Engineering Strategies and Practice

University of Toronto
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Executive Summary

The Toronto Worker's Health and Safety Legal Clinic has reported the need for a new design for curtain walls in high-rise buildings. Dr. Michael Grossman has requested that the University of Toronto design a system that makes curtain walls safer. The stakeholders include office workers who wish to not have the design hinder their work and the minister of municipal affairs and housing. Stakeholders are directly affected by the engineering design for the Toronto Worker's Health and Safety Legal Clinic. After applying the black box method, a method to identify the inputs and outputs of the design, the functional basis for this design was to secure mass, particularly the individuals within. Applying pairwise comparison and thorough team discussion, the top two objectives were determined to be safety and durability. Consequently, the design shall follow the National Building Code of Canada. The safety of the design, as measured by the Canadian Building Code, cannot be compromised.

The final design was decided to be "Window Guard". It contains features that enhance the safety of curtain walls. These are steel bars attached to the frames and corrosion coupons are used. Corrosion tags (small sheets of metal) monitor the average levels of corrosion for the curtain wall frame. When placed on the frame for a given time and sent back for inspection, it determines how long the frame is kept before it needs to be replaced. The steel bars make it difficult to come in contact with the curtain wall and reduce unintended loadings in the interior of the structure.

Before the design can be implemented, a building permit must be obtained to make the alterations in the curtain wall. This process involves checking building and fire codes as well as a review of the mechanical plans for the design. The objectives to be tested for this design are durability, safety and functionality. To test durability the windows will need to pass the safety ball drop test. The production of the steel bars (resulting in slag wastes) affects the environment, but is mitigated by recycling processes. The human factors for the design are team, psychological, and physical. Various costs are involved for the system's execution, such as the purchasing of the steel bars and corrosion coupons. The main social impact of this design is the effect it has on the safety of the society. The design lessens the dangers of curtain walls of high-rise buildings and reduces impacts of factors that affect the failure of a curtain wall.

The final presentation of the design will be on April 24, in which various diagrams will be shown.

1.0 Problem Requirements

The client Dr. Michael Grossman, part of the Toronto Worker's Health and Safety Legal Clinic, has requested an engineering design to help secure mass more effectively in high-rise buildings in order to uphold the main factors of safety for the workplace.

1.1 Problem Statement

The Toronto Worker's Health and Safety Legal Clinic, or the TWHSLC has been providing legal advice and free information to members of the society with low incomes [1]. They have been encouraging health and safety in workplaces and assisting those who do not have unionized protection [1]. The TWHSLC mainly specializes in representing individuals who have been punished for their actions in regards to the health and safety of their workplace [1]. A specific case that was examined by the clinic, tied in well with workplace safety. The case was on the death of a lawyer who fell from a tall office building in an attempt to test the window's strength [2]. However, the window gave in and this resulted in the violations of workplace safety. The client, Dr Michael Grossman, has tasked the group to search for ways to reduce these recurring incidents. In particular, focusing on the development of systems and designs, which will promote the safety of curtain walls within the workforce.

The curtain wall from the incident examined by the client was established to be unsafe. It is the poor design in the window (frame, glass, where it connects etc.) and the glass falling off easily [2] that needs to be addressed. There is a need for a design that enhances safety and secures mass for curtain walls found within high rise buildings. The design needs to ensure that strength and safety are met. In addition, it should be able to resolve the potential hazards and dangers of curtain walls and meet the Ontario building codes.

1.2 Identification of Stakeholders

Stakeholders are individuals or groups that will be affected by the design. The following (Table 1) displays possible stakeholders and how their interests affect the design.

Table 1: Table of stakeholders with interest and possible impacts on the design

Stakeholder:	**Interests:**	**Possible impact:**
Architects - individuals or firms, design and oversee building development [3]	- Taking commissions and creating artistic buildings. [3]	-Design limits boundary of their creativity.[4] - Affects safety factor of objectives and possible dimensional constraints
Companies and corporations (and its CEO's, office workers, etc.)	- Providing goods and/or services to their customers [5] - To contribute to the economy and produce a profit [5]	- Design may hinder their employees effectiveness to work [6] - Impacts objective for being safe and the function of securing them within the building
Construction companies (and its workers, managers etc.)	- Are interested in being hired by a client and architect to construct the project assigned [7]	- Each company has its own strict project budget, accepting designs as low cost and simple as possible [8] - Impacts unintended function of cost
Government -Ministry of municipal affairs and housing	- Encourage safety in the communities [9]	- Are interested in safety for the community [10] - Impacts objective of safety
Society - Pedestrians passing by the buildings	- Concerned with their own safety and the safety of their environment	- Concern of not being underneath falling windows affects the objective of safety

1.3 Functions

1.3.1 Functional Basis

The team used the black box method, a technique where the input and outputs of the design are identified, to establish the functional basis.
The functionality of this design is to **secure mass.**

1.3.2 Primary Functions

The client wants a design that will perform the following tasks:

- Secure mass inside and outside the building
- Communicate information on factors that compromise curtain wall safety

1.3.3 Secondary Functions

The following function of the design result from or enable the primary functions:

- Prevent window from breaking or coming loose from its frame.

1.3.4 Unintended Functions

The following functions are not intended but may arise as the design is implemented:

- Increase the cost
- Decrease the aesthetic appeal (of the architect's design)

1.4 Objectives

- **Durable -** should be resistant to environmental damage
    - Strength- pass safety ball drop test in accordance with CSA A440-00 [11]

- **Safe -** should not compromise safety of windows
    - Design is stable - pass a cyclic loading test [12]
    - Predict and warn against causes of curtain wall failure

- **Functionality -** should allow a passage of light from exterior to interior
    - Able to pass allowable UV rays (below UV index 2) according to CCS [13]

- **Cost effective -** should be competitive in the market
    - Windows should still cost around $15/ft^2 [14]

- **Easily operable -** should be easy to operate by workers in buildings

- Pass ease of operation test in accordance with CSA A440-00 Table 9 [11]

1.5 Constraints

- Shall abide by sections 9.8.8.1, 9.7.2, 9.7.5, and 9.7.4 of the National Building Code of Canada. [15]
- Shall abide by sections 4.4.4.1., 3.7.2, and 9.7.2.3 of the Ontario building code [16]
- Shall abide by section 9.8.3.4 of the Fire Protection And Prevention Act, 1997 [39]

1.6 Service Environment

Given that the client highlights health and safety factors for the design, the service environment is mostly focused on elevated spaces in buildings. These areas can have varying sizes and characteristics such as the ones listed.

1.6.1 Physical Environment

Physical environment describes the surroundings of where the design is located (Table 2)

Table 2: Physical Environment

Conditions	**Canada**
Average Temperature (Indoors)	20 - 21 °C (room temperature) [17]
Average Temperature (Outdoor)	Winter: (-1.3) - (-7.9) °C Summer: 17.6 - 26.5 °C Fall: 7.2 - 14.2 °C Spring: 3.5 - 11.5 °C [18]
Atmospheric Pressure	101.3 KPa [19]
Noise Level	88.2 Db (Based on a 12 hour workshift) [20]
Humidity	20-29 (Comfortable humidity) [20] (See Appendix E)
Average Wind Speeds (Some Examples)	(See Appendix G) [21]

1.6.2 Living Environment

Humans:

- Various workers:
  Examples:
    - Office workers
    - Clients

Non-Human Species:

Examples:

- Rodents, insects, arachnids
- Mold on the building
- Household plants

1.6.3 Virtual Environment

- Probable use of Wifi in office rooms
- Cellular networks available
- Electrical outlets 120V, 60Hz [22]
- Use of personal computers
    - Microsoft Windows, iOS, Linux

1.7 Client Ethics and Values

The client's primary objective is the health and safety of workers. Thus, the design must avoid solutions that compromise workers' health or safety in any way. It should also give equal priority to both preventing solutions that may create a safer environment but have negative long term effects on health. All precautions should be taken when testing the safety of the design, although this may add to the overall cost of the project.

2.0 Detailed Design

This design "Window Guard" is a system of precautions made to prevent the failure of curtain walls. The design focuses on the maintenance of the longevity of the curtain wall. There are two main components of the design. These aspects are made to measure corrosion, and prevent unintended loadings. The aesthetics of the window and fitting will depend on the architect.

The first aspect of the design "Window Guard" are corrosion tags. The design implements corrosion tags that monitor the average rate of corrosion for the window fittings in the surrounding area. These tags are metal sheets that are close to the material that the fittings are

made of. They are small enough to not obscure the span of the window. This is used as an indicator of when the frames will need to be changed. The steel coupons are distributed by commercial vendors who determine the original weight in their laboratory before installing them onto the window frames [26]. Usually, one coupon is needed per side of the building [26]. After 90 days, the coupons are removed by the vendors and taken back to the lab to be cleaned and weighed again. When a numerical value of corrosion rate is determined, they indicate the building owners when the frames will need to be changed [26].

Lastly, the design implements steel bars that prevent large sized unintended loadings from increasing the likelihood of failure for the curtain wall. The bars make it so that it is not possible to run into the window. The dimensions of the guard depend on the size of the window itself, so it varies from building to building. It will be placed 85cm from the ground since that is the average height of an adult's center of gravity [27][28]. The guard will span the width of the window and be able to withstand 1600 pounds of force (average tackle of a football player from 40 yards distance in 4.56 seconds)[29]. This ensures that an average human would not be able to break the metal bar with the force of their body. Hot rolled steel will be used as the material of the bars. They have a minimum yield stress of 36000 pounds per square inch (psi) [30]; this is much greater than the tackle of a human.

The corrosion tags will account for corrosion of the fittings and decide whether fittings need to be replaced, making sure they do not loosen. Therefore, secondary function is met. The bars can prevent people from lunging through the window whether accidently or intentionally. All these parts in the system meet the functional basis of our design, which is to secure mass. These aspects of the design will reinforce the "design for safety" factors (durability and corrosion inspection to maintain strength) for the curtain wall.

The design best meets all of the key objectives, which are durability, safety and functionality. The objective of functionality was considered to promote solutions that did not reduce the performance of windows as a trade off to safety. This is achieved by the design as it still functions as a window, and is transparent. The design achieves durability through the use of a metal bar installed across the windows. This reduces the risk of damaging the windows due to unexpected loads from the interior of the building. The most important objective, safety, is addressed through components of the design. The corrosion tags allow prediction of when window fittings will fail preventing unexpected fitting failure. The metal bar across the windows provides a hindrance to accidental leaning onto windows making them safer. The design also utilizes patents and therefore the building manager will have to pay for rights in order to use the corrosion coupons. The design must adhere to strict regulations and standards set forth by the government and standard making agencies. The design is in compliance with all building and fire codes stated in the Ontario Building Code, National Building Code, and The Fire Protection and Prevention act. The design not only maintains safety of the workplace but enhances it as well.

The following is a brief image of the design:

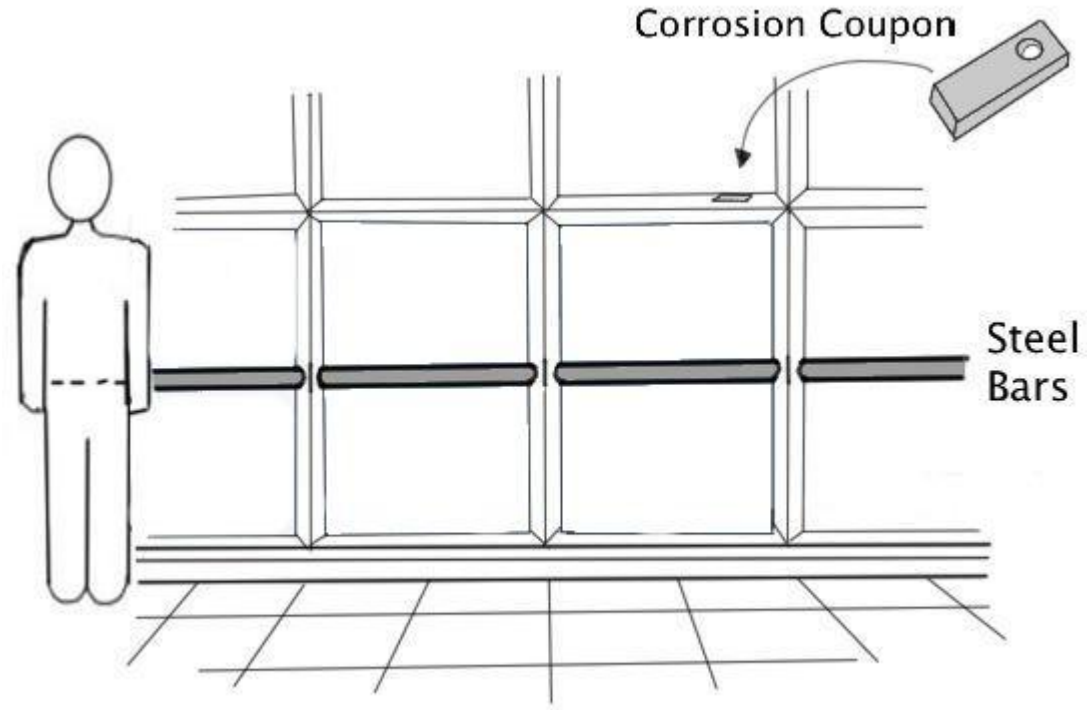

Figure 1: Brief visual of the final design
(refer to appendix B for a closer look at the design)

2.1. Regulations, Standards, and Intellectual Property

Our design must abide by specific codes and regulations. In our design we use corrosion coupons to measure the average rate of corrosion on a specific window. There are no standard sizes for corrosion coupons as their dimensions depend on the size on the window their being implemented on.

Table 3: Patents, regulations and codes for the design

Patent, Regulation or Code	**Explanation**
National building code 9.7.2 [15]	The window must abide by CAN/CSA-A440 and CAN/CSA-A440.1 of the standards for window, Door, and Skylight Installation.[15]
National building code 9.7.4 [15]	"The window must be using mpound used to seal the glass component of a factory-sealed double-glazed unit to the sash component shall be compatible with the sealing compound used to edge seal the glass component."[15]
Patent-CN203101237 U- Corrosion coupons [32*]	Corrosion coupons are used to determine the rate of corrosion of the windows. These corrosion coupons are a patented product and there will be a need to pay to use them.[32]
Laminated glass standard- ASTM C1172[33*]	"The glass used for the windows must be laminated in compliance with this standard.Depending on the number, thickness and the number and thickness of interlayers, the glass shall be laminated accordingly for applications including but not limited to safety security."[33]
Section 9.8.3.4 of the Fire Protection And Prevention Act, 1997[39]	"The window is not less than 1060 mm high and 560 mm wide, the sill of the window is not more than 900 mm above the inside floor, the sill of the window is not less than 1 m and not more than 5 m above the adjacent ground level."[39]

2.2. Testing

The top objectives to be tested for this design are durability, safety and functionality.

To test **durability** the windows will need to pass the safety ball drop test which is a regular requirement of curtain walls[34]. This test requires dropping a 2.3kg steel ball at a height ranging from 1.5-9m onto the glass. The design is laminated glass, used by most curtain walls[35]. The glass is expected to not fracture at drop heights below 48 inches[34].

To measure the **safety**, a cyclic loading test must be used[36]. A wind loading is applied to the specimen to test its resistance [36]. During the loading tests, deformation should not exceed 20mm or 1/180 of the specimens total length (the smaller value applies)[36]. After 15 minutes, the specimen should recover 95%, and should not show signs of plastic deformation or shear on the material [36].

To test the design's **functionality**, the light emitted through the windows will be measured to see what wavelengths are being reflected. The light that passes through will be measured with a spectroscope. The window will reflect wavelengths below a UV index of 2[13].

2.3. Market Issues

This design is not intended to be manufactured and distributed, as the client is not planning to sell this design solution. Therefore, market issues do not apply.

2.4. Implementation Requirements

There are several requirements needed in order for the implementation of the design to be successful.

In order for this design to be implemented, a building permit must be obtained to proceed with the alterations for the curtain wall [37]. This is required due to the guard that must be installed in the interior of the structure.

The steps to obtain a building permit are:

- Review of the zoning and building code [37].
    - These steps involve the review of acts and codes such as the planning act and ontario building code[37].
    - A relevant code would be 9.7.6.1. pertaining to the installation of windows, doors and skylights from the Building code act, 1992[38].

- Review of the mechanical plan and fire prevention examinations[37].

    - This is where the design is checked to see if it satisfies the ontario building, and fire codes[37].
    - The implementation of the design must comply with section 2.3 in the Ontario fire code regarding refurbished buildings[39].

- Wait for the results of the process, seeing if the permit was obtained[37].

Table 4: An outline of the basic resources needed. A more detailed outline will be in section 2.8 (economics).

Component/Resource	**Price**
Corrosion coupons	$175[40]
Steel bars (Hot rolled)	$2-$4 per kilogram[43]
Workers (carpenters)	$20.96 per hour per worker[44]

The implementation of this design requires the purchase of the corrosion tags and the bars that will be used as the guard. The installation of the product would require workers to install the corrosion tags. After the implementation of the design, inspectors are needed to ensure the quality of installation is adequate. Because the design is targeted for high-rise buildings, pedestrians must be informed of potential hazards from construction of the curtain wall design. The workers inside the building area must also be cleared for proper installation of the design.

2.5. Life Cycle and Environmental Impact

Engineering Strategies and Practice

The following displays the process in creating the design, and the impacts each stage has on the environment.

Figure 2:Life cycle of proposed design

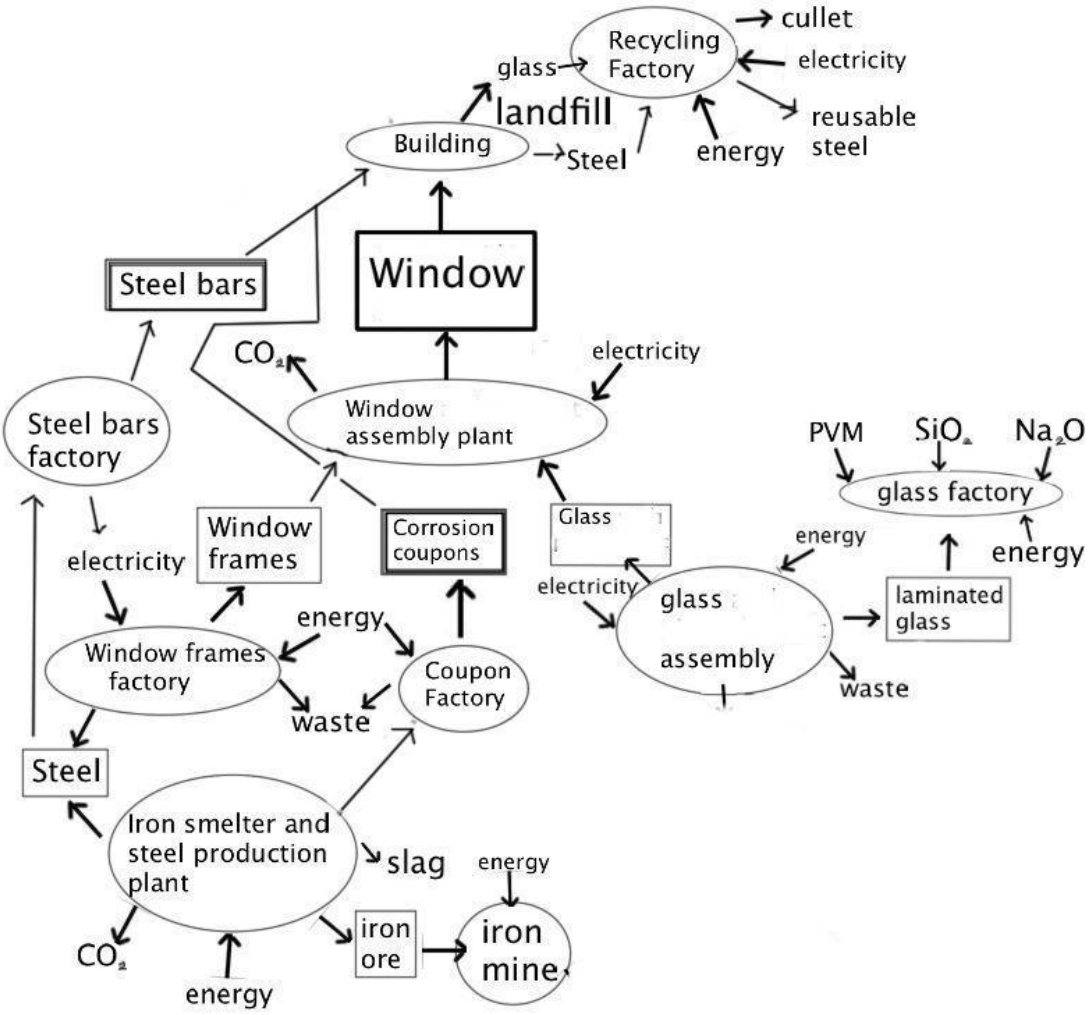

Table 5: Environmental impacts and mitigation

Life stages	Negative impact	Mitigation

Iron smelter and steel production for the frames, corrosion coupons and bars	- Large amounts of slag waste is disposed when separated from molten iron [45]	- Slag residual is being reduced by being used in combination with other materials to make cement[46]
Laminated glass and steel disposal	- Glass in general takes a long time to decompose, and when put in landfill, it occupies a lot of space [45] - Steel also takes up large amounts of space[47]	- Recycling programs are used to create cullet from disposed glass, which can be reused in future products[45] - Steel (also known as scrap) is recycled and reused (melted down)[47]

2.6. Human Factors

The following displays the human factors the design addresses and gives examples of each (Table 3)

Table 6: Human factors

Human Factor	**How The Design Addresses The Human Factor**
Physical	● **Material** of the steel bars allows for entities to be contained within the curtain wall
Psychological	● **Informs** the building owner and inhabitants of possible hazards from the window
Team	● Allows for quick **communication** for the condition of the curtain wall by sending the corrosion tags for analysis ○ Allows for the estimation of the frame lifespan ● Changes the **communication** patterns of individuals inside the building ○ When the frames will need to be changed from corrosion damages

2.7. Social Impact

The main social impact of this design is the effect it has on the safety of the society. The design

lessens the dangers of curtain walls of high-rise buildings and reduces the negative impact of falling windows in areas with people. The design increases the positive impacts of a safer environment, for it alerts the possibility of danger before it occurs (corrosion). The design also decreases the risks and hazards by increasing durability and it prevents people from lunging onto the glass. It increases the safety of the society, which is the goal of the client.

This design, with its social impact, affects both the stakeholders of society and companies (office workers, managers etc.). The design alerts them beforehand of the dangers so they will not attempt to run into the glass (the bar will be uncomfortable to run into). The glass will also be strong enough to reduce failure and thus their safety is ensured.

2.8. Economics

These are costs required for the implementation of the design.

Table 7: Costs required for the design

Component	Capital cost	Ongoing cost	Disposal cost	External cost	Total
Corrosion coupons	$175[40]		scrap metal is sold		$175
Safety bars	$2-$4 per kg[43]		scrap metal is sold		$2-$4 per kg
Workers (carpenters)		$20.96 per hour per worker[44]			$20.96x total time of constuction x # of workers

3.0 Updated Project Management Plan

The Final Design Specification(FDS) will be completed on April the 2nd (internal deadline). This document will describe in detail, the proposed design. Finally, it will be submitted on Friday, April the 4th,(milestone) and the final presentation to the client will be on April the 24th.

4.0 Conclusion/Recommendation

The final design to be implemented is "Window Guard". There are mainly two parts in this final design: corrosion tags and steel bars. Through this design, safety of the curtain wall has been greatly improved. There are many factors that need to be considered when implementing this design. This design needs to pass several tests to make sure it is durable and safe. Finally, there are many economic costs for the steel bars and corrosion coupons.

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Appendices

Appendix A

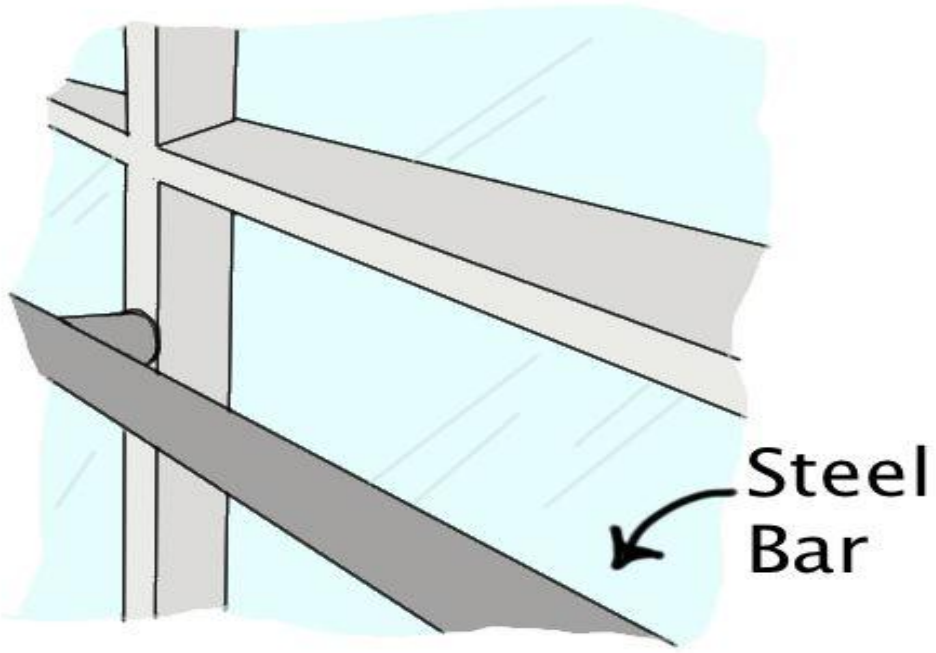

Figure A1: Steel bar diagram

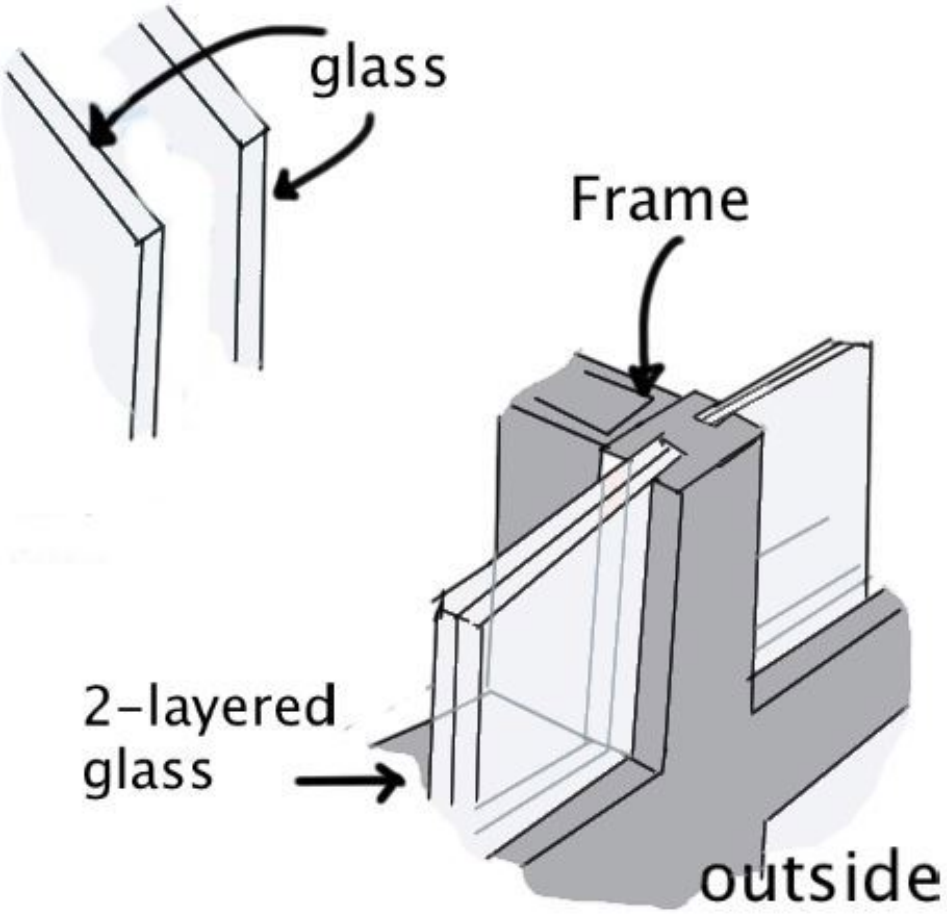

Figure A2: A closer look at the frames and insertion of the glass

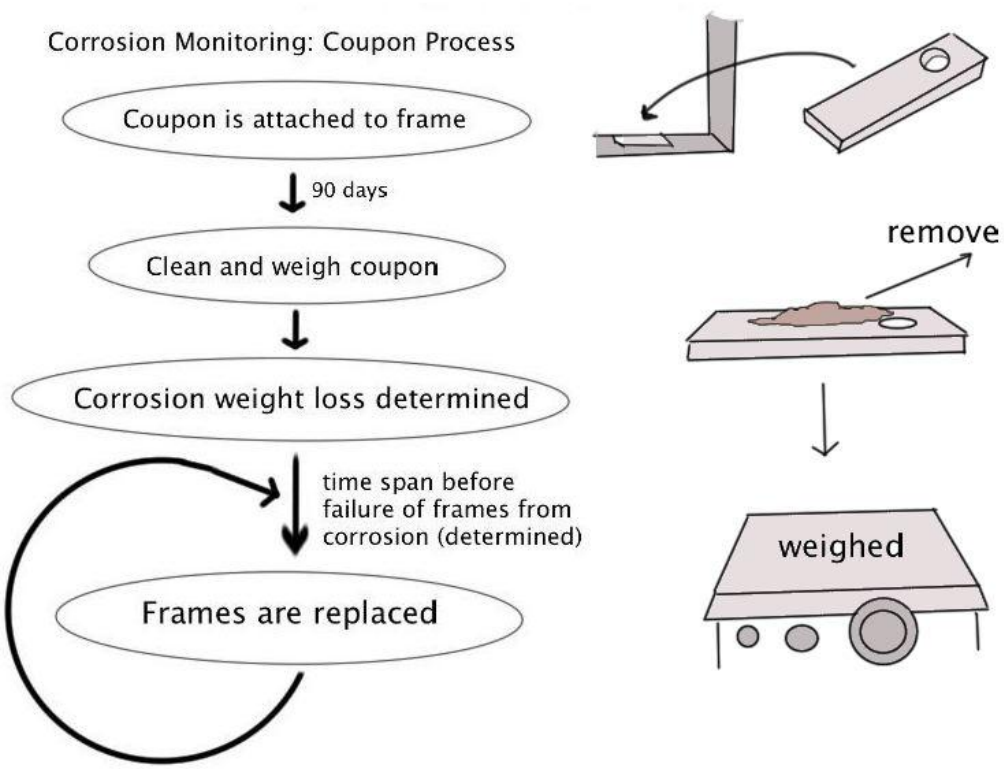

Figure A
3: Corrosion Coupon process diagram