SCAN-BIM-FEA A STRUCTURAL INTEGRITY INVESTIGATION IN A CURTAIN WALL

By

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ABSTRACT

GOUREE PRAKASH PATIL. SCAN-BIM-FEA A structural integrity investigation in a curtain wall.
(Under the direction of Dr. DON CHEN)

Evaluating the structural integrity of curtain walls during the life cycle of a building project can assist architects in developing better designs, inform manufacturers on the needs to produce stronger building elements, help contractors establish better installation methods, and allow facilities managers make informed maintenance decisions. Data obtained and recorded from manual inspections is inaccurate, insufficient and unreliable, and thus an automated process is needed. A case study included in this paper presents the effort to develop an automated process to identify a seamless association between three different technologies used to evaluate structural integrity specifically, deformities as the focus of this study, in building elements. A curtain wall component of an existing building was investigated in this study. As more buildings incorporate daylighting, storefront and curtain wall construction has become a much larger portion of the building envelope. Although Finite Element Analysis (FEA) for structural analysis has been studied with regards to its use in conjunction with Building Information Modeling (BIM), curtain wall analysis has been limited. The study included the steps as follows: A Light Detection and Ranging (LiDAR) scans were obtained and then a 3D as-built model was created from a set of point clouds, and further analysis was completed using FEA to potentially identify any structural issues. The combination of scan-to-BIM to FEA was used to showcase the potential of software packages already in use in the design and construction industry. To obtain exact geometry of the wall, 3D laser scanning, using a Faro Focus3D Lidar scanner was used to accelerate the data collection process. SCENE software was then used to automatically register the multiple scans to develop an as-built model of the curtain wall. Lastly, FEA on the BIM model of the curtain wall was completed. When conducting FEA, the model is split into minute elements which act as a prototype on which the forces are applied, and deformation and distress is calculated accordingly. This deformation and distress are developed on one singular element which represents the deformation of the entire wall system. SOLIDWORKS structural analysis software was used for FEA. The results from FEA informs of deformities in the structure and shows the amount of load the structure can support before there is a risk of structural damage. This harmonious three-step technique quickens the entire process of identifying the risks to a building element and the more prevalent use for these commonly used software packages would be beneficial to all the stakeholders involved in the life cycle of the building, including professionals in design, construction, and facilities management (FM).

Keywords: Laser scanning, LiDAR, Finite Element Analysis, as-built BIM.

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CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION AND BACKGROUND

Glass panels are extensively used in today's day and age in the curtain wall system bifurcating the interior from the exterior of the building. At the same time, they provide transparency and clear sight of the outdoors to the occupants. While aesthetically they are generally more appealing (especially in a commercial front) than other building façade types (Kwon et al., 2004), their need has increased over time. Structurally glazed with structural sealant on either all four sides or two sides with two edges compressed along the transom, and a weathering sealant on the outside edge, they prove to be quite robust. However, it's structural reputation cannot be completely trusted (Kwon et al., 2004). Architects and engineers are combating difficulty with the glass design process, due to the incompetency to perform failure prediction analysis (So & Chan, 1996). Therefore, it is important to pay more attention to the structural safety in construction, which is the root cause of the numerous accidents in the industry(Epaarachchi, Stewart, & Rosowsky, 2002; Hu & Zhang, 2011; Puente, Azkune, & Insausti, 2007). Hence the main goal of this study was to integrate technologies to determine the structural integrity especially defects in a glass curtain wall panels to reduce the risks that might be encountered during the life cycle of a building and avoid failure.

The failure of a curtain wall's structure can lead to glass fragments all over the street leading to fatal accidents, commonly encountered in a lot of buildings. Apart from its heavy dead load, the curtain wall system is mostly attacked by strong wind loads in its normal life. Due to the brittle nature of glass, under strong dead load and wind action, the glass panels deflect considerably so much that there can be breakage without any warning (So & Chan, 1996). Therefore, being able to predict the deformities and discrepancies in the structural as-built and as designed model through structural analysis can aid in repairs and maintenance of the curtain wall system. Understanding the inconsistencies beforehand will assist in taking remedial actions on time, saving a lot of money specially allocated for contingencies. The necessity for precise as-built data is also essential for operation and maintenance (O&M) tasks throughout the lifecycle of the building and not just the construction phase (Liu, Eybpoosh, & Akinci, 2012). Manually measuring the geometry of the building elements, here curtain wall, for the as-built data, would really be inefficient in terms of labor time and cost. Various studies show that laser scanning is a faster and more efficient method of getting the geometric data for an as-built model.

A set of dense laser scanning point clouds can capture the geometric complexity of the structure (Barazzetti et al., 2015). Where BIM technology can create a 3D virtual model, these point clouds can graphically show the complexities. BIM is defined as a "shared digital representation of physical and functional characteristics of any built object"("ISO Standard," 2010). Thus, the BIM model captures all the characteristics and geometric data required for structural analysis. The integration of BIM and laser scanning by automatically recognizing the construction objects from the point clouds and extracting them into a BIM model takes the research one step closer to structural analysis. For structural analysis, the route to use is Computer-aided-engineering (CAE) used for the testing/ simulating of building materials and strength. The current CAE platforms are developed on FEA- Finite element analysis. In FEA the simple approximation developed for each element is used to model the entire problem by assembling all the finite elements (Ren et al., 2018).

This paper focuses on laser scanning, BIM and its integration with structural analysis specifically FEA, aiming to determine the structural integrity under conditions such as dead and wind load, with the help of a case study of a curtain wall of the Cameron building located on UNC Charlotte campus. Three dimensional as-built model of this curtain wall is created by recording the dimensions and geometry through laser scanning and storing the characteristic data in BIM, so as to perform FEA on the model to determine the structural integrity of the curtain wall.

1.2. RESEARCH GOALS AND OBJECTIVES

The focus of this research is seamlessly integrating the three techniques of Laser scanning, building information modeling and Finite Element Analysis for determining the structural abnormalities and defects developed over-time in a building element so that further precautions can be applied to reduce possible risks that might be encountered during the life cycle of a building.

This is a three-step study with an expected goal at every step. In the first step of laser scanning leading to spatial geometric modeling, the objective is to scan the entire building and then stitch the scans together with minimum noise and zero glitches, in the process called registration. Performing heat mapping to graphically present the existing deflection in the curtain wall to this stitched 3D surface is an additional research objective.

In the next step of creating an as-built BIM model, the goal is to automatically recognize building elements from point clouds with the help of a software called Edgewise. The goal for this step is to create a complete BIM representation with all the characteristic data stored in the model so that it could be further used for structural analysis in the next step.

The last step is performing Finite element analysis on the BIM as-built model. The objective of this study was to perform a finite element analysis on a curtain wall model, to know exactly where the wall can be damaged when subjected to typical loads over-time. The loads taken into consideration were the dead load of the curtain wall system and the wind load.

1.3. SIGNIFICANCE OF THE STUDY

This study integrates three of most researched technologies in the construction industry currently where automating design and analysis techniques is the only way to go for saving the resource. Three-dimensional laser scanning, building information modeling, and FEA technologies have offered new potentials for mapping, capturing and structurally analyzing building information (Mahdjoubi, Moobela, & Laing, 2013).

The three-dimensional spatial surfaces developed from laser scanning and registration process of the scans provide the architects and engineers the drawings of the as-built condition of the facility which can totally vary from the design drawings. These as-built drawings are the most useful during the operation and maintenance (O&M) phase of the building and prove beneficial for repairs and replacements. Another feature of the laser 3D scanned surfaces is heat mapping which is used to determine the flatness of the structural surface. This feature can quickly help in locating the area of deformity prior to the structural analysis.

This 3D spatial geometry when converted into an as-built 3D BIM model, will help facility managers integrate building operation and maintenance schedules, allowing them to locate the repairs and update them accordingly (Bosché et al., 2015).

Laser scanning for existing buildings develops a 3D spatial surface that can help locate structural deformities, and BIM can act as a database for the recorded data which is interoperable to different stakeholders in various formats (Ghaffarianhoseini et al., 2017). By performing FEA on this recorded data and structurally analyzing the data the deformities due to various loads on that building are brought to knowledge, so that the designers, engineers, property managers, owners, and manufacturers can develop better installations for future use.

The study is significant, as it not only helps determine structural deformities but also provides an as-built model and the interoperable BIM format with a database, to use the model in any further studies as well.

1.4. LIMITATIONS

The aim of this study was to develop an accurate BIM model generated from point clouds, meshed to perform structural analysis by using FEA as a medium. This study not only depends on the generation of the new model for structural analysis but also emphasizes more on the transition between the three different technologies infused together to save money and time in the construction industry. As a result, the demand for more research on 3D laser scanning, BIM, FEA, and a combination of these technologies is prevalent.

This three-step technique is very advantageous yet owns few limitations. Selection of optimal laser scanner and its scan parameters is out of the scope of this study. The technique appears to be seamless but is not completely hassle-free. Automated point cloud-BIM-FEA conversion is at the starting point in terms of the research, as manual corrections and applications are still required.

The programs that were tried and used for performing FEA in this study were Autodesk Robot, ANSYS, and SOLIDWORKS, out of which SOLIDWORKS was the successful one. Robot Structural analysis had its limitations in the user interface and algorithm, while the full version of ANSYS which was suitable for this study was unavailable due to the license issues. The transference from one format to another, to import into different software, is not challenging but isn't completely harmonious either. This study is only applicable to the regular shaped curtain wall, as irregular shaped walls and components are not easily identifiable in the Edgewise software. Also, Edgewise recognizes the curtain wall only as a normal basic wall/ building element and does apply material characteristics (glass panels and mullions) to it. The wall must be remodeled in Revit (BIM software) by editing the Edgewise model, changing the wall type into curtain wall and adding the respective material properties to it. This process is also not completely automated. A modeler must make all the inputs manually in the software. Manual recording of material properties and boundary conditions is required in the FEA software since transferring the BIM model into FEA leads to loss of some information based on the geometric complexity of the structure.

Apart from the limitations in the programming of the software, recognition of the discrepancies between the as-is BIM model geometry and the as-planned BIM model geometry isn't completely automated but involves manual corrections.

CHAPTER 2: LITERATURE REVIEW

1.1. THE NEED FOR LASER SCANNING, BIM AND FEA

In the early 2000s, the AEC which is the Architectural, Engineering and Construction industry recognized that quick, precise and automated project progress tracking is the need of the hour (Bosché et al., 2015). The Construction industry can save money and time by automating the process of planning for the challenges, errors, risks, and costs of construction in the project. There's also quite some proof in history that creating a 3D model can alleviate risks, errors and save time and costs on labor-intensive jobs, while simultaneously recuperate the project quality (Eastman et al., 2008). The sooner the differences between the as-built and the as-design models are identified, the faster the remedial required actions can be introduced so that high costs for rework are not required (Bosché et al., 2015). Laser scanning, BIM and FEA if seamlessly integrated into a completely automated process, will have a great advantage in reducing discrepancies between the as-built and the as-planned models, that either go unnoticed due to human error or are not reflected in the design documents. As times have changed, technologically advancing the construction business has become inevitable since saving money and time is the priority of any business today. As a result, the demand for more research on 3D laser scanning, BIM and FEA, and an integration of these technologies is prevalent.

1.2. BUILDING INFORMATION AND MODELING

2.2.1. WHY BIM AND NOT 2D FORMATS?

The History of BIM goes back to the 1970s when the groundbreaking works of Eastman et al. (1974) laid the foundation of BIM. In the first 10 years of the new century, BIM grabbed even more interest especially from contractors and engineers (Hill, 2014; Ren et al., 2018).

The Construction industry has been working with 2D formats by separate programs, unable to prop up the necessary communication or integration among different groups responsible for carrying out a project (J. D. Goedert & Meadati, 2008). Even though it is quite possible to construct a CAD-based model as a designed condition, this CAD model wouldn't seize a comprehensive depiction of the structure as it was built or in its existing state (Tang et al., 2010). Along with the issue of not being interoperable and all the other drawbacks and chores of these 2D formats propelled the experts to move to a better 3D technology benefiting them in saving huge volumes of spatial and geometric data for designing, and effectively condense the cost and resources (Salehi et al., 2015). This is how the construction industry began using BIM. Azhar et al. (2008) mentioned Building information modeling as a data-rich, object-oriented and intelligent parametric digital depiction of the proficiency from which the appropriate data and views for respective users, can not only be obtained but evaluated to generate decision making significant information. Whereas Gu & London (2010) describe BIM as a technology that involves the application and maintenance of an integrated digital representation of building data and information for different phases of the building's lifecycle in the form of a data repository (storehouse). Information stored in BIM software can be input into databases so that it can be queried, reused and manipulated as needed (McGuire et al., 2016). Use of BIM for the documentation of damages and distortions simplifies the process of inputting the damage information into any analysis tool for further knowledge on the building. BIM is appreciated as a graphical tool in its level of detail and parametric ability to portray the damaged volumes as a three-dimensional entity in real time (McGuire et al., 2016). At its core, BIM software provides a three-dimensional (3D) modeling environment that is based on three basic principles: object-based design, parametric manipulation, and a relational database (Quirk, 2012). Hence simplifying this 3D modeling provides and stores a lot more information within one entity than any 2D format. Other benefits that help BIM triumph over 2D formats are as follows:

1. MATERIAL AND GEOMETRY INFORMATION IN BIM LIBRARY

The physical and functional characteristics of a building or a building element such as the material or geometric information can be reviewed, carried and updated all within the BIM software which assists in keeping the information organized in one place (Azhar et al., 2008). Thus, this capability of BIM in adding textural information (properties, materials, geometry, lifecycle, spatial relationships, geographic information, quantities, fire ratings for building product materials, finishes, costs, carbon content) to designed objects into the architects' vision and engineers structure, keeps BIM at the topmost of the technological food chain. The availability of all these features in one software allows the project stakeholders to keep track of the relationships between the building elements and their respective maintenance details (Ghaffarianhoseini et al., 2017).

2. INTEROPERABILITY OF BIM IN CONSTRUCTION

The different stakeholders including potential buyers, involved in a project today can communicate effortlessly and efficiently through BIM thereby savings costs, because of its interoperable nature (Mahdjoubi et al., 2013). A lot of credit for this goes to the Autodesk BIM 360 Field program, that accompanies Revit to offer mobile access to BIM by using cloud-based information management and a tablet computer (*Autodesk: Building design and construction* software, 2014). Apart from this advantage, it can also help Revit update the comprehensive inspection results (McGuire et al., 2016). This access available on the tablet can help a superintendent to make an important decision based on a comparison of the drawing and the actual work on site, or it can help a facility manager repair and maintain a particular electrical duct without having to open all the electrical ducts to find out which one needs repairs.

With the help of some more research BIM 360 Field in the future can include mobile access to BIM, plans, reference information, photographic documentation and most importantly the potential to link to global positioning system (GPS) with augmented reality, so as to update the deterioration results, locations and effects during the inspection of the building element (McGuire et al., 2016). Thus, BIM refers to a set of technologies and solutions that improves the inter-organizational collaboration to increase productivity while enhancing the design, construction and maintenance practices (Ghaffarianhoseini et al., 2017).

3. INTEGRATED BENEFITS:

Apart from all the benefits offered by BIM alone, integrating BIM with other facilities provides some more advantages such as heritage and historical documentation and maintenance, quality control, structural safety, energy management, retrofit planning, monitoring, assessment for safety and control, planning and 4D scheduling etc. This integration of BIM with various technologies can be used as an interactive manual for safety and operation management for the structure, electrical and mechanical systems of a building which in return helps sustain the building over a longer span (Ghaffarianhoseini et al., 2017). Another application called Autodesk BIM 360 Field complements Revit to provide mobile field access to BIM by making use of the cloud-based information management and a tablet computer (*Autodesk: Building design and construction software*, 2014). An added advantage of BIM 360 Field is that it uses augmented reality to deliver a real-time interactive view of the physical environment in the model through a tablet's video camera (*Autodesk: Building design and construction software*, 2014; Quirk, 2012)

2.2.2. WHY IS REVIT USED AS A BIM SOFTWARE?

Revit as a software is supported by a parametric change engine (Demchak et al., 2009). Building Information modeling is popular because of its interoperable feature which not only helps all the stakeholders receive and pursue the same information without any significant difference between the documents, but also assist in the exchange of data between non-native file types (*Autodesk: Building design and construction software*, 2014; Demchak et al., 2009). Revit is one of the most widespread and broadly used BIM software because along with this interoperable feature it also offers custom families and user-defined parameters.

2.2.3. NEED FOR FURTHER RESEARCH IN BIM:

Due to the dawn of 3D BIM, most of the newer approaches dynamically use the 3D information in BIM models for object detection and recognition algorithm for effectively processing point cloud data. Even after the limitations in BIM, it is being adopted across the construction industry for building design execution, construction and asset management with the hope of these limitations diminishing over time (Bosché et al., 2015). The interoperability factor and intellectual property of BIM not only distorts the level of responsibility among various team members but also brings in a major risk of cybersecurity due to the illegal access available online and copyright issues.

2.3 SCAN AND INSPECTION

2.3.1. AS-BUILT MODELING AND ITS VARIOUS METHODS

While BIM is the most lucrative way of presenting the designed building information, it cannot single-handedly represent the drawings and building data, of already existing drawings with prevailing deformities and issues which appeared over time and were not designed to exist. The recent construction practices hardly maintain and locate the severity and location of deterioration within a structure. The location of failure in any building element is significant since different loads act more crucially depending on its location, along with the length of a span. Location-based measurements help in recognizing and recording the inspection results (McGuire et al., 2016). But done manually the results are unreliable and subjective. Subjectivity brings in unpredictability between the actual outcome and the interpretation of it (Phares et al., 2004). By quantifying the amount and location of deterioration by field measurements, the variability could be decreased. However, additional field measurements require additional labor and time increasing the overall cost. If the measurements of the deterioration are computerized and stored in a file, it not only helps accelerate the measuring process but also saves costs in maintenance planning. Construction management will develop if the potential of structure inspections is taped through an organized documentation of the dented issues (McGuire et al., 2016).

Here as-built spatial modeling assists in recognizing the infrastructure's spatial information and adapting it into an organized, object-oriented representation (Brilakis et al., 2010). Numerous stakeholders working on a project can use this spatial modeling technique to resolve complexities such as design deviations and updates, supervising construction process in real time, quantity take-off, 3D/4D simulation, maintenance during different phases of the facility's life cycle and the most important one, monitoring the health of the structure (Brilakis et al., 2010). As mentioned by Goedert et al. (2005), creating a 3D surface by collecting data through remote sensing and then recognizing, extricating and modeling of objects are the two phases of achieving as-built spatial modeling. The conception of the as-built 3D model, accommodating all the organized documentation from material properties to the location of deformities, needs the acquirement of geometric data, traditionally measured with hand or power tools (e.g. measuring tapes) or non-conventional and progressive techniques such as total stations, photogrammetry and laser scanning (Barazzetti et al., 2015). The two corroborated spatial modeling methods as mentioned in Brilakis et al. (2010) are time-of-flight based sensors and terrestrial (close-range) photogrammetry.

The time-of-flight sensors or commonly known as laser scanners exploit the principle of time-of-flight to assemble range and reflected data from distinct points in a setting. This laser scanning technique transforms collected data into point clouds, which the operators can manipulate and influence permitting for construction of as-built circumstances in a virtual environment, with the help of commercially available software packages (Jaselskis et al., 2003). On the other hand, Photogrammetry uses visual information, photographs, radiation scanner/sensors, imagery, video/CCD cameras to evaluate 2D or 3D objects (Mikhail et al., 2001). Photogrammetry entails more manual user intervention, comparatively to laser scanning, for generation of 3D data. Nevertheless, it makes up for the time loss there with lower equipment cost and faster data acquisition in the field (Brilakis et al., 2010).

2.3.2. 3D LASER SCANNING: THE PROCESS

3D laser scanning comes into the picture as there increases the requirement of measuring a building's geometry, appearance, and other characteristics and then converting those quantities into innovative visual depictions, that are open to interrogation (Mahdjoubi et al., 2013). A laser scanner sweeps its entire surrounding space with laser light to acquire 3D data point with good accuracy, high density and great speed (Bosché & Guenet, 2014). A laser scanner captures distance measurements of surfaces which are perceptible from the vantage point of the sensor, and these dimensions can be transformed into 3D points called point cloud (Xiong et al., 2013). Due to advantages such as speedy and long-range measurements (up to 6000m) of large surfaces, millimeter-level accuracy, and greater spatial resolution ("RIEGL VZ-6000 :Technical

Specification," 2014), 3D laser scanning technique is executed in the construction industry for 3D modeling of structures, topographical surveys and monitoring the construction progress and safety through detecting deflection and deformation (Kim et al., 2013; Kim et al., 2015; Park et al., 2007). In this paper, laser scanning is used as the first stepping stone in creating the as-is BIM model which can be further subjected to FEA, to determine the structural integrity of the building element.

2.3.3. SPATIAL MODELING THROUGH LASER SCANNING OVER OTHER METHODS:

Even after the expensive equipment costs and excruciating time spans to model a structure (due to attention to detailing), laser scanning technique (time-of-flight principle) is a preferred option to develop a 3D as-built spatial model. The capability to manipulate and view data with complete liberty and ease is an exclusive characteristic of laser scanning that differentiates it from other traditional surveying methods and puts it on the pedestal (Brilakis et al., 2010). Moreover, laser scanners permit a wide range of measurement at high resolution which is not restricted to ambient operation conditions (Jaselskis et al., 2003). Another reason that makes laser scanner an optimal choice is its ability of fast data collection and delivering a great amount of information, in the form of a dense cluster of 3D points, about the surface of a facility simply with three instruments: a laser scanner, a tripod and a laptop/ desktop computer (Brilakis et al., 2010). It doesn't require fancy and heavy equipment to generate data with high quality of surfaces. These generated surfaces are so accurate and comprehensive that they are readily sourced in fine modeling applications such as spatial modeling of soil or obstacle stacking (Hashash et al., 2005). Therefore, there appears to be the greatest potential for laser scanning to record the spatial condition of existing buildings whose drawn records are absent or inaccessible, by curling up the limitations of using this technique. Laser scanning technology is also appropriate for larger than life, grand buildings with large surface areas, with little access to lighting, as most of the scanners have a range greater than 200m (Mahdjoubi et al., 2013). Indeed, former researches have described successful recording and rapid surveying of irregular surfaces through laser scanner (Laing & Scott, 2011), because of which this technique is pursed and chosen over photogrammetry in this research.

2.3.4. SCAN PLANNING: SELECTING OPTIMAL LASER SCANNER & SCANNING LOCATION:

The scan parameters of the laser scanner should be optimized to obtain the best dimensional and surface quality inspection results. The angular resolution (the incident angle between the laser scanner and the scan point) of the scanner and the scanning distance are two main factors that affect the density of the point cloud data (Kim et al., 2015). The higher the scan point density the greater quality inspection results, but if the density of the scan point is too high, the scanning time increases evidently increasing the computing cost. Therefore, a reasonable compromise is important amongst accuracy, cost and time in selecting the optimum scan parameters depending on the inspection requirements of the project (Kim et al., 2015). Wrong selection of scanning parameters has a negative impact on the quality of scans (Laefer et al., 2009; Lichti, 2007; Soudarissanane et al., 2011). Hence scan planning is essential. Scan planning aims to prepare a scanning strategy ahead of time to obtain the scan data with vital requirements and minimum data acquisition time (Wang et al., 2018). Several studies including Biswas et al., (2015) have proven how important scan planning is by automatically generating scanning policies based on 3D BIM model and the specifications and features of the scanner. Scan planning not only aims to find the ideal laser scanner but also helps to find the scanning location from the target, to minimize the total number of scans while fulfilling the following six criteria (Wang et al., 2018):

Six criteria for the selection of a laser scanner are

1. LEVEL OF ACCURACY AND TOLERANCE

The accuracy level of a scan point being decided by many factors from scanner's measurement model, the incident angle of the laser beam, reflectivity of the surface and scanning distance to the target, the most principal factor is the incident angle of laser beams (Boehler, Marbs, & Vicent, 2003). The measurement accuracy is inversely proportional to the incident angle, especially if the angle is larger than 70 degrees (Soudarissanane et al., 2009). The phase shift scanners have high accuracy (0.078-0.78 inches) as compared to the time-of-flight scanners(0.15-3.94 inches) ("Faro 3D Laser Scanner Software | SCENE Software," n.d.; Olsen et al., 2010). The specific laser scanner model used in this study has a ranging accuracy with a scanning distance of fewer than 98.42 feet between each scan and a surface reflectivity higher than 10% which is always greater than 0.043 inches ("FARO Focus | FARO Technologies," 2017).

Level of tolerance refers to the tolerable inconsistencies between the as-built and the reference model (Kim et al., 2015). For example, the tolerance level for a precast slab is + or – 0.24 inches according to (Schneider et al., 2000.)

2. LEVEL OF DETAIL:

To satiate this criterion the spatial resolution should be below the threshold value of ‘s’ in FIGURE 1. The spatial resolution (spacing between two adjacent scan points) is decided by the scanning distance to the target, the angular resolution of the beams and their incident angle (Kim et al., 2015).

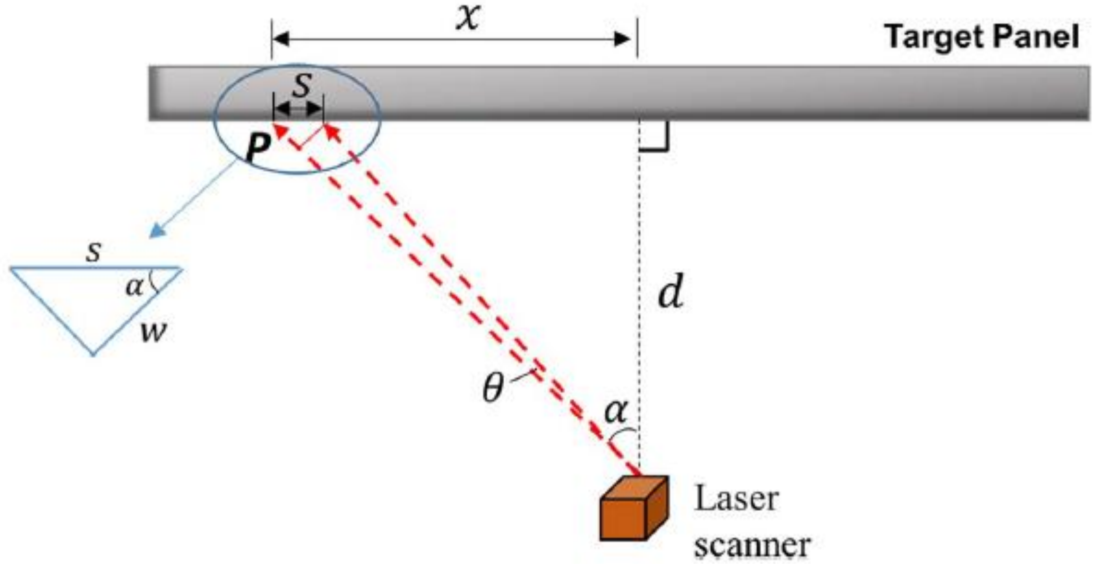

FIGURE 1: Illustrative scanning setting for a target panel showing the relationships between scan parameters such as d, α, s, and ϑ

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3. SCAN COVERAGE (MEASUREMENT RANGE):

The most preferred scanner location is the one that covers a large area (Kim et al., 2015). The measurement range is the permissible distance for the laser scanner which is chiefly affected due to the working principle and the laser source of the scanner. The Time of Flight (TOF) scanners here have a longer measurement range up to 19685 feet, while the range for phase-shift scanners is below 393.70 feet (“FARO Focus | FARO Technologies,” 2017; “RIEGL VZ-6000 : Technical Specification,” 2014).

"A time-of-flight camera is a range imaging camera system that resolves distance based on the known speed of light, measuring the time-of-flight of a light signal between the camera and the subject for each point of the image" ("A time-of-flight camera," n.d.).

4. SCANNING TIME

The angular resolution of the scanner decides the horizontal and vertical scanning rate of the laser scanner on which the scanning time is dependent. The size of the target also has an impact on the scanning time (Kim et al., 2015).

5. ENABLING FULLY AUTOMATIC SCAN REGISTRATION

Scanner location plays an important role in enabling automatic registration, which happens to be the next step in developing a 3D point cloud since scans get registered based on the common planes between them (Kim et al., 2015). Hence the scanner should be located keeping in mind the shared planes.

6. PRICE

In this study, a commercial scanner Faro Focus LiDar 3D is used, and the cost of such scanners lie in the range of $40,000 to $200,000 (Kim et al., 2015).

2.3.5. INTEGRATION OF LASER SCANNING AND BIM

Integrating these two technologies has proven to be a boon to the construction industry. Point clouds can be used for some applications such as clash detections, but its more useful feature is creating a 3D structural model which is seamlessly transported to BIM, where a higher-level BIM 3D model is developed. This as-is BIM model developed from point clouds allows assessment and manipulation of the model at the component level i.e. doors windows etc., rather than at the point level. This process is more natural, efficient, compact and seamless. This two-step technique of converting point cloud data into an as-is BIM model is referred to as 'Scan-to-BIM' (Xiong et al., 2013). An integrated combination of BIM and laser scanning has accelerated various aspects of architecture and construction industry such as evaluating the energy performance of existing buildings, condition surveys, measurements, material characteristics, compliance with building regulations, inventory of fixtures and fittings. (Smith & Tardif, 2009). These two techniques together have a great potential in creating a medium for visualizing the rich 3D data seized by the scanning technology and examine the health of the building structure in a graphical manner (Mahdjoubi et al., 2013). For example, the conventional method to assess the deformations and cracks in the building structure is visually through measuring tapes where one must count on the skills and accuracy of judgment of the surveyor and is heavily time-consuming. Whereas laser scanning and BIM together provides a more precise and independent inspection technique to monitor the health of the building (Mahdjoubi et al., 2013).

2.3.6. NEED FOR INTEGRATING LASER SCANNING AND BIM

A detailed building information cannot be processed just by the interpolation of the point cloud with mesh-based algorithms. Additional information to create an intelligent parametric model is essential (Barazzetti et al., 2015). Even though the laser scanning process is eventful in recording the dimensional properties, it cannot document the information relating to the materials scanned. Another drawback is the complex and dense points collected as a cluster acting individually on selecting (Mahdjoubi et al., 2013). Using laser scanning technology combined with different tools has more potential benefits, than using it individually. In a study done previously Bosché (2010) has pronounced a process where automatically a 3D scan data can relate to CAD-based design/construction model, thus comparing the as-built structure to the designed model. Bosché (2010) also mentions, that by extrapolation and mixing two or more techniques together in construction, it becomes quite easy to evaluate the changes occurring in the building during its lifetime and apply that information with building and facilities management. The variance among a generated 3D surface and an as-built object-oriented model is that the former one doesn't possess any semantics regarding the elements it contains, their material information or structural health, or any data on the association between these elements with their adjacent ones (Brilakis et al., 2010). Therefore, it needs to be transformed into an information-rich, object-oriented model with wide range attributed elements including data on their material, schedule, and cost. Converting a 3D spatial surface into an object-oriented model requires various procedures and software such as Autodesk's Revit or Graphisoft's ArchiCAD, and a human modeler to perform these procedures and recognize necessary elements to crop out from the point cloud (Brilakis et al., 2010). Therefore, for this research integration of BIM and laser scanning is an important milestone.

Assimilating these two techniques is a 2-step process:

1. THE REGISTRATION OF MULTIPLE SCANS

The modeling process, following a scan, works from an essentially dissimilar beginning point and then followed by the typical architectural additive software (Mahdjoubi et al., 2013). The scanning process operates by recognizing the location of points on the surface and effectively hallowing the space around the scanner head (Smits, 2011). Therefore, only the planes, that impede the path of the laser beam, are detected by the scanner. As a result, to get a complete 3D representation of the building, it would logically require two or more scans which would be then stitched together in the process called registration (Mahdjoubi et al., 2013). Scan registration intents to register multiple scans in a global coordinate system depending on the common planes reflected within the different scans (Wang et al., 2018). It is a four-step process:

a. Extraction of planes from each scan by using the RANSAC algorithm.

b. Identification of common planes between scans (Usually performed in Scan planning stage)

c. Coarse registration of two scans based on their common plane

d. Fine registration of two scans with a common plane by using the Iterative closest point (ICP) algorithm (Wang et al., 2018). "It is an algorithm employed to minimize the difference between two clouds of points. ICP is often used to reconstruct 2D or 3D surfaces from different scans, to localize robots and achieve optimal path planning (especially when wheel odometry is unreliable due to slippery terrain) and to co-register bone models, etc." ("Iterative closest point," n.d.).

The recent scanning technology developments have aided point clouds to automatically register without having the operator manually struggle with the process afterward (Mahdjoubi et al., 2013). The software 'SCENE' enables registration of scans manually by following the given required steps. But it additionally provides an automatic registration option, where with the help of just a click, all the scans are processed, and a complete 3D surface is generated based on the common planes shared by different scans. SCENE software is explicitly designed for use with FARO Focus 3D laser scanners ("Faro 3D Laser Scanner Software | SCENE Software," 2017).

'FARO SCENE' is FARO's 3D documentation software for terrestrial as well as handheld scanners. This software helps you navigate through your point cloud, identify and remove noise, validate overall registration of your point cloud, perform heat mapping on the cloud cluster to determine surface flatness and surface deformities, derive simple measurements, generate ortho-images, 3D visualizations and triangulated meshes and export the point cloud to various formats ("FARO Scene 3D Laser Scan Registration," 2017). By using SCENE Web Share Cloud, the projects can be shared online and published on a web server. This aids the project partners in inspecting and interacting with the 360-degree panoramic imagery and take dimensions & areas, etc., from anywhere in the world in a secure manner ("Faro 3D Laser Scanner Software | SCENE Software," 2017).

After the scans are registered, object recognition and geometric modeling as a head start to the as-built BIM model is the obligatory step.

2. OBJECT RECOGNITION AND GEOMETRIC MODELING

In the construction industry as compared to other industries such as automation, object recognition is heavily guided by material images having low variability and high similarity as opposed to general databases (Brilakis & Soibelman, 2008). Xiong et al. (2013), proposed another method to use visibility reasoning to fuse measurements from various scans then detect the occluded region in the surface and finally by applying a learning algorithm to approximate the window or doorway opening shapes. Shape-based and material-based techniques are the two recent methods of geometric modeling and object recognition. In the material-based technique, color, texture, and structure are the features which are used to detect and categorize elements (Brilakis & Soibelman, 2008). Shape-based recognition is a complementary technology for automatic recognition, that uses shapes for automatic identification of linear/nonlinear construction objects (Zaboli, Rahmati, & Mirzaei, 2008). It uses different features such as silhouette, the points, or the skeleton to identify the geometry of the object (Brilakis et al., 2010). Although these techniques and algorithms are established to detect the shape and geometry of a building element from the point cloud, to smoothen the process of as-built BIM modeling, doing it manually is time and labor exhaustive. Even with substantial amount of efforts and post-processing for automated shape recognition to develop a useable surface, solid or object-oriented models (Hajian & Becerik, 2010; Mantle & Laing, 2013), there are still challenges with not only geometric modeling or object recognition but also with appending the object-specific data to the laser scanned model itself (Tang et al., 2010).

Therefore, software such as Edgewise is developed with the help of scientists at clearEdge 3D, that used both the material and shape-based techniques for geometric modeling and object recognition. Edgewise makes use of revolutionary algorithms to automatically recognize and extract walls and windows from point clouds to transfer them into Revit family objects. This will save uncountable hours over building a BIM model from the point clouds originally in Revit ("Edgewise Building Modeling Tools," n.d.). Rather than manually outlining walls or other features, Edgewise processes most of the manual work by detecting essential surfaces in the point clouds, extracting compact, precise feature geometry and removing all the unrelated data. It helps lower the modeling time by up to 80% as it contains automated structured modeling tools ("Edgewise 3D modeling software - Position Partners," n.d.).

Following all these steps assures the development of a data-rich model, object-oriented and parametric digital representation of the structure, from which extracting and analyzing data as entailed by different users for valuable decision making is possible (Fischer & Kunz, 2004).

2.4 FINITE ELEMENT ANALYSIS FOR STRUCTURAL EVALUATION

The structural analysis of a building aids in determining the subsequent state of danger and in predicting the behavior of the structure in the future (Guarnieri, Milan, & Vettore, 2013). The finite element method has been popularly used, that has large acceptance rate in various engineering applications (Barazzetti et al., 2015), and its application in structural analysis is a very effective numerical method which is globally recognized. One of the most important numerical techniques used by structural designers for physical phenomenon simulation is the Finite element Analysis which permits them to simulate the natural behavior of solids, liquids, and gases as well as their interaction. Through FEA dynamic as well as static analysis of simple as well as complex structures can be simulated with high accuracy, only with some manual inputs. Interoperability of FEA and BIM assists in simulating the structural behavior of a structure before, during and post construction until the end of its lifecycle (Fedorik et al., 2016).

2.4.1. WHAT IS FEA?

“The finite element Analysis (FEA) is a mathematical technique for resolving problems that are explained by partial differential equations or can be expressed as functional minimization” (Nikishkov, 2004). It is useful for using math to understand and compute any physical phenomena, such as fluid or structural nature, wave propagation, the growth of biological cells, thermal transport etc. Partial differential equations (PDEs) are used to characterize most of these techniques (Nikishkov, 2004). Nevertheless, for a computer to decipher these equations, numerical techniques have been developed over the last few decades and one of the most prominent today is the finite element method (“SimScale - CFD, FEA, and Thermal Simulation in the Cloud | CAE,” n.d.).

In FEA large problem is partitioned into simple finite elements and generates equations modeling these elements. These finite elements when assembled together gives calculations/numerical values for larger systems, modeling the entire problem.

“A continuous physical problem is transformed into a discretized finite element problem with unknown nodal values” (Nikishkov, 2004). In simple words, rather than attempting to solve larger problems directly, in FEA the estimated solution of the problem is generated for each element separately and then modeled for the whole problem by compiling all the finite elements (Ren et al., 2018).

IMPORTANT FEATURES OF FEA

1. Approximating the physical problem piece-wise into finite elements provides good accuracy even with simple approximating functions (Precision/accuracy is directly proportional to the number of elements in FEA) (Nikishkov, 2004).
2. Problems with a large number of nodal unknowns can be solved by approximating sparse equation systems for a discretized problem (Nikishkov, 2004).

Finite element analysis permits the structural behavioral simulation quite close to the reality that leads to designs that are more precise and economically competent

FEA has accuracy and a wide range of usability in many professional fields. But FEA is heavily dependent on the experience and judgment of the user and is far from being used by the normal consumer. In the case where contradictions arise during the preprocessing stage, fatal errors might be caused in the sequential design. Hence FEA must be used in collaboration with other software, and for the sake of this research, a merger with BIM is extremely beneficial. A lucrative integration of BIM and FEA includes appropriate communication between the applications to control the efficiency of design and correct data transfer (Fedorik et al., 2016).

2.4.2. INTEGRATION OF BIM AND FEA

A few years ago, the construction field was dependent on imaginative designers and engineers for building a 3D model in CAE software from 2D CAD drawings with mathematical considerations. But at present BIM is the next generation model. Hence Integration of BIM to FEA helps in providing a dynamic 3D model for FEA just by removal of some redundant information and reasonable simplification (Ren et al., 2018). The traditional FEA tactics preferred in structural analysis depend on the simplifications of the structural elements into 1D (beams, trusses) or 2D (plates, shells) elements, which can be easily divided into simpler 2D finite elements (Barazzetti et al., 2015). BIM to FEA transference requires more study for complex vaulted historical structures, as their geometry is difficult to develop and discretize. But the integration of 3D FEA and BIM technology is already a success for simple regular shaped building elements with basic geometry which is easily isolatable (Barazzetti et al., 2015). This is possible through a variety of software. For instance, the structural analysis tool, Autodesk Robot Structure is fully integrated with Revit. Variety of plugins are available to ensure interoperability with other structural analysis software such as SOLIDWORKS or Ansys.

These tools allow transferring the model from Revit to obtain a simplified version for finite element analysis (Barazzetti et al., 2015). However, there are disadvantages to these plugins, that they are applicable only if the geometry of the structure is simple enough for them. Considering that the proposed research is on such structures with uncomplicated geometry, it is possible to go ahead with any of the suitable plugins and perform finite element analysis on the model.

Here are few of the software used to perform FEA on structures:

ANSYS WORKBENCH:

With the ANSYS Workbench, the product is a high-fidelity virtual prototype, used to mimic the behavior of the products in their real working surroundings. It manages to provide, innovative technologies for system simulation embedded, software design, and 3D physics simulation. The ANSYS simulation platform can unify the broadcast suite simulation technology with CAD/BIM applications.

This mutual platform of ANSYS smoothens the consistent, reliable and competent sharing of engineering information across an organization and field operations, accelerating the agility of the operations (“Platform,” n.d.). ANSYS is not only used in the construction field but majorly used in the mechanical field for performing FEA on the automobile parts and sub-parts.

ROBOT STRUCTURAL ANALYSIS:

This software helps engineers and architects to rapidly perform simulation and analysis for any type of structure and run data on a wide range and types of projects. Structural engineers make use of the advantage of simple and effective static analysis, modal analysis and non-linear analysis on seismic studies, time history analysis and more. Robot structural analysis can simulate loads both locally on a computer and in the cloud. It is a powerful auto-meshing generation that works easily with complex models also supporting the manual definition of meshing parameters ("Structural Software | Robot Structural Analysis | Autodesk," n.d.). The Revit file can be directly imported into Robot with just one step, unlike ANSYS in which the Revit file must be converted into an AutoCAD file, as Revit cannot export the file into a format that is compatible with Ansys.

SOLIDWORKS SIMULATION:

SOLIDWORKS software makes use of the displacement formulation of the FEA to estimate the component displacements, strains, and stresses under different load types such as internal and external. "This software analyzes the structure by meshing it by using tetrahedral (3D), triangular (2D), and beam elements" ("SOLIDWORKS," 2016).

Comparing SOLIDWORKS SIMULATION with ANSYS Workbench, SOLIDWORKS is user efficient and takes lesser time for FE analysis. In ANSYS force is applied on the face only after meshing while in SOLIDWORKS simulation force can be applied before starting the meshing process. In SOLIDWORKS simulation the load and boundary conditions are shown with a symbol, the force with force symbol, and the constraint with constrain symbol making it quite easy in terms of graphical presentation and understanding.

The current state of integration of BIM and FEA includes developing a BIM model and then transferring the model to FEA where the numerical simulation is carried out for evaluating the obtained results. If the results are accepted the model is used as it is and not transferred back to BIM but if the model is revised to achieve the expected goal, then it is transferred back to BIM. The software used in BIM and FEA require a lot of future research on seamless integration as a lot of information including material properties and boundary conditions are lost during the transfer of the model (Fedorik et al., 2016). Therefore, the input parameters for performing FEA include boundary conditions, material properties and loading conditions which are partially available from BIM model and partially have to be manually keyed, whereas the irregular stress information or deformation patterns can be easily recognized under self-weight (Barazzetti et al., 2015).

2.4.3. REQUIREMENTS TO BE FULFILLED BEFORE FEA IS PERFORMED:

The FEA is generally represented by three procedures: preprocessing, solution and post-processing. The post-processing step includes converting the modified model back into BIM (Fedorik et al., 2016). But since the model isn't modified in terms of design or material properties; the third step is not provided in this study. In the recent scenario, total automatic BIM to FEA conversion is unrealistic and some human involvement is definitely required (Ren et al., 2018). The preprocessing step is the one that requires all the manual inputting work while the second step which is finding the graphical solution is an automated process which develops with just one click.

Here is how the preprocessing is carried out:

1. GEOMETRIC CLEAN-UP

The first step of preprocessing is geometric clean-up. Since BIM is data exhaustive software, it contains detailed information about the building. Such comprehensive information is not required for structural analysis. Hence all the redundant data has to be cleaned up either in the BIM software or the FEA software (Ren et al., 2018). This is called Geometric clean-up since all the unnecessary architectural geometry is removed in this step.

2. MODEL DIMENSIONALITY REDUCTION

The structural members in BIM are still modeled as 3D entities. However, from the point of view of mechanics, the structural members in buildings are not real 3D members. Beams and columns are to be modeled as lines while slabs and shear walls (including curtain walls) are modeled as planes (Ren et al., 2018). Beam and Shell elements are often referred to as structural elements in the monograph of FEA (Belytschko et al., 2013). Generating lines, planes and surfaces based on these 3D entities is the main mission of model conversion (Ren et al., 2018). Software such as Autodesk Robot, ANSYS Workbench, and SOLIDWORKS automatically convert these 3D entities of BIM into structural 3D entities that are meant to be used for structural analysis.

3. ENTERING MATERIAL PROPERTIES

BIM manages to define the materials used for the structure (such as concrete, steel or glass). But the manual recording for the mechanical properties of the materials used is a mandatory requirement since the BIM and the FEA software does not automatically record these properties. The main mechanical properties to be considered for completing the analysis are the elastic modulus, the Poisson coefficient and the specific weight of the material (Ren et al., 2018).

4. LOADING THE MODEL

The self-weight of the structural elements is automatically computed by the FEA software by using the information stored in the BIM model. However, the wind loads, seismic loads etc. must be manually applied. The dead load of the structure including the weight of the finishes is applied as distributed pressure loads (Ren et al., 2018).

5. BOUNDARY CONDITIONS

The surrounding conditions along the structure such as a water body, soil conditions or a tree uprooting into the structure's foundation often affects the structural behavior of the element. Hence Boundary conditions must be considered during FEA.

6. FEA MESH DEVELOPMENT

In FEA, elements are established on lines and planes (for beams and surfaces). Beam element could be developed along the line and each length is a parameter of mesh development. Whereas, shell elements are developed on the planes based on standard meshing tools. The line and plane mesh coincide with each other and are not separate from each other to form a complete structural system that can resist loads. These meshes should be connected according to the structural design (Ren et al., 2018). Some software discussed earlier support auto-meshing by recording few manual inputs. However, auto meshing to create Finite element analysis is not a trivial task but has issues such as:

a. MESH COMPATIBILITY: To guarantee the geometric link between different objects, single entities need a perfect node-to-node agreement (Barazzetti et al., 2015).
b. LOCAL DISTORTIONS: An ideal mesh must be composed of regular tetrahedral objects. However, with complex geometry and distorted elements, it's difficult to achieve an ideal mesh (Barazzetti et al., 2015).
c. SMALL ELEMENTS: Detailed elements without any direct connection with the structural function, must be eliminated. If even a few detailed small elements exist, they can create an error in running FEA (Barazzetti et al., 2015).

d. SMALL IMPERFECTIONS: A finite element analysis requires the exact correspondence of the nodes to avoid the creation of thin faces/planes with distorted 'fissure elements' (Barazzetti et al., 2015).
e. COMPLEX ARCHITECTURAL OBJECTS: Curved objects such as vaults or domes in historical buildings have a completely different method of mesh generation (Barazzetti et al., 2015).

These listed problems are primary concerns to obtain an alveolar FEA mesh. Thus, automatic re-adaptation of the BIM model towards a consistent mesh requires various manual corrections to ensure a node-node continuity that considers various BIM elements (Barazzetti et al., 2015).

The last step is graphically analyzing the results after FEA is generated. The results showing deformations, stress, and strain on the structural elements are shown in the form of color coding, generally varying from red to blue, with blue being the least deformed. This color-coding changes with the software being used for performing Finite Element Analysis.

2.5 OBJECTIVES BEHIND AUTOMATION OF THE ENTIRE PROCESS

Why is it necessary to document the location and severity of deformities, automate the process, documenting it, storing it, evaluating the loads on the building element and inspecting the structure?

These questions form the basis of every research performed on the structural analysis through FEA and BIM. One of such research was on a bridge project. The three objectives of that research varied from demonstrating the capacity of BIM software to recording the damage information gathered during an inspection, using the inspection results in examining the structure and recognizing the availability of practical application of BIM software in the OM stages (McGuire et al., 2016).

Automating the process supports in multi-user operation along with simultaneous modification without or with slight conflicts (some more future research required to avoid the conflicts completely). Automation in construction helps to store the documented data and later utilize it to the fullest (Hu & Zhang, 2011). These objectives prove that automation in the field of structural analysis from the very beginning of the process (from measuring the geometry of a building to analyzing and planning for maintenance depending on the deformities) is really required in the construction business today.

CHAPTER 3: METHODOLOGY

The integration of the proposed three-step technique involved, scanning a curtain wall in the Cameron building located on the UNC Charlotte Campus, converting it into an as-built BIM model, and performing Finite Element analysis on it. SCAN to BIM to FEA is a three-step technique and these three steps are as follows:

FIGURE 2 shows how the integration of SCAN-BIM-FEA was adopted trying and using various software to achieve the semi-seamless transference of files from the first step to the last.

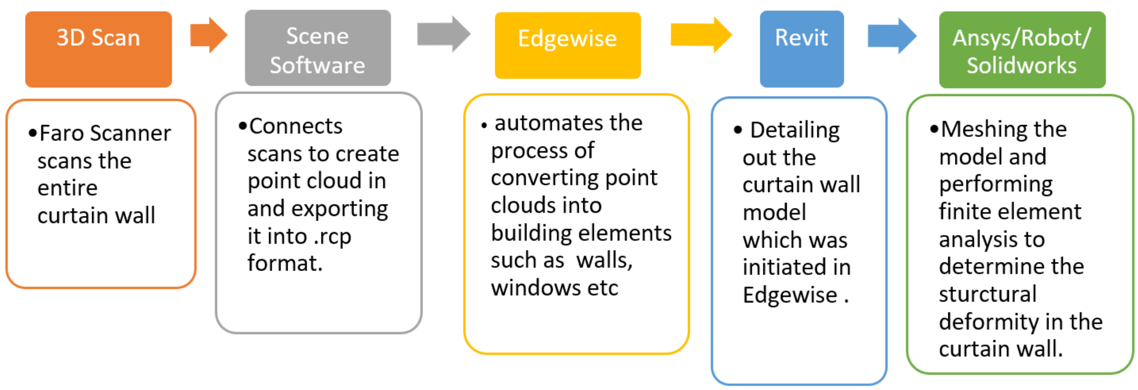


FIGURE 2: Sequence of Software Uses (and file types)

3.1. STEP ONE: LASER SCANNING

3.1.1. 3D LASER SCANNING

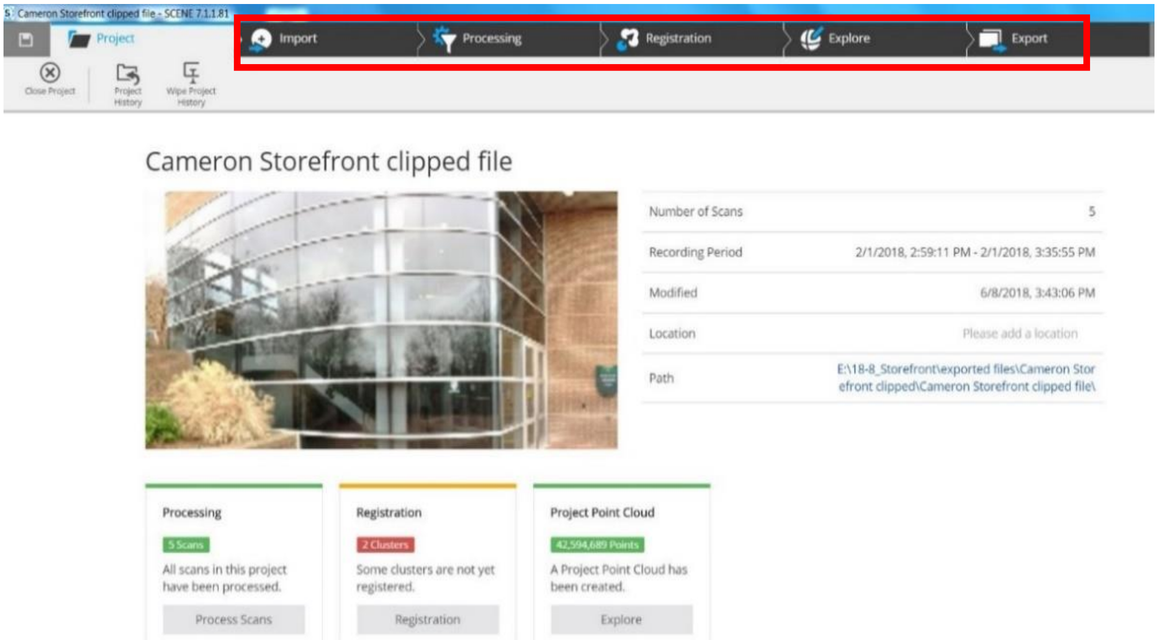


FIGURE 3: Five-step SCENE process

The first step in the technique was getting the curtain wall completely scanned to develop an as-built model of this scan, to be used later in the following steps. The instrument used in scanning the wall was a Faro Focus3D Lidar Scanner, that scans up to a maximum distance of 130m from its scanning head. This scanner provides two options for registering the individual scans, either using targets for scanning or performing target-less scans. In this study, 5 spherical white balls are used as targets to properly orient and combine the scans during the process of scanning. The scanner was fixed on a light-weight tripod and moved around the building to capture the scans from various vantage points. For capturing the point cloud and registering the scans without any loss of information, the vantage points were within 30 feet of each other. Since the resolution of the laser scanner camera was up to 70 megapixels, it took only around 5-8 minutes to document the space at every vantage point. The scanner is a "volumetric" measuring and imaging tool that distributes the laser beam at a vertical range of 305^{0} and a horizontal range of 360^{0} ("FARO Focus | FARO Technologies," 2017). The curtain wall being 2 floors tall, couldn't be captured in one scan. Hence 5 scans were conducted, which were further stitched to form one single as-built 3D point cloud model.

3.1.2. REGISTRATION OF SCANS

The point clouds collected from these different locations were combined by the process known as registration (Xiong et al., 2013). A software called SCENE (FIGURE 3) helped to complete this step of registering point clouds.

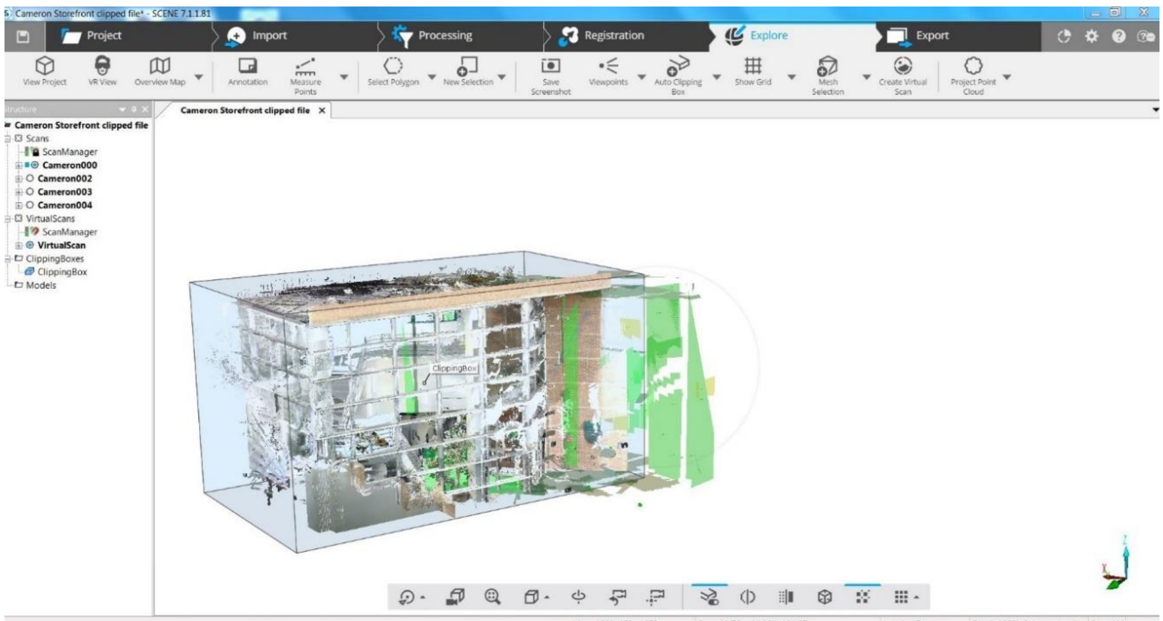


FIGURE 4: Exploring the point cloud in SCENE

Five steps are involved in the registration process where all the scans are imported into the software SCENE, and all the unnecessary noise is removed from the point cloud. These are the first two steps. In the next step of registration, SCENE offers an automatic registration option, which is the preferred option over the manual one at least for this study. The automatic registration option, which is the third step in this software, was used in this research to orient and combine all the scans properly. The white spherical targets and the planes of the building acted as targets to support the registration process. The registration process is complete here, but two more steps are required to export the scans into a more suitable format for Revit. After the scans are registered, in the fourth step is exploring the 3D volume and editing it according to the needs of the project (FIGURE 4). Tools such as clipping box and polygon tool are used to erase unnecessary data in the point cloud. The fifth and last step is the critical one and can take up to several hours to accomplish. For a seamless transition of the point cloud into a BIM software, one needs to export this scene file into a .rcp file. This .rcp file is later transported to BIM software to create a BIM model.

3.1.3. HEAT MAPPING

Another benefit of the SCENE software is the feature of heat mapping, which can determine whether a surface is flat or not by detecting the distance of the points from the standard selected plane. This function of heat mapping is inside an app called the Builder app which is a plugin to the SCENE software. This function helped determine the deformation that has occurred in the curtain wall over the years since it was built. The color coding shown in FIGURE 5, shows that the wall deforms maximum in its central top half. This function also helps in better contemplating the results of the study.

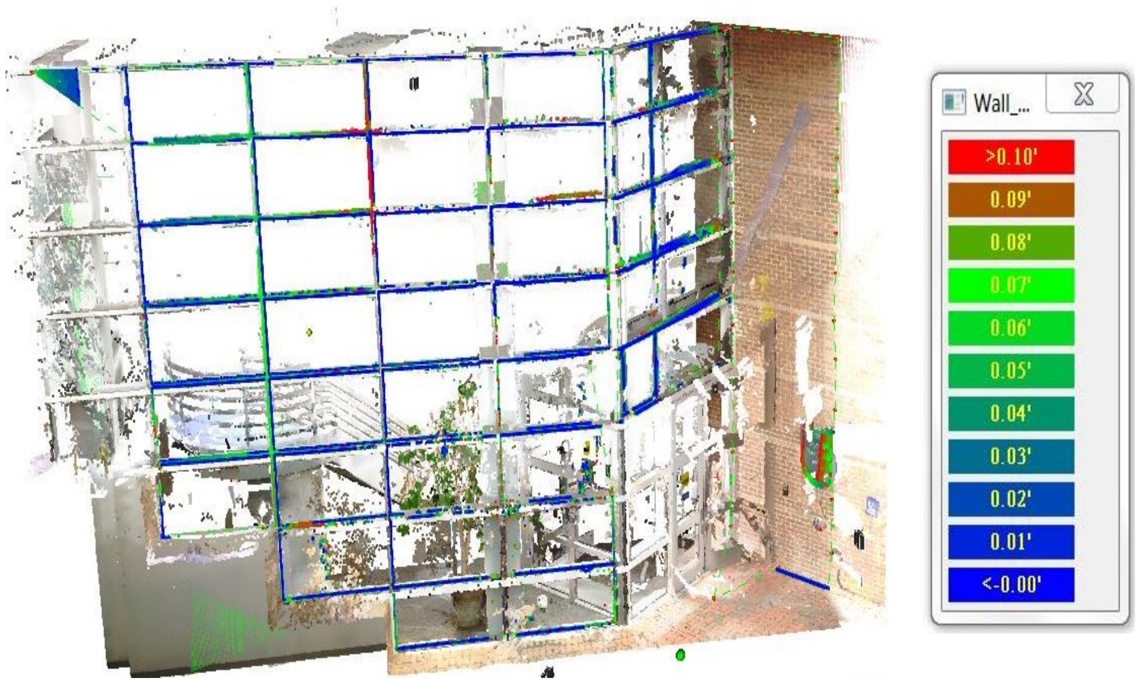


FIGURE 5: Heat mapping of the Cameron curtain wall

3.2. STEP TWO: BUILDING AN AS-BUILT BIM MODEL

The goal of the analysis was to determine where and how much the wall would deform due to typical dead and wind loads over-time. This was achieved by performing Finite Element Analysis of the as-built BIM model. After completion of the first step i.e. scanning, the second step of SCAN-BIM-FEA technique was creating an as-built BIM model of the Cameron curtain wall. Two software called Edgewise, and Autodesk Revit were used in this step.

3.2.1. EDGEWISE: A HEAD START TO THE AS-BUILT BIM MODEL

Edgewise software is used to automatically generate basic architectural elements such as walls, windows, and doors, from point clouds registered in SCENE, by grouping all the points on one plane as one component. This software only gives a head start to create an as-built BIM model by coarsely modeling from the point clouds without any details. But this is necessary to model the wall exactly as it is, with all the existing deformities that occurred over the years due to loading. Once the scans are processed in Edgewise, one can pick the levels manually (FIGURE 7), so that when this model is transferred to a BIM software, it automatically has the actual levels and heights recorded. As seen in FIGURE 6, Edgewise provides only a basic solid wall, which has to be further modeled as a curtain wall in Revit.

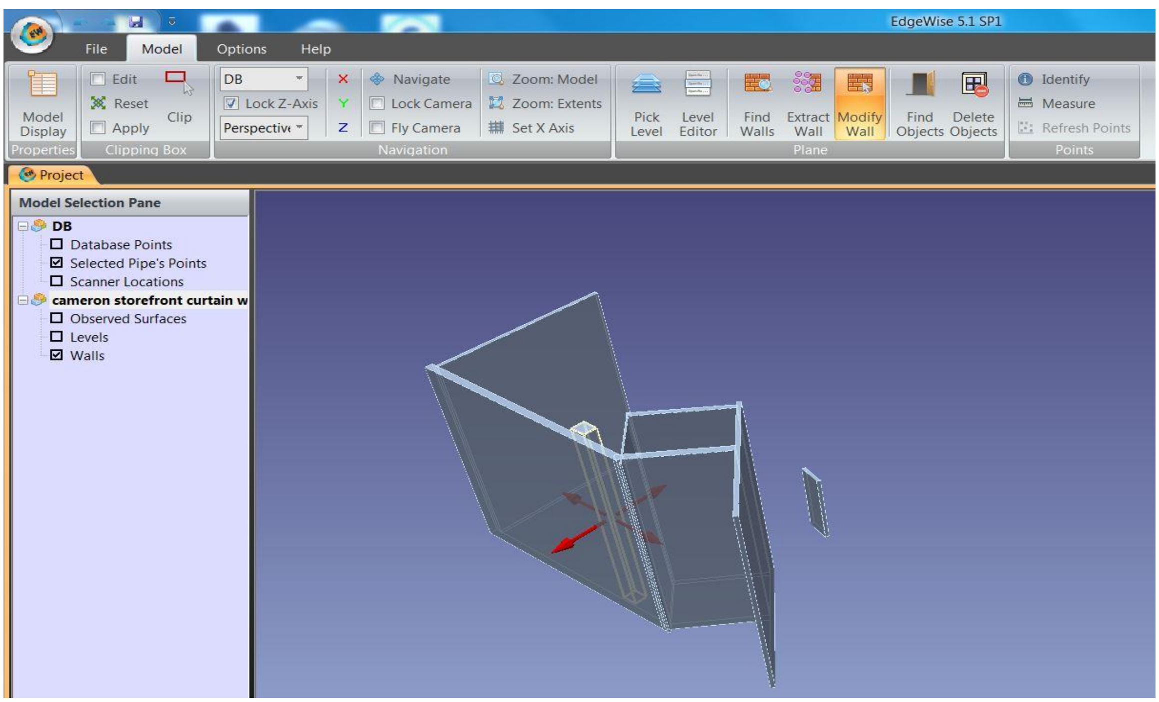


FIGURE 6: Modified Curtain wall in Edgewise

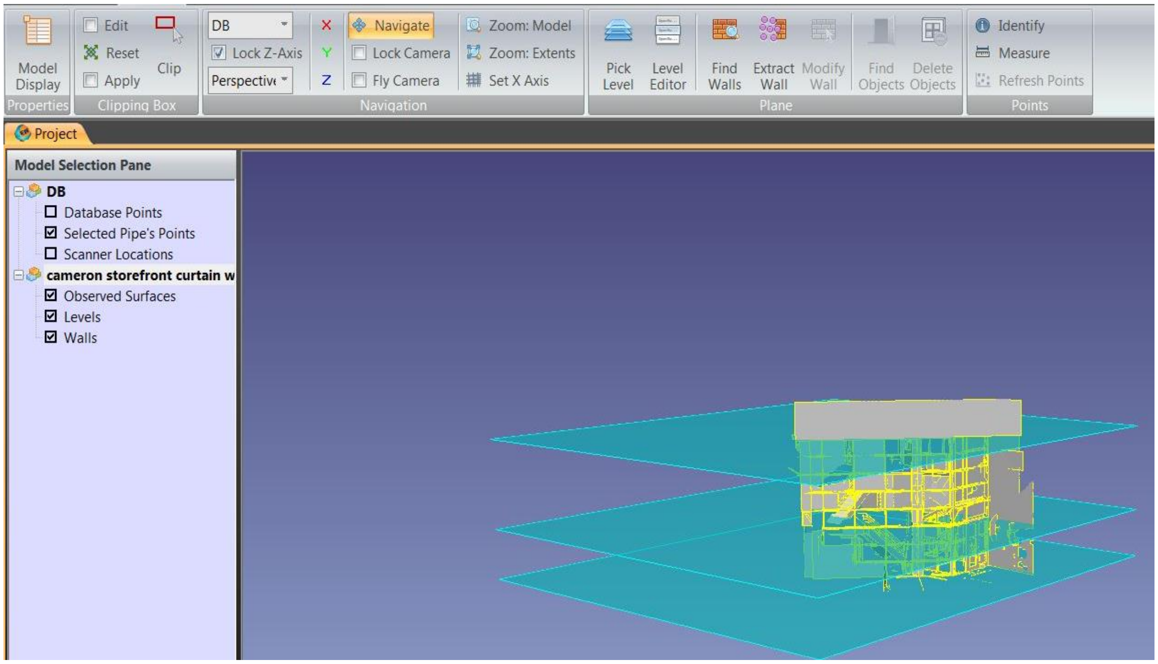


FIGURE 7: Levels automatically picked up in Edgewise

3.2.2. REVIT: A PARAMETRIC CHANGE ENGINE

Revit is one of the most widespread and broadly used BIM software because along with this interoperable feature it also offers custom families and user-defined parameters, therefore Revit was the preferred software for this study. In Revit the exported SCENE file in. rcp format and the Edgewise model, both are imported so as to create an as-built BIM model. The Edgewise walls were converted into the storefront curtain wall, from the curtain wall family in Revit. Further, with the help of the point cloud data, the thickness and the position of the mullions, transoms and glass panels were edited, and an approximate as-built 3D model was developed. Even though the materials for the curtain wall were recorded in Revit as stainless steel alloy for the mullions and transoms and glass for the panels, they had to be updated further in SOLIDWORKS for performing FEA on the model. As seen in FIGURE 8, the model looks approximately like the actual curtain wall.

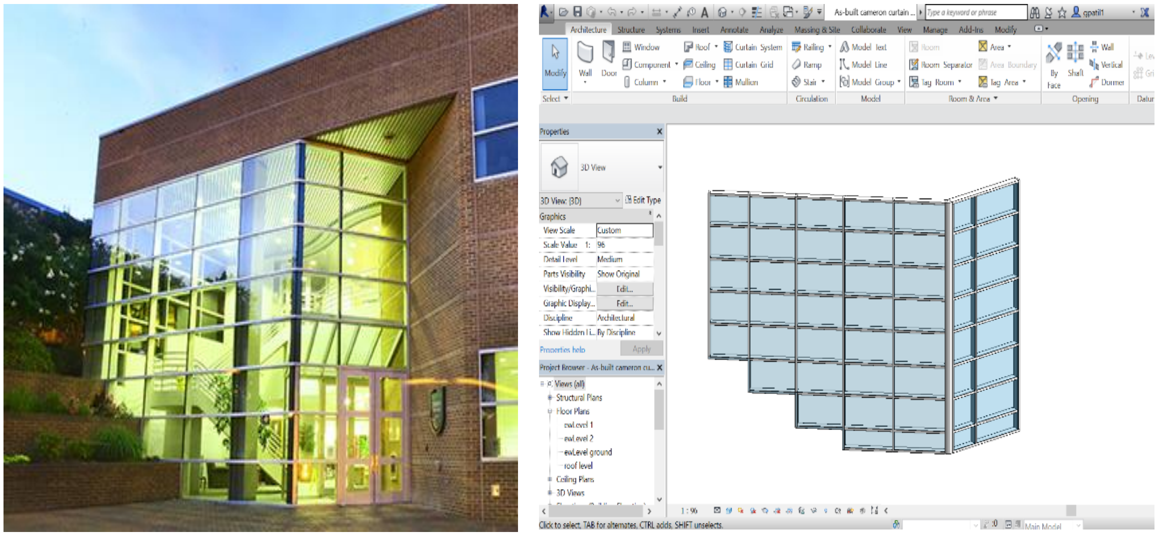


FIGURE 8: Cameron Curtain wall: Actual wall vs as-built model

3.3. STEP THREE: PERFORMING FINITE ELEMENT ANALYSIS

The last step in the SCAN-BIM-FEA technique is developing a structural model with proper boundary parameters and loading conditions, and then performing finite element analysis on it. For this step three software were experimented with, out of which two failed and SOLIDWORKS emerged successfully. For converting the .rvt file (Revit file) into .iges file, the medium used is AutoCAD, where the Revit file can be imported and then converted into .iges file which is the preferred format for Ansys software. But ANSYS had limitations. Since only the student version was available for this study, only 20,000 meshing entities could be generated, which weren't enough to mesh the entire curtain wall. Hence Ansys was discarded. The other option was to use Robot Structural Analysis. Although Robot provided a direct tab to convert the model from Revit to Robot, its user interface was quite difficult to handle, and it led to a lot of unknown errors. As a result, Robot was also not chosen. SOLIDWORKS proved to be successful in finely meshing the curtain wall and providing proper deformation results.

3.3.1. CALCULATING AND APPLYING THE LOADS AND BOUNDARY CONDITIONS

In this study, two main loads are considered to develop the deformation graphs of the curtain wall. In SOLIDWORKS, the software calculates the dead load of the entity depending on the materialistic property of the entity and by applying gravitational force. That's how the vertical dead load was applied. For the lateral wind load, it was calculated manually for each glazed panel of the curtain wall. The formula used for calculating wind load was as follows:

Wind Force = $A * P * C_d * K_z * G_h$ ("How to Calculate Wind Load," n.d.)

Where,

A = Area of the glass panel

Wind speed in Charlotte on windy days

= 12mph =5.36448 m/s = 17.6 ft/s

Average Air density in Charlotte = 94%

Therefore, P= Wind pressure ……………………………………… using ("Wind Calculator," n.d.)

= 1.3766 kg/m^2 = 0.2819 $lb./ft^2$

C_d= drag coefficient

= 2 (long flat plate) or 1.4 (short flat plate)

K_z= exposure coefficient

= $(z/33)^{2/7}$ ft………where z= height of the ground from the midpoint of the panel

G^h = gust response factor

= $0.65 + 0.60/ (h/33)^{1/7}$ ft^{-1}………. where h= height of the ground from the panel's top.

Using this Formula, wind loads from the bottom right panel of the curtain wall to top left panel of the curtain wall were calculated for different wind speeds from 12 mph up to 70 mph and the legend of these forces is given in FIGURE 9. These calculations are shown in the tables in APPENDIX: WIND LOADS CALCULATED FOR DIFFERENT WIND SPEEDS.

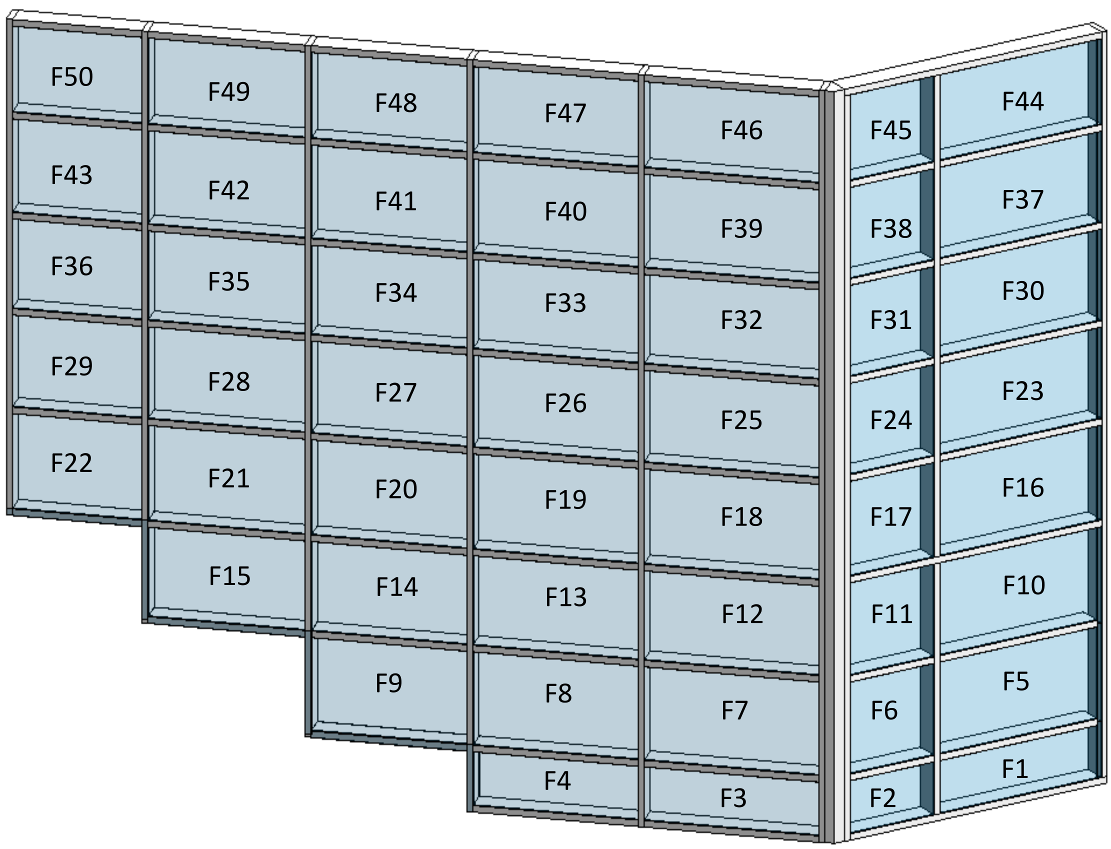


FIGURE 9: Legend of the forces applied to the curtain wall panels

TABLE 1: Wind Load Calculations for the as-designed model (Case 1)

For wind speed = 12 mph= 5.36448 m/s = 17.6 ft/s, and air density = 94 % (Case 1)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	Value	approximate
F1	0.944	1.3766	1.6	0.2575	1.7208	0.921313368	0.9
F2	0.536	1.3766	1.4	0.2575	1.7208	0.457728782	0.5
F3	0.922	1.3766	1.6	0.2575	1.7208	0.899842082	0.9
F4	0.904	1.3766	1.6	0.2575	1.7208	0.882274666	0.9
F5	1.643	1.3766	2	0.3761	1.5812	2.690081659	2.7
F6	0.932	1.3766	1.8	0.3761	1.5812	1.373366096	1.4
F7	1.617	1.3766	2	0.3761	1.5812	2.647511894	2.6
F8	1.613	1.3766	2	0.3761	1.5812	2.6409627	2.6
F9	1.351	1.3766	2	0.3761	1.5812	2.211990457	2.2
F10	1.62	1.3766	2	0.4511	1.519	3.056211295	3.1
F11	1.0414	1.3766	1.8	0.4511	1.519	1.768188023	1.8
F12	1.571	1.3766	2	0.4511	1.519	2.963770336	3
F13	1.568	1.3766	2	0.4511	1.519	2.958110685	3
F14	1.341	1.3766	2	0.4511	1.519	2.529863794	2.5
F15	1.413	1.3766	2	0.4511	1.519	2.665695407	2.7
F16	1.596	1.3766	2	0.5026	1.479	3.266339374	3.3
F17	0.906	1.3766	1.8	0.5026	1.479	1.668780154	1.7
F18	1.557	1.3766	2	0.5026	1.479	3.186522811	3.2
F19	1.553	1.3766	2	0.5026	1.479	3.178336496	3.2
F20	1.329	1.3766	2	0.5026	1.479	2.7199029	2.7
F21	1.378	1.3766	2	0.5026	1.479	2.820185249	2.8
F22	1.114	1.3766	2	0.5026	1.479	2.279888511	2.3
F23	1.655	1.3766	2	0.5441	1.4509	3.597095479	3.6
F24	0.939	1.3766	1.8	0.5441	1.4509	1.836800839	1.8
F25	1.62	1.3766	2	0.5441	1.4509	3.521023973	3.5
F26	1.616	1.3766	2	0.5441	1.4509	3.512330087	3.5
F27	1.383	1.3766	2	0.5441	1.4509	3.005911207	3
F28	1.434	1.3766	2	0.5441	1.4509	3.116758258	3.1
F29	1.118	1.3766	2	0.5441	1.4509	2.429941236	2.4
F30	1.604	1.3766	2	0.5789	1.4288	3.652726168	3.7
F31	0.91	1.3766	1.8	0.5789	1.4288	1.865076516	1.9
F32	1.567	1.3766	2	0.5789	1.4288	3.568467522	3.6
F33	1.563	1.3766	2	0.5789	1.4288	3.559358479	3.6
F34	1.337	1.3766	2	0.5789	1.4288	3.04469756	3
F35	1.387	1.3766	2	0.5789	1.4288	3.158560596	3.2
F36	1.082	1.3766	2	0.5789	1.4288	2.463996081	2.5
F37	1.622	1.3766	2	0.6089	1.4109	3.83646127	3.8
F38	0.921	1.3766	1.8	0.6089	1.4109	1.960568895	2
F39	1.585	1.3766	2	0.6089	1.4109	3.748946432	3.7
F40	1.581	1.3766	2	0.6089	1.4109	3.739485369	3.7
F41	1.353	1.3766	2	0.6089	1.4109	3.200204746	3.2
F42	1.403	1.3766	2	0.6089	1.4109	3.318468041	3.3
F43	1.094	1.3766	2	0.6089	1.4109	2.587600881	2.6
F44	1.55	1.3766	2	0.6349	1.3965	3.783691559	3.8
F45	0.88	1.3766	1.8	0.6349	1.3965	1.933344332	1.9
F46	1.514	1.3766	2	0.6349	1.3965	3.695812272	3.7
F47	1.511	1.3766	2	0.6349	1.3965	3.688488998	3.7
F48	1.292	1.3766	2	0.6349	1.3965	3.153889997	3.2
F49	1.341	1.3766	2	0.6349	1.3965	3.273503472	3.3
F50	1.045	1.3766	2	0.6349	1.3965	2.550940438	2.6
Fvertical Transomes	2.032576119	1.3766	1.4	0.5284	1.3974	2.892452046	2.9
F Horizontal	2.819	1.3766	1.4	0.5284	1.3974	4.01157046	4

TABLE 2: Wind Load Calculations for the as-built model (Case 1)

For wind speed = 12 mph= 5.36448 m/s = 17.6 ft/s, and air density = 94 % (Case 1)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	1.3766	1.6	0.2575	1.7208	0.906673855	0.9
F2	0.497	1.3766	1.4	0.2575	1.7208	0.424423889	0.4
F3	0.915	1.3766	1.6	0.2575	1.7208	0.893010309	0.9
F4	0.863	1.3766	1.6	0.2575	1.7208	0.842259997	0.8
F5	1.612	1.3766	2	0.3761	1.5812	2.639325401	2.6
F6	0.861	1.3766	1.8	0.3761	1.5812	1.268742713	1.3
F7	1.592	1.3766	2	0.3761	1.5812	2.606579428	2.6
F8	1.502	1.3766	2	0.3761	1.5812	2.459222551	2.5
F9	1.416	1.3766	2	0.3761	1.5812	2.318414868	2.3
F10	1.624	1.3766	2	0.4511	1.519	3.063757495	3.1
F11	0.868	1.3766	1.8	0.4511	1.519	1.473773002	1.5
F12	1.524	1.3766	2	0.4511	1.519	2.875102477	2.9
F13	1.437	1.3766	2	0.4511	1.519	2.710972611	2.7
F14	1.355	1.3766	2	0.4511	1.519	2.556275496	2.6
F15	1.367	1.3766	2	0.4511	1.519	2.578914099	2.6
F16	1.663	1.3766	2	0.5026	1.479	3.403460137	3.4
F17	0.889	1.3766	1.8	0.5026	1.479	1.637467502	1.6
F18	1.623	1.3766	2	0.5026	1.479	3.321596995	3.3
F19	1.531	1.3766	2	0.5026	1.479	3.133311768	3.1
F20	1.443	1.3766	2	0.5026	1.479	2.953212855	3
F21	1.457	1.3766	2	0.5026	1.479	2.981864955	3
F22	1.2	1.3766	2	0.5026	1.479	2.455894266	2.5
F23	1.601	1.3766	2	0.5441	1.4509	3.479728013	3.5
F24	0.856	1.3766	1.8	0.5441	1.4509	1.674442512	1.7
F25	1.567	1.3766	2	0.5441	1.4509	3.405829979	3.4
F26	1.478	1.3766	2	0.5441	1.4509	3.212391008	3.2
F27	1.393	1.3766	2	0.5441	1.4509	3.027645923	3
F28	1.406	1.3766	2	0.5441	1.4509	3.055901053	3.1
F29	1.158	1.3766	2	0.5441	1.4509	2.516880099	2.5
F30	1.601	1.3766	2	0.5789	1.4288	3.645894386	3.6
F31	0.856	1.3766	1.8	0.5789	1.4288	1.754401646	1.8
F32	1.524	1.3766	2	0.5789	1.4288	3.470545312	3.5
F33	1.437	1.3766	2	0.5789	1.4288	3.272423631	3.3
F34	1.355	1.3766	2	0.5789	1.4288	3.085688253	3.1
F35	1.367	1.3766	2	0.5789	1.4288	3.113015382	3.1
F36	1.126	1.3766	2	0.5789	1.4288	2.564195552	2.6
F37	1.601	1.3766	2	0.6089	1.4109	3.786790687	3.8
F38	0.856	1.3766	1.8	0.6089	1.4109	1.82220084	1.8
F39	1.595	1.3766	2	0.6089	1.4109	3.772599091	3.8
F40	1.504	1.3766	2	0.6089	1.4109	3.557359895	3.6
F41	1.418	1.3766	2	0.6089	1.4109	3.353947029	3.4
F42	1.431	1.3766	2	0.6089	1.4109	3.384695486	3.4
F43	1.179	1.3766	2	0.6089	1.4109	2.788648482	2.8
F44	1.506	1.3766	2	0.6349	1.3965	3.676283541	3.7
F45	0.805	1.3766	1.8	0.6349	1.3965	1.768570668	1.8
F46	1.467	1.3766	2	0.6349	1.3965	3.581080979	3.6
F47	1.383	1.3766	2	0.6349	1.3965	3.376029307	3.4
F48	1.304	1.3766	2	0.6349	1.3965	3.183183093	3.2
F49	1.317	1.3766	2	0.6349	1.3965	3.21491728	3.2
F50	1.084	1.3766	2	0.6349	1.3965	2.646143	2.6
Fvertical Transomes	2.032576119	1.3766	1.4	0.5284	1.3974	2.892452046	2.9
F Horizontal	2.819	1.3766	1.4	0.5284	1.3974	4.01157046	4

The formula used to calculate the wind loads applied in this research generates point load, which the software SOLIDWORKS uniformly distributes across the glass panels as shown in FIGURE 10. Every glass panel is applied with a separate point load calculated in

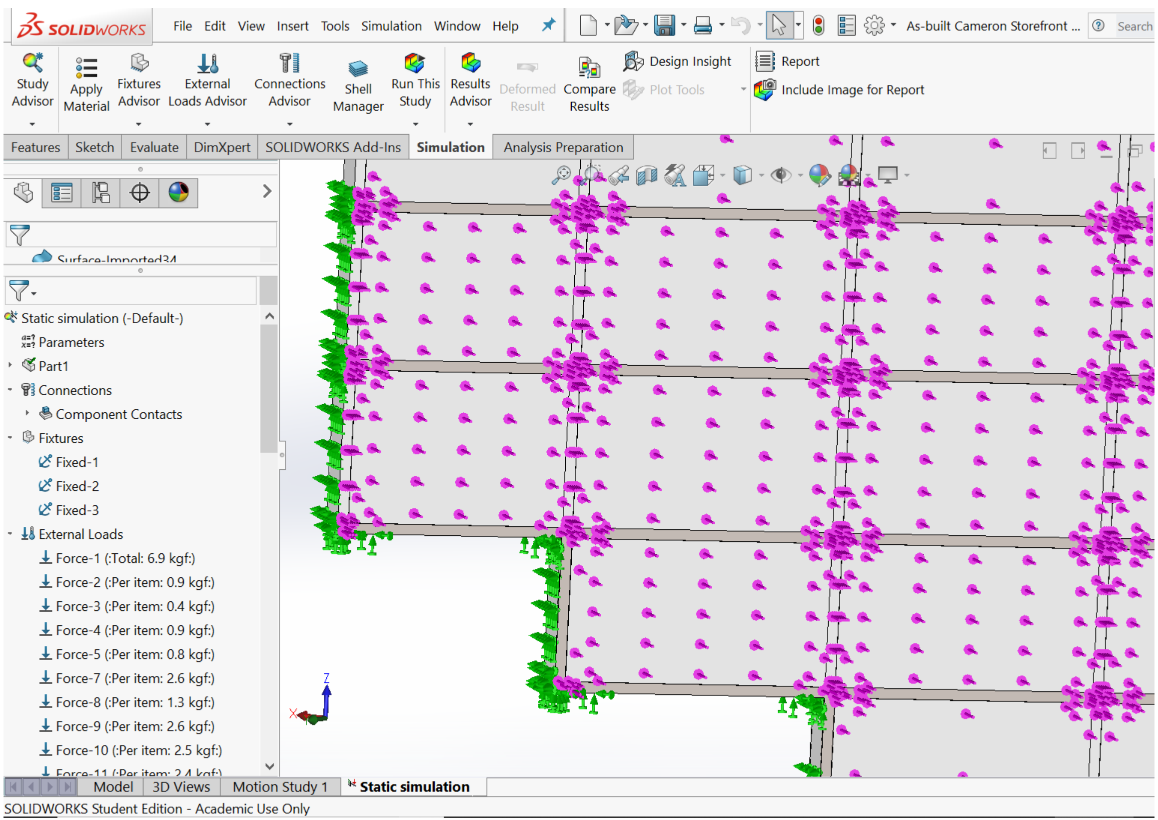


TABLE 1: for the as-designed model and TABLE 2 for the as-built model. The calculations for all the other wind loads depending on the wind speeds are shown in the tables in APPENDIX**:** WIND LOADS CALCULATED FOR DIFFERENT WIND SPEEDS.

FIGURE 10: Point load uniformly distributed across glass panels in SOLIDWORKS.

Boundary conditions and loads were applied as shown in FIGURE 11. Along with the laterally applied wind load, a dead load was applied to the curtain wall vertically. SOLIDWORKS automatically calculates and associates the dead load once gravity is applied, based on the weight of the materials formerly allocated to the different parts of the curtain wall.

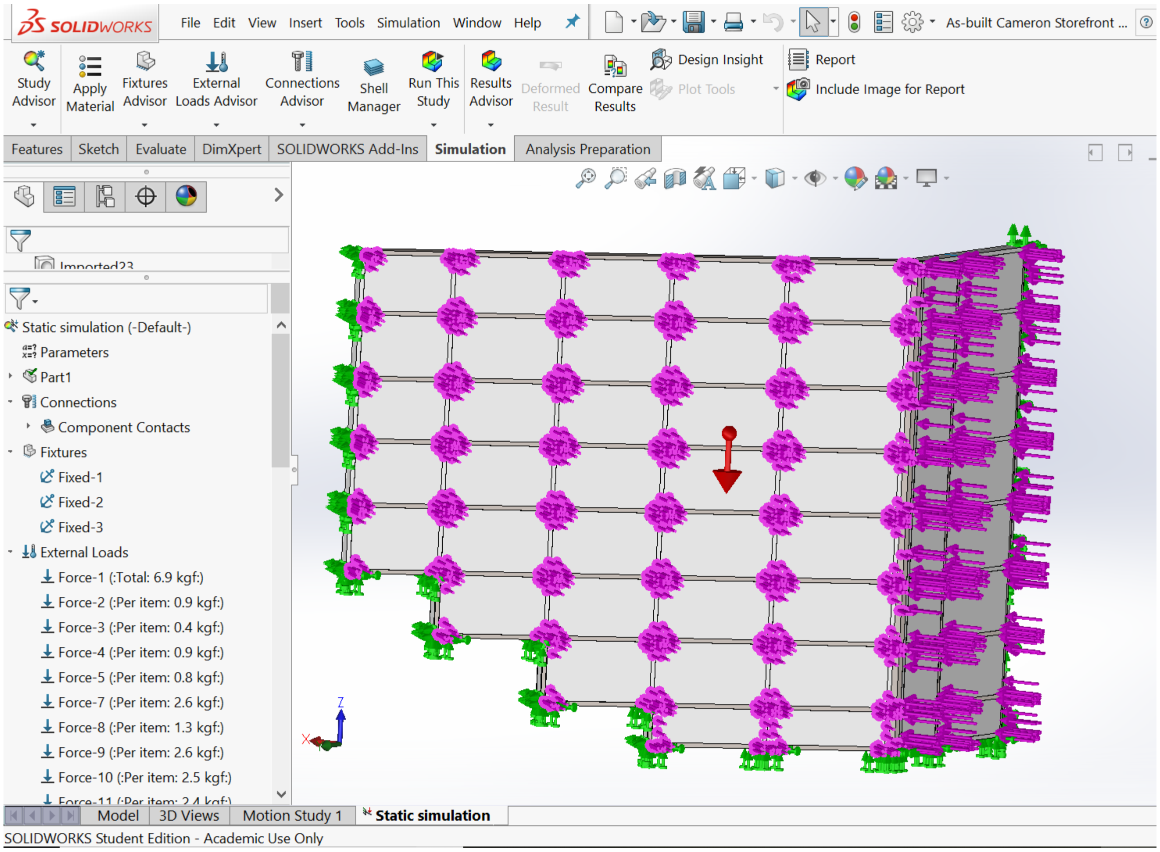
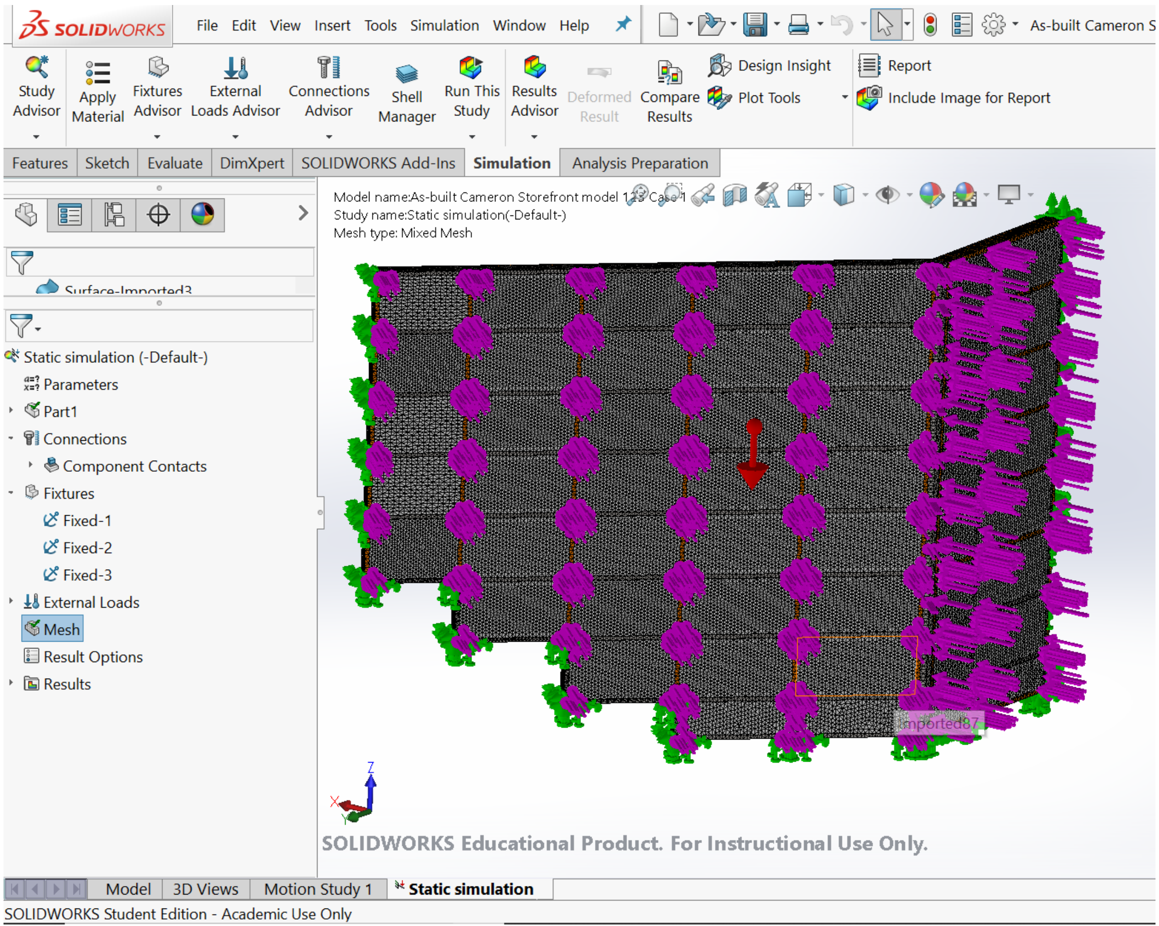


FIGURE 11: Boundary conditions and Loads applied to the wall

3.3.2. SOLIDWORKS: PERFORMING FEA ON THE MODEL

The main Objective of this research was to recognize what damage would typical loading cause to the curtain wall through the help of a structural software which would assist in performing FEA on the model. SOLIDWORKS proved to be quite user-friendly and a complete licensed version was also available. Since it is a CAD software, the Revit file can be directly imported into SOLIDWORKS in a format called standard ACIS format or. sat format. This provides a one-step direct link from Revit to SOLIDWORKS(BIM-FEA).

The material used for glazed panels was glass with elastic modulus as 9998176.446 psi while the mullions and transoms were made up of stainless-steel casting with elastic modulus as



27992282.99 psi. After updating the Solid works model with material properties of the curtain wall, loading it with dead load and wind load and adding the boundary conditions of the wall, it meshes into smaller components.

FIGURE 12: Meshed Curtain wall

The mesh is approximately 65 mm standard mesh with 3.5 mm meshing along the intersections and connections. Curvature mesh is applied to parts that failed to be meshed using a standard mesh. FIGURE 12 shows the meshed curtain wall. The software calculated the dead load of the wall after a gravitational force was applied to it while the wind load had to be manually calculated for each glass panel of the wall and then applied. These two loads together created certain deformities in the curtain wall which were graphically represented in SOLIDWORKS.

12 different wind loads were applied for the as-built models and the as-designed models giving a total of 24 different results. The as-built models show different results as compared to the as-designed models, but the deformation pattern remains the same in both the as-built and as-designed models.

CHAPTER 4: RESULTS

After performing FEA on the curtain wall, SOLIDWORKS helped graphically represent the deformation on the curtain wall. An updated SOLIDWORKS model with material properties of the curtain wall, loading it with dead load and wind load and adding the boundary conditions of the wall, is meshed into smaller components. The software calculated the dead load of the wall after a gravitational force was applied to it while the wind load had to be manually calculated for each glass panel of the wall as mentioned in the section 3.3.1 of CHAPTER 3: METHODOLOGY. The wind load gradually decreases towards the bottom of the curtain wall, as the formula demonstrates that how wind load reduces as the height decreases and how it increases as the surface area of the object increases. These two loads together created certain deformities in the curtain wall which were graphically represented in SOLIDWORKS, in two different models, the as-built and the as-designed models. Different loads are applied to these two models varying according to varying wind speeds. There are around 12 different wind loads applied to the as-built and as-designed models, giving a total of 24 varied results.

FIGURE 13 shows the deformations detected in the model due to the load applied by the wind at the speed of 12 mph. This was manually drafted in Revit with the help of point cloud, while FIGURE 14 shows the deformations in the model due to the same wind loads. This model was automatically generated in Edgewise and further detailed out in Revit. This model in FIGURE 14 is the as-built model with existing deflections caused over time. As seen in the legend the areas which are red color-coded have the maximum deformation while the blue areas have the least deformation.

The scale of the maximum deformation and the minimum deformation is kept constant in both the models. The minimum deformation is $1.00 * 10^{-3}$ mm (3.937 * 10^{-5} inches) and the maximum deformation is $7.3 * 10^{-2}$ mm (2.8740157 * 10^{-3} inches). The red, green, yellow and blue colors change according to the different deformations in different models.

After comparing the heat map and the as-built model results, it is evident that the maximum deformation occurs at the top part of the curtain wall proving the fact that as the wind load goes on increasing towards the top, more distortion is bound to happen in the curtain wall. The heat map (FIGURE 5) shows the deformation that exists currently, while the results from SOLIDWORKS shows the computer-generated deformation due to the typical wind and dead load.

The manually drafted model has no input of the existing deflections, and only represents the deformation caused due to the applied wind and dead loads. While the model in FIGURE 14 contains the existing deformation caused over the years along with the deflections caused due to the applied wind and dead loads. The as-built model can also contain deflections caused due to improper installations, or any kind of unknown impact or force. That is the reason why the deformation of the glass panels is much larger in the as-built models than the as-designed models, and why both the models follow a different deformation pattern. The 12 different cases studied for 12 different wind speeds support this statement. The deformation in the as-built model at the highest wind speed of 70 mph remains at the top central part of the curtain wall. This is probably because of the already existing deformation at the top central part of the curtain wall which does not exist in the as-designed model. The as-designed model shows a different pattern of deformation. As the wind speeds increase the deformation pattern change. The maximum deformation in the as-designed model changes from the top central part of the entire curtain wall to the central part of every glass panel separately, as the wind speed increases from 12mph to 70 mph. The minimum deformation also changes from the bottom of the entire curtain wall to the circumfixal area of every glass panel. This proves that as the wind speed starts increasing every panel is at the risk of breakage.

In FIGURE 35, the deformation goes on decreasing from the center of the curtain wall panel towards the circumference, individually for every panel. Whereas in FIGURE 36, It is clear that the maximum deformation is still at the center top and as the wind speed increases, the deformation starts spreading across the entire curtain wall in a circular pattern from the top center of the curtain wall.

The graphical results are as follows:

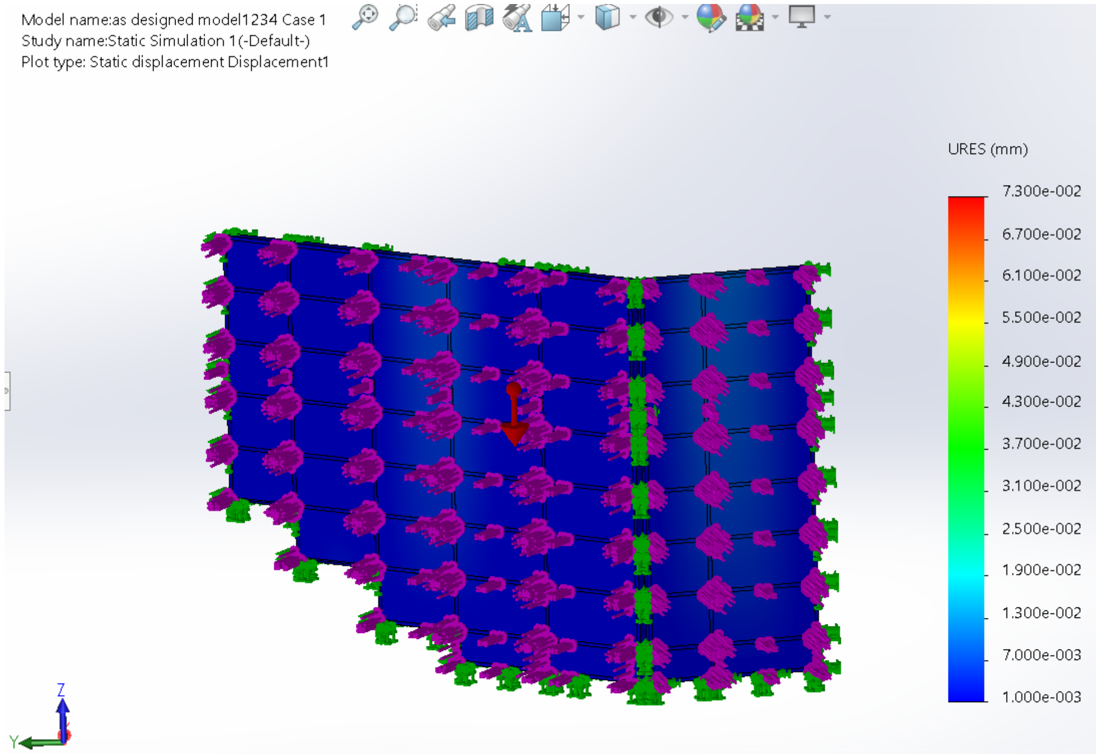


FIGURE 13: Deformation of the as-designed Model (Case 1- 12 mph)

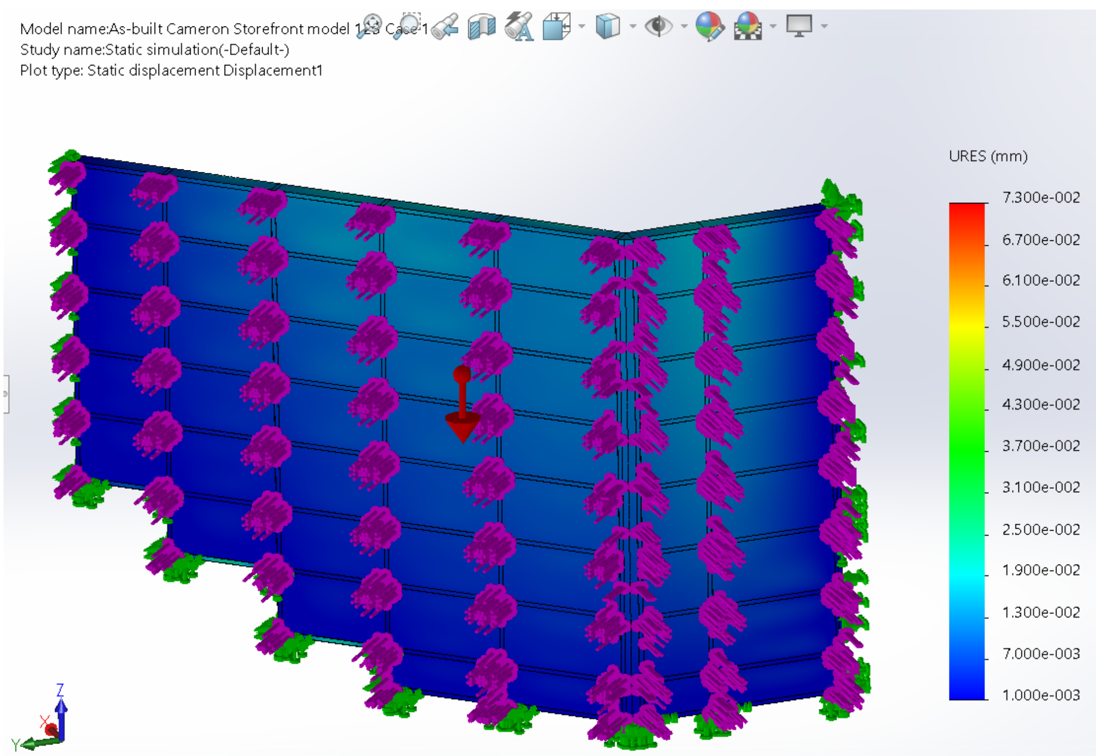


FIGURE 14: Deformation of the as-built Model (Case 1- 12mph)

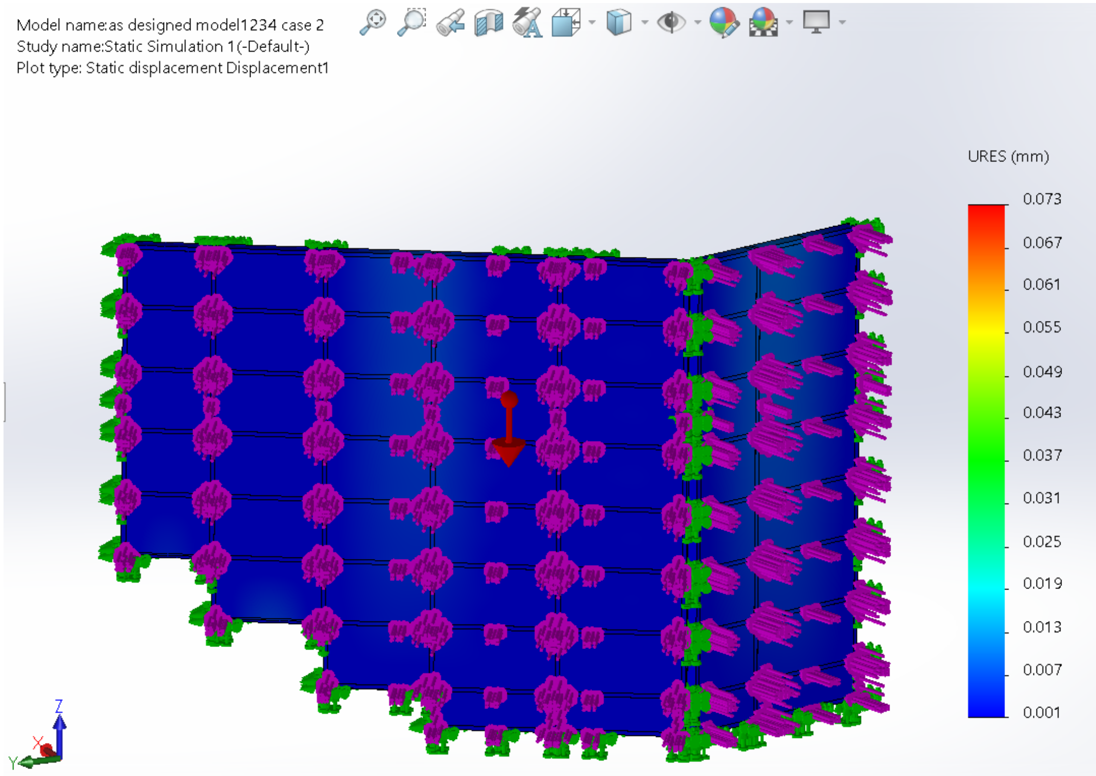


FIGURE 15: Deformation of the as-designed Model (Case 2- 20mph)

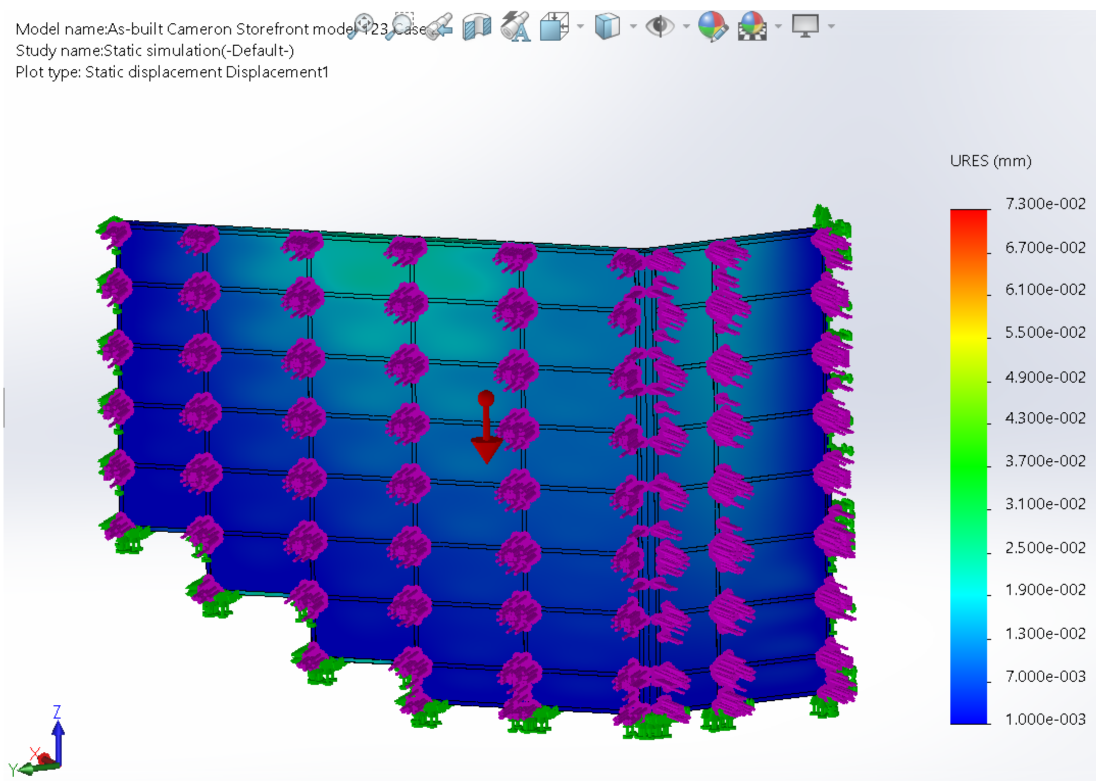


FIGURE 16: Deformation of the as-built Model (Case 2- 20mph)

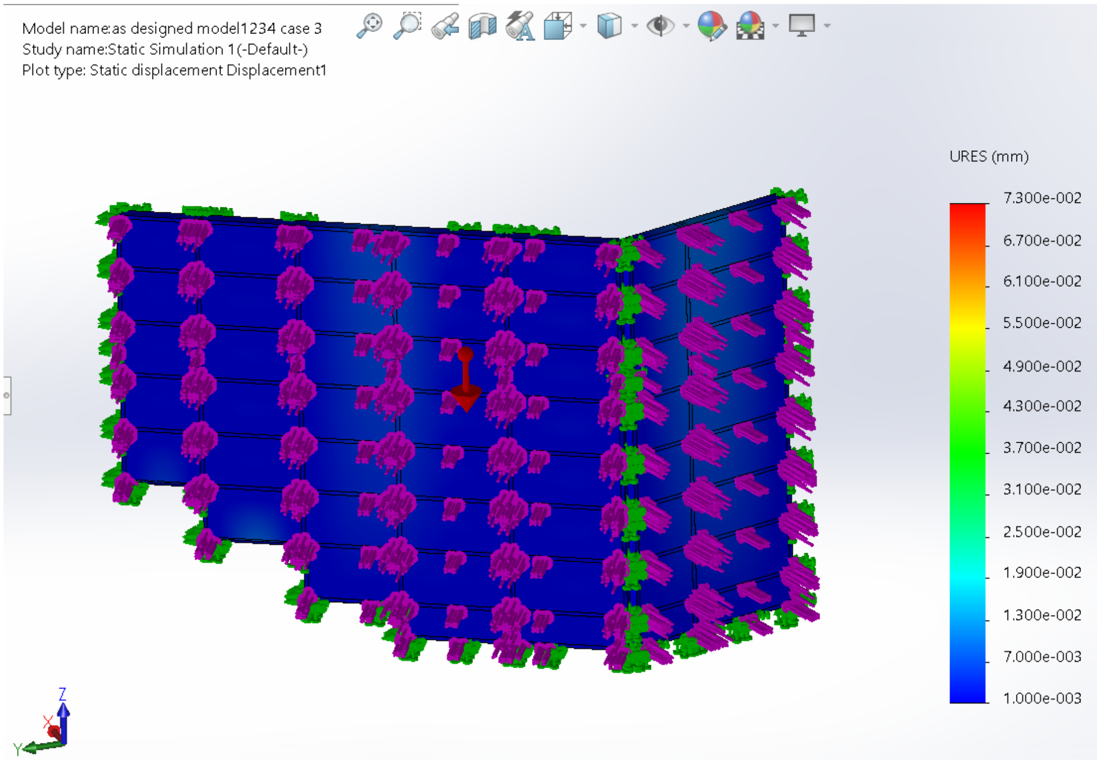


FIGURE 17: Deformation of the as-designed Model (Case 3- 25mph)

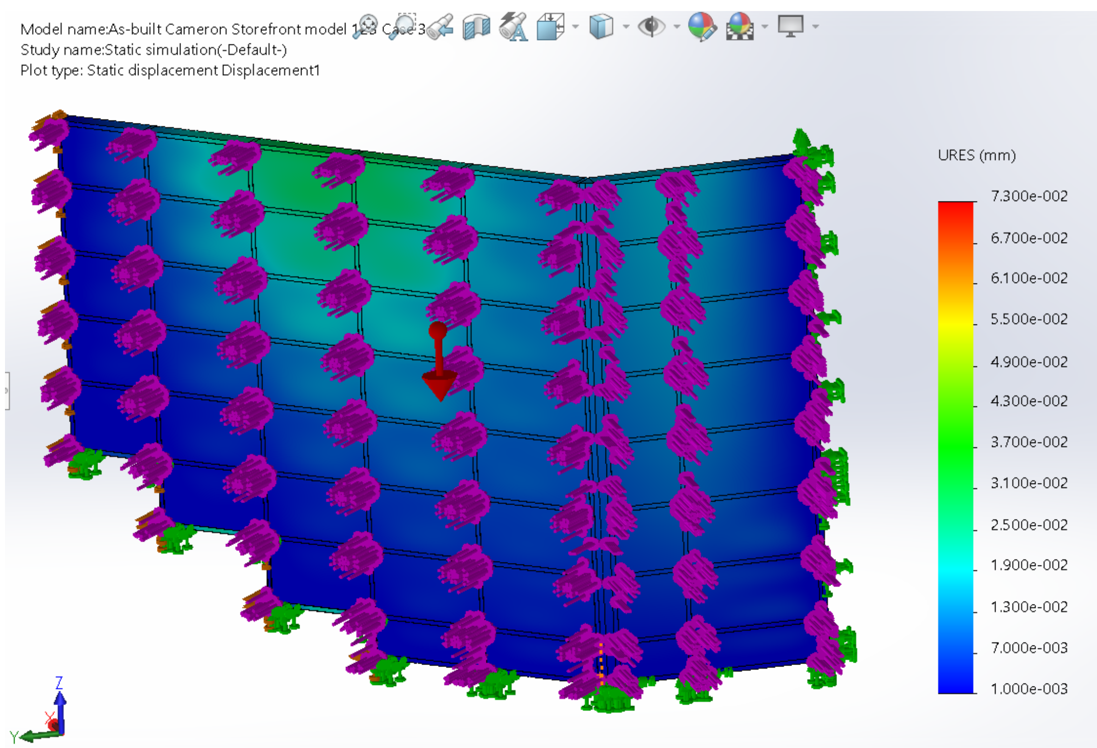


FIGURE 18: Deformation of the as-built Model (Case 3- 25mph)

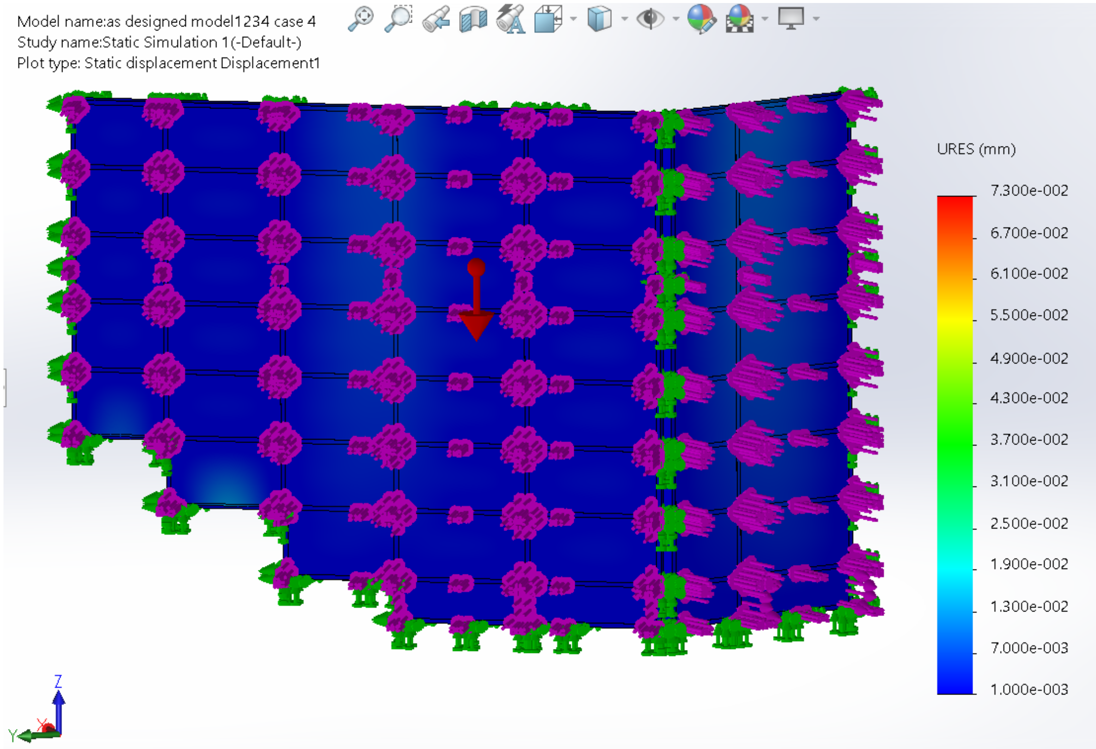


FIGURE 19: Deformation of the as-designed Model (Case 4- 30mph)

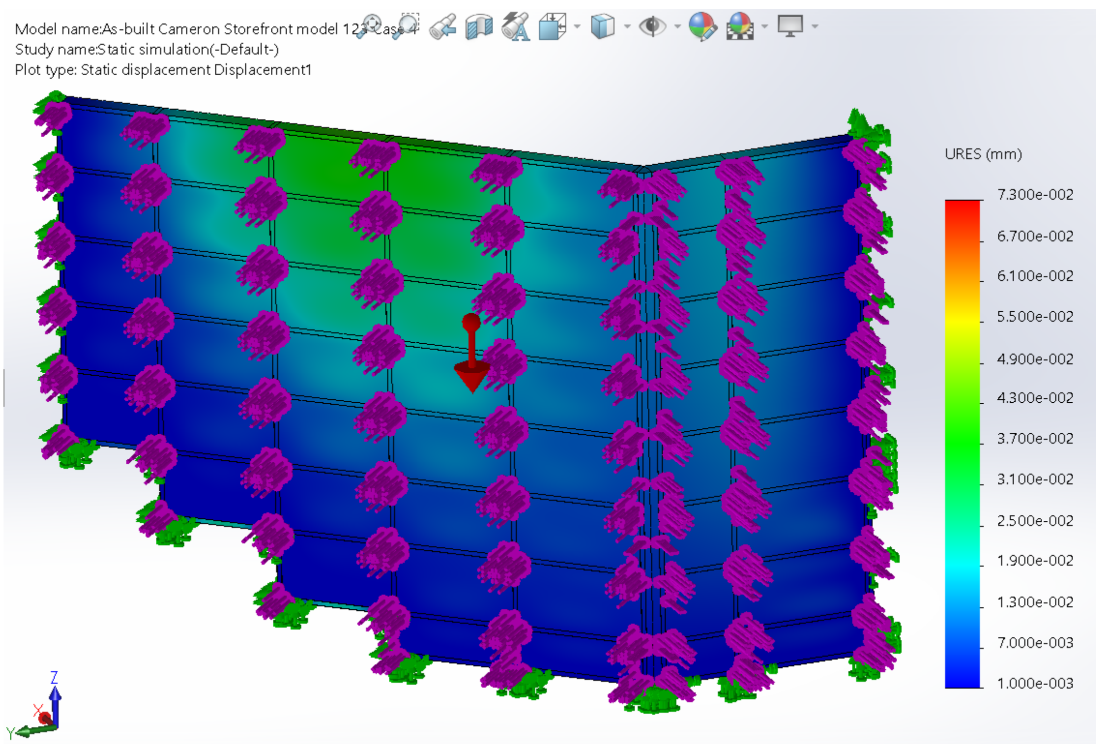


FIGURE 20: Deformation of the as-built Model (Case 4- 30mph)

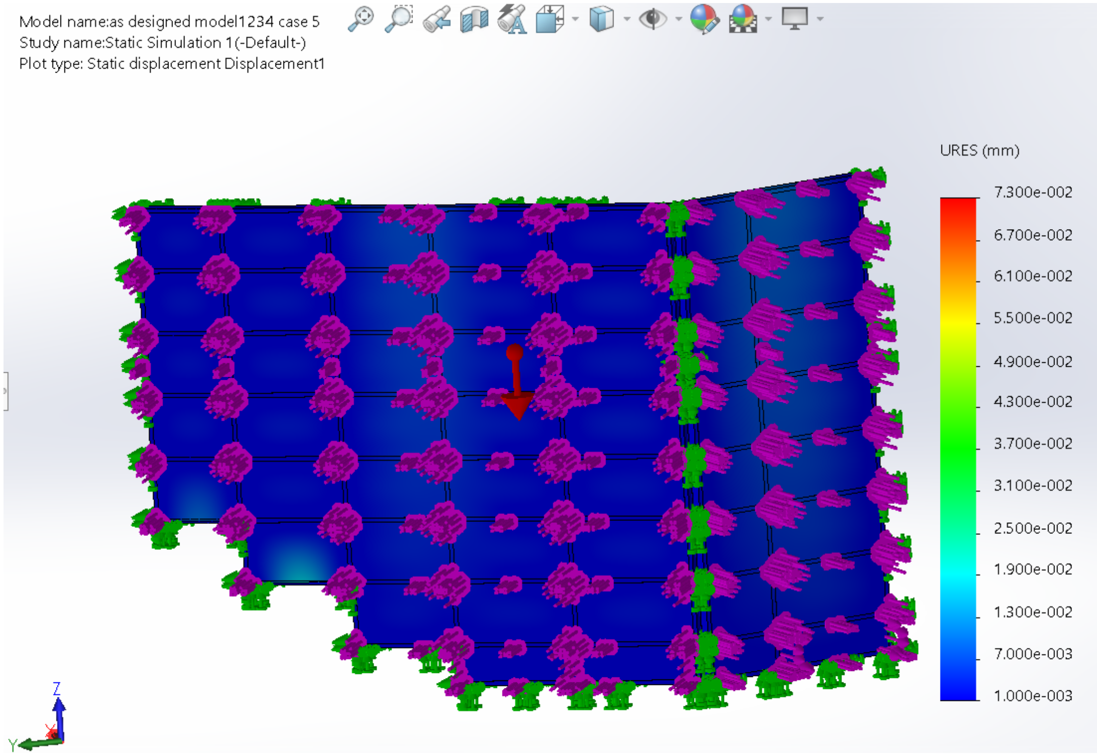


FIGURE 21: Deformation of the as-designed Model (Case 5- 35mph)

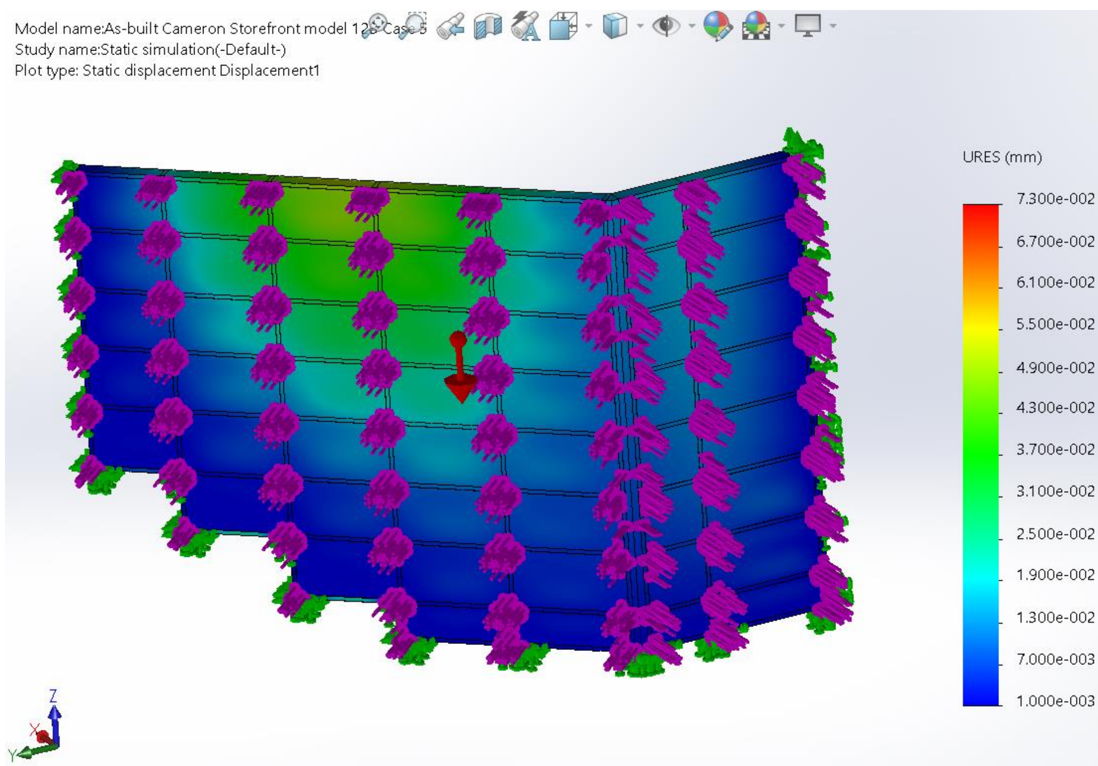


FIGURE 22: Deformation of the as-built Model (Case 5- 35mph)

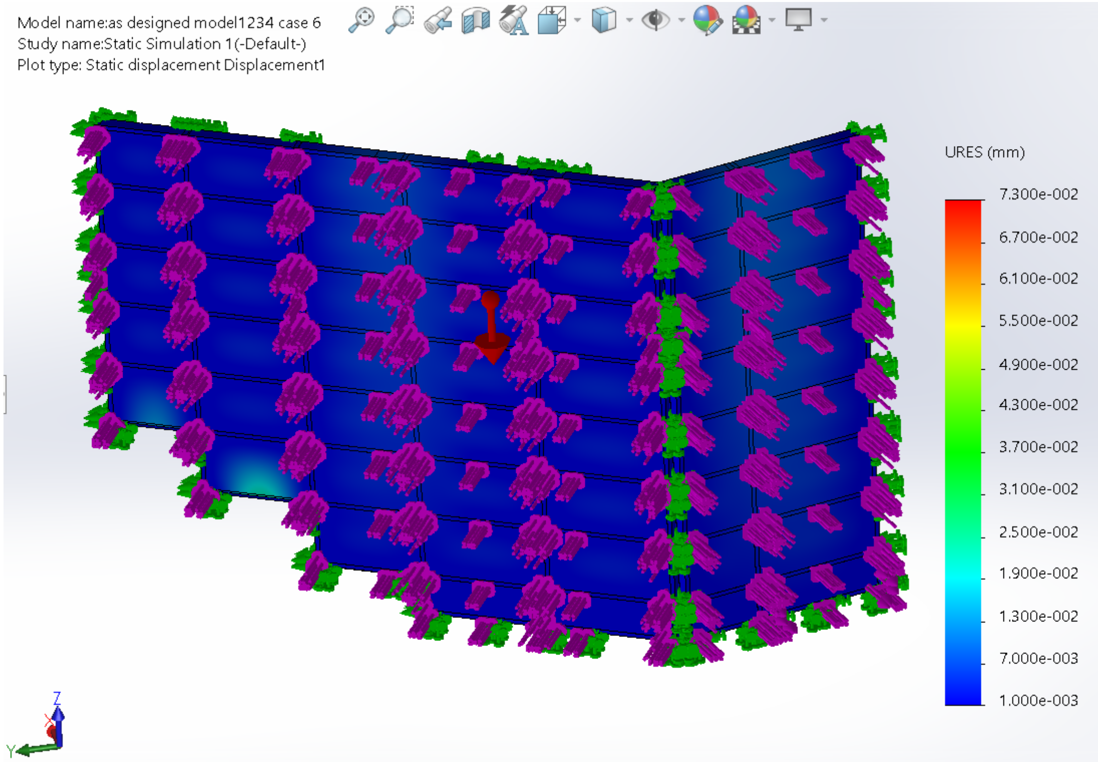


FIGURE 23: Deformation of the as-designed Model (Case 6- 40mph)

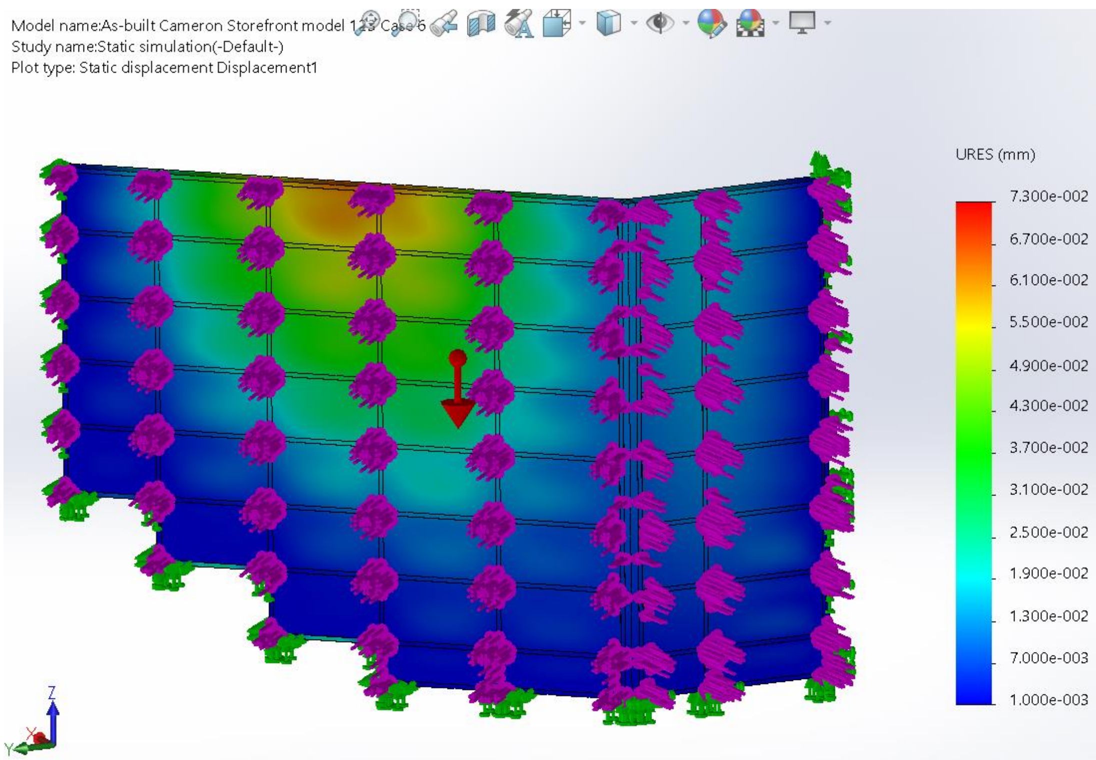


FIGURE 24: Deformation of the as-built Model (Case 6- 40mph)

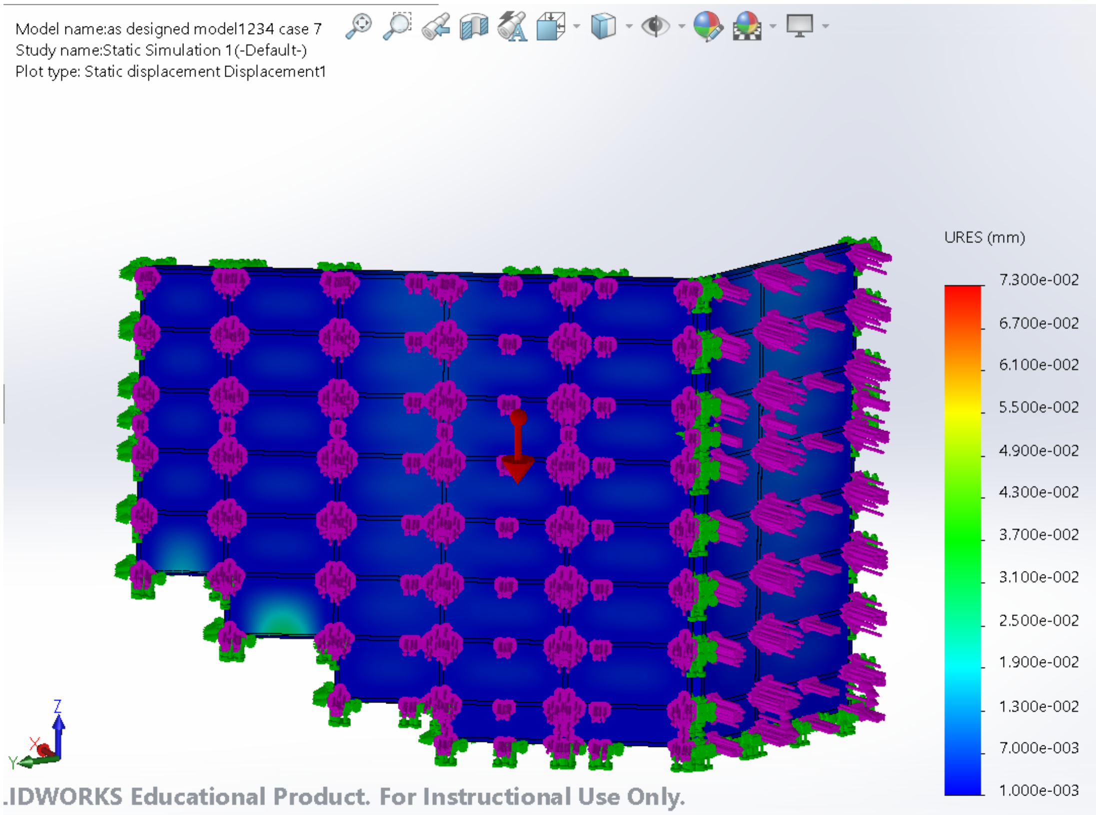


FIGURE 25: Deformation of the as-designed Model (Case 7- 45mph)

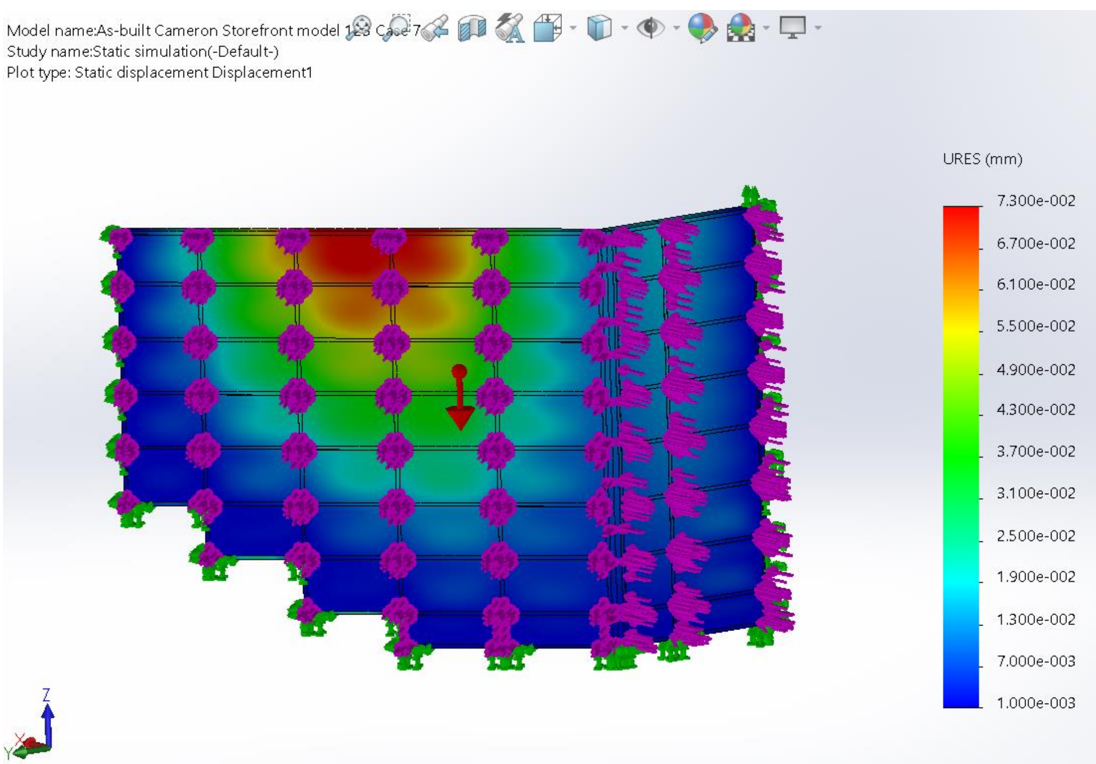


FIGURE 26: Deformation of the as-built Model (Case 7- 45mph)

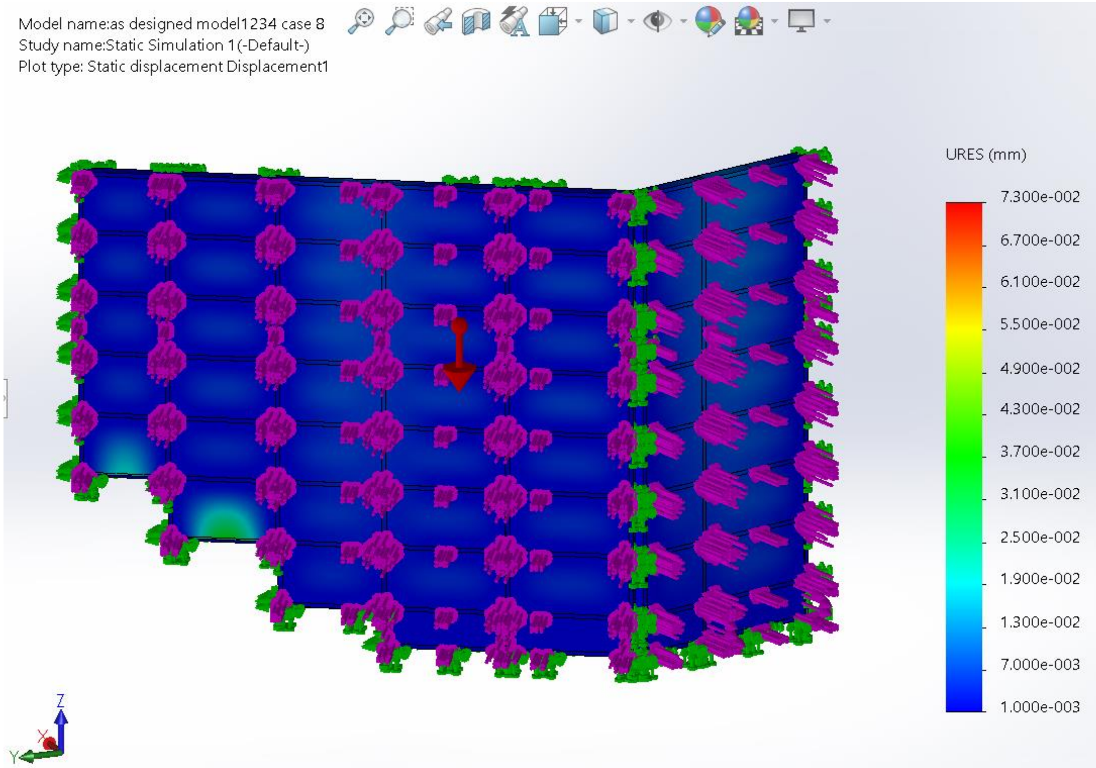


FIGURE 27: Deformation of the as-designed Model (Case 8- 50mph)

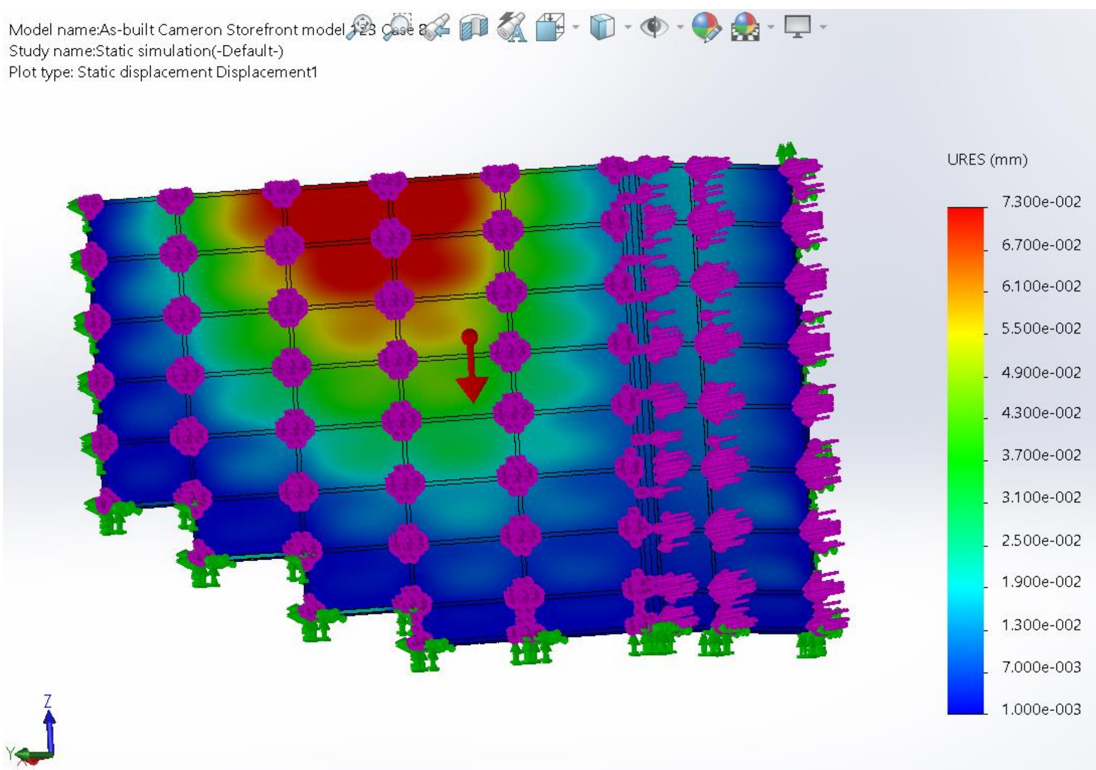


FIGURE 28: Deformation of the as-built Model (Case 8- 50mph)

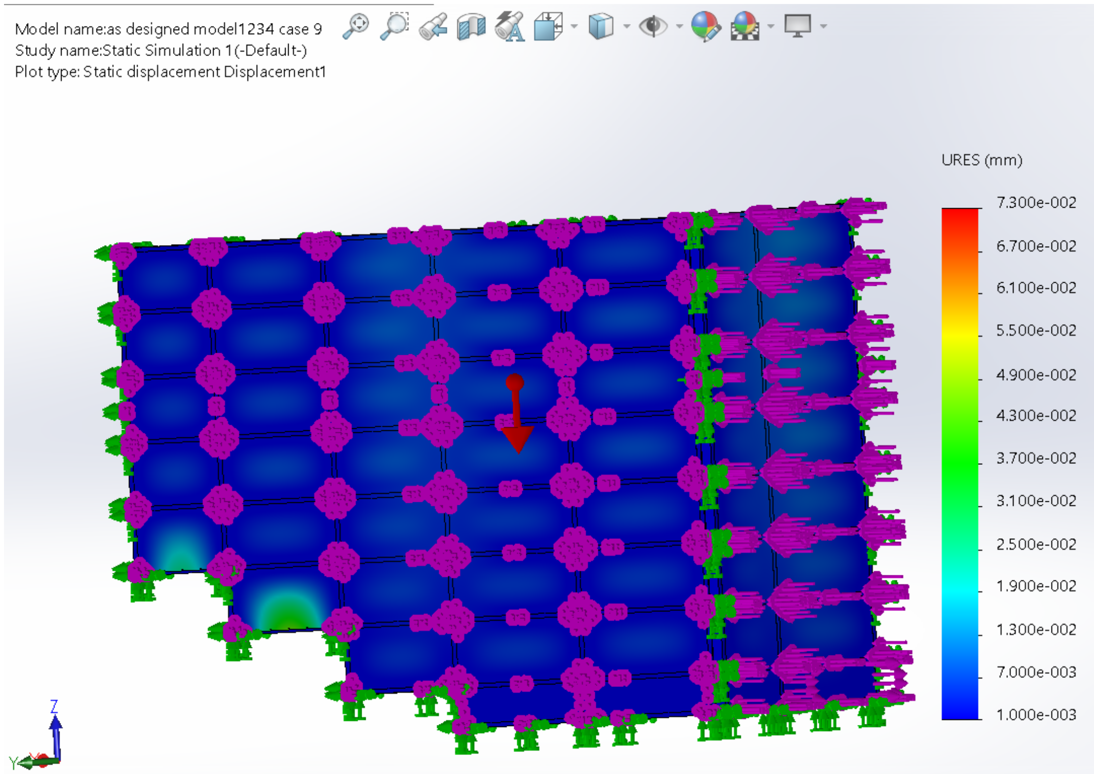


FIGURE 29: Deformation of the as-designed Model (Case 9- 55mph)

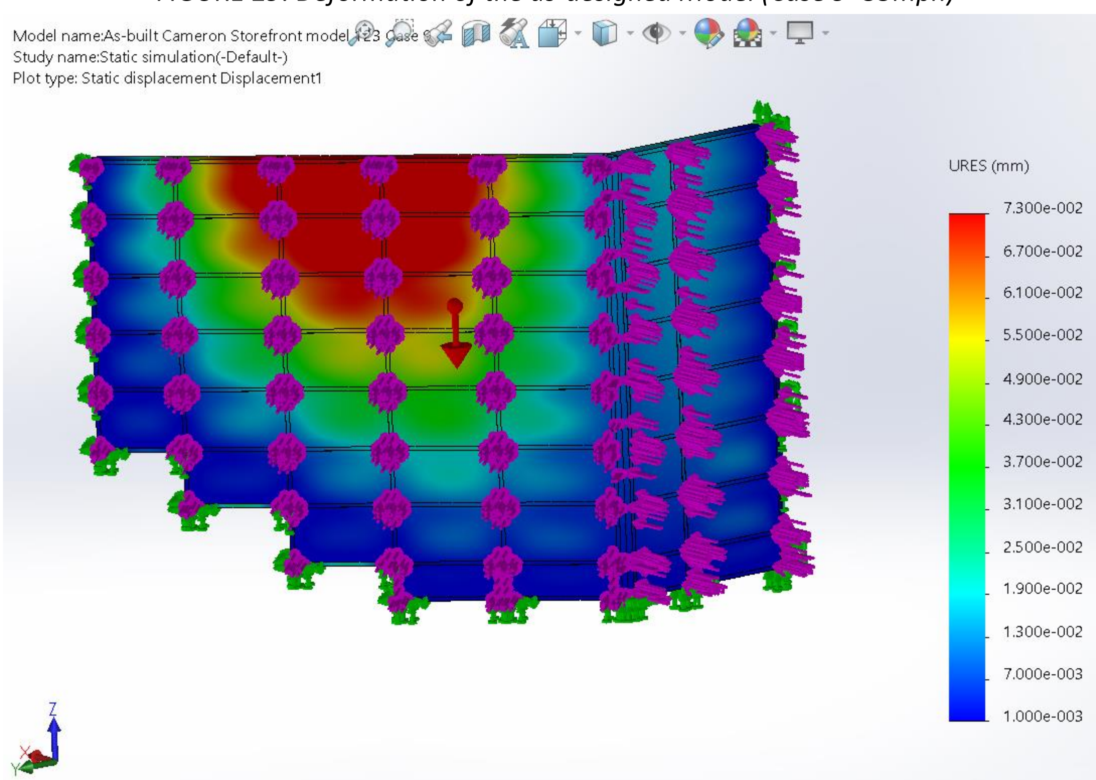


FIGURE 30: Deformation of the as-built Model (Case 9- 55mph)

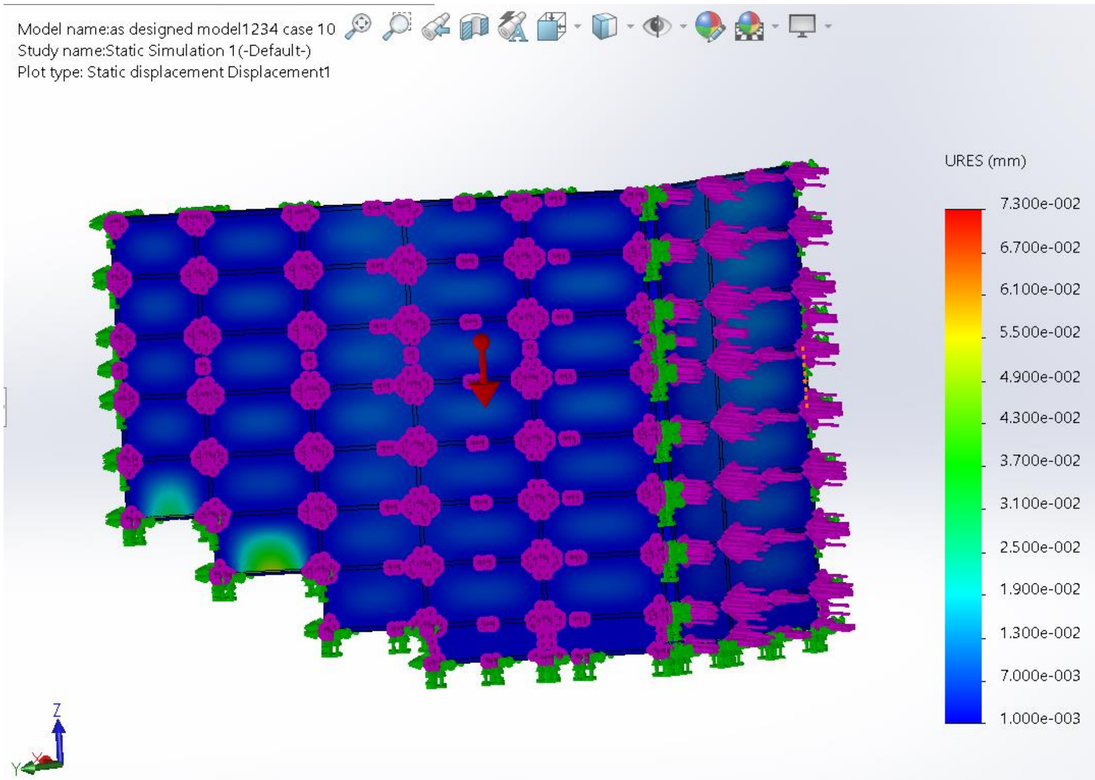


FIGURE 31: Deformation of the as-designed Model (Case 10- 60mph)

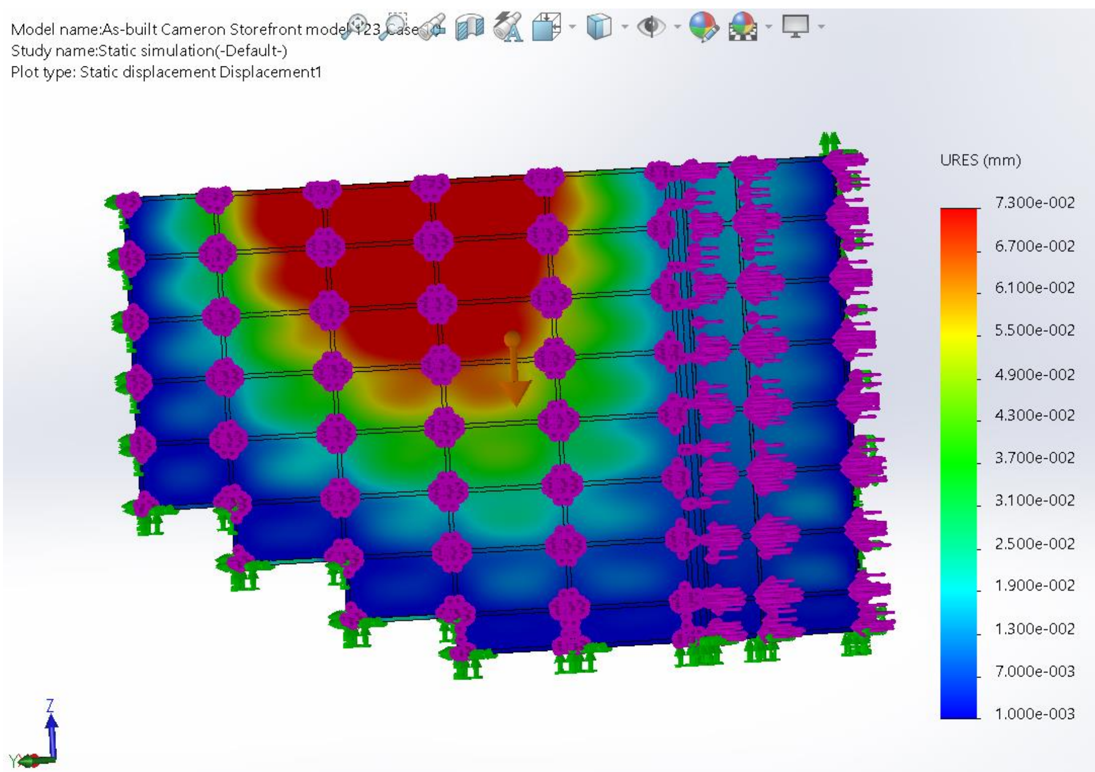


FIGURE 32: Deformation of the as-built Model (Case 10- 60mph)

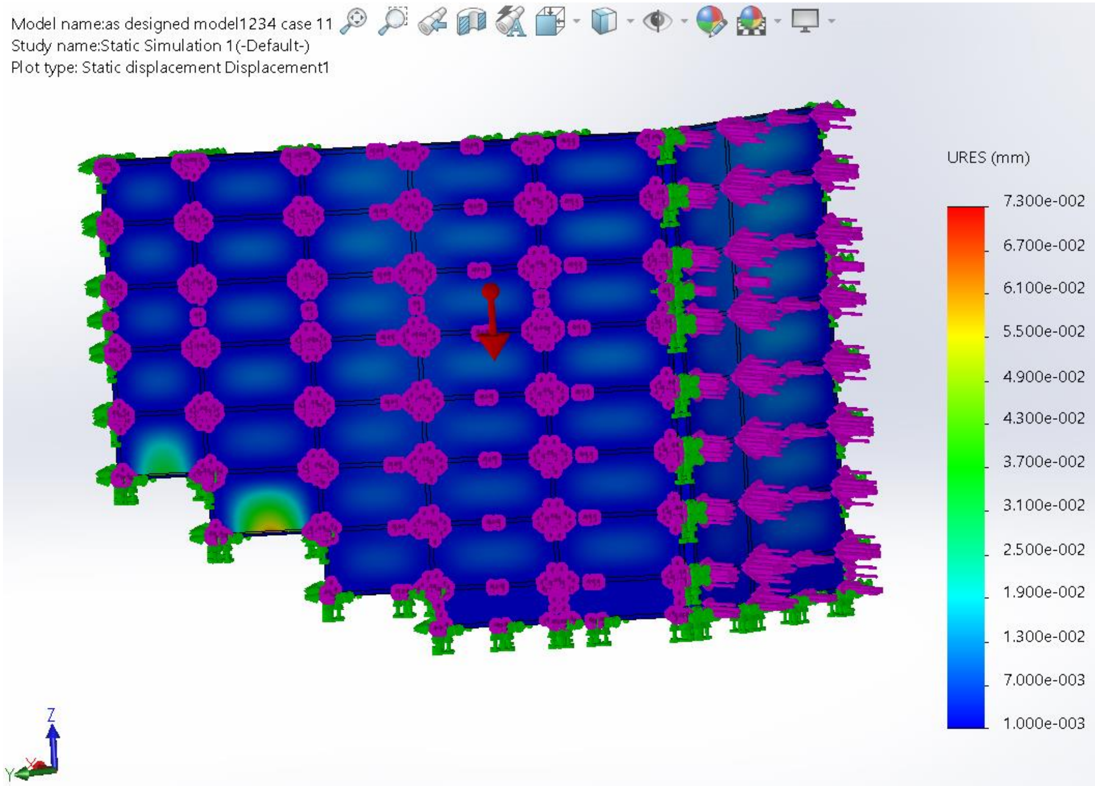


FIGURE 33: Deformation of the as-designed Model (Case 11- 65mph)

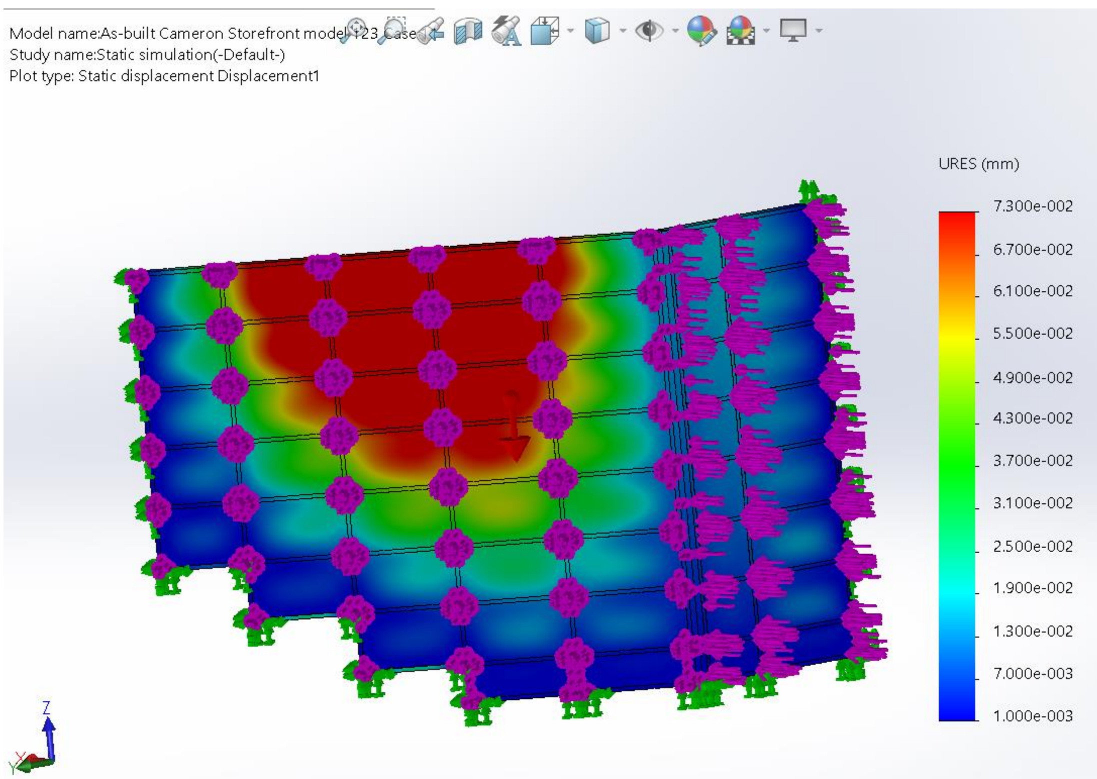


FIGURE 34: Deformation of the as-built Model (Case 11- 65mph)

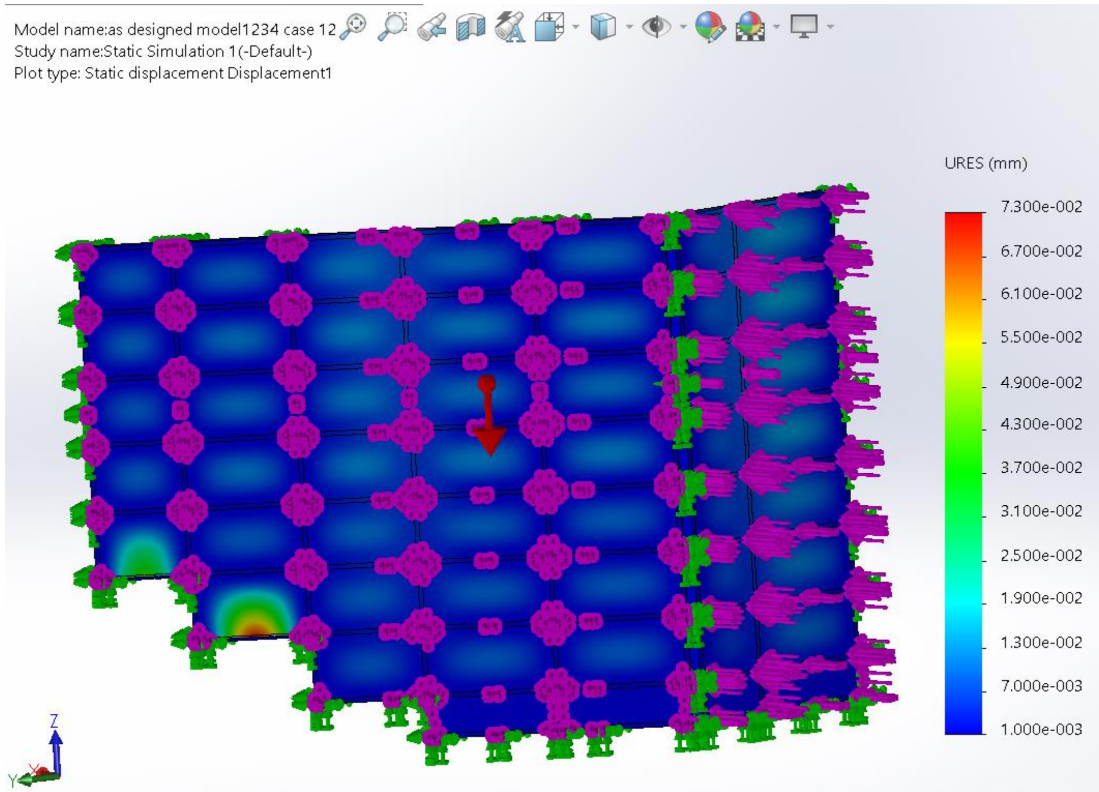


FIGURE 35: Deformation of the as-designed Model (Case 12- 70mph)

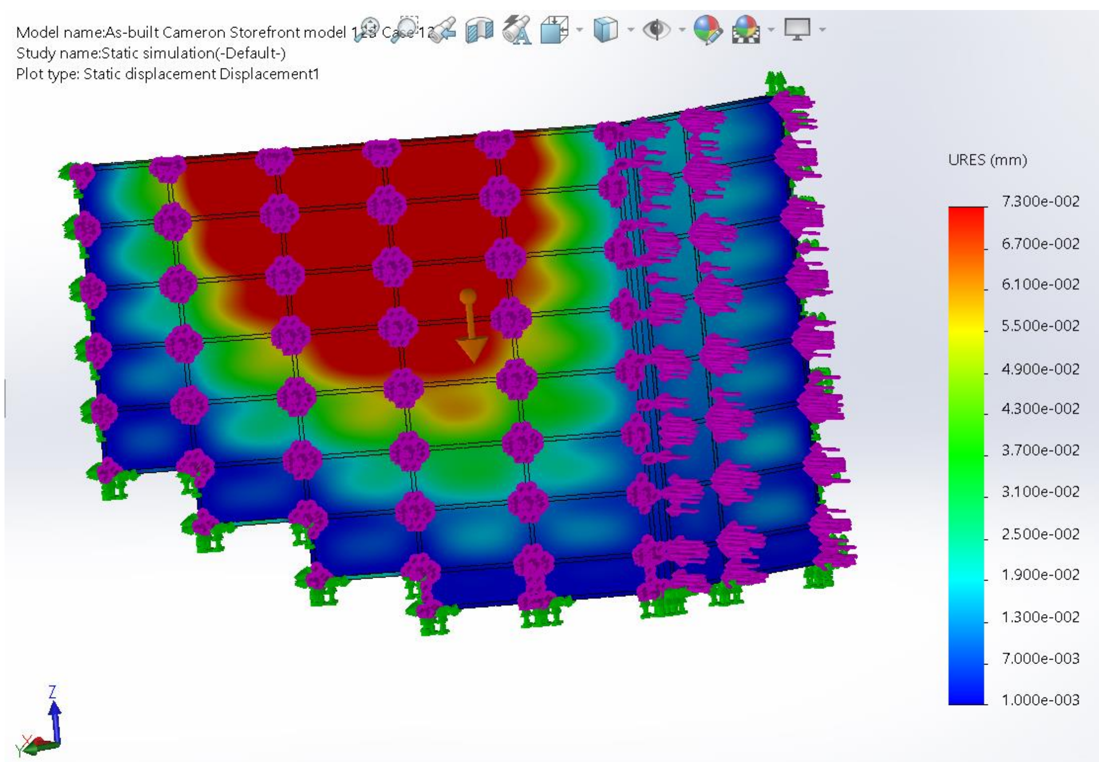


FIGURE 36: Deformation of the as-built Model (Case 12- 70mph)

The as-designed model presents a what-if scenario, helping the engineers and designers determine the structural strength of the curtain wall. It can help the engineers make better cost-effective investment decisions, in deciding which glass panels require to be stronger and better designed structurally. The as-designed model, which is the newly made model also helps in identifying the failure mechanism and pattern in the curtain wall, as the wind loads go on increasing.

In the case of the as-built model, the deformation results can help in planning and scheduling the preventative maintenance according to the needs. This will also help the facility management team to keep a track of the panels repaired and the ones to be repaired in the future depending on the deformations caused due to the particular wind loads in a particular geographical area. The deformation results will also help in optimizing the number of panels to be repaired over the damage caused by the wind loads.

Analyzing the similarities and differences between the as-built and the as-designed models for different wind speeds may assist in post-construction applications to evaluate actual deformities as compared to the design analysis. These results aid in identifying the structural risks to a building element and furthermore, may assist architects in developing better designs, inform manufacturers on the needs to produce stronger building elements, help contractors establish better installation methods, and allow facilities managers make informed maintenance decisions.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Health monitoring of structures is an important concern, in not just the construction industry but also other sectors, and would substantively assist designers, engineers, contractors, property developers, homebuyers, sellers, manufacturers, and facility managers. The application of 3D laser scanning for buildings has accelerated the speed and enhanced the accuracy of building information captured for geometric definition and creation of as-is 3D models. The integration of 3D laser scanning, building information and modeling and Finite Element Analysis would not only help the designers and engineers of the structural integrity and the breakage point of the curtain wall but will also help facility managers to regulate and schedule maintenance operations and keep O&M on track.

The work carried out in this study is only the beginning of automating the process of performing FEA on an as-built model developed in BIM. At various points, manual corrections and inputs were necessary due to algorithmic lack in the software. The integration of cloud-BIM-FEA isn't seamless when it comes to complete automation. Future work is needed especially on the programming of the Laser scanning and BIM software, to accommodate the smooth transition between different formats and recognition of a variety of shapes and geometry. Some manual methods to identify the deformations between as-is and as-planned dimensions should be automated in the future since there is quite a potential in the seamless constructive integration of SCAN-BIM-FEA, that can gauge the behavior of the structural elements. The user interface, error recognition, and help availability can make Robot a more widely preferred software for Structural analysis of construction elements and components since it provides a simpler smoother link between BIM-to-FEA as compared to other software. The interoperability between BIM and FEA transference cooperates only up to a certain level in terms of material properties, boundary conditions, and external loading.

As of 2018, 3D laser scanning, BIM, as well as structural analysis is being outsourced due to lack of skills and understanding (Mahdjoubi et al., 2013). But if SCAN-BIM-FEA is completely automated with the simpler user interface, in-house technicians can easily grasp the software knowledge, to run structural analysis on the as build or as designed BIM model developed through laser scanning, saving money on the company budgets

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APPENDIX: WIND LOADS CALCULATED FOR DIFFERENT WIND SPEEDS

TABLE 3: Wind Load Calculations for the as-designed model (Case 2)

For wind speed = 20 mph= 8.94 m/s=29.333 ft/s, and air density = 94 % (Case 2)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	3.834133	1.6	0.2575	1.7208	2.56605985	2.6
F2	0.536	3.834133	1.4	0.2575	1.7208	1.274875074	1.3
F3	0.922	3.834133	1.6	0.2575	1.7208	2.506257608	2.5
F4	0.904	3.834133	1.6	0.2575	1.7208	2.4573285	2.5
F5	1.643	3.834133	2	0.3761	1.5812	7.492467572	7.5
F6	0.932	3.834133	1.8	0.3761	1.5812	3.825125867	3.8
F7	1.617	3.834133	2	0.3761	1.5812	7.373901439	7.4
F8	1.613	3.834133	2	0.3761	1.5812	7.355660496	7.4
F9	1.351	3.834133	2	0.3761	1.5812	6.160878692	6.2
F10	1.62	3.834133	2	0.4511	1.519	8.512218931	8.5
F11	1.0414	3.834133	1.8	0.4511	1.519	4.924791552	4.9
F12	1.571	3.834133	2	0.4511	1.519	8.25475058	8.3
F13	1.568	3.834133	2	0.4511	1.519	8.238987212	8.2
F14	1.341	3.834133	2	0.4511	1.519	7.04622567	7
F15	1.413	3.834133	2	0.4511	1.519	7.424546512	7.4
F16	1.596	3.834133	2	0.5026	1.479	9.09747173	9.1
F17	0.906	3.834133	1.8	0.5026	1.479	4.647918828	4.6
F18	1.557	3.834133	2	0.5026	1.479	8.87516509	8.9
F19	1.553	3.834133	2	0.5026	1.479	8.852364409	8.9
F20	1.329	3.834133	2	0.5026	1.479	7.575526272	7.6
F21	1.378	3.834133	2	0.5026	1.479	7.854834614	7.9
F22	1.114	3.834133	2	0.5026	1.479	6.349989666	6.3
F23	1.655	3.834133	2	0.5441	1.4509	10.01870004	10
F24	0.939	3.834133	1.8	0.5441	1.4509	5.115893297	5.1
F25	1.62	3.834133	2	0.5441	1.4509	9.806824212	9.8
F26	1.616	3.834133	2	0.5441	1.4509	9.782609831	9.8
F27	1.383	3.834133	2	0.5441	1.4509	8.372122151	8.4
F28	1.434	3.834133	2	0.5441	1.4509	8.680855506	8.7
F29	1.118	3.834133	2	0.5441	1.4509	6.767919425	6.8
F30	1.604	3.834133	2	0.5789	1.4288	10.17364372	10.2
F31	0.91	3.834133	1.8	0.5789	1.4288	5.19464726	5.2
F32	1.567	3.834133	2	0.5789	1.4288	9.938964904	9.9
F33	1.563	3.834133	2	0.5789	1.4288	9.913594221	9.9
F34	1.337	3.834133	2	0.5789	1.4288	8.480150655	8.5
F35	1.387	3.834133	2	0.5789	1.4288	8.797284187	8.8
F36	1.082	3.834133	2	0.5789	1.4288	6.86276964	6.9
F37	1.622	3.834133	2	0.6089	1.4109	10.68538628	10.7
F38	0.921	3.834133	1.8	0.6089	1.4109	5.460614483	5.5
F39	1.585	3.834133	2	0.6089	1.4109	10.44163826	10.4
F40	1.581	3.834133	2	0.6089	1.4109	10.41528712	10.4
F41	1.353	3.834133	2	0.6089	1.4109	8.913272283	8.9
F42	1.403	3.834133	2	0.6089	1.4109	9.242661503	9.2
F43	1.094	3.834133	2	0.6089	1.4109	7.207036125	7.2
F44	1.55	3.834133	2	0.6349	1.3965	10.53841106	10.5
F45	0.88	3.834133	1.8	0.6349	1.3965	5.384788105	5.4
F46	1.514	3.834133	2	0.6349	1.3965	10.29364797	10.3
F47	1.511	3.834133	2	0.6349	1.3965	10.27325104	10.3
F48	1.292	3.834133	2	0.6349	1.3965	8.784275544	8.8
F49	1.341	3.834133	2	0.6349	1.3965	9.117425313	9.1
F50	1.045	3.834133	2	0.6349	1.3965	7.104928749	7.1
Fvertical Transomes	2.032576119	3.834133	1.4	0.5284	1.3974	8.056113496	8.1
F Horizontal	2.819	3.834133	1.4	0.5284	1.3974	11.17310379	11.2

TABLE 4: Wind Load Calculations for the as-designed model (Case 3)

For wind speed = 25 mph= 11.176 m/s=36.666 ft/s, and air density = 94 % (Case 3)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	5.985734	1.6	0.2575	1.7208	4.006056047	4
F2	0.536	5.985734	1.4	0.2575	1.7208	1.990296913	2
F3	0.922	5.985734	1.6	0.2575	1.7208	3.912694571	3.9
F4	0.904	5.985734	1.6	0.2575	1.7208	3.836307909	3.8
F5	1.643	5.985734	2	0.3761	1.5812	11.69701674	11.7
F6	0.932	5.985734	1.8	0.3761	1.5812	5.971672333	6
F7	1.617	5.985734	2	0.3761	1.5812	11.51191483	11.5
F8	1.613	5.985734	2	0.3761	1.5812	11.48343762	11.5
F9	1.351	5.985734	2	0.3761	1.5812	9.618179926	9.6
F10	1.62	5.985734	2	0.4511	1.519	13.28902213	13.3
F11	1.0414	5.985734	1.8	0.4511	1.519	7.688437578	7.7
F12	1.571	5.985734	2	0.4511	1.519	12.88707022	13.1
F13	1.568	5.985734	2	0.4511	1.519	12.86246092	12.9
F14	1.341	5.985734	2	0.4511	1.519	11.0003572	11
F15	1.413	5.985734	2	0.4511	1.519	11.59098041	11.6
F16	1.596	5.985734	2	0.5026	1.479	14.20270133	14.2
F17	0.906	5.985734	1.8	0.5026	1.479	7.256192145	7.3
F18	1.557	5.985734	2	0.5026	1.479	13.85564284	13.9
F19	1.553	5.985734	2	0.5026	1.479	13.82004709	13.8
F20	1.329	5.985734	2	0.5026	1.479	11.8266855	11.8
F21	1.378	5.985734	2	0.5026	1.479	12.26273335	12.3
F22	1.114	5.985734	2	0.5026	1.479	9.913414335	9.9
F23	1.655	5.985734	2	0.5441	1.4509	15.64089547	15.6
F24	0.939	5.985734	1.8	0.5441	1.4509	7.986779919	8
F25	1.62	5.985734	2	0.5441	1.4509	15.31012125	15.3
F26	1.616	5.985734	2	0.5441	1.4509	15.27231848	15.3
F27	1.383	5.985734	2	0.5441	1.4509	13.07030721	13.1
F28	1.434	5.985734	2	0.5441	1.4509	13.55229251	13.6
F29	1.118	5.985734	2	0.5441	1.4509	10.5658738	10.6
F30	1.604	5.985734	2	0.5789	1.4288	15.88278891	15.9
F31	0.91	5.985734	1.8	0.5789	1.4288	8.109728254	8.1
F32	1.567	5.985734	2	0.5789	1.4288	15.51641535	15.5
F33	1.563	5.985734	2	0.5789	1.4288	15.4768074	15.5
F34	1.337	5.985734	2	0.5789	1.4288	13.23895809	13.2
F35	1.387	5.985734	2	0.5789	1.4288	13.7340575	13.7
F36	1.082	5.985734	2	0.5789	1.4288	10.71395112	10.7
F37	1.622	5.985734	2	0.6089	1.4109	16.68170613	16.7
F38	0.921	5.985734	1.8	0.6089	1.4109	8.524948345	8.5
F39	1.585	5.985734	2	0.6089	1.4109	16.301174	16.3
F40	1.581	5.985734	2	0.6089	1.4109	16.26003539	16.3
F41	1.353	5.985734	2	0.6089	1.4109	13.91513465	13.9
F42	1.403	5.985734	2	0.6089	1.4109	14.42936727	14.4
F43	1.094	5.985734	2	0.6089	1.4109	11.25140969	11.3
F44	1.55	5.985734	2	0.6349	1.3965	16.45225281	16.5
F45	0.88	5.985734	1.8	0.6349	1.3965	8.406570466	8.4
F46	1.514	5.985734	2	0.6349	1.3965	16.07013597	16.1
F47	1.511	5.985734	2	0.6349	1.3965	16.0382929	16
F48	1.292	5.985734	2	0.6349	1.3965	13.71374879	13.7
F49	1.341	5.985734	2	0.6349	1.3965	14.23385227	14.2
F50	1.045	5.985734	2	0.6349	1.3965	11.0920027	11.1
Fvertical Transomes	2.032576119	5.985734	1.4	0.5284	1.3974	12.57696393	12.6
F Horizontal	2.819	5.985734	1.4	0.5284	1.3974	17.44311615	17.4

TABLE 5: Wind Load Calculations for the as-designed model (Case 4)

For wind speed = 30 mph= 13.411 m/s=43.999 ft/s, and air density = 94 % (Case 4)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	8.616602	1.6	0.2575	1.7208	5.766809976	5.8
F2	0.536	8.616602	1.4	0.2575	1.7208	2.865078262	2.9
F3	0.922	8.616602	1.6	0.2575	1.7208	5.632413981	5.6
F4	0.904	8.616602	1.6	0.2575	1.7208	5.522453621	5.5
F5	1.643	8.616602	2	0.3761	1.5812	16.83812509	16.8
F6	0.932	8.616602	1.8	0.3761	1.5812	8.596359906	8.6
F7	1.617	8.616602	2	0.3761	1.5812	16.57166663	16.6
F8	1.613	8.616602	2	0.3761	1.5812	16.53067302	16.5
F9	1.351	8.616602	2	0.3761	1.5812	13.8455916	13.8
F10	1.62	8.616602	2	0.4511	1.519	19.12985352	19.1
F11	1.0414	8.616602	1.8	0.4511	1.519	11.06768303	11.1
F12	1.571	8.616602	2	0.4511	1.519	18.55123449	18.6
F13	1.568	8.616602	2	0.4511	1.519	18.51580884	18.5
F14	1.341	8.616602	2	0.4511	1.519	15.83526763	15.8
F15	1.413	8.616602	2	0.4511	1.519	16.68548335	16.7
F16	1.596	8.616602	2	0.5026	1.479	20.44511578	20.4
F17	0.906	8.616602	1.8	0.5026	1.479	10.44545577	10.4
F18	1.557	8.616602	2	0.5026	1.479	19.94551709	19.9
F19	1.553	8.616602	2	0.5026	1.479	19.8942762	19.9
F20	1.329	8.616602	2	0.5026	1.479	17.02478626	17
F21	1.378	8.616602	2	0.5026	1.479	17.65248718	17.7
F22	1.114	8.616602	2	0.5026	1.479	14.27058833	14.3
F23	1.655	8.616602	2	0.5441	1.4509	22.51542939	22.5
F24	0.939	8.616602	1.8	0.5441	1.4509	11.4971537	11.5
F25	1.62	8.616602	2	0.5441	1.4509	22.03927227	22
F26	1.616	8.616602	2	0.5441	1.4509	21.98485432	22
F27	1.383	8.616602	2	0.5441	1.4509	18.81500837	18.8
F28	1.434	8.616602	2	0.5441	1.4509	19.50883731	19.5
F29	1.118	8.616602	2	0.5441	1.4509	15.20981877	15.2
F30	1.604	8.616602	2	0.5789	1.4288	22.86364057	22.9
F31	0.91	8.616602	1.8	0.5789	1.4288	11.67414066	11.7
F32	1.567	8.616602	2	0.5789	1.4288	22.33623739	22.3
F33	1.563	8.616602	2	0.5789	1.4288	22.27922083	22.3
F34	1.337	8.616602	2	0.5789	1.4288	19.05778519	19.1
F35	1.387	8.616602	2	0.5789	1.4288	19.77049219	19.8
F36	1.082	8.616602	2	0.5789	1.4288	15.42297949	15.4
F37	1.622	8.616602	2	0.6089	1.4109	24.01370032	24
F38	0.921	8.616602	1.8	0.6089	1.4109	12.27185955	12.3
F39	1.585	8.616602	2	0.6089	1.4109	23.46591554	23.5
F40	1.581	8.616602	2	0.6089	1.4109	23.40669556	23.4
F41	1.353	8.616602	2	0.6089	1.4109	20.03115692	20
F42	1.403	8.616602	2	0.6089	1.4109	20.77140662	20.8
F43	1.094	8.616602	2	0.6089	1.4109	16.19666347	16.2
F44	1.55	8.616602	2	0.6349	1.3965	23.68339696	23.7
F45	0.88	8.616602	1.8	0.6349	1.3965	12.10145187	12.1
F46	1.514	8.616602	2	0.6349	1.3965	23.13333097	23.1
F47	1.511	8.616602	2	0.6349	1.3965	23.08749214	23.1
F48	1.292	8.616602	2	0.6349	1.3965	19.74125734	19.7
F49	1.341	8.616602	2	0.6349	1.3965	20.48995827	20.5
F50	1.045	8.616602	2	0.6349	1.3965	15.96719344	16
Fvertical Transomes	2.032576119	8.616602	1.4	0.5284	1.3974	18.10482935	18.1
F Horizontal	2.819	8.616602	1.4	0.5284	1.3974	25.10976758	25.1

TABLE 6: Wind Load Calculations for the as-designed model (Case 5)

For wind speed = 35 mph= 15.65 m/s= 51.33 ft/s, and air density = 94 % (Case 5)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	11.7267	1.6	0.2575	1.7208	7.848296875	7.8
F2	0.536	11.7267	1.4	0.2575	1.7208	3.899206816	3.9
F3	0.922	11.7267	1.6	0.2575	1.7208	7.665391651	7.7
F4	0.904	11.7267	1.6	0.2575	1.7208	7.515741923	7.5
F5	1.643	11.7267	2	0.3761	1.5812	22.91572032	22.9
F6	0.932	11.7267	1.8	0.3761	1.5812	11.69915167	11.7
F7	1.617	11.7267	2	0.3761	1.5812	22.55308567	22.6
F8	1.613	11.7267	2	0.3761	1.5812	22.49729572	22.5
F9	1.351	11.7267	2	0.3761	1.5812	18.84305426	18.8
F10	1.62	11.7267	2	0.4511	1.519	26.03463097	26
F11	1.0414	11.7267	1.8	0.4511	1.519	15.06248038	15.1
F12	1.571	11.7267	2	0.4511	1.519	25.24716373	25.2
F13	1.568	11.7267	2	0.4511	1.519	25.19895145	25.2
F14	1.341	11.7267	2	0.4511	1.519	21.55088897	21.6
F15	1.413	11.7267	2	0.4511	1.519	22.70798368	22.7
F16	1.596	11.7267	2	0.5026	1.479	27.8246273	27.8
F17	0.906	11.7267	1.8	0.5026	1.479	14.21566485	14.2
F18	1.557	11.7267	2	0.5026	1.479	27.1447022	27.1
F19	1.553	11.7267	2	0.5026	1.479	27.07496629	27.1
F20	1.329	11.7267	2	0.5026	1.479	23.16975544	23.2
F21	1.378	11.7267	2	0.5026	1.479	24.02402031	24
F22	1.114	11.7267	2	0.5026	1.479	19.42145038	19.4
F23	1.655	11.7267	2	0.5441	1.4509	30.64220511	30.6
F24	0.939	11.7267	1.8	0.5441	1.4509	15.64696528	15.6
F25	1.62	11.7267	2	0.5441	1.4509	29.99418264	30
F26	1.616	11.7267	2	0.5441	1.4509	29.92012293	29.9
F27	1.383	11.7267	2	0.5441	1.4509	25.60614481	25.6
F28	1.434	11.7267	2	0.5441	1.4509	26.55040612	26.6
F29	1.118	11.7267	2	0.5441	1.4509	20.69968901	20.7
F30	1.604	11.7267	2	0.5789	1.4288	31.11610051	31.1
F31	0.91	11.7267	1.8	0.5789	1.4288	15.88783436	15.9
F32	1.567	11.7267	2	0.5789	1.4288	30.3983351	30.4
F33	1.563	11.7267	2	0.5789	1.4288	30.32073884	30.3
F34	1.337	11.7267	2	0.5789	1.4288	25.93655011	25.9
F35	1.387	11.7267	2	0.5789	1.4288	26.90650337	26.9
F36	1.082	11.7267	2	0.5789	1.4288	20.9897885	21
F37	1.622	11.7267	2	0.6089	1.4109	32.68126571	32.7
F38	0.921	11.7267	1.8	0.6089	1.4109	16.70129541	16.7
F39	1.585	11.7267	2	0.6089	1.4109	31.93576212	31.9
F40	1.581	11.7267	2	0.6089	1.4109	31.85516713	31.9
F41	1.353	11.7267	2	0.6089	1.4109	27.26125309	27.3
F42	1.403	11.7267	2	0.6089	1.4109	28.26869038	28.3
F43	1.094	11.7267	2	0.6089	1.4109	22.04272792	22
F44	1.55	11.7267	2	0.6349	1.3965	32.23174183	32.2
F45	0.88	11.7267	1.8	0.6349	1.3965	16.46938034	16.5
F46	1.514	11.7267	2	0.6349	1.3965	31.48313364	31.5
F47	1.511	11.7267	2	0.6349	1.3965	31.42074962	31.4
F48	1.292	11.7267	2	0.6349	1.3965	26.86671642	26.9
F49	1.341	11.7267	2	0.6349	1.3965	27.88565535	27.9
F50	1.045	11.7267	2	0.6349	1.3965	21.7304324	21.7
Fvertical Transomes	2.032576119	11.7267	1.4	0.5284	1.3974	24.63963199	24.6
F Horizontal	2.819	11.7267	1.4	0.5284	1.3974	34.17295025	34.2

TABLE 7: Wind Load Calculations for the as-designed model (Case 6)

For wind speed = 40mph= 17.88 m/s= 58.67 ft/s, and air density = 94 % (Case 6)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	15.2957	1.6	0.2575	1.7208	10.23691188	10.2
F2	0.536	15.2957	1.4	0.2575	1.7208	5.08592338	5.1
F3	0.922	15.2957	1.6	0.2575	1.7208	9.998339778	10
F4	0.904	15.2957	1.6	0.2575	1.7208	9.803144425	9.8
F5	1.643	15.2957	2	0.3761	1.5812	29.89007847	29.9
F6	0.932	15.2957	1.8	0.3761	1.5812	15.25976739	15.3
F7	1.617	15.2957	2	0.3761	1.5812	29.41707662	29.4
F8	1.613	15.2957	2	0.3761	1.5812	29.34430711	29.3
F9	1.351	15.2957	2	0.3761	1.5812	24.57790385	24.6
F10	1.62	15.2957	2	0.4511	1.519	33.95822396	34
F11	1.0414	15.2957	1.8	0.4511	1.519	19.64671913	19.6
F12	1.571	15.2957	2	0.4511	1.519	32.93109249	32.9
F13	1.568	15.2957	2	0.4511	1.519	32.86820689	32.9
F14	1.341	15.2957	2	0.4511	1.519	28.10986316	28.1
F15	1.413	15.2957	2	0.4511	1.519	29.61911756	29.6
F16	1.596	15.2957	2	0.5026	1.479	36.29300245	36.3
F17	0.906	15.2957	1.8	0.5026	1.479	18.54217681	18.5
F18	1.557	15.2957	2	0.5026	1.479	35.40614336	35.4
F19	1.553	15.2957	2	0.5026	1.479	35.31518346	35.3
F20	1.329	15.2957	2	0.5026	1.479	30.22142873	30.2
F21	1.378	15.2957	2	0.5026	1.479	31.33568758	31.3
F22	1.114	15.2957	2	0.5026	1.479	25.33233379	25.3
F23	1.655	15.2957	2	0.5441	1.4509	39.96810498	40
F24	0.939	15.2957	1.8	0.5441	1.4509	20.40909095	20.4
F25	1.62	15.2957	2	0.5441	1.4509	39.12285805	39.1
F26	1.616	15.2957	2	0.5441	1.4509	39.0262584	39
F27	1.383	15.2957	2	0.5441	1.4509	33.39932882	33.4
F28	1.434	15.2957	2	0.5441	1.4509	34.63097435	34.6
F29	1.118	15.2957	2	0.5441	1.4509	26.99960204	27
F30	1.604	15.2957	2	0.5789	1.4288	40.58622959	40.6
F31	0.91	15.2957	1.8	0.5789	1.4288	20.7232681	20.7
F32	1.567	15.2957	2	0.5789	1.4288	39.65001357	39.7
F33	1.563	15.2957	2	0.5789	1.4288	39.54880103	39.5
F34	1.337	15.2957	2	0.5789	1.4288	33.83029237	33.8
F35	1.387	15.2957	2	0.5789	1.4288	35.09544915	35.1
F36	1.082	15.2957	2	0.5789	1.4288	27.37799278	27.4
F37	1.622	15.2957	2	0.6089	1.4109	42.62775	42.6
F38	0.921	15.2957	1.8	0.6089	1.4109	21.78430455	21.8
F39	1.585	15.2957	2	0.6089	1.4109	41.65535373	41.7
F40	1.581	15.2957	2	0.6089	1.4109	41.55022981	41.6
F41	1.353	15.2957	2	0.6089	1.4109	35.55816631	35.6
F42	1.403	15.2957	2	0.6089	1.4109	36.87221532	36.9
F43	1.094	15.2957	2	0.6089	1.4109	28.75139242	28.8
F44	1.55	15.2957	2	0.6349	1.3965	42.04141434	42
F45	0.88	15.2957	1.8	0.6349	1.3965	21.48180655	21.5
F46	1.514	15.2957	2	0.6349	1.3965	41.06496859	41.1
F47	1.511	15.2957	2	0.6349	1.3965	40.98359811	41
F48	1.292	15.2957	2	0.6349	1.3965	35.04355312	35
F49	1.341	15.2957	2	0.6349	1.3965	36.37260428	36.4
F50	1.045	15.2957	2	0.6349	1.3965	28.34405032	28.3
Fvertical Transomes	2.032576119	15.2957	1.4	0.5284	1.3974	32.13865956	32.1
F Horizontal	2.819	15.2957	1.4	0.5284	1.3974	44.57342604	44.6

TABLE 8: Wind Load Calculations for the as-designed model (Case 7)

For wind speed = 45mph= 20.1168 m/s= 66 ft/s, and air density = 94 % (Case 7)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	19.3746	1.6	0.2575	1.7208	12.96678628	13
F2	0.536	19.3746	1.4	0.2575	1.7208	6.442185131	6.4
F3	0.922	19.3746	1.6	0.2575	1.7208	12.66459422	12.7
F4	0.904	19.3746	1.6	0.2575	1.7208	12.41734618	12.4
F5	1.643	19.3746	2	0.3761	1.5812	37.86085726	37.9
F6	0.932	19.3746	1.8	0.3761	1.5812	19.32908525	19.3
F7	1.617	19.3746	2	0.3761	1.5812	37.26172014	37.3
F8	1.613	19.3746	2	0.3761	1.5812	37.1695452	37.2
F9	1.351	19.3746	2	0.3761	1.5812	31.13208652	31.1
F10	1.62	19.3746	2	0.4511	1.519	43.01385395	43
F11	1.0414	19.3746	1.8	0.4511	1.519	24.88590417	24.9
F12	1.571	19.3746	2	0.4511	1.519	41.71281763	41.7
F13	1.568	19.3746	2	0.4511	1.519	41.63316234	41.6
F14	1.341	19.3746	2	0.4511	1.519	35.60591244	35.6
F15	1.413	19.3746	2	0.4511	1.519	37.51763928	37.5
F16	1.596	19.3746	2	0.5026	1.479	45.97124716	46
F17	0.906	19.3746	1.8	0.5026	1.479	23.48681387	23.5
F18	1.557	19.3746	2	0.5026	1.479	44.84788962	44.8
F19	1.553	19.3746	2	0.5026	1.479	44.73267346	44.7
F20	1.329	19.3746	2	0.5026	1.479	38.28056859	38.3
F21	1.378	19.3746	2	0.5026	1.479	39.69196653	39.7
F22	1.114	19.3746	2	0.5026	1.479	32.08770009	32.1
F23	1.655	19.3746	2	0.5441	1.4509	50.62638825	50.6
F24	0.939	19.3746	1.8	0.5441	1.4509	25.85157747	25.9
F25	1.62	19.3746	2	0.5441	1.4509	49.55573956	49.6
F26	1.616	19.3746	2	0.5441	1.4509	49.43337971	49.4
F27	1.383	19.3746	2	0.5441	1.4509	42.3059184	42.3
F28	1.434	19.3746	2	0.5441	1.4509	43.8660065	43.9
F29	1.118	19.3746	2	0.5441	1.4509	34.19957829	34.2
F30	1.604	19.3746	2	0.5789	1.4288	51.40934797	51.4
F31	0.91	19.3746	1.8	0.5789	1.4288	26.24953615	26.2
F32	1.567	19.3746	2	0.5789	1.4288	50.22347149	50.2
F33	1.563	19.3746	2	0.5789	1.4288	50.09526863	50.1
F34	1.337	19.3746	2	0.5789	1.4288	42.85180688	42.9
F35	1.387	19.3746	2	0.5789	1.4288	44.45434267	44.5
F36	1.082	19.3746	2	0.5789	1.4288	34.67887438	34.7
F37	1.622	19.3746	2	0.6089	1.4109	53.99528006	54
F38	0.921	19.3746	1.8	0.6089	1.4109	27.59351889	27.6
F39	1.585	19.3746	2	0.6089	1.4109	52.76357515	52.8
F40	1.581	19.3746	2	0.6089	1.4109	52.63041786	52.6
F41	1.353	19.3746	2	0.6089	1.4109	45.04045248	45
F42	1.403	19.3746	2	0.6089	1.4109	46.70491857	46.7
F43	1.094	19.3746	2	0.6089	1.4109	36.41851811	36.4
F44	1.55	19.3746	2	0.6349	1.3965	53.25258643	53.3
F45	0.88	19.3746	1.8	0.6349	1.3965	27.21035384	27.2
F46	1.514	19.3746	2	0.6349	1.3965	52.01575217	52
F47	1.511	19.3746	2	0.6349	1.3965	51.91268265	51.9
F48	1.292	19.3746	2	0.6349	1.3965	44.38860753	44.4
F49	1.341	19.3746	2	0.6349	1.3965	46.07207639	46.1
F50	1.045	19.3746	2	0.6349	1.3965	35.90255021	35.9
Fvertical Transomes	2.032576119	19.3746	1.4	0.5284	1.3974	40.70906683	40.7
F Horizontal	2.819	19.3746	1.4	0.5284	1.3974	56.45980897	56.5

TABLE 9: Wind Load Calculations for the as-designed model (Case 8)

For wind speed = 50mph= 22.352 m/s=73.33 ft/s, and air density = 94 % (Case 8)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	23.9633	1.6	0.2575	1.7208	16.03785315	16
F2	0.536	23.9633	1.4	0.2575	1.7208	7.96795882	8
F3	0.922	23.9633	1.6	0.2575	1.7208	15.66408962	15.7
F4	0.904	23.9633	1.6	0.2575	1.7208	15.3582831	15.4
F5	1.643	23.9633	2	0.3761	1.5812	46.82786126	46.8
F6	0.932	23.9633	1.8	0.3761	1.5812	23.90700549	23.9
F7	1.617	23.9633	2	0.3761	1.5812	46.08682389	46.1
F8	1.613	23.9633	2	0.3761	1.5812	45.97281815	46
F9	1.351	23.9633	2	0.3761	1.5812	38.50544161	38.5
F10	1.62	23.9633	2	0.4511	1.519	53.20129894	53.2
F11	1.0414	23.9633	1.8	0.4511	1.519	30.77990706	30.8
F12	1.571	23.9633	2	0.4511	1.519	51.59212385	51.6
F13	1.568	23.9633	2	0.4511	1.519	51.49360292	51.5
F14	1.341	23.9633	2	0.4511	1.519	44.03885301	44
F15	1.413	23.9633	2	0.4511	1.519	46.40335518	46.4
F16	1.596	23.9633	2	0.5026	1.479	56.85912417	56.9
F17	0.906	23.9633	1.8	0.5026	1.479	29.04945479	29
F18	1.557	23.9633	2	0.5026	1.479	55.46970948	55.5
F19	1.553	23.9633	2	0.5026	1.479	55.32720541	55.3
F20	1.329	23.9633	2	0.5026	1.479	47.34697745	47.3
F21	1.378	23.9633	2	0.5026	1.479	49.09265232	49.1
F22	1.114	23.9633	2	0.5026	1.479	39.68738366	39.7
F23	1.655	23.9633	2	0.5441	1.4509	62.61679362	62.6
F24	0.939	23.9633	1.8	0.5441	1.4509	31.97429141	32
F25	1.62	23.9633	2	0.5441	1.4509	61.29257139	61.3
F26	1.616	23.9633	2	0.5441	1.4509	61.14123171	61.1
F27	1.383	23.9633	2	0.5441	1.4509	52.32569521	52.3
F28	1.434	23.9633	2	0.5441	1.4509	54.25527616	54.3
F29	1.118	23.9633	2	0.5441	1.4509	42.29944125	42.3
F30	1.604	23.9633	2	0.5789	1.4288	63.58519032	63.6
F31	0.91	23.9633	1.8	0.5789	1.4288	32.46650304	32.5
F32	1.567	23.9633	2	0.5789	1.4288	62.11844964	62.1
F33	1.563	23.9633	2	0.5789	1.4288	61.95988308	62
F34	1.337	23.9633	2	0.5789	1.4288	53.00087248	53
F35	1.387	23.9633	2	0.5789	1.4288	54.98295447	55
F36	1.082	23.9633	2	0.5789	1.4288	42.89225432	42.9
F37	1.622	23.9633	2	0.6089	1.4109	66.78357719	66.8
F38	0.921	23.9633	1.8	0.6089	1.4109	34.12879601	34.1
F39	1.585	23.9633	2	0.6089	1.4109	65.26015403	65.3
F40	1.581	23.9633	2	0.6089	1.4109	65.09545964	65.1
F41	1.353	23.9633	2	0.6089	1.4109	55.70787912	55.7
F42	1.403	23.9633	2	0.6089	1.4109	57.76655906	57.8
F43	1.094	23.9633	2	0.6089	1.4109	45.04391704	45
F44	1.55	23.9633	2	0.6349	1.3965	65.86498325	65.9
F45	0.88	23.9633	1.8	0.6349	1.3965	33.65488176	33.7
F46	1.514	23.9633	2	0.6349	1.3965	64.3352159	64.3
F47	1.511	23.9633	2	0.6349	1.3965	64.20773529	64.2
F48	1.292	23.9633	2	0.6349	1.3965	54.90165056	54.9
F49	1.341	23.9633	2	0.6349	1.3965	56.9838339	57
F50	1.045	23.9633	2	0.6349	1.3965	44.40574677	44.4
Fvertical Transomes	2.032576119	23.9633	1.4	0.5284	1.3974	50.35064369	50.4
F Horizontal	2.819	23.9633	1.4	0.5284	1.3974	69.83180764	69.8

TABLE 10: Wind Load Calculations for the as-designed model (Case 9)

For wind speed = 55mph=24.5872 m/s=80.67 ft/s, and air density = 94 % (Case 9)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	28.9599	1.6	0.2575	1.7208	19.38191415	19.4
F2	0.536	28.9599	1.4	0.2575	1.7208	9.629362009	9.6
F3	0.922	28.9599	1.6	0.2575	1.7208	18.930217	18.9
F4	0.904	28.9599	1.6	0.2575	1.7208	18.5606466	18.6
F5	1.643	28.9599	2	0.3761	1.5812	56.59196268	56.6
F6	0.932	28.9599	1.8	0.3761	1.5812	28.8918675	28.9
F7	1.617	28.9599	2	0.3761	1.5812	55.69641123	55.7
F8	1.613	28.9599	2	0.3761	1.5812	55.55863409	55.6
F9	1.351	28.9599	2	0.3761	1.5812	46.53423103	46.5
F10	1.62	28.9599	2	0.4511	1.519	64.29432912	64.3
F11	1.0414	28.9599	1.8	0.4511	1.519	37.19784131	37.2
F12	1.571	28.9599	2	0.4511	1.519	62.34962411	62.3
F13	1.568	28.9599	2	0.4511	1.519	62.23056053	62.2
F14	1.341	28.9599	2	0.4511	1.519	53.22141689	53.2
F15	1.413	28.9599	2	0.4511	1.519	56.07894262	56.1
F16	1.596	28.9599	2	0.5026	1.479	68.71484937	68.7
F17	0.906	28.9599	1.8	0.5026	1.479	35.10657154	35.1
F18	1.557	28.9599	2	0.5026	1.479	67.03572711	67
F19	1.553	28.9599	2	0.5026	1.479	66.86350944	66.9
F20	1.329	28.9599	2	0.5026	1.479	57.21932006	57.2
F21	1.378	28.9599	2	0.5026	1.479	59.32898649	59.3
F22	1.114	28.9599	2	0.5026	1.479	47.96262043	48
F23	1.655	28.9599	2	0.5441	1.4509	75.67305344	75.7
F24	0.939	28.9599	1.8	0.5441	1.4509	38.64126735	38.6
F25	1.62	28.9599	2	0.5441	1.4509	74.07271696	74.1
F26	1.616	28.9599	2	0.5441	1.4509	73.88982136	73.9
F27	1.383	28.9599	2	0.5441	1.4509	63.23615281	63.2
F28	1.434	28.9599	2	0.5441	1.4509	65.56807168	65.6
F29	1.118	28.9599	2	0.5441	1.4509	51.11931948	51.1
F30	1.604	28.9599	2	0.5789	1.4288	76.84337103	76.8
F31	0.91	28.9599	1.8	0.5789	1.4288	39.23611027	39.2
F32	1.567	28.9599	2	0.5789	1.4288	75.0707995	75.1
F33	1.563	28.9599	2	0.5789	1.4288	74.87917015	74.9
F34	1.337	28.9599	2	0.5789	1.4288	64.05211164	64.1
F35	1.387	28.9599	2	0.5789	1.4288	66.44747857	66.4
F36	1.082	28.9599	2	0.5789	1.4288	51.83574031	51.8
F37	1.622	28.9599	2	0.6089	1.4109	80.70865519	80.7
F38	0.921	28.9599	1.8	0.6089	1.4109	41.24500881	41.2
F39	1.585	28.9599	2	0.6089	1.4109	78.86758229	78.9
F40	1.581	28.9599	2	0.6089	1.4109	78.66854739	78.7
F41	1.353	28.9599	2	0.6089	1.4109	67.32355763	67.3
F42	1.403	28.9599	2	0.6089	1.4109	69.81149398	69.8
F43	1.094	28.9599	2	0.6089	1.4109	54.43604734	54.4
F44	1.55	28.9599	2	0.6349	1.3965	79.59852476	79.6
F45	0.88	28.9599	1.8	0.6349	1.3965	40.67227846	40.7
F46	1.514	28.9599	2	0.6349	1.3965	77.74978483	77.7
F47	1.511	28.9599	2	0.6349	1.3965	77.59572317	77.6
F48	1.292	28.9599	2	0.6349	1.3965	66.34922193	66.3
F49	1.341	28.9599	2	0.6349	1.3965	68.86556239	68.9
F50	1.045	28.9599	2	0.6349	1.3965	53.66481186	53.7
Fvertical Transomes	2.032576119	28.9599	1.4	0.5284	1.3974	60.84928229	60.8
F Horizontal	2.819	28.9599	1.4	0.5284	1.3974	84.39247375	84.4

TABLE 11: Wind Load Calculations for the as-designed model (Case 10)

For wind speed = 60mph=26.82 m/s=88 ft/s, and air density = 94 % (Case 10)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	34.4664	1.6	0.2575	1.7208	23.06723455	23.1
F2	0.536	34.4664	1.4	0.2575	1.7208	11.46031039	11.5
F3	0.922	34.4664	1.6	0.2575	1.7208	22.5296507	22.5
F4	0.904	34.4664	1.6	0.2575	1.7208	22.08980936	22.1
F5	1.643	34.4664	2	0.3761	1.5812	67.35248473	67.4
F6	0.932	34.4664	1.8	0.3761	1.5812	34.38543164	34.4
F7	1.617	34.4664	2	0.3761	1.5812	66.28665113	66.3
F8	1.613	34.4664	2	0.3761	1.5812	66.12267673	66.1
F9	1.351	34.4664	2	0.3761	1.5812	55.38235354	55.4
F10	1.62	34.4664	2	0.4511	1.519	76.51939631	76.5
F11	1.0414	34.4664	1.8	0.4511	1.519	44.27072185	44.3
F12	1.571	34.4664	2	0.4511	1.519	74.20492075	74.2
F13	1.568	34.4664	2	0.4511	1.519	74.06321816	74.1
F14	1.341	34.4664	2	0.4511	1.519	63.34105584	63.3
F15	1.413	34.4664	2	0.4511	1.519	66.7419179	66.7
F16	1.596	34.4664	2	0.5026	1.479	81.78044414	81.8
F17	0.906	34.4664	1.8	0.5026	1.479	41.78181338	41.8
F18	1.557	34.4664	2	0.5026	1.479	79.78204983	79.8
F19	1.553	34.4664	2	0.5026	1.479	79.57708631	79.6
F20	1.329	34.4664	2	0.5026	1.479	68.09912924	68.1
F21	1.378	34.4664	2	0.5026	1.479	70.60993235	70.6
F22	1.114	34.4664	2	0.5026	1.479	57.08234009	57.1
F23	1.655	34.4664	2	0.5441	1.4509	90.06169666	90.1
F24	0.939	34.4664	1.8	0.5441	1.4509	45.98860414	46
F25	1.62	34.4664	2	0.5441	1.4509	88.15706863	88.2
F26	1.616	34.4664	2	0.5441	1.4509	87.93939686	87.9
F27	1.383	34.4664	2	0.5441	1.4509	75.260016	75.3
F28	1.434	34.4664	2	0.5441	1.4509	78.03533112	78
F29	1.118	34.4664	2	0.5441	1.4509	60.83926094	60.8
F30	1.604	34.4664	2	0.5789	1.4288	91.45454105	91.5
F31	0.91	34.4664	1.8	0.5789	1.4288	46.69655182	46.7
F32	1.567	34.4664	2	0.5789	1.4288	89.34492882	89.3
F33	1.563	34.4664	2	0.5789	1.4288	89.11686263	89.1
F34	1.337	34.4664	2	0.5789	1.4288	76.23112306	76.2
F35	1.387	34.4664	2	0.5789	1.4288	79.0819504	79.1
F36	1.082	34.4664	2	0.5789	1.4288	61.69190362	61.7
F37	1.622	34.4664	2	0.6089	1.4109	96.05477897	96.1
F38	0.921	34.4664	1.8	0.6089	1.4109	49.08742681	49.1
F39	1.585	34.4664	2	0.6089	1.4109	93.86364036	93.9
F40	1.581	34.4664	2	0.6089	1.4109	93.62676051	93.6
F41	1.353	34.4664	2	0.6089	1.4109	80.12460909	80.1
F42	1.403	34.4664	2	0.6089	1.4109	83.08560721	83.1
F43	1.094	34.4664	2	0.6089	1.4109	64.78663883	64.8
F44	1.55	34.4664	2	0.6349	1.3965	94.73356586	94.7
F45	0.88	34.4664	1.8	0.6349	1.3965	48.40579623	48.4
F46	1.514	34.4664	2	0.6349	1.3965	92.53330239	92.5
F47	1.511	34.4664	2	0.6349	1.3965	92.34994711	92.3
F48	1.292	34.4664	2	0.6349	1.3965	78.96501103	79
F49	1.341	34.4664	2	0.6349	1.3965	81.95981408	82
F50	1.045	34.4664	2	0.6349	1.3965	63.86875892	63.9
Fvertical Transomes	2.032576119	34.4664	1.4	0.5284	1.3974	72.41930058	72.4
F Horizontal	2.819	34.4664	1.4	0.5284	1.3974	100.439047	100.4

TABLE 12: Wind Load Calculations for the as-designed model (Case 11)

For wind speed = 65mph=29.0576 m/s=95.33 ft/s, and air density = 94 % (Case 11)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	40.4827	1.6	0.2575	1.7208	27.09374742	27.1
F2	0.536	40.4827	1.4	0.2575	1.7208	13.4607707	13.5
F3	0.922	40.4827	1.6	0.2575	1.7208	26.46232534	26.5
F4	0.904	40.4827	1.6	0.2575	1.7208	25.94570728	25.9
F5	1.643	40.4827	2	0.3761	1.5812	79.10923199	79.1
F6	0.932	40.4827	1.8	0.3761	1.5812	40.38759817	40.4
F7	1.617	40.4827	2	0.3761	1.5812	77.85735127	77.9
F8	1.613	40.4827	2	0.3761	1.5812	77.66475423	77.7
F9	1.351	40.4827	2	0.3761	1.5812	65.04964846	65
F10	1.62	40.4827	2	0.4511	1.519	89.8762785	89.9
F11	1.0414	40.4827	1.8	0.4511	1.519	51.99842024	52
F12	1.571	40.4827	2	0.4511	1.519	87.15779847	87.2
F13	1.568	40.4827	2	0.4511	1.519	86.99136091	87
F14	1.341	40.4827	2	0.4511	1.519	74.39758609	74.4
F15	1.413	40.4827	2	0.4511	1.519	78.39208735	78.4
F16	1.596	40.4827	2	0.5026	1.479	96.05567121	96.1
F17	0.906	40.4827	1.8	0.5026	1.479	49.07505909	49.1
F18	1.557	40.4827	2	0.5026	1.479	93.70844616	93.7
F19	1.553	40.4827	2	0.5026	1.479	93.46770513	93.5
F20	1.329	40.4827	2	0.5026	1.479	79.98620742	80
F21	1.378	40.4827	2	0.5026	1.479	82.93528504	82.9
F22	1.114	40.4827	2	0.5026	1.479	67.04637702	67
F23	1.655	40.4827	2	0.5441	1.4509	105.782462	105.8
F24	0.939	40.4827	1.8	0.5441	1.4509	54.01616834	54
F25	1.62	40.4827	2	0.5441	1.4509	103.5453706	103.5
F26	1.616	40.4827	2	0.5441	1.4509	103.289703	103.3
F27	1.383	40.4827	2	0.5441	1.4509	88.39706641	88.4
F28	1.434	40.4827	2	0.5441	1.4509	91.65682807	91.7
F29	1.118	40.4827	2	0.5441	1.4509	71.45908911	71.5
F30	1.604	40.4827	2	0.5789	1.4288	107.418435	107.4
F31	0.91	40.4827	1.8	0.5789	1.4288	54.8476922	54.8
F32	1.567	40.4827	2	0.5789	1.4288	104.9405784	104.9
F33	1.563	40.4827	2	0.5789	1.4288	104.672702	104.7
F34	1.337	40.4827	2	0.5789	1.4288	89.53768555	89.5
F35	1.387	40.4827	2	0.5789	1.4288	92.88614051	92.9
F36	1.082	40.4827	2	0.5789	1.4288	72.46056527	72.5
F37	1.622	40.4827	2	0.6089	1.4109	112.8216698	112.8
F38	0.921	40.4827	1.8	0.6089	1.4109	57.65590759	57.7
F39	1.585	40.4827	2	0.6089	1.4109	110.2480559	110.2
F40	1.581	40.4827	2	0.6089	1.4109	109.9698274	110
F41	1.353	40.4827	2	0.6089	1.4109	94.11080102	94.1
F42	1.403	40.4827	2	0.6089	1.4109	97.58865767	97.6
F43	1.094	40.4827	2	0.6089	1.4109	76.09550356	76.1
F44	1.55	40.4827	2	0.6349	1.3965	111.2698317	111.3
F45	0.88	40.4827	1.8	0.6349	1.3965	56.85529464	56.9
F46	1.514	40.4827	2	0.6349	1.3965	108.6855001	108.7
F47	1.511	40.4827	2	0.6349	1.3965	108.4701391	108.5
F48	1.292	40.4827	2	0.6349	1.3965	92.74878873	92.7
F49	1.341	40.4827	2	0.6349	1.3965	96.26635115	96.3
F50	1.045	40.4827	2	0.6349	1.3965	75.01740265	75
Fvertical Transomes	2.032576119	40.4827	1.4	0.5284	1.3974	85.06048847	85.1
F Horizontal	2.819	40.4827	1.4	0.5284	1.3974	117.971236	118

TABLE 13: Wind Load Calculations for the as-designed model (Case 12)

For wind speed = 70 mph=31.2928 m/s=102.67 ft/s, and air density = 94 % (Case 12)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.944	46.9069	1.6	0.2575	1.7208	31.39325443	31.4
F2	0.536	46.9069	1.4	0.2575	1.7208	15.59686052	15.6
F3	0.922	46.9069	1.6	0.2575	1.7208	30.66163197	30.7
F4	0.904	46.9069	1.6	0.2575	1.7208	30.06303178	30.1
F5	1.643	46.9069	2	0.3761	1.5812	91.66307668	91.7
F6	0.932	46.9069	1.8	0.3761	1.5812	46.79670646	46.8
F7	1.617	46.9069	2	0.3761	1.5812	90.21253499	90.2
F8	1.613	46.9069	2	0.3761	1.5812	89.98937473	90
F9	1.351	46.9069	2	0.3761	1.5812	75.37237772	75.4
F10	1.62	46.9069	2	0.4511	1.519	104.1387459	104.1
F11	1.0414	46.9069	1.8	0.4511	1.519	60.25004998	60.3
F12	1.571	46.9069	2	0.4511	1.519	100.9888702	101
F13	1.568	46.9069	2	0.4511	1.519	100.7960207	100.8
F14	1.341	46.9069	2	0.4511	1.519	86.20373964	86.2
F15	1.413	46.9069	2	0.4511	1.519	90.83212835	90.8
F16	1.596	46.9069	2	0.5026	1.479	111.2987465	111.3
F17	0.906	46.9069	1.8	0.5026	1.479	56.86278062	56.9
F18	1.557	46.9069	2	0.5026	1.479	108.5790403	108.6
F19	1.553	46.9069	2	0.5026	1.479	108.300096	108.3
F20	1.329	46.9069	2	0.5026	1.479	92.67921934	92.7
F21	1.378	46.9069	2	0.5026	1.479	96.09628611	96.1
F22	1.114	46.9069	2	0.5026	1.479	77.68596715	77.7
F23	1.655	46.9069	2	0.5441	1.4509	122.5690817	122.6
F24	0.939	46.9069	1.8	0.5441	1.4509	62.58799455	62.6
F25	1.62	46.9069	2	0.5441	1.4509	119.9769864	120
F26	1.616	46.9069	2	0.5441	1.4509	119.6807469	119.7
F27	1.383	46.9069	2	0.5441	1.4509	102.4247976	102.4
F28	1.434	46.9069	2	0.5441	1.4509	106.2018509	106.2
F29	1.118	46.9069	2	0.5441	1.4509	82.79893256	82.8
F30	1.604	46.9069	2	0.5789	1.4288	124.4646674	124.5
F31	0.91	46.9069	1.8	0.5789	1.4288	63.55147293	63.6
F32	1.567	46.9069	2	0.5789	1.4288	121.5935996	121.6
F33	1.563	46.9069	2	0.5789	1.4288	121.2832139	121.3
F34	1.337	46.9069	2	0.5789	1.4288	103.7464216	103.7
F35	1.387	46.9069	2	0.5789	1.4288	107.6262429	107.6
F36	1.082	46.9069	2	0.5789	1.4288	83.95933298	84
F37	1.622	46.9069	2	0.6089	1.4109	130.7253415	130.7
F38	0.921	46.9069	1.8	0.6089	1.4109	66.80532404	66.8
F39	1.585	46.9069	2	0.6089	1.4109	127.7433208	127.7
F40	1.581	46.9069	2	0.6089	1.4109	127.4209402	127.4
F41	1.353	46.9069	2	0.6089	1.4109	109.0452448	109
F42	1.403	46.9069	2	0.6089	1.4109	113.0750026	113.1
F43	1.094	46.9069	2	0.6089	1.4109	88.17109965	88.2
F44	1.55	46.9069	2	0.6349	1.3965	128.9272422	128.9
F45	0.88	46.9069	1.8	0.6349	1.3965	65.87766182	65.9
F46	1.514	46.9069	2	0.6349	1.3965	125.932803	125.9
F47	1.511	46.9069	2	0.6349	1.3965	125.6832664	125.7
F48	1.292	46.9069	2	0.6349	1.3965	107.4670948	107.5
F49	1.341	46.9069	2	0.6349	1.3965	111.5428592	111.5
F50	1.045	46.9069	2	0.6349	1.3965	86.9219149	86.9
Fvertical Transomes	2.032576119	46.9069	1.4	0.5284	1.3974	98.55873809	98.6
F Horizontal	2.819	46.9069	1.4	0.5284	1.3974	136.6920924	136.7

TABLE 14: Wind Load Calculations for the as-built model (Case 2)

For wind speed = 20 mph= 8.94 m/s=29.333 ft/s, and air density = 94 % (Case 2)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	3.834133	1.6	0.2575	1.7208	2.525285594	2.5
F2	0.497	3.834133	1.4	0.2575	1.7208	1.182113641	1.2
F3	0.915	3.834133	1.6	0.2575	1.7208	2.487229622	2.5
F4	0.863	3.834133	1.6	0.2575	1.7208	2.345878867	1.3
F5	1.612	3.834133	2	0.3761	1.5812	7.35110026	7.4
F6	0.861	3.834133	1.8	0.3761	1.5812	3.533726794	3.5
F7	1.592	3.834133	2	0.3761	1.5812	7.259895542	7.3
F8	1.502	3.834133	2	0.3761	1.5812	6.849474311	6.8
F9	1.416	3.834133	2	0.3761	1.5812	6.457294025	6.5
F10	1.624	3.834133	2	0.4511	1.519	8.533236755	8.5
F11	0.868	3.834133	1.8	0.4511	1.519	4.104781129	4.1
F12	1.524	3.834133	2	0.4511	1.519	8.007791142	8
F13	1.437	3.834133	2	0.4511	1.519	7.550653459	7.6
F14	1.355	3.834133	2	0.4511	1.519	7.119788056	7.4
F15	1.367	3.834133	2	0.4511	1.519	7.18284153	7.2
F16	1.663	3.834133	2	0.5026	1.479	9.479383138	9.5
F17	0.889	3.834133	1.8	0.5026	1.479	4.560706223	4.6
F18	1.623	3.834133	2	0.5026	1.479	9.251376327	9.3
F19	1.531	3.834133	2	0.5026	1.479	8.726960664	8.7
F20	1.443	3.834133	2	0.5026	1.479	8.225345681	8.2
F21	1.457	3.834133	2	0.5026	1.479	8.305148065	8.3
F22	1.2	3.834133	2	0.5026	1.479	6.840204308	6.8
F23	1.601	3.834133	2	0.5441	1.4509	9.691805903	9.7
F24	0.856	3.834133	1.8	0.5441	1.4509	4.663689736	4.7
F25	1.567	3.834133	2	0.5441	1.4509	9.485983667	9.5
F26	1.478	3.834133	2	0.5441	1.4509	8.947213695	8.9
F27	1.393	3.834133	2	0.5441	1.4509	8.432658103	8.4
F28	1.406	3.834133	2	0.5441	1.4509	8.511354841	8.5
F29	1.158	3.834133	2	0.5441	1.4509	7.010063233	7
F30	1.601	3.834133	2	0.5789	1.4288	10.15461571	10.2
F31	0.856	3.834133	1.8	0.5789	1.4288	4.886393466	4.9
F32	1.524	3.834133	2	0.5789	1.4288	9.666230066	9.7
F33	1.437	3.834133	2	0.5789	1.4288	9.11441772	9.1
F34	1.355	3.834133	2	0.5789	1.4288	8.594318727	8.6
F35	1.367	3.834133	2	0.5789	1.4288	8.670430774	8.7
F36	1.126	3.834133	2	0.5789	1.4288	7.141847148	7.1
F37	1.601	3.834133	2	0.6089	1.4109	10.54704281	10.5
F38	0.856	3.834133	1.8	0.6089	1.4109	5.075229096	5.1
F39	1.595	3.834133	2	0.6089	1.4109	10.50751611	10.5
F40	1.504	3.834133	2	0.6089	1.4109	9.908027726	9.9
F41	1.418	3.834133	2	0.6089	1.4109	9.341478269	9.3
F42	1.431	3.834133	2	0.6089	1.4109	9.427119466	9.4
F43	1.179	3.834133	2	0.6089	1.4109	7.766997799	7.8
F44	1.506	3.834133	2	0.6349	1.3965	10.23925617	10.2
F45	0.805	3.834133	1.8	0.6349	1.3965	4.9258573	4.9
F46	1.467	3.834133	2	0.6349	1.3965	9.974096148	10
F47	1.383	3.834133	2	0.6349	1.3965	9.402982258	9.4
F48	1.304	3.834133	2	0.6349	1.3965	8.865863243	8.9
F49	1.317	3.834133	2	0.6349	1.3965	8.954249916	9
F50	1.084	3.834133	2	0.6349	1.3965	7.370088769	7.4
Fvertical Transomes	2.032576119	3.834133	1.4	0.5284	1.3974	8.056113496	8.1
F Horizontal	2.819	3.834133	1.4	0.5284	1.3974	11.17310379	11.2

TABLE 15: Wind Load Calculations for the as-built model (Case 3)

For wind speed = 25 mph= 11.176 m/s=36.666 ft/s, and air density = 94 % (Case 3)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	5.985734	1.6	0.2575	1.7208	3.942400495	3.9
F2	0.497	5.985734	1.4	0.2575	1.7208	1.845480533	2
F3	0.915	5.985734	1.6	0.2575	1.7208	3.882988647	3.9
F4	0.863	5.985734	1.6	0.2575	1.7208	3.662316068	3.7
F5	1.612	5.985734	2	0.3761	1.5812	11.47631831	11.5
F6	0.861	5.985734	1.8	0.3761	1.5812	5.516748797	5.5
F7	1.592	5.985734	2	0.3761	1.5812	11.33393223	11.3
F8	1.502	5.985734	2	0.3761	1.5812	10.69319485	10.7
F9	1.416	5.985734	2	0.3761	1.5812	10.0809347	10.1
F10	1.624	5.985734	2	0.4511	1.519	13.32183453	13.3
F11	0.868	5.985734	1.8	0.4511	1.519	6.40826178	6.4
F12	1.524	5.985734	2	0.4511	1.519	12.50152452	13.1
F13	1.437	5.985734	2	0.4511	1.519	11.78785481	11.8
F14	1.355	5.985734	2	0.4511	1.519	11.1152006	11.1
F15	1.367	5.985734	2	0.4511	1.519	11.21363781	11.2
F16	1.663	5.985734	2	0.5026	1.479	14.79893002	14.8
F17	0.889	5.985734	1.8	0.5026	1.479	7.120038429	7.1
F18	1.623	5.985734	2	0.5026	1.479	14.44297259	14.4
F19	1.531	5.985734	2	0.5026	1.479	13.62427051	13.6
F20	1.443	5.985734	2	0.5026	1.479	12.84116417	12.8
F21	1.457	5.985734	2	0.5026	1.479	12.96574927	13
F22	1.2	5.985734	2	0.5026	1.479	10.6787228	10.7
F23	1.601	5.985734	2	0.5441	1.4509	15.1305581	15.1
F24	0.856	5.985734	1.8	0.5441	1.4509	7.280813217	7.3
F25	1.567	5.985734	2	0.5441	1.4509	14.80923457	14.8
F26	1.478	5.985734	2	0.5441	1.4509	13.96812297	14
F27	1.393	5.985734	2	0.5441	1.4509	13.16481414	13.2
F28	1.406	5.985734	2	0.5441	1.4509	13.28767313	13.3
F29	1.158	5.985734	2	0.5441	1.4509	10.94390149	10.9
F30	1.601	5.985734	2	0.5789	1.4288	15.85308295	15.9
F31	0.856	5.985734	1.8	0.5789	1.4288	7.628491633	7.6
F32	1.524	5.985734	2	0.5789	1.4288	15.09062987	15.1
F33	1.437	5.985734	2	0.5789	1.4288	14.2291569	14.2
F34	1.355	5.985734	2	0.5789	1.4288	13.41719388	13.4
F35	1.367	5.985734	2	0.5789	1.4288	13.53601773	13.5
F36	1.126	5.985734	2	0.5789	1.4288	11.1496386	11.1
F37	1.601	5.985734	2	0.6089	1.4109	16.46572843	16.5
F38	0.856	5.985734	1.8	0.6089	1.4109	7.923296181	7.9
F39	1.595	5.985734	2	0.6089	1.4109	16.40402052	16.4
F40	1.504	5.985734	2	0.6089	1.4109	15.46811716	15.5
F41	1.418	5.985734	2	0.6089	1.4109	14.58363705	14.6
F42	1.431	5.985734	2	0.6089	1.4109	14.71733753	14.7
F43	1.179	5.985734	2	0.6089	1.4109	12.12560514	12.1
F44	1.506	5.985734	2	0.6349	1.3965	15.98522111	16
F45	0.805	5.985734	1.8	0.6349	1.3965	7.690101392	7.7
F46	1.467	5.985734	2	0.6349	1.3965	15.5712612	15.6
F47	1.383	5.985734	2	0.6349	1.3965	14.67965525	14.7
F48	1.304	5.985734	2	0.6349	1.3965	13.84112107	13.8
F49	1.317	5.985734	2	0.6349	1.3965	13.97910771	14
F50	1.084	5.985734	2	0.6349	1.3965	11.50596261	11.5
Fvertical Transomes	2.032576119	5.985734	1.4	0.5284	1.3974	12.57696393	12.6
F Horizontal	2.819	5.985734	1.4	0.5284	1.3974	17.44311615	17.4

TABLE 16: Wind Load Calculations for the as-built model (Case 4)

For wind speed = 30 mph= 13.411 m/s=43.999 ft/s, and air density = 94 % (Case 4)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	8.616602	1.6	0.2575	1.7208	5.675176343	5.7
F2	0.497	8.616602	1.4	0.2575	1.7208	2.656611746	2.7
F3	0.915	8.616602	1.6	0.2575	1.7208	5.589651619	5.6
F4	0.863	8.616602	1.6	0.2575	1.7208	5.271988358	5.3
F5	1.612	8.616602	2	0.3761	1.5812	16.52042462	16.5
F6	0.861	8.616602	1.8	0.3761	1.5812	7.941486995	7.9
F7	1.592	8.616602	2	0.3761	1.5812	16.31545657	16.3
F8	1.502	8.616602	2	0.3761	1.5812	15.39310036	15.4
F9	1.416	8.616602	2	0.3761	1.5812	14.51173775	14.5
F10	1.624	8.616602	2	0.4511	1.519	19.17708772	19.2
F11	0.868	8.616602	1.8	0.4511	1.519	9.224840475	9.2
F12	1.524	8.616602	2	0.4511	1.519	17.99623257	18
F13	1.437	8.616602	2	0.4511	1.519	16.96888858	17
F14	1.355	8.616602	2	0.4511	1.519	16.00058736	16
F15	1.367	8.616602	2	0.4511	1.519	16.14228998	16.1
F16	1.663	8.616602	2	0.5026	1.479	21.30340072	21.3
F17	0.889	8.616602	1.8	0.5026	1.479	10.24945936	10.2
F18	1.623	8.616602	2	0.5026	1.479	20.7909918	20.8
F19	1.531	8.616602	2	0.5026	1.479	19.61245129	19.6
F20	1.443	8.616602	2	0.5026	1.479	18.48515167	18.5
F21	1.457	8.616602	2	0.5026	1.479	18.6644948	18.7
F22	1.2	8.616602	2	0.5026	1.479	15.3722675	15.4
F23	1.601	8.616602	2	0.5441	1.4509	21.78078698	21.8
F24	0.856	8.616602	1.8	0.5441	1.4509	10.48089837	10.5
F25	1.567	8.616602	2	0.5441	1.4509	21.31823435	21.3
F26	1.478	8.616602	2	0.5441	1.4509	20.10743483	20.1
F27	1.393	8.616602	2	0.5441	1.4509	18.95105326	19
F28	1.406	8.616602	2	0.5441	1.4509	19.12791161	19.1
F29	1.158	8.616602	2	0.5441	1.4509	15.75399833	15.8
F30	1.601	8.616602	2	0.5789	1.4288	22.82087815	22.8
F31	0.856	8.616602	1.8	0.5789	1.4288	10.98138946	11
F32	1.524	8.616602	2	0.5789	1.4288	21.72330937	21.7
F33	1.437	8.616602	2	0.5789	1.4288	20.48319919	20.5
F34	1.355	8.616602	2	0.5789	1.4288	19.31435971	19.3
F35	1.367	8.616602	2	0.5789	1.4288	19.48540939	19.5
F36	1.126	8.616602	2	0.5789	1.4288	16.05016165	16.1
F37	1.601	8.616602	2	0.6089	1.4109	23.70279544	23.7
F38	0.856	8.616602	1.8	0.6089	1.4109	11.4057674	11.4
F39	1.595	8.616602	2	0.6089	1.4109	23.61396548	23.6
F40	1.504	8.616602	2	0.6089	1.4109	22.26671102	22.3
F41	1.418	8.616602	2	0.6089	1.4109	20.99348153	21
F42	1.431	8.616602	2	0.6089	1.4109	21.18594646	21.2
F43	1.179	8.616602	2	0.6089	1.4109	17.45508796	17.5
F44	1.506	8.616602	2	0.6349	1.3965	23.01109408	23
F45	0.805	8.616602	1.8	0.6349	1.3965	11.07007813	11.1
F46	1.467	8.616602	2	0.6349	1.3965	22.41518925	22.4
F47	1.383	8.616602	2	0.6349	1.3965	21.13170193	21.1
F48	1.304	8.616602	2	0.6349	1.3965	19.92461267	19.9
F49	1.317	8.616602	2	0.6349	1.3965	20.12324761	20.1
F50	1.084	8.616602	2	0.6349	1.3965	16.56309826	16.6
Fvertical Transomes	2.032576119	8.616602	1.4	0.5284	1.3974	18.10482935	18.1
F Horizontal	2.819	8.616602	1.4	0.5284	1.3974	25.10976758	25.1

TABLE 17: Wind Load Calculations for the as-built model (Case 5)

For wind speed = 35 mph= 15.65 m/s= 51.33 ft/s, and air density = 94 % (Case 5)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	11.7267	1.6	0.2575	1.7208	7.723588768	7.7
F2	0.497	11.7267	1.4	0.2575	1.7208	3.615495872	3.6
F3	0.915	11.7267	1.6	0.2575	1.7208	7.607194535	7.6
F4	0.863	11.7267	1.6	0.2575	1.7208	7.174873097	7.2
F5	1.612	11.7267	2	0.3761	1.5812	22.48334823	22.5
F6	0.861	11.7267	1.8	0.3761	1.5812	10.80790729	10.8
F7	1.592	11.7267	2	0.3761	1.5812	22.2043985	22.2
F8	1.502	11.7267	2	0.3761	1.5812	20.94912472	20.9
F9	1.416	11.7267	2	0.3761	1.5812	19.74964088	19.7
F10	1.624	11.7267	2	0.4511	1.519	26.09891401	26.1
F11	0.868	11.7267	1.8	0.4511	1.519	12.5544776	12.6
F12	1.524	11.7267	2	0.4511	1.519	24.49183802	24.5
F13	1.437	11.7267	2	0.4511	1.519	23.09368191	23.1
F14	1.355	11.7267	2	0.4511	1.519	21.7758796	21.8
F15	1.367	11.7267	2	0.4511	1.519	21.96872872	22
F16	1.663	11.7267	2	0.5026	1.479	28.99270376	29
F17	0.889	11.7267	1.8	0.5026	1.479	13.948925	13.9
F18	1.623	11.7267	2	0.5026	1.479	28.29534468	28.3
F19	1.531	11.7267	2	0.5026	1.479	26.69141879	26.7
F20	1.443	11.7267	2	0.5026	1.479	25.15722882	25.2
F21	1.457	11.7267	2	0.5026	1.479	25.4013045	25.4
F22	1.2	11.7267	2	0.5026	1.479	20.92077241	20.9
F23	1.601	11.7267	2	0.5441	1.4509	29.64239902	29.6
F24	0.856	11.7267	1.8	0.5441	1.4509	14.26390019	14.3
F25	1.567	11.7267	2	0.5441	1.4509	29.01289148	29
F26	1.478	11.7267	2	0.5441	1.4509	27.36506293	27.4
F27	1.393	11.7267	2	0.5441	1.4509	25.79129409	25.8
F28	1.406	11.7267	2	0.5441	1.4509	26.03198815	26
F29	1.158	11.7267	2	0.5441	1.4509	21.44028611	21.4
F30	1.601	11.7267	2	0.5789	1.4288	31.05790331	31.1
F31	0.856	11.7267	1.8	0.5789	1.4288	14.94503979	14.9
F32	1.524	11.7267	2	0.5789	1.4288	29.56417529	29.6
F33	1.437	11.7267	2	0.5789	1.4288	27.87645663	27.9
F34	1.355	11.7267	2	0.5789	1.4288	26.28573328	26.3
F35	1.367	11.7267	2	0.5789	1.4288	26.51852207	26.5
F36	1.126	11.7267	2	0.5789	1.4288	21.84334736	21.8
F37	1.601	11.7267	2	0.6089	1.4109	32.25814205	32.3
F38	0.856	11.7267	1.8	0.6089	1.4109	15.52259378	15.5
F39	1.595	11.7267	2	0.6089	1.4109	32.13724957	32.1
F40	1.504	11.7267	2	0.6089	1.4109	30.3037137	30.3
F41	1.418	11.7267	2	0.6089	1.4109	28.57092156	28.6
F42	1.431	11.7267	2	0.6089	1.4109	28.83285526	28.8
F43	1.179	11.7267	2	0.6089	1.4109	23.75537132	23.8
F44	1.506	11.7267	2	0.6349	1.3965	31.31677626	31.3
F45	0.805	11.7267	1.8	0.6349	1.3965	15.06573997	15.1
F46	1.467	11.7267	2	0.6349	1.3965	30.50578405	30.5
F47	1.383	11.7267	2	0.6349	1.3965	28.75903159	28.8
F48	1.304	11.7267	2	0.6349	1.3965	27.11625249	27.1
F49	1.317	11.7267	2	0.6349	1.3965	27.38658322	27.4
F50	1.084	11.7267	2	0.6349	1.3965	22.54142461	22.5
Fvertical Transomes	2.032576119	11.7267	1.4	0.5284	1.3974	24.63963199	24.6
F Horizontal	2.819	11.7267	1.4	0.5284	1.3974	34.17295025	34.2

TABLE 18: Wind Load Calculations for the as-built model (Case 6)

For wind speed = 40mph= 17.88 m/s= 58.67 ft/s, and air density = 94 % (Case 6)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	15.2957	1.6	0.2575	1.7208	10.07424908	10.1
F2	0.497	15.2957	1.4	0.2575	1.7208	4.715865522	4.7
F3	0.915	15.2957	1.6	0.2575	1.7208	9.922430474	9.9
F4	0.863	15.2957	1.6	0.2575	1.7208	9.358532786	9.4
F5	1.612	15.2957	2	0.3761	1.5812	29.32611473	29.3
F6	0.861	15.2957	1.8	0.3761	1.5812	14.09727438	14.1
F7	1.592	15.2957	2	0.3761	1.5812	28.96226715	29
F8	1.502	15.2957	2	0.3761	1.5812	27.32495305	27.3
F9	1.416	15.2957	2	0.3761	1.5812	25.76040847	25.8
F10	1.624	15.2957	2	0.4511	1.519	34.04207142	34
F11	0.868	15.2957	1.8	0.4511	1.519	16.37541022	16.4
F12	1.524	15.2957	2	0.4511	1.519	31.94588476	31.9
F13	1.437	15.2957	2	0.4511	1.519	30.12220236	30.1
F14	1.355	15.2957	2	0.4511	1.519	28.4033293	28.4
F15	1.367	15.2957	2	0.4511	1.519	28.6548717	28.7
F16	1.663	15.2957	2	0.5026	1.479	37.81658087	37.8
F17	0.889	15.2957	1.8	0.5026	1.479	18.19425517	18.2
F18	1.623	15.2957	2	0.5026	1.479	36.90698181	36.9
F19	1.531	15.2957	2	0.5026	1.479	34.81490397	34.8
F20	1.443	15.2957	2	0.5026	1.479	32.81378605	32.8
F21	1.457	15.2957	2	0.5026	1.479	33.13214572	33.1
F22	1.2	15.2957	2	0.5026	1.479	27.28797176	27.3
F23	1.601	15.2957	2	0.5441	1.4509	38.66400971	38.7
F24	0.856	15.2957	1.8	0.5441	1.4509	18.60509249	18.6
F25	1.567	15.2957	2	0.5441	1.4509	37.84291269	37.8
F26	1.478	15.2957	2	0.5441	1.4509	35.69357049	35.7
F27	1.393	15.2957	2	0.5441	1.4509	33.64082794	33.6
F28	1.406	15.2957	2	0.5441	1.4509	33.9547768	34
F29	1.158	15.2957	2	0.5441	1.4509	27.96559853	28
F30	1.601	15.2957	2	0.5789	1.4288	40.51032018	40.5
F31	0.856	15.2957	1.8	0.5789	1.4288	19.49353571	19.5
F32	1.524	15.2957	2	0.5789	1.4288	38.56197874	38.6
F33	1.437	15.2957	2	0.5789	1.4288	36.36060593	36.4
F34	1.355	15.2957	2	0.5789	1.4288	34.28574881	34.3
F35	1.367	15.2957	2	0.5789	1.4288	34.58938644	34.6
F36	1.126	15.2957	2	0.5789	1.4288	28.49133075	28.5
F37	1.601	15.2957	2	0.6089	1.4109	42.07584942	42.1
F38	0.856	15.2957	1.8	0.6089	1.4109	20.2468672	20.2
F39	1.595	15.2957	2	0.6089	1.4109	41.91816353	41.9
F40	1.504	15.2957	2	0.6089	1.4109	39.52659433	39.5
F41	1.418	15.2957	2	0.6089	1.4109	37.26643003	37.3
F42	1.431	15.2957	2	0.6089	1.4109	37.60808277	37.6
F43	1.179	15.2957	2	0.6089	1.4109	30.98527574	31
F44	1.506	15.2957	2	0.6349	1.3965	40.84798065	40.8
F45	0.805	15.2957	1.8	0.6349	1.3965	19.65097077	19.7
F46	1.467	15.2957	2	0.6349	1.3965	39.79016441	39.8
F47	1.383	15.2957	2	0.6349	1.3965	37.51179099	37.5
F48	1.304	15.2957	2	0.6349	1.3965	35.36903503	35.4
F49	1.317	15.2957	2	0.6349	1.3965	35.72164044	35.7
F50	1.084	15.2957	2	0.6349	1.3965	29.40186655	29.4
Fvertical Transomes	2.032576119	15.2957	1.4	0.5284	1.3974	32.13865956	32.1
F Horizontal	2.819	15.2957	1.4	0.5284	1.3974	44.57342604	44.6

TABLE 19: Wind Load Calculations for the as-built model (Case 7)

For wind speed = 45mph= 20.1168 m/s= 66 ft/s, and air density = 94 % (Case 7)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	19.3746	1.6	0.2575	1.7208	12.76074624	12.8
F2	0.497	19.3746	1.4	0.2575	1.7208	5.973444049	6
F3	0.915	19.3746	1.6	0.2575	1.7208	12.56844221	12.6
F4	0.863	19.3746	1.6	0.2575	1.7208	11.85417008	11.9
F5	1.612	19.3746	2	0.3761	1.5812	37.14650146	37.1
F6	0.861	19.3746	1.8	0.3761	1.5812	17.85659056	17.9
F7	1.592	19.3746	2	0.3761	1.5812	36.68562675	36.7
F8	1.502	19.3746	2	0.3761	1.5812	34.61169057	34.6
F9	1.416	19.3746	2	0.3761	1.5812	32.62992932	32.6
F10	1.624	19.3746	2	0.4511	1.519	43.120061	43.1
F11	0.868	19.3746	1.8	0.4511	1.519	20.74223624	20.7
F12	1.524	19.3746	2	0.4511	1.519	40.46488483	40.5
F13	1.437	19.3746	2	0.4511	1.519	38.15488156	38.2
F14	1.355	19.3746	2	0.4511	1.519	35.9776371	36
F15	1.367	19.3746	2	0.4511	1.519	36.29625824	36.3
F16	1.663	19.3746	2	0.5026	1.479	47.90111781	47.9
F17	0.889	19.3746	1.8	0.5026	1.479	23.04611206	23
F18	1.623	19.3746	2	0.5026	1.479	46.74895623	46.7
F19	1.531	19.3746	2	0.5026	1.479	44.09898459	44.1
F20	1.443	19.3746	2	0.5026	1.479	41.5642291	41.6
F21	1.457	19.3746	2	0.5026	1.479	41.96748566	42
F22	1.2	19.3746	2	0.5026	1.479	34.56484749	34.6
F23	1.601	19.3746	2	0.5441	1.4509	48.97453027	49
F24	0.856	19.3746	1.8	0.5441	1.4509	23.56650726	23.6
F25	1.567	19.3746	2	0.5441	1.4509	47.93447153	47.9
F26	1.478	19.3746	2	0.5441	1.4509	45.21196486	45.2
F27	1.393	19.3746	2	0.5441	1.4509	42.61181803	42.6
F28	1.406	19.3746	2	0.5441	1.4509	43.00948754	43
F29	1.158	19.3746	2	0.5441	1.4509	35.42317679	35.4
F30	1.601	19.3746	2	0.5789	1.4288	51.31319583	51.3
F31	0.856	19.3746	1.8	0.5789	1.4288	24.69187137	24.7
F32	1.524	19.3746	2	0.5789	1.4288	48.84529072	48.8
F33	1.437	19.3746	2	0.5789	1.4288	46.05687845	46.1
F34	1.355	19.3746	2	0.5789	1.4288	43.42871977	43.4
F35	1.367	19.3746	2	0.5789	1.4288	43.81332835	43.8
F36	1.126	19.3746	2	0.5789	1.4288	36.08910587	36.1
F37	1.601	19.3746	2	0.6089	1.4109	53.2962043	53.3
F38	0.856	19.3746	1.8	0.6089	1.4109	25.64609356	25.6
F39	1.595	19.3746	2	0.6089	1.4109	53.09646837	53.1
F40	1.504	19.3746	2	0.6089	1.4109	50.06714008	50.1
F41	1.418	19.3746	2	0.6089	1.4109	47.2042584	47.2
F42	1.431	19.3746	2	0.6089	1.4109	47.63701958	47.6
F43	1.179	19.3746	2	0.6089	1.4109	39.24811047	39.2
F44	1.506	19.3746	2	0.6349	1.3965	51.74090011	51.7
F45	0.805	19.3746	1.8	0.6349	1.3965	24.89128959	24.9
F46	1.467	19.3746	2	0.6349	1.3965	50.40099632	50.4
F47	1.383	19.3746	2	0.6349	1.3965	47.5150497	47.5
F48	1.304	19.3746	2	0.6349	1.3965	44.80088562	44.8
F49	1.317	19.3746	2	0.6349	1.3965	45.24752022	45.2
F50	1.084	19.3746	2	0.6349	1.3965	37.242454	37.2
Fvertical Transomes	2.032576119	19.3746	1.4	0.5284	1.3974	40.70906683	40.7
F Horizontal	2.819	19.3746	1.4	0.5284	1.3974	56.45980897	56.5

TABLE 20: Wind Load Calculations for the as-built model (Case 8)

For wind speed = 50mph= 22.352 m/s=73.33 ft/s, and air density = 94 % (Case 8)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	23.9633	1.6	0.2575	1.7208	15.78301438	15.8
F2	0.497	23.9633	1.4	0.2575	1.7208	7.388200622	7.4
F3	0.915	23.9633	1.6	0.2575	1.7208	15.54516486	15.5
F4	0.863	23.9633	1.6	0.2575	1.7208	14.6617238	14.7
F5	1.612	23.9633	2	0.3761	1.5812	45.94431671	45.9
F6	0.861	23.9633	1.8	0.3761	1.5812	22.08576366	22.1
F7	1.592	23.9633	2	0.3761	1.5812	45.37428796	45.4
F8	1.502	23.9633	2	0.3761	1.5812	42.80915862	42.8
F9	1.416	23.9633	2	0.3761	1.5812	40.35803502	40.4
F10	1.624	23.9633	2	0.4511	1.519	53.33266017	53.3
F11	0.868	23.9633	1.8	0.4511	1.519	25.6548486	25.7
F12	1.524	23.9633	2	0.4511	1.519	50.04862937	50
F13	1.437	23.9633	2	0.4511	1.519	47.19152258	47.2
F14	1.355	23.9633	2	0.4511	1.519	44.49861732	44.5
F15	1.367	23.9633	2	0.4511	1.519	44.89270102	44.9
F16	1.663	23.9633	2	0.5026	1.479	59.24606735	59.2
F17	0.889	23.9633	1.8	0.5026	1.479	28.50437672	28.5
F18	1.623	23.9633	2	0.5026	1.479	57.82102664	57.8
F19	1.531	23.9633	2	0.5026	1.479	54.54343302	54.5
F20	1.443	23.9633	2	0.5026	1.479	51.40834347	51.4
F21	1.457	23.9633	2	0.5026	1.479	51.90710771	51.9
F22	1.2	23.9633	2	0.5026	1.479	42.75122118	42.8
F23	1.601	23.9633	2	0.5441	1.4509	60.5737079	60.6
F24	0.856	23.9633	1.8	0.5441	1.4509	29.14802284	29.1
F25	1.567	23.9633	2	0.5441	1.4509	59.2873206	59.3
F26	1.478	23.9633	2	0.5441	1.4509	55.92001267	55.9
F27	1.393	23.9633	2	0.5441	1.4509	52.70404441	52.7
F28	1.406	23.9633	2	0.5441	1.4509	53.19589838	53.2
F29	1.158	23.9633	2	0.5441	1.4509	43.81283807	43.8
F30	1.601	23.9633	2	0.5789	1.4288	63.4662654	63.5
F31	0.856	23.9633	1.8	0.5789	1.4288	30.53991934	30.5
F32	1.524	23.9633	2	0.5789	1.4288	60.41385913	60.4
F33	1.437	23.9633	2	0.5789	1.4288	56.96503646	57
F34	1.355	23.9633	2	0.5789	1.4288	53.71442199	53.7
F35	1.367	23.9633	2	0.5789	1.4288	54.19012167	54.2
F36	1.126	23.9633	2	0.5789	1.4288	44.63648647	44.6
F37	1.601	23.9633	2	0.6089	1.4109	65.91893161	65.9
F38	0.856	23.9633	1.8	0.6089	1.4109	31.72014048	31.7
F39	1.595	23.9633	2	0.6089	1.4109	65.67189002	65.7
F40	1.504	23.9633	2	0.6089	1.4109	61.92509253	61.9
F41	1.418	23.9633	2	0.6089	1.4109	58.38416304	58.4
F42	1.431	23.9633	2	0.6089	1.4109	58.91941982	58.9
F43	1.179	23.9633	2	0.6089	1.4109	48.54367294	48.5
F44	1.506	23.9633	2	0.6349	1.3965	63.9952676	64
F45	0.805	23.9633	1.8	0.6349	1.3965	30.78656798	30.8
F46	1.467	23.9633	2	0.6349	1.3965	62.33801963	62.3
F47	1.383	23.9633	2	0.6349	1.3965	58.76856248	58.8
F48	1.304	23.9633	2	0.6349	1.3965	55.41157301	55.4
F49	1.317	23.9633	2	0.6349	1.3965	55.963989	56
F50	1.084	23.9633	2	0.6349	1.3965	46.06299474	46.1
Fvertical Transomes	2.032576119	23.9633	1.4	0.5284	1.3974	50.35064369	50.4
F Horizontal	2.819	23.9633	1.4	0.5284	1.3974	69.83180764	69.8

TABLE 21: Wind Load Calculations for the as-built model (Case 9)

For wind speed = 55mph=24.5872 m/s=80.67 ft/s, and air density = 94 % (Case 9)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	28.9599	1.6	0.2575	1.7208	19.07393882	19.1
F2	0.497	28.9599	1.4	0.2575	1.7208	8.928718132	8.9
F3	0.915	28.9599	1.6	0.2575	1.7208	18.78649518	18.8
F4	0.863	28.9599	1.6	0.2575	1.7208	17.71884736	17.7
F5	1.612	28.9599	2	0.3761	1.5812	55.5241898	55.5
F6	0.861	28.9599	1.8	0.3761	1.5812	26.69087759	26.7
F7	1.592	28.9599	2	0.3761	1.5812	54.83530407	54.8
F8	1.502	28.9599	2	0.3761	1.5812	51.73531829	51.7
F9	1.416	28.9599	2	0.3761	1.5812	48.77310965	48.8
F10	1.624	28.9599	2	0.4511	1.519	64.45308055	64.5
F11	0.868	28.9599	1.8	0.4511	1.519	31.00415427	31
F12	1.524	28.9599	2	0.4511	1.519	60.48429481	60.5
F13	1.437	28.9599	2	0.4511	1.519	57.0314512	57
F14	1.355	28.9599	2	0.4511	1.519	53.77704689	53.8
F15	1.367	28.9599	2	0.4511	1.519	54.25330118	54.3
F16	1.663	28.9599	2	0.5026	1.479	71.5994953	71.6
F17	0.889	28.9599	1.8	0.5026	1.479	34.44783896	34.4
F18	1.623	28.9599	2	0.5026	1.479	69.87731863	69.9
F19	1.531	28.9599	2	0.5026	1.479	65.91631227	65.9
F20	1.443	28.9599	2	0.5026	1.479	62.12752359	62.1
F21	1.457	28.9599	2	0.5026	1.479	62.73028542	62.7
F22	1.2	28.9599	2	0.5026	1.479	51.66530028	51.7
F23	1.601	28.9599	2	0.5441	1.4509	73.20396287	73.2
F24	0.856	28.9599	1.8	0.5441	1.4509	35.22569207	35.2
F25	1.567	28.9599	2	0.5441	1.4509	71.64935029	71.6
F26	1.478	28.9599	2	0.5441	1.4509	67.57992325	67.6
F27	1.393	28.9599	2	0.5441	1.4509	63.69339181	63.7
F28	1.406	28.9599	2	0.5441	1.4509	64.2878025	64.3
F29	1.158	28.9599	2	0.5441	1.4509	52.94827546	52.9
F30	1.601	28.9599	2	0.5789	1.4288	76.69964902	76.7
F31	0.856	28.9599	1.8	0.5789	1.4288	36.90781362	36.9
F32	1.524	28.9599	2	0.5789	1.4288	73.01078395	73
F33	1.437	28.9599	2	0.5789	1.4288	68.84284549	68.8
F34	1.355	28.9599	2	0.5789	1.4288	64.91444373	64.9
F35	1.367	28.9599	2	0.5789	1.4288	65.4893318	65.5
F36	1.126	28.9599	2	0.5789	1.4288	53.9436632	53.9
F37	1.601	28.9599	2	0.6089	1.4109	79.66372193	79.7
F38	0.856	28.9599	1.8	0.6089	1.4109	38.33412328	38.3
F39	1.595	28.9599	2	0.6089	1.4109	79.36516956	79.4
F40	1.504	28.9599	2	0.6089	1.4109	74.83712541	74.8
F41	1.418	28.9599	2	0.6089	1.4109	70.55787489	70.6
F42	1.431	28.9599	2	0.6089	1.4109	71.20473834	71.2
F43	1.179	28.9599	2	0.6089	1.4109	58.66553913	58.7
F44	1.506	28.9599	2	0.6349	1.3965	77.33895374	77.3
F45	0.805	28.9599	1.8	0.6349	1.3965	37.20589109	37.2
F46	1.467	28.9599	2	0.6349	1.3965	75.33615215	75.3
F47	1.383	28.9599	2	0.6349	1.3965	71.02242564	71
F48	1.304	28.9599	2	0.6349	1.3965	66.96546858	67
F49	1.317	28.9599	2	0.6349	1.3965	67.63306911	67.6
F50	1.084	28.9599	2	0.6349	1.3965	55.66761345	55.7
Fvertical Transomes	2.032576119	28.9599	1.4	0.5284	1.3974	60.84928229	60.8
F Horizontal	2.819	28.9599	1.4	0.5284	1.3974	84.39247375	84.4

TABLE 22: Wind Load Calculations for the as-built model (Case 10)

For wind speed = 60mph=26.82 m/s=88 ft/s, and air density = 94 % (Case 10)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	34.4664	1.6	0.2575	1.7208	22.7007001	22.7
F2	0.497	34.4664	1.4	0.2575	1.7208	10.62644452	10.6
F3	0.915	34.4664	1.6	0.2575	1.7208	22.35860129	22.4
F4	0.863	34.4664	1.6	0.2575	1.7208	21.08794854	21.1
F5	1.612	34.4664	2	0.3761	1.5812	66.08168313	66.1
F6	0.861	34.4664	1.8	0.3761	1.5812	31.76594061	31.8
F7	1.592	34.4664	2	0.3761	1.5812	65.26181113	65.3
F8	1.502	34.4664	2	0.3761	1.5812	61.57238714	61.6
F9	1.416	34.4664	2	0.3761	1.5812	58.04693754	58
F10	1.624	34.4664	2	0.4511	1.519	76.70833309	76.7
F11	0.868	34.4664	1.8	0.4511	1.519	36.89935333	36.9
F12	1.524	34.4664	2	0.4511	1.519	71.98491357	72
F13	1.437	34.4664	2	0.4511	1.519	67.87553858	67.9
F14	1.355	34.4664	2	0.4511	1.519	64.00233457	64
F15	1.367	34.4664	2	0.4511	1.519	64.56914491	64.6
F16	1.663	34.4664	2	0.5026	1.479	85.21358309	85.2
F17	0.889	34.4664	1.8	0.5026	1.479	40.99782792	41
F18	1.623	34.4664	2	0.5026	1.479	83.1639479	83.2
F19	1.531	34.4664	2	0.5026	1.479	78.44978696	78.4
F20	1.443	34.4664	2	0.5026	1.479	73.94058954	73.9
F21	1.457	34.4664	2	0.5026	1.479	74.65796185	74.7
F22	1.2	34.4664	2	0.5026	1.479	61.48905575	61.5
F23	1.601	34.4664	2	0.5441	1.4509	87.1231277	87.1
F24	0.856	34.4664	1.8	0.5441	1.4509	41.92358375	41.9
F25	1.567	34.4664	2	0.5441	1.4509	85.27291762	85.3
F26	1.478	34.4664	2	0.5441	1.4509	80.42972064	80.4
F27	1.393	34.4664	2	0.5441	1.4509	75.80419543	75.8
F28	1.406	34.4664	2	0.5441	1.4509	76.5116287	76.5
F29	1.158	34.4664	2	0.5441	1.4509	63.01597869	63
F30	1.601	34.4664	2	0.5789	1.4288	91.28349141	91.3
F31	0.856	34.4664	1.8	0.5789	1.4288	43.92554765	43.9
F32	1.524	34.4664	2	0.5789	1.4288	86.89321731	86.9
F33	1.437	34.4664	2	0.5789	1.4288	81.93277773	81.9
F34	1.355	34.4664	2	0.5789	1.4288	77.2574209	77.3
F35	1.367	34.4664	2	0.5789	1.4288	77.94161946	77.9
F36	1.126	34.4664	2	0.5789	1.4288	64.20063168	64.2
F37	1.601	34.4664	2	0.6089	1.4109	94.81115976	94.8
F38	0.856	34.4664	1.8	0.6089	1.4109	45.62305901	45.6
F39	1.595	34.4664	2	0.6089	1.4109	94.45583998	94.5
F40	1.504	34.4664	2	0.6089	1.4109	89.06682341	89.1
F41	1.418	34.4664	2	0.6089	1.4109	83.97390664	84
F42	1.431	34.4664	2	0.6089	1.4109	84.74376615	84.7
F43	1.179	34.4664	2	0.6089	1.4109	69.82033564	69.8
F44	1.506	34.4664	2	0.6349	1.3965	92.04435496	92
F45	0.805	34.4664	1.8	0.6349	1.3965	44.28030224	44.3
F46	1.467	34.4664	2	0.6349	1.3965	89.6607362	89.7
F47	1.383	34.4664	2	0.6349	1.3965	84.52678812	84.5
F48	1.304	34.4664	2	0.6349	1.3965	79.69843218	79.7
F49	1.317	34.4664	2	0.6349	1.3965	80.49297177	80.5
F50	1.084	34.4664	2	0.6349	1.3965	66.25237767	66.3
Fvertical Transomes	2.032576119	34.4664	1.4	0.5284	1.3974	72.41930058	72.4
F Horizontal	2.819	34.4664	1.4	0.5284	1.3974	100.439047	100.4

TABLE 23: Wind Load Calculations for the as-built model (Case 11)

For wind speed = 65mph=29.0576 m/s=95.33 ft/s, and air density = 94 % (Case 11)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	40.4827	1.6	0.2575	1.7208	26.66323237	26.7
F2	0.497	40.4827	1.4	0.2575	1.7208	12.48134895	12.5
F3	0.915	40.4827	1.6	0.2575	1.7208	26.26141832	26.3
F4	0.863	40.4827	1.6	0.2575	1.7208	24.76896613	24.8
F5	1.612	40.4827	2	0.3761	1.5812	77.61660498	77.6
F6	0.861	40.4827	1.8	0.3761	1.5812	37.31086054	37.3
F7	1.592	40.4827	2	0.3761	1.5812	76.6536198	76.7
F8	1.502	40.4827	2	0.3761	1.5812	72.32018652	72.3
F9	1.416	40.4827	2	0.3761	1.5812	68.17935028	68.2
F10	1.624	40.4827	2	0.4511	1.519	90.09819523	90.1
F11	0.868	40.4827	1.8	0.4511	1.519	43.34033874	43.3
F12	1.524	40.4827	2	0.4511	1.519	84.55027681	84.6
F13	1.437	40.4827	2	0.4511	1.519	79.72358778	79.7
F14	1.355	40.4827	2	0.4511	1.519	75.17429467	75.2
F15	1.367	40.4827	2	0.4511	1.519	75.84004488	75.8
F16	1.663	40.4827	2	0.5026	1.479	100.0880835	100.1
F17	0.889	40.4827	1.8	0.5026	1.479	48.15422465	48.2
F18	1.623	40.4827	2	0.5026	1.479	97.68067316	97.7
F19	1.531	40.4827	2	0.5026	1.479	92.14362946	92.1
F20	1.443	40.4827	2	0.5026	1.479	86.84732679	86.8
F21	1.457	40.4827	2	0.5026	1.479	87.68992039	87.7
F22	1.2	40.4827	2	0.5026	1.479	72.22230918	72.2
F23	1.601	40.4827	2	0.5441	1.4509	102.3309496	102.3
F24	0.856	40.4827	1.8	0.5441	1.4509	49.24157625	49.2
F25	1.567	40.4827	2	0.5441	1.4509	100.1577752	100.2
F26	1.478	40.4827	2	0.5441	1.4509	94.46917147	94.5
F27	1.393	40.4827	2	0.5441	1.4509	89.03623536	89
F28	1.406	40.4827	2	0.5441	1.4509	89.867155	89.9
F29	1.158	40.4827	2	0.5441	1.4509	74.01576493	74
F30	1.601	40.4827	2	0.5789	1.4288	107.2175277	107.2
F31	0.856	40.4827	1.8	0.5789	1.4288	51.59299398	51.6
F32	1.524	40.4827	2	0.5789	1.4288	102.0609071	102.1
F33	1.437	40.4827	2	0.5789	1.4288	96.23459547	96.2
F34	1.355	40.4827	2	0.5789	1.4288	90.74312934	90.7
F35	1.367	40.4827	2	0.5789	1.4288	91.54675853	91.5
F36	1.126	40.4827	2	0.5789	1.4288	75.40720563	75.4
F37	1.601	40.4827	2	0.6089	1.4109	111.36097	111.4
F38	0.856	40.4827	1.8	0.6089	1.4109	53.5868153	53.6
F39	1.595	40.4827	2	0.6089	1.4109	110.9436272	110.9
F40	1.504	40.4827	2	0.6089	1.4109	104.6139281	104.6
F41	1.418	40.4827	2	0.6089	1.4109	98.63201467	98.6
F42	1.431	40.4827	2	0.6089	1.4109	99.5362574	99.5
F43	1.179	40.4827	2	0.6089	1.4109	82.00785987	82
F44	1.506	40.4827	2	0.6349	1.3965	108.1112042	108.1
F45	0.805	40.4827	1.8	0.6349	1.3965	52.00967294	52
F46	1.467	40.4827	2	0.6349	1.3965	105.3115117	105.3
F47	1.383	40.4827	2	0.6349	1.3965	99.28140465	99.3
F48	1.304	40.4827	2	0.6349	1.3965	93.61023259	93.6
F49	1.317	40.4827	2	0.6349	1.3965	94.54346343	94.5
F50	1.084	40.4827	2	0.6349	1.3965	77.81709519	77.8
Fvertical Transomes	2.032576119	40.4827	1.4	0.5284	1.3974	85.06048847	85.1
F Horizontal	2.819	40.4827	1.4	0.5284	1.3974	117.971236	118

TABLE 24: Wind Load Calculations for the as-built model (Case 12)

For wind speed = 70 mph=31.2928 m/s=102.67 ft/s, and air density = 94 % (Case 12)							
Number	Area	Pressure (kgf/m^2)	Cd	Kz	Gh	#VALUE!	approximate
F1	0.929	46.9069	1.6	0.2575	1.7208	30.89442093	30.9
F2	0.497	46.9069	1.4	0.2575	1.7208	14.46201432	14.5
F3	0.915	46.9069	1.6	0.2575	1.7208	30.42884301	30.4
F4	0.863	46.9069	1.6	0.2575	1.7208	28.69955357	28.7
F5	1.612	46.9069	2	0.3761	1.5812	89.93358466	89.9
F6	0.861	46.9069	1.8	0.3761	1.5812	43.23172131	43.2
F7	1.592	46.9069	2	0.3761	1.5812	88.81778337	88.8
F8	1.502	46.9069	2	0.3761	1.5812	83.79667752	83.8
F9	1.416	46.9069	2	0.3761	1.5812	78.99873194	79
F10	1.624	46.9069	2	0.4511	1.519	104.3958786	104.4
F11	0.868	46.9069	1.8	0.4511	1.519	50.21801746	50.2
F12	1.524	46.9069	2	0.4511	1.519	97.96756094	98
F13	1.437	46.9069	2	0.4511	1.519	92.37492459	92.4
F14	1.355	46.9069	2	0.4511	1.519	87.10370411	87.1
F15	1.367	46.9069	2	0.4511	1.519	87.87510223	87.9
F16	1.663	46.9069	2	0.5026	1.479	115.9710623	116
F17	0.889	46.9069	1.8	0.5026	1.479	55.79581895	55.8
F18	1.623	46.9069	2	0.5026	1.479	113.18162	113.2
F19	1.531	46.9069	2	0.5026	1.479	106.7659028	106.8
F20	1.443	46.9069	2	0.5026	1.479	100.6291298	100.6
F21	1.457	46.9069	2	0.5026	1.479	101.6054346	101.6
F22	1.2	46.9069	2	0.5026	1.479	83.68326802	83.7
F23	1.601	46.9069	2	0.5441	1.4509	118.5698489	118.6
F24	0.856	46.9069	1.8	0.5441	1.4509	57.0557224	57.1
F25	1.567	46.9069	2	0.5441	1.4509	116.0518133	116.1
F26	1.478	46.9069	2	0.5441	1.4509	109.4604851	109.5
F27	1.393	46.9069	2	0.5441	1.4509	103.1653963	103.2
F28	1.406	46.9069	2	0.5441	1.4509	104.1281746	104.1
F29	1.158	46.9069	2	0.5441	1.4509	85.76132728	85.8
F30	1.601	46.9069	2	0.5789	1.4288	124.2318781	124.2
F31	0.856	46.9069	1.8	0.5789	1.4288	59.78028662	59.8
F32	1.524	46.9069	2	0.5789	1.4288	118.2569533	118.3
F33	1.437	46.9069	2	0.5789	1.4288	111.5060642	111.5
F34	1.355	46.9069	2	0.5789	1.4288	105.1431573	105.1
F35	1.367	46.9069	2	0.5789	1.4288	106.0743144	106.1
F36	1.126	46.9069	2	0.5789	1.4288	87.37357572	87.4
F37	1.601	46.9069	2	0.6089	1.4109	129.0328433	129
F38	0.856	46.9069	1.8	0.6089	1.4109	62.09050747	62.1
F39	1.595	46.9069	2	0.6089	1.4109	128.5492723	128.5
F40	1.504	46.9069	2	0.6089	1.4109	121.2151132	121.2
F41	1.418	46.9069	2	0.6089	1.4109	114.2839299	114.3
F42	1.431	46.9069	2	0.6089	1.4109	115.3316669	115.3
F43	1.179	46.9069	2	0.6089	1.4109	95.02168784	95
F44	1.506	46.9069	2	0.6349	1.3965	125.2673721	125.3
F45	0.805	46.9069	1.8	0.6349	1.3965	60.26308837	60.3
F46	1.467	46.9069	2	0.6349	1.3965	122.0233963	122
F47	1.383	46.9069	2	0.6349	1.3965	115.0363716	115
F48	1.304	46.9069	2	0.6349	1.3965	108.4652412	108.5
F49	1.317	46.9069	2	0.6349	1.3965	109.5465664	109.5
F50	1.084	46.9069	2	0.6349	1.3965	90.16589067	90.2
Fvertical Transomes	2.032576119	46.9069	1.4	0.5284	1.3974	98.55873809	98.6
F Horizontal	2.819	46.9069	1.4	0.5284	1.3974	136.6920924	136.7