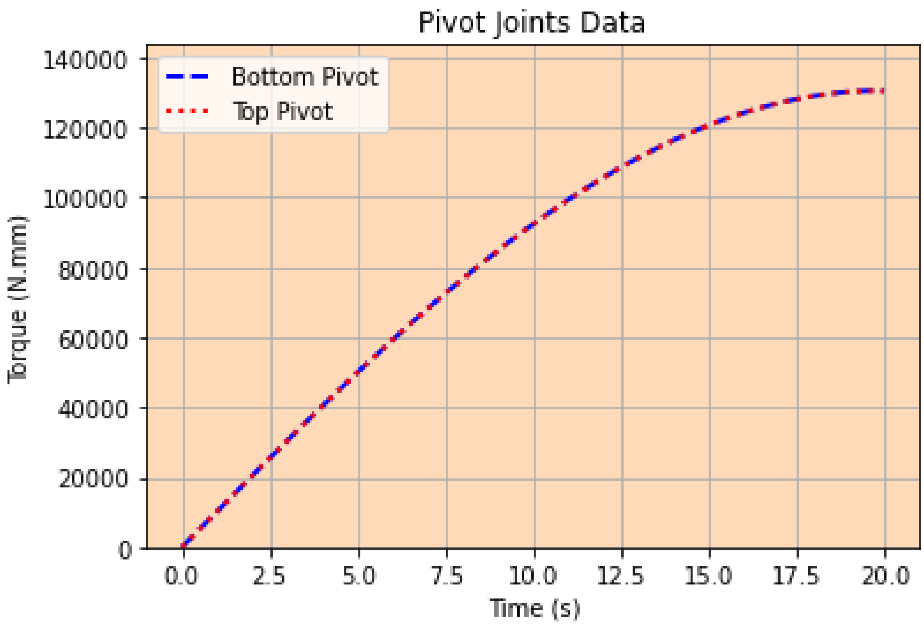

Figure 51 Torque measurements for Pivots (Source-Adams View)

The rotation angle of the bi-folding gate opening mechanism is another critical factor in its operation. The rotation angle is the amount of rotation that the gate undergoes during its opening and closing motion.

The Figure 52 shows a pie chart that represents the rotation angle of the gate during its opening motion. The chart displays a single section that covers 90 degrees, which represents the total rotation angle of the pivot joints and first panel during its opening motion, and the second pie chart represents the negative direction of the second panel, which means that the angle is the same 90 degrees but only in the opposite direction. Knowing the opening angle of the bi-folding gate mechanism is essential for understanding its functionality and performance. The opening angle of the gate determines the amount of space it covers when it is fully opened, which is an important consideration for many applications.

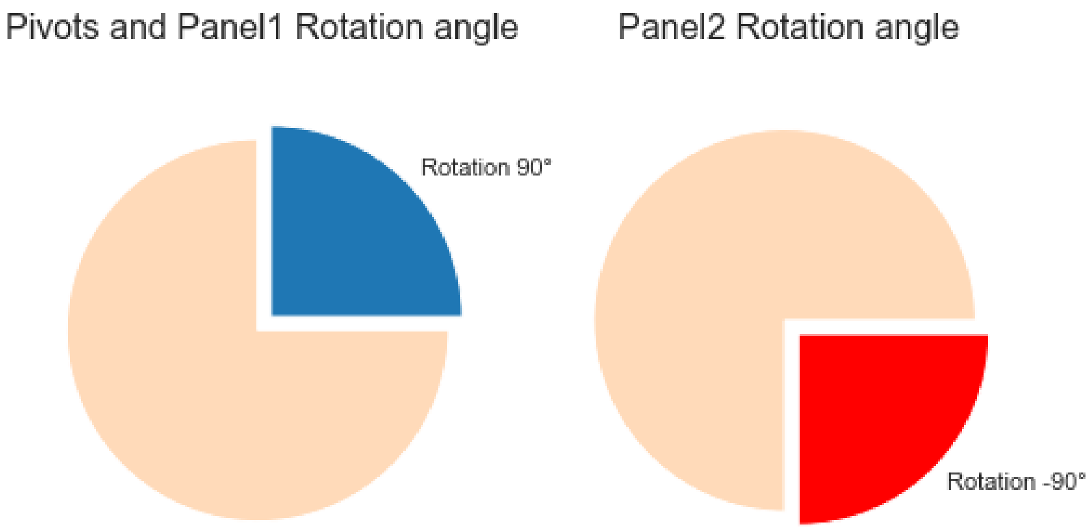

Figure 52 Rotation angle measurements for Pivot joints, Panel1 and Panel2 (Source-Adams View)

In the *Figure 53* the angular velocities of the joints were analyzed. The plot showed that the top and bottom pivots had an angular velocity of 4.5, while the hinges had an angular velocity of -4.5. This indicates that the pivots and hinges are rotating in opposite directions.

Angular velocity is an important parameter to consider in the analysis of a bi-folding gate mechanism. It refers to the rate of change of the angle of rotation of an object with respect to time. In this mechanism, the angular velocity of the joints determines the speed and direction of the gate movement. The values of the angular velocities of the pivots and hinges in the third plot provide crucial information for the design and optimization of the bi-folding gate mechanism.

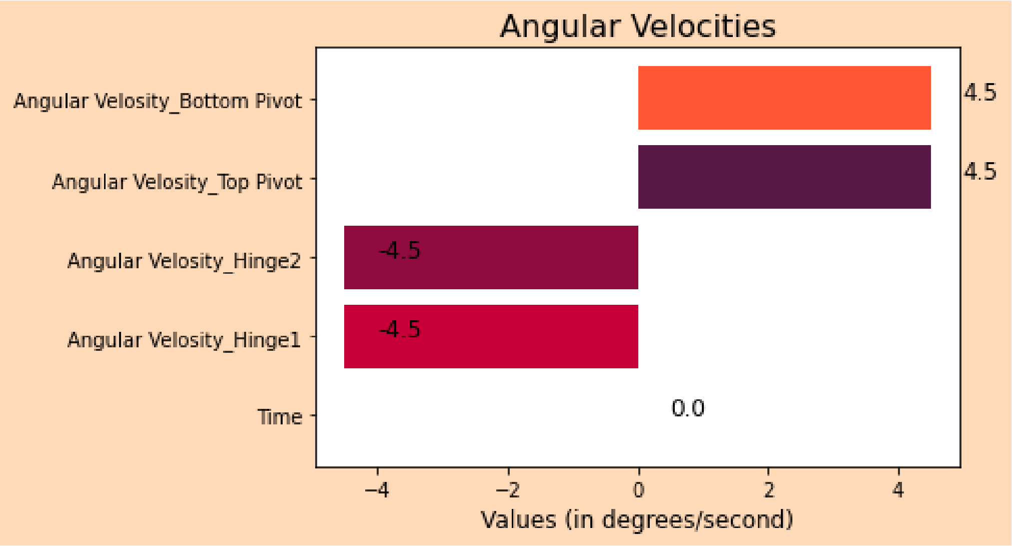

Figure 53 Angular Velocities measurements for Joints (Source-Adams View)

In conclusion, the design of the gate presented in this thesis is a challenging and complex process, requiring careful consideration of numerous elements such as the gate's size, materials, and mechanism. The gate consists of four panels, each measuring 1.8x0.94x0.05m and made of high-quality stainless steel 18/8 material. The area that the gate is covering is 4x2m which means 8 m^2. The half of the gate mechanism includes a linear motor actuator, two hinges, a top pivot joint, a bottom pivot point, and leaf and column joints. The use of Optical Feedback Linear Actuators enabled precise control of the gate's movement, resulting in an angular velocity of 4.5m/s and an opening time of 20s.

The final product, weighing in at 250.4kg for the panels and 13.8kg for the whole kit, is not only functional but also visually appealing. This project highlights the importance of 3D CAD software in modern design, which allows for the creation and visualization of complex structures before construction.

Overall, the design of this gate demonstrates the power of combining advanced technology with careful planning and consideration. The process may be lengthy and challenging, but the end result is a beautiful and functional piece of architecture. This project also showcases the potential for similar design processes to be utilized in other fields, such as building construction and industrial design. The possibilities are endless when it comes to combining innovative technology with careful planning and execution.

6 Summary

In the field of mechanical engineering, mechanics is crucial. The study of forces acting on bodies and the motion that results is known as mechanics. Engineering mechanics is the foundation of or a strength in several engineering disciplines, including mechanical, civil, aeronautical, industrial, and material engineering. Because of mechanics, this technology century has gotten simpler for humans. Engineering mechanics' main goal is to design and analyze systems that are both stationary and in motion. The support and loading methods used for beams are known as their service conditions.

The widespread use of mechanical systems around the world is an important point to emphasize. The usage of mechanical systems in everything from transportation to production to everyday objects makes them a crucial component of modern society. Mechanical systems have completely changed the way we work and live, and it is crucial to acknowledge their significance in the construction sector as well.

Gates play a significant role in the construction industry since they are both useful and eye-catching components of a building. Bi-folding gates, in particular, offer several benefits that make them a popular choice in both residential and commercial settings. One of the primary advantages of bi-folding gates is their space-saving design, which allows for maximum use of available space. This makes them an excellent choice for areas where space is limited or where there are access restrictions. Bi-folding gates give an aesthetic appeal that can improve a building's overall appearance and feel in addition to its functional advantages. They may match any architectural style or design aesthetic due to the variety of materials, finishes, and colors that are offered.

Furthermore, bi-folding gates are commonly used in various industries and applications. For instance, they are popular in residential settings as a way to improve security and privacy, while also enhancing the curb appeal of the property. In commercial and industrial settings, they are often used as a way to control access to the premises, improve safety and security, and increase efficiency.

For bi-folding gates to be successfully used in construction, the engineering designing procedure is very important. To ensure that the gates are practical, secure, long-lasting, and fulfill the particular needs of the application, proper design is required.

The design process of a bi-folding gate is looked at in this master's thesis to show the different factors that must be taken into consideration when creating such gates. The dimensions, which are essential in determining the size and shape of the gate overall, are the first step in the design process for a bi-folding gate.

Accurate measurements of the opening where the gate will be mounted are necessary before the design process for a bi-folding gate can start. This is due to the fact that the size of the opening will define the gate's maximum size, which will affect the materials utilized, the gate's weight, and the motor type needed to run it. Accurate measurements would help designers avoid mistakes like designing a gate that is either too small or too big for the opening, which can cause instability, safety concerns, and even gate failure.

After determining the dimensions, the choice of materials is another important factor to consider. The materials used in the construction of the gate must be strong enough to withstand the forces acting upon it, while also being lightweight and durable. The selection of materials will depend on factors such as the application, the environment in which the gate will be used, and the desired level of security.

Once the materials have been chosen, calculations must be performed to determine the mass and weight of the gate. This is essential to ensure that the gate is stable and can be operated safely. Furthermore, calculations must be made to determine the forces acting upon the gate, including torque and angular velocity. These calculations are critical in selecting the appropriate motor for the gate, which must be powerful enough to operate the gate smoothly and efficiently.

For the gate to perform effectively, choosing the right motor is also crucial. This thesis attempts to offer insight into the different elements that must be taken into account in the design of mechanical systems by investigating the design process of a bi-folding gate.

Once all the necessary calculations have been performed, the next step in the design process of a bi-folding gate is to create a 3D model of the gate. This is where 3D CAD (Computer-Aided Design) software comes into play.

Designers may produce accurate, realistic, and detailed models of their concepts using 3D CAD software. It offers an effective toolkit for producing complex mechanical designs, such as the bi-folding gate. Designers can see their creations in three dimensions using 3D CAD software, simulate how they will act in different scenarios, and make quick changes.

In today's world, 3D CAD software has revolutionized the mechanical design industry, making it far easier to create, modify, and test designs than ever before. This has resulted in faster design cycles, more accurate designs, and ultimately, better products.

The 3D CAD program of choice for this master's thesis was Autodesk Inventor. The bi-folding gate is one of the many mechanical designs that can be created with this program. The gate was designed in 3D using Autodesk Inventor, and all the necessary components—including the motor, top pivot joint, bottom pivot joint, leaf joint, column joint, hinges, and panels were integrated.

Once the 3D model of the bi-folding gate has been created, the next step is to simulate its operation using specialized software. In this thesis, Adams View was used for simulation, which is a user-friendly software designed for multi body dynamics simulations.

The bi-folding gate model is imported into Adams View for the simulation, and the appropriate angular velocity is applied to the gate's motion. Following that, the simulation will forecast how the gate will behave, enabling designers to test the gate's functionality under different situations.

It is crucial to ensure that each part of the gate is connected with proper joints and has the correct motion applied to it during the simulation. This will ensure that the gate operates correctly and that all the necessary components are working as intended.

Adams View allows designers to simulate the operation of the gate, including how it will move, the forces it will encounter, and how it will respond to external loads. This provides designers with valuable insights into how the gate will behave in the real world and helps them to refine the design to make it safer, more efficient, and more reliable.

In the bi-folding gate design, there are four panels that are arranged in pairs, with one pair next to the other. To enable the panels to rotate, pivots are added at the top and bottom of the panel that is next to the supporting beam, which also supports the rotation movement. The panels are also connected by hinges, which play a critical role in ensuring the gate operates smoothly.

In the simulation process, the panels are shown to rotate when a motor is applied to the gate. As the first panel begins to rotate, the column joint pushes the leaf joint, and the second panel rotates in the opposite direction (-90 degrees). This process continues until all four panels have rotated, and the gate is fully open or closed, depending on the desired configuration.

The simulation process provides designers with valuable insights into how the gate operates, including how the panels rotate and the forces that act on the gate's various components. This allows designers to make necessary adjustments to the design to ensure that the gate operates safely and efficiently. When a motor is supplied to the gate, the bi-folding gate works by using pivots and hinges to allow the panels to revolve. The simulation procedure offers insightful information about the motion of the gate and the forces acting on its various parts, enabling designers to improve the design to make sure the gate runs securely and effectively.

The ability to analyze and assess the outcomes of a design in a virtual environment is one of the key advantages of employing simulation software in the mechanical design process. Prior to performing any physical testing or prototyping, this can assist in identifying potential problems or areas of concern.

Gates are a common design element in mechanical engineering, with uses ranging from simple home gates to complex industrial gates. A thorough understanding of mechanical concepts, materials science, and manufacturing processes is necessary for the design and production of gates.

It is the responsibility of mechanical engineers to design the finest possible mechanisms for each application, taking into account elements like robustness, safety, dependability, and affordability. They must also be skilled at using contemporary and advanced tools like simulation software and 3D CAD modeling to solve issues that develop during the design and building process.

Ultimately, the goal of mechanical engineering is to create functional and efficient mechanisms that improve the quality of life for people and advance various industries. The design and construction of gates are just one example of how mechanical engineering principles and techniques can be applied to solve complex problems and create innovative solutions.

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DECLARATION

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Appendix

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