Thesis ARCI 591

Title: How could a work of architecture that is designed to evoke a Bilbao effect be designed sustainably and in accordance with Vitruvius's principle?

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Student: Akito Kamiya

Supervisor: Dr. Robin Skinner
Second supervisor: Dr. Geoff Thomas

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Due to the level of detail shown on my drawings printed at an A3 format, readers who want to examine these closely are advised to view the electronic version of this thesis.

The Acknowledgement

Appreciation could be indicated to the people who have positively influenced my thesis.
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The Abstract

The economy of a region could potentially be enhanced if numerous travelers were attracted by an outstanding work of architecture . The region enhanced economically could also lead to improving the economy of the nation. This thesis considers three primary aspects which are Vitruvius 's principle (or 'triad') regarding "form follows function", the sustainable design, and the Bilbao effect. Furthermore, Vitruvius's principle historically consists of "strength", "utility", and "beauty". In this thesis, the proposed building combines a museum, concert hall and accommodation to fulfill those three primary aspects.

However, many problems could currently be identified in architecture. For instance, there has been fuzzy understanding of what architecture means authentically. In addition, while some complex architecture exists in the world, there are many different approachesto design it.

The methodology of this thesis-project considers how a proposed site may achieve a "Bilbao effect" before undertaking further design exploration. Subsequently, the experimentation of architectural forms integrates the meanings into the forms . The forms created manually are then digitized by the software and the plug-in, Rhinoceros and Grasshopper. Subsequent to the finalization of the architectural form, the environmental and building - performance simulations are undertaken with other plug-ins, Honeybee and Ladybug. Besides the literature and precedent review, the sustainable strategies are specified, which are based on the result of the simulations. Then, the architectural form is customized with the necessary building components in order to develop a work of functional architecture in the developed design.

As a result, the architecture which could potentially invoke a Bilbao effect with the sustainability and Vitruvius 's principle is achieved. In the future, complex architecture which resembles projects such as Guggenheim Museum Bilbao will be able to be designed relatively easily, with integrating the sustainable aspect and achieving an authentic architectural style.

Contents

The research question

How could a work of architecture that is designed to evoke a Bilbao effect be designed sustainably and in accordance with Vitruvius's principle?

The research objective

The objective is to design a building that could invoke a Bilbao effect, contain sustainable design and follow Vitruvius's principle.

The scope of the research

To investigate the following three aspects

1. Designing architecture following Vitruvius's principle
2. Designing architecture that is sustainable
3. Designing a complex building that could attract tourists as Guggenheim Museum Bilbao does

The Literature and Precedent Review

This literature and precedents review includes precedents and projects which have been understood and explained by reading literature and analysis. This literature and precedents review considers three aspects which have been Vitruvius's principle and"form follows function", sustainable design and the Bilbao effect.

1. “Form follows function”

<u>Marcus Vitruvius Pollio’s architectural principle</u>

A Roman architect, Marcus Vitruvius Pollio established the principle of what architecture should be like, during his career in the 1st century BC. He defined that architecture should contain the three elements of its structures as the strength, its function as the utility, and its ornamentation with its meaning as the beauty (Lambert 7).

I. Prudential (Guaranty) Building

Louis Sullivan referred to Vitruvius’s definition of architecture in order to conceive his theory “form follows function” in 1896. As a result, he determined a true general solution to what a tall office-building should be like rather than a specific solution to it. As a result, Sullivan designed the Guaranty Building as a model solution, so that most floors of the office-building have been designed as a natural character of an office-building straightforwardly with the simple steel structures except its lightwell (Lambert 6) (fig.1). It could also be speculated that those floors fulfill the

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Fig.1. : The Guaranty Building, from The Guaranty Building: owned and operated by the Guaranty Building Company, Buffalo, NY. Chicago: Adler & Sullivan, 1896. Public domain. Sentem morit. Loculturs

requirement for utility. In addition, the building originally possessed its lightwell in the U shape floor plan, so that the occupants could obtain daylight (LaChiusa sec. 3; par. 4) (fig.2). Moreover, there was a functional space as a metaphorical attic at the top of the building, according to Frampton (56). The functional space was utilized for tanks and machines. Moreover, the metaphor was conceived about the accessories around the circular windows, and it has been conveyed that the accessories which “completes itself and makes its grand turn ascending and descending” symbolizes the machinery of the Guaranty Building as its function (56). The circular decorations symbolize mechanical cylinders, gears, wheels and other circular compo-

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Fig.2. : The Guaranty Building’s typical floor plan indicating the lightwell oriented to the south, *Buffalo as an Architectural Museum* (Dennis Galucki, Sep 2013), https://buffaloah.com/a/church/28/02ext/.

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Fig.3. Blair Kamin, The Guaranty Building’s the metaphorical circular windows, *Chicago Tribune,* (Chicago Tribune, Jun 2016), https://www.chicagotribune.com/news/ct-xpm-2013-09-01-ct-met-kamin-sullivan-buffalo-0901-20130902-story.html. Copyright 2021 by Chicago Tribune.

nents (fig.3).
Therefore, the ornamentation with its meaning could be identified on the attic of the building. To sum up, the building possesses the three features of strength, utility, and beauty. Thus, the building designed by Louis Sullivan follows his slogan “form follows function” which was developed from the principle defied by Marcus Vitruvius Pollio.

II. Bauhaus in Dessau

It can be argued that the Bauhaus also followed the three elements of Vitruvius’s principle. Walter Gropius’s design for the Bauhaus building in Dessau was constructed of steel and concrete. The building consists of different sections that were used for different purposes such as laboratories, student housing and administration offices (fig.4). Notably, the bridge that was physically constructed at the central part of the building was used as administration offices which were functionally the central part of the school-organization. The bridge might appear valuable aesthetically since it has been interesting to that the offices-part floats above a road. Furthermore, according to Lambert, it “can be argued that functional form was as symbolic and associative as form at any period” (28). This has meant that a functional building

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Fig.4. A floor plan of Bauhaus in Dessau, *Buffalo as an Architectural Museum* (Dennis Galucki, Sep 2013), https://artchist.blogspot.com/2015/02/edificio-de-la-bauhaus-walter-gropius.html
Artchist

could also represent its notion and remind people of it. Therefore, the bridge of Bauhaus in Dessau reminds us of the school-concept (fig.5). The Dessau Bauhaus bridged its near road in order to symbolize the school’s progressive attitude as its beauty with its meaning (fig.6). Thus, the Dessau Bauhaus fulfills “form follows function” and the three attributes defined by Vitruvius, according to Lambert (28).

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Fig.5. The bridge above the road,
An Architectural Pilgrimage, (Christopher Johnson, Sep, 2013), http://glasspilgrim.blogspot.com/2013/09/bauhausgebaude-dessau.html.

This content has been redacted.

Fig.6 An aerial view of Bauhaus in Dessau, *chloé roubert,* (Chloé Roubert), http://www.chloeroubert.com/new-page.

III. The Solomon R. Guggenheim Museum

The Solomon R. Guggenheim Museum designed by Frank Lloyd Wright who worked under Louis Sullivan appears to contain the influence of “form follows function” and Marcus Vitruvius Pollio’s definition. The design began in 1943 although the building was completed in 1959 (Levine 320, 347). The museum’s first director of Solomon R. Guggenheim Museum, Hilla Rebay requested that the museum would be a temple of art or a spiritual space of art, because she was an ambitious collector of non-objective art. Furthermore, Rebay thought that a spiral form could symbolize a dynamic sense of growth, and the architect, Frank Lloyd Wright agreed with her thought (Levine 353). Thus, Wright referred to a temple, Tower of Babel (fig.7). However, Wright thought that the Tower of Babel never reached its ultimate goal, considering its geometry. Thus, Wright thought that the form of the tower would be pessimistic, but that if the form was inverted, the inverted form could be optimistic (Levine 354). Moreover, the designed form of the museum was related to the non-objective art of Kandinsky and Bauer, although the form was con-

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Fig. 7. Pieter Bruegel the Elder. "Tower of Babel",1563 Neil Levine, *The Architecture of Frank Lloyd Wright,* (Princeton University Press, 1996), p.352.

structed of concrete and steel (McCarter 280) (Pfeiffer and Larkin 144). Thus, the shape which has shown positive dynamism in appearance could also indicate its meaning as well as the director's ambition and the architect's response (fig.8).

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Fig.8 Laurian Ghinitoiu, "Gallery: Frank Lloyd Wright's Solomon R. Guggenheim Museum", *ArchDaily,* (David Basulto and David Assael, 2008), https://www.archdaily.com/788914/gallery-frank-lloyd-wrights-solomon-r-guggenheim-museum-by-laurian-ghinitoi-u/57552501e58eceff0900065d-gallery-frank-lloyd-wrights-solomon-r-guggenheim-museum-by-laurian-ghinitoiu-photo. Copyright by Laurian Ghinitoiu.

Furthermore, the Solomon R. Guggenheim Museum contains a functional circulation system. When people walk in an ordinary museum, they will frequently have to repeat their steps entering a same exhibition space. This is because one floor of the normal museum is not one simple continuous space from the entry to the exit. Thus, after they have completed viewing all the artworks, the people have to retrace their routes, viewing the same artworks due to the circulation system. However, Wright preferred efficiency without these repetitions in his new museum. Therefore, a continuous spiral route was embodied into the new museum (fig.9).

Consequently, when people visit his new museum,

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Fig.9 Spiral circulation system,*Guggenheim,* (Solomon R Guggenheim Museum), https://www.guggenheim.org/teaching-materials/the-architecture-of-the-solomon-r-guggenheim-museum/form-follows-function, Copyright 2021 by Solomon R Guggenheim Foundation.

they will go up to the top floor by lift, and they will just need to descend the ramp to enjoy the non-objective artworks (Wright and Pfeiffer 111). Then, the visitors will be able to complete their journeys straightforwardly from the top to the bottom without an unnecessary climb.

Secondly, natural daylight could be obtained through each glazed part above displaying the paintings and the atrium of the museum, and its artificial lights could supplement its lighting system (Etlin 39) (Pfeiffer, vol. 5; p. 246) (fig.10). The natural and artificial lighting systems could be regulated flexibly as one of its functions.

Finally, although the interior space of the Solomon

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Fig.10. A section of Solomon R. Guggenheim Museum, *ArchDaily,* (Princeton Architectural Press, 2016), https://www.archdaily.com/793424/studying-the-manual-of-section-architectures-most-intriguing-drawing/57b42bb5e58ece8ae3000196-studying-the-manual-of-section-architectures-most-intriguing-drawing-photo?next_project=no.

R. Guggenheim Museum may prompt a strange feeling, the space was designed to mirror the imaginary worlds of the non-objective art. The "relaxing influence" and "healing embrace" of non-objective art would be provided in the exhibition space, as requested by the first director, Rebay (Levine 356). Thus, the unusual atmosphere would fulfill the director's intention and the desired meaning (fig.11).

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Fig. 11Georges Mathieu's works, *W Art Foundation,* (W Art Foundation, 2019), http://wart-foundation.com/exhibitions.aspx.

In conclusion, although Wright reinterpreted "form follows function" as "form and function are as one", he appeared to have followed Sullivan's teaching (Jones 17). Consequently, the Solomon R. Guggenheim Museum has a reinforced concrete structure, a functional space, and grace drawn from non-objective art as the three qualities defined by Vitruvius.

IV. Vitra Fire Station

However, buildings sometimes do not meet Vitruvius's definition. Following a 1981 fire Zaha Hadid designed the Vitra Fire Station. She was interested that the railway and roads near the project site were not parallel to each other (fig.12). This prompted her deconstructivist design. Through sketching she developed a design that symbolized "movement" of the building which was ready for action at any moment (fig.13). It incorporated beauty with the meaning of a fire station. However, it was closed due a limited need for a fire service (Vitra; par. 1). Thus, without its functional need, the fire station has not followed "form follows function" or Vitruvius's principle.

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Fig. 12 An aerial view of Vitra Fire Station with the inspiration of the site, *Google Maps,* (Google, 2021), https://www.google.com/maps/place/Vitra+Fire+Station+by+Zaha+Hadid/@47.5988122,7.6136085,377a,35y,356.48h,22.6t/data=!3m1!1e3!4m5!3m4!1s0x4791ba3d51416b0d:0xd7cb3fef18f5a581!8m2!3d47.6003832!4d7.6147605. Copyright 2021 by Google, Flotron/Jermann, GeoBasis-DK/BKG.

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Fig.13. The painting of Vitra Fire Station Indicating the Movement, *Zaha Hadid Architects,* (Zaha Hadid Foundaion, 1993), https://www.zaha-hadid.com/architecture/vitra-fire-station-2/.

2. Sustainable design

Net Zero energy buildings and low energy consumption buildings

This section includes precedents of sustainable design and other sustainable features, since the programs of the proposed design for this thesis would include accommodation, a museum and a concert hall which is introduced in the chapter "The Program". The precedents have been selected in order to justify the proposed sustainable design on the proposed site which is discussed in the chapter of the proposed site.

I. ENERPOS

Types of climate could affect whether or not a building could become a net zero energy building. The University of La Reunion's ENERPOS is a net zero energy building which integrates cross ventilation systems, HVAC systems, artificial lighting systems and other sustainable design-features into its design (fig.14). As a result, it provides a model for sustainable design. Furthermore, its photovoltaic panels could generate more amount of electricity than the amount consumed by the occupants (Lenoir 52). Moreover, the university is situated on Reunion Island with a tropical climate. Due to the climate, heating has not been required for the thermal comfort even in winter so that this feature has been a crucial factor in the building being a net zero energy building (Lenoir et al. 11).

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Fig. 14. Jérôme Balleydier, The University of La Reunion's ENERPOS, *High Performing Buildings,* (Aurélie Lenoir, Jul 2012), https://www.hpbmagazine.org/university-of-la-reunions-enerpos-saint-pierre-la-reunion-france/. Copyright 2021 by ASHRAE.org.

II. A residential house designed by Glamuzina Architects

Glamuzina Architects have designed a sustainable low energy-consumption residential house adjacent to Matiatia Wharf on Waiheke island Auckland (appendix A). This house, which is adjacent to the proposed site for this thesis, was investigated with its owner's generous permission during a site-visit on 5th September 2020. Waiheke island has a subtropical climate, so that if a house is designed well, a low energy-consumption house can be built on the island. When I visited the house on the Waiheke Island, I interviewed the owner. The house has had an overhang which was sized appropriately, and it has protected the internal spaces against the sunshine that is sent from a higher position of the sun in summer. On the other hand, the overhang has been able to let warm sunshine which is sent from a lower position of the sun, in the house in winter. The sun rises at a different position between summer and winter, so that the architect took the advantage of the solar movement. Due to its concrete floor slab, and its linear-form with a longer face oriented to north, the house is warm during winter. This is because the concrete floor slab could absorb the solar heat through its large glazed walls and radiate the heat to its internal spaces. The dwelling has also had a pool right next to the house, and it could help cooling the house in summer through an evaporative cooling effect. This has meant that water of the pool could evaporate so that the air temperatures will drop in summer. The pool could drain in winter. Due to the void of the house, the entire house has also been easy to ventilate by opening the windows of each room in summer (appendixes B, C & D). In fact, the owner has commented that they would hardly use mechanical heating and cooling systems such as heat pumps or air conditioners through their lives (Alexander). Generally, residential houses have frequently been equipped with rainwater tanks and some of them have been hidden underground on Waiheke island. Rainwater is harvested and some greywater is reused. In fact, they have suffered water scarcity really few times. Furthermore, the owner investigated electricity generation by solar panel, but the maintenance cost made it unprofitable. Therefore, electricity has primarily been purchased from Auckland city. The owner's only concern is electricity which is used for using cooking electrical appliances, a washing machine, a computer and other electrical appliances. A low energy consumption building could actually be erected on Waiheke island, following this precedent.

III. Solarsiedlung am Schlierberg

A net zero energy building of accommodation, Solarsiedlung am Schlierberg, in Freiburg Germany has been analyzed. This has been because one of the programs of the proposed building would be accommodation. Solarsiedlung am Schlierberg is a group of residential buildings which accommodate approximately 157 people and those buildings have been net zero energy buildings (fig.15). The buildings have enlarged roofs that are oriented to the south in North hemisphere, and they have been equipped with grid-connected PV whose total amount has been 445 kWp (Hagemann 8). The installed on- grid system allows export of electricity generated by its PVs to the

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Fig. 15. Solarsiedlung am Schlierberg, *Gardens of My Life,* (Daniela Prieto, Jan 2012), http://gardensofmylife.blogspot.com/2012/01/schlierberg-bairro-solar-em-freiburg.html. Copyright 2011 by Daniela Prieto.

grid when the building does not need the electricity, whereas electricity can be imported to the building from the grid when the building needs the electricity. However, this on-grid system has a disadvantage. When the building suffers a blackout, the PVs will not be able to operate due to safety. However, there is a hybrid system where PVs are connected to grids and can also operate independently during a blackout. Thus, Solarsiedlung am Schlierberg, Freiburg and the hybrid solar system could be suitable precedents for the proposed building which would have accommodation.

IV. Alpine Refuge – Schiestlhaus

A net zero energy building could be erected on a site that is an isolated site from cities or towns. Accommodation is one of the functions of the proposed building for this thesis. Alpine Refuge – Schiestlhaus could be considered as a medium sized accommodation which has possessed its kitchen for 70 occupants' living and as a typical example of buildings in "island locations" which are separate from regions where people inhabit (Austrian Federal Ministry for Transport, Innovation and Technology 2) (fig.16).

Solar energy and rapeseed oil is utilized to generate the power used in the refuge. The generated energy is used economically with an accumulator which has been installed in the refuge. For instance, if energy is used for two purposes such as a kitchen electrical appliance and a vacuum cleaner, the performance of the electrical appliances could be degraded or the electricity could be wasted. If the capacity of the accumulator falls below 50% by using more than two electrical appliances, the electrical appliance mainly used will be prioritized. This system has saved the electrical consumption of the refuge, and once the capacity rises up to 70% again, the use of the other secondary electrical appliances will be resumed (4).

However, the way to obtain clean water has been another key feature of this refuge. Water has been crucial on the site, so that rainwater has been collected and purified for the occupants' use. In the system, the collected rainwater stored in the underground cistern is sent through coarse filter into a drinking water tank. The water passes through a UV sterilization unit which hinder the water from being polluted by bacteria, germs, and fungi. This has been the system by which the occupants could consume rain water for their living in the refuge. Furthermore, "a food safe stainless steel roof" has been used in order to collect water to be used in the kitchen, since the requirement of the quality of the water has been strict. All the waste water has been cleansed by a UV sterilization unit again, and thrown away. Unfortunately, only dry toilets have been used in the refuge in order to save the water. Other necessary items could be flown in (Austrian Federal Ministry for Transport, Innovation and Technology 6). Therefore, a net zero energy building could be achievable on a site that is isolated from cities or towns as long as the climate is suitable.

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Fig. 16. Harald Weissenbök, Alpine Refuge – Schiestlhaus, *Wanderungen und Bergtouren,* (Harald Weissenbök, Aug 2014) https://www.weissenboek.com/2014/08/2-tagestour-hochschwab/. Copyright 2014 by Harald Weissenbök.

V. CCHP (combined cooling heating and power) system

A large building such as the building proposed for this thesis could have a CCHP (combined cooling heating and power) system. This system combines the three different systems which supply electricity, cooling and heating. The CCHP system will be able to save energy, compared to a conventional separate supply system of those three (Ming et al. 406).

The CCHP system contains five elements which are gas energy, a waste heat boiler, compression refrigerating machine, a gas boiler and an absorption chiller (fig.17). In a CCHP system, electricity demand of a building could be satisfied by natural gas energy or the grid which are both purchased. However, a compression refrigerating machine could produce the cooling load of the building and an absorption chiller could recycle waste heat of the gas energy in order to also provide the cooling load. Furthermore, the gas boiler could produce the heating load and the waste heat boiler could recycle waste heat of the gas energy in order to also yield the heating load. As a result, the three types of demands which are of the electricity, the cooling and the heating could be fulfilled efficiently. On the other hand, the conventional separate supply system only possesses two of the five elements needed in order to operate without recycling the waste of heat of the gas energy, compared to the five elements of the CCHP system (fig.18) (Ming et al. 404).

However, using the CCHP system has been more economic than the conventional separate supply system conditionally. Due to the large installation cost of the CCHP system, it is only when the ratio of the price of electricity to the price of gas is greater than 0.11 that using the CCHP system would be beneficial. (Ming et al. 406) For instance, electricity costs 167.74 cents per day in Auckland in the company of ENERGYONLINE Brilliantly Simple, whereas natural gas costs 100 cents per day (ENERGYONLINE Brilliantly Simple "Plans & Pricing"; fig.1). In this case, the ratio between electricity and gas is larger than 0.11, so that a CCHP system installed in a large building in Auckland would operate economically. If such a ratio is below 0.11, the conventional separate supply system would be more economical.

Moreover, solar energy technologies with solar panels and solar thermal collectors could be integrated into the CCHP system. Such solar devices which would generate electricity could heat air or water and could also be utilized for cooling with an absorption chiller that could decrease the amount of used fossil fuel; such as natural gas. On the other hand, the CCHP system could improve the efficiency of providing electricity, heating and cooling systems. As explained, the CCHP system has utilized natural gas, so that if the solar energy technologies and the CCHP system are combined as one and used together in a building, the sustainable performance of the building could be improved further (Yang and Zhai 647). Thus, the strategy of combining the CCHP System and the solar panels for the proposal design would be achievable.

The conclusion of the sustainable aspect

One solution might not be able to solely provide a net zero energy building or a low energy consumption building, but multiple sustainable features such as insulated windows, LED lighting with occupancy sensors and dimming besides the sustainable design features which have already been introduced would be able to contribute slightly (Bakshi and Donn 41). Therefore, the proposed design will integrate such multiple types of sustainable design features into itself.

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Fig. 17. Zeng Ming, et al., "The Mechanism of the CCHP System" *Economy benefit comparison of CCHP system and conventional separate supply system,* (IEEE, 2015), p. 4; *IEEE*, https://ieeexplore.ieee.org/document/7473320. Copyright 2015 by IEEE.

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Fig. 18. Zeng Ming, et al., "The Mechanism of the conventional Separate Supply System" *Economy benefit comparison of CCHP system and conventional separate supply system,* (IEEE, 2015), p. 4; *IEEE*, https://ieeexplore.ieee.org/document/7473320. Copyright 2015 by IEEE.

3. The Bilbao effect

I. Guggenheim Museum Bilbao

Since its construction in 1997 the Guggenheim Museum Bilbao has created a dramatic economic improvement in its region in Bilbao, Spain. Built at a cost of $166 million, its unique form has attracted numerous tourists. It has recovered the amount of the civic investment of the project within 7 years and the total investment in ten years (Lindsay 37) (Franklin 80). Moreover, the museum has dramatically enhanced the economy of the city further. This phenomenon has been termed "the Bilbao effect".

There have been multiple reasons why the economy improved, though it has superficially seemed that the phenomenon was evoked by the eccentric appearance of the building. Previously the area attracted approximately 1 million people annually. However, about the time the museum opened, the Basque terrorist threat reduced, so that increasing numbers started visiting the country (Gomez and Gonzalez 899) (fig.19). It may be speculated that museum's visitor numbers have been impacted by by recent periodic ceasefires and attacks (Plaza 386). Moreover, tourist amenities such as hotels have boosted the economic effect (Franklin 88). As a result, the museum's average annual visitor numbers have been 1,039,500.8 people from 1988 to 2019 except 2008 and 2009 (fig.20, 21). The number of the tourists increased by 39% after the museum opened. The table shows the numbers of 83,898 and 116,678 for incoming travelers before and after the opening of the museum, respectively (fig.22). Therefore, the Bilbao effect has been invoked by such multiple aspects including the safety of the region, the facilities for tourism and the interesting architectural form.

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Fig. 19. "Guggenheim Museum Bibao," *Phaidon,* (Phaidon, 2020), https://www.phaidon.com/agenda/architecture/articles/2012/november/23/buildings-that-changed-the-world-the-guggenheim-muse. Copyright 2014 by Phaidon.

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Fig. 20. Visitors to the Guggenheim Museum Bilbao 1997-2007, *"Museums for urban regeneration? Exploring conditions for their effectiveness,"*(Silke N. Haarich, Jan 2009), p.16, ***Research Gate***, https://www.researchgate.net/publication/286751702_Museums_for_urban_regeneration_Exploring_conditions_for_their_effectiveness. Copyright 2009 by Beatriz Plaza and Silke N. Haarich.

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Fig. 21. The Number of Visitors to the Guggenheim Museum Bilbao from 2010 to 2019. *Statista,* (Statista, Jan 2020), https://www.statista.com/statistics/781335/annual-number-of-visitors-in-the-museum-guggenheim-in-bilbao/. Copyright 2020 by Statista.

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Fig. 22. Calculating the Guggenheim Museum Bilbao (GMB) Effect and the Truce Effect *A Note on "Panorama of the Basque Country and its Competence for Self-government": Terrorism and the Guggenheim Museum Bilbao Effect,* (Taylor & Francis Group, 2002), p.385; *European Planning Studies,* https://www.tandfonline.com/doi/pdf/10.1080/09654310220121095?needAccess=true. Copyright 2002 by Taylor & Francis Ltd.

Using software is essential in the design of a complex building. In the project of the museum, Frank Gehry utilized paper in order to create conceptual forms of the museum at Bilbao. A 3d scanner was utilized in order to digitize the complex model, although he had wanted to avoid using computer at the beginning of the project (Center for Design Informatics 17) (Bruggen 136). The conceptual paper model was 3D scanned so that a digital model which had the same geometry as that of the conceptual model.

The computer was also utilized to develop the structural scheme of the museum. The images of the structures show the curvy steel structures which form the actual shape of the museum and the brace of each bay (fig.23). The museum has been supported by load bearing walls and load bearing ceilings (Pagnotta sec. 6). The load bearing steel columns have been spaced three meters apart in the load bearing walls. Furthermore, the software, Catia was utilized for calculating the sizes of the structures and determining the positions and the number of the braces (Center for Design Informatics 10). In this thesis-project, the size of the steel column used for the Guggenheim Museum Bilbao was measured from published floor plans which indicated that the size could be from 350mm x 350mm to 400mm x 400mm (Foster 17).

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Fig. 23. Aitor Ortiz, The Load Baring Walls and the Ceiling Structures of Guggenheim Museum Bilbao, *Google Arts & Culture,* [Google Arts & Culture], https://artsandculture.google.com/asset/_/BQGwZRbUzwEVcg. Copyright 1994-97 by Aitor Ortiz.

The Guggenheim Museum Bilbao still has ten orthogonal traditional exhibition rooms, contrary to the building's curvy form. The positions of the orthogonal rooms may be identified since such zones can be seen as rectangular forms from the outside (Bruggen 122). It could be speculated that the conventional boxy spaces are still demanded for exhibitions. This might be because ordinary rectangular layouts allow exhibition space to be used more efficiently since paintings and drawings could be fixed on flat walls straightforwardly so that the visitors could comfortably appreciate the artworks. In fact, a wall of the museum was unable to display a painting by Francis Bacon as the artwork would appear awkward near the distracting wall and ceiling, as the image indicates (fig.24).

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Fig. 24. Francis Bacon's painting Displayed in Solomon R. Guggenheim Museum, *Corriere Della Sera,* (Corriere della Sera, 2019), https://www.corriere.it/19_maggio_23/guggenheim-artistic-license-new-curators-mastepieces-exhibition-1644a662-7d43-11e9-bf38-280379b6a560.shtml?refresh_ce-cp. Copyright 2019 by RIPRODUZIONE RISERVATA.

The Guggenheim Museum Bilbao contains lightwells in order to provide an amount of natural daylight without lowering the value of the architectural expression or damaging the artworks. The architect cared was aware that too much daylight could damage the artworks when he designed the glazed walls and lightwells. Thus, the sizes of skylights are minimized and the lightwells are not distracting in the exterior view of the silver shell of the museum (fig.25). Therefore, it could be considered that the lightwells have been designed wisely.

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Fig. 25. "Guggenheim in Bilbao - "not dry and dull","
Bernard Smith, (Bernard Smith, Nov. 2019), http://www.bernardsmith.name/visiting_spain/guggenheim/.Copyright 2020 by Bernard Smith.

II. Denver Art Museum's Hamilton Building

Some architects have been attempting to invoke a similar phenomenon to the Bilbao effect by designing an eccentric architecture, though it has been difficult to repeat the phenomenon. In 2006, Denver Art Museum's Hamilton Building was constructed as an extension to Denver Art Museum in order to invoke a similar effect to the Bilbao effect, in Denver, the United States (fig.26). The same number of the visitors to Guggenheim Museum Bilbao was expected to visit the new Denver Art Museum, but the new museum did not achieve the expectation during its first four years (Lindsay 71). Furthermore, the number of the visitors did not change dramatically before and after 2006. This analysis indicates that the extension of Denver Art Museum failed to invoke the effect. Furthermore, the Quadracci Pavilion designed by Santiago Calatrava as an addition to Milwaukee Art and other projects where architects have attempted to invoke the Bilbao effect have failed (Franklin 80). Thus, it has not been straightforward to design to create a Bilbao effect.

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Fig. 26. Bitter Bredt,"Denver Art Museum / Studio Libeskind," *Archdaily (*ArchDaily,2021), https://www.archdaily.com/80309/denver-art-museum-daniel-libeskind. Copyright 2008-2021 by ArchDaily.

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Fig.27."Night View of the Gherkin in London," *Ask Ideas,(*Askideas.com, Dec 2016), https://www.askideas.com/35-adorable-night-view-pictures-of-the-gherkin-in-london/, Copyright 2019 by Askideas.com.

III. 30 St Mary Axe (The Gherkin)

A complex or an unusual architectural design could risk its owner's finance. Since such architecture has been expensive to build, the owners frequently consider the cost of erecting such a new building as an investment for creating more amount of future income by the business held in the building. However, if the business does not succeed, the owner could suffer a financial problem. The Gherkin was built as offices of a reinsurance company, Swiss Re in 2003 (fig.27). The building was described "as a successful brand maker and a speculative real estate venture" (Kaika 978). However, it was also commented that the origin of the Swiss Re had not matched the reason of the existence of the building. As a result, Swiss Re sold the Gherkin at much higher price than the first cost three years after the completion of the building. Furthermore, the successive owner of the Gherkin underwent a bankruptcy in 2013 so as to decide to sell the building (For sale: Stirling Prize-winning Gherkin). Therefore, the Gherkin has been sold twice since it was completed in 2003. Thus, it could be questioned if an owner of a building would normally sell their building if their business is conducted well in it. Hence, it could be speculated that the architecture had caused the failures of the businesses, so that selling the building at an unusual high price and the bankruptcy happened. Thus, an unusual architectural design such as the design of the Gherkin could potentially cause an opposite effect of Bilbao effect, which is a negative economic effect.

The Program

The program of the proposed design has been a combination of museum, concert hall and accommodation with sustainability. The study has shown that museums and art galleries could attract plenty of international visitors as a primary tourism factor. Performing arts such as music, and sightseeing of famous natural sites or architecture could also attract tourists as a primary tourism factor, according to the study (Kolb 10-11). Accommodation has been a secondary tourism factor, since tourists could gather for hostels naturally, according to the same study. Thus, the proposed program of my design has been a combination of museum, music center and accommodation in a work of architecture surrounded by nature of Waiheke island in order to invoke a Bilbao effect, but with minimal impact the natural environment.

The Proposed Site and the Site Analysis

1. The tourist attraction

Waiheke island, Auckland has been chosen as the proposed site, carefully. This is because the original Bilbao effect was evoked by the multiple attributes of the site, and because Waiheke island has seemed to have features which match some of the attributes. Firstly, as the bar charts indicate, Auckland has attracted the largest number of visitors to New Zealand, and 1.2 million people of the visitors to Auckland normally visit the region for holiday annually (fig.28, 29). On the other hand, the number of the visitors to Christchurch, Wellington, Queenstown and other places of New Zealand have been much smaller than the number of the visitors to Auckland. In addition, Auckland where more than half of its population came from foreign countries could be the most welcoming spot to international visitors in New Zealand. However, other cities such as Christchurch could have problems with the foreigners' safety due to the places' being exclusive against outsiders. Furthermore, Queenstown has suffered a problem of its capacity for tourism, compared to Auckland ("Queenstown, Wanaka locals say area 'can't keep up' with increasing tourist numbers."; par. 1). Thus, Auckland would be the most suitable region to invoke a Bilbao effect in New Zealand.

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Fig. 28. "International Visitor Arrivals: Auckland vs. New Zealand airports (2010-2019)", *A Auckland*, (Auckland Unlimited, 2020), https://www.aucklandnz.com/. Copyright 2020 by Auckland Unlimited.

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Fig. 29. "Annual Auckland International Airport Visitors by Purpose (2010-2019)", *A Auckland*, (Auckland Unlimited, 2020), https://www.aucklandnz.com/. Copyright 2020 by Auckland Unlimited.

Furthermore, Waiheke island would be attractive enough to invoke a similar effect to the Bilbao effect. This is because Waiheke island has the following attributes. Firstly, one million people normally visit Waiheke island annually for popular visits to wineries and for escaping to the nature from the society in which they normally live (Waiheke Local Board 7). Secondly, there has been a certain common ferry-route thorough which most of the one million visitors go to the island. Moreover, Waiheke island has contained its attractive nature which could be integrated into new architectural design. However, it could actually be questioned whether or not Waiheke island which has already been a popular island is a suitable site for a Bilbao effect. Prior to Guggenheim Museum Bilbao opening, approximately 1 million people visited the Basque country annually. This increased by 39 % following the opening the museum. Therefore, Waiheke island which can already attract 1 million people annually, could also be considered an appropriate and similar site to invoke a Bilbao effect, also. Furthermore, the payback period of a large project could tend to be long, since the entire cost of such a project would become high. However, such a duration could be shortened if a popular site is chosen. This means that if a really unpopular site is chosen and an expensive building is constructed on the site, the businesses to be held in the area could not succeed. As a result, the region or the owner of the building could suffer a financial problem which could be a similar case to the issue of the Gherkin. The proposed site has been selected as a flat field of Matiatia beach front because an imposing architecture will be able to attract the visitors approaching via ferries (fig.30, 31). As a result, a Bilbao effect could be likely to occur. Overall, such a site of Waiheke island has been selected as a proposed site for those reasons.

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Fig. 30. The proposed site indicated in the red circle and the entire Waiheke island, *Google Maps,* (Google, 2021), https://www.google.com/maps/place/Waiheke+Island/@-36.7930189,175.0220256,17028m/data=!3m2!1e3!4b1!4m5!3m4!1s0x6d72c882cf34cebd:0xcb6ce79667d0cc2c!8m2!3d-36.8000487!4d175.1009721. Copyright 2021 by TerraMetrics)

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Fig. 31. The proposed site specifically indicated in the red box, *Waiheke Escapes Holiday Accommodation,* (Waiheke Escapes, 2020), https://www.waihekeescapes.co.nz/. Copyright 2020 by Waiheke Escapes.

2. <u>The meanings of Waiheke island</u>

The name of Waiheke island has had its meanings. Firstly, the ancient Maori name for Waiheke was Te Motu-arai-roa, "the long sheltering island". It originally meant that the island sheltered canoe traffic passing through the Tamaki Strait which is located between Auckland isthmus and Waiheke island, from bad weather which came from the north (fig.32)("Waiheke Island: An Outline of the Early History up to the Arrival of the Europeans." ; par. 2). Furthermore, the island has had another meaning. When European visitors enter the island for the first time, the name was altered to "Motu-Wai-Heke" which means "island of trickling waters, or descending waters". The European named the island because of the island's natural world which was the large amount of leaf litter which soaked up the enormous amount of rainwater to be gradually freed up as dribbling narrow rivers of purified water (fig.33) (par. 16). Those two meanings are to be utilized for "beauty" of Marcus Vitruvius Pollio's principle during the design process of the proposed design.

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Fig. 32. Waiheke Island and Tamaki Strait, *NZ Topo Map,* (Gavin Harriss, Oct 2020), https://www.topomap.co.nz/NZTopoMap?v=2&ll=-36.838677,174.885727&z=11. Copyright 2010 - 2021 by Gavin Harriss

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Fig. 33. An existing creek on Waiheke Island, Indicating Its Fluidity and Its Complexity, *Picuki* (Picuki, 2019), https://www.picuki.com/tag/whakanewha, Copyright 2019 by The Photographer.

3. The atmosphere

The proposed architecture is to change the atmosphere of Matiatia bay positively. A site visit was conducted during the project. On 4 September 2020, the ferry that was used to access Waiheke island for this project arrived at the island. The atmosphere of the proposed site adjacent to Matiatia wharf was outmoded while better nature and beaches could be identified on the island. It was considered that such a site would be transformed dramatically into an attractive new touring venue.

4. The reserved vegetation

The proposed site has vegetation on the adjacent hill and the vegetation that is to be preserved (fig.31). This vegetation did not exist in 1993, when the hill was then covered with grass. However, the grass was damaged and abolished because of the solar effect and animals that ate the grass. The grass was replaced with trees artificially (The Report of the Board Existing in the Hillside; par. 1). It appears that the green of the land could revive in spite of some degrees of destruction of the nature. The new growing trees would absorb carbon dioxide and generate oxygen, which would be harmless to the Waiheke island. Therefore, destroying such growing trees is to be minimized for the proposed design.

5. The Climate

Waiheke island has turned out relatively easy for the inhabitants to live in due to its climate. Moreover, according to the website, the temperatures vary from 20 °C to 25 °C during the summer, whereas the average of the highest temperatures during the coldest winter has been 14°C (World Weather & Climate Information; par. 2). Another source has shown that the climate of Waiheke island is a slightly warmer and drier one compared to the one of Auckland isthmus ("Climate."; par. 1).

6. The psychrometric chart

The plug-ins Honeybee and Ladybug can produce the psychrometric chart. Using the chart, it is checked if the crossing point of the temperature and the humidity of any time in a specific place exists within the thicker dark red zone which represents the comfortable zone. The place of the chart has been Auckland Airport, but it has been assumed that the similar outcome will be produced for the proposed site. The larger the red lines-boundary is, the more frequently the place can potentially become comfortable. Thus, the boundary should be enlarged by adding thermal strategies. For instance, if evaporative cooling strategy is applied, the boundary will be extended rightwards (fig. 34).

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Fig.34. The Psychrometric Chart of Auckland Airport Produced by Plug-in Ladybug, Indicating the Boundary Extended Rightwards by the Evaporative Cooling Effect.

In this simulation, the simple model which was smaller and less complex than the proposed design was utilized, since the actual proposed design would be too large and too complex to run the Honeybee and Ladybug-simulation with. The plug-ins Honeybee and Ladybug are still under development, so that the plug-ins are sometimes unable to produce the energy or environmental simulation-results properly. However, the simple model which measured approximately 10 m long, 6 m wide and 5 m high as a sort of a triangular prism was created as twisting, pointing and concave, so that the simple model could still demonstrate the energy simulation of a complex building (fig. 35). The surfaces of the simple model were curved, but such models normally need to be remodeled with planar surfaces, rather than with curved surfaces, otherwise the Honeybee Ladybug simulation will not be able to operate successfully. The concave surfaces were modeled with planar diamond-shape surfaces by Kangaroo and Lunchbox plug-ins. As a result, the really similar geometry of the simple model was created without any round surfaces, but with only flat surfaces (fig. 36). Then, the Honeybee Ladybug simulation was run with the similar model and the psychrometric chart was produced for the simple model(fig. 37).

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Fig.35. Akito Kamiya, *The Simple Model*, 2020, Wellington.

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Fig.36. Akito Kamiya, *The Simple Model Created with Only Flat Surfaces*, 2020, Wellington.

Specifically, more than 97% of the thermal comfort of the simple model could be achieved by utilizing the psychrometric chart. The occupant's behavior and the how much they wear clothes could be specified. For instance, the occupants normally stand rather than walk in the simple building, and such a behavior affects their thermal comfort. Moreover, numbers could be assigned to the levels of the clothes, so that shorts and a t shirt is described as 0.5, a 3 piece suit is described as 1, and a thick winter jacket is described as from 2 to 4 in the used script. Therefore, if the clothes level is 1. 5, the occupant's clothes will be warmer than a 3 piece suit but less warm than a thick winter jacket. Then, the thermal strategies of the psychrometric chart were chosen as "evaporative cooling" and "passive solar heating". Additionally, "capture internal heat gain" which is the heat obtained from artificial lights and other artificial devices indirectly, and that could somehow contribute the internal heating. As a result, the most of the colorful region which indicates temperatures and humidity of every hour through a year was covered by the polygonal thick red boundaries, and 97.488584 % of the thermal comfort of the simple building could be realized (fig. 37,38). The rest of the thermal comfort could be provided by using a heat pumps in cold winter or cross ventilation by opening the windows and the doors in hot summer as actually conducted on Waiheke island. "Evaporative cooling" would be effective because the proposed site is near the sea, the thermal comfort will dramatically be improved in a hot summer. To sum up, 97% of the thermal comfort of the simple building at Auckland Airport could be produced by manipulating the psy-

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Fig.37. Akito Kamiya, The *Psychrometric Chart for the Simple Model Indicating the Thicker Red Boundaries for Capture Internal Heat Gain, Passive Solar Heating, No Additional Strategy and Evaporative Cooling from the Left to the Right*, 2020, Wellington..

chrometric chart. Likewise, the proposed building on Waiheke island erected as a low energy consumption building would be possible in the same way, which would be supplemented by the precedent sustainable strategies.

7. The trend

The proposed programs could suit the trend of Waiheke island. This is because art activities and sustainability could easily be identified on Waiheke island in the amenities such as galleries and restaurants. Thus, the project of designing a sustainable large museum and concert hall could be welcomed by the local people.

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Fig.38. Akito Kamiya, *The Script of the Psychrometric Chart for the Simple Model, Indicating the Level of the Clothes, the Thermal Strategies and the Outcome of the Thermal Comfort in Percentage*, 2020, Wellington.

The Material

Timber was selected as the primary material for sustainability for this project. This is because it has been discovered which material is the most harmless to the environment, by using LCAQuick supplied by Branz. LCAQuick uses an excel sheet in which the types of materials of a building and the quantity of the materials are entered, so that the amount of greenhouse gas released during any phases of the life cycle of the building can be determined and that it can also be determined how much greenhouse gas is absorbed into the used material from the atmosphere. In this case, the life cycle of the building is a period from the time when necessary materials to be used for constructing a building are produced until the time when the building cannot operate any more. Such a period includes the construction time of the building and the time of the maintenance and the replacement during using the building. For instance, if concrete is selected as the material of a building, the greenhouse gas emission during the manufacturing concrete is included into the life cycle analysis, and the emission harms the earth. On the other hand, trees can absorb harmful carbon dioxide, while they grow. After their growth stops, trees will stop absorbing carbon dioxide, and when they are burnt or decay, they will emit carbon dioxide. Thus, if trees that have stopped their growth are felled for constructing a building, the trees which have already absorbed carbon dioxide within themselves during their growth will keep the harmful gas within themselves, unless the timbers are burnt or decay. Furthermore, as long as the amount of the felled trees is below the amount of trees growing in nature, the entire amount of absorbed carbon dioxide will increase from a theoretical point of view. Thus, using timber in such a way would be eco-friendly (Hess Timber Limitless, 5)

I have utilized LCAQuick only for specifying the main material for my project. Three simple same buildings were modeled by Software of Revit, but the material of one of the three buildings was selected as concrete, the material of second building was chosen as timber, and the third one was modeled of steel. The volumes of the three used materials would be different in reality since the durability of the materials is different. However, it has been assumed that volumes of the three used materials were equivalent in this examination, and it has been estimated how the used materials would affect the environment. The three tables have produced the values of how much greenhouse gas is emitted as positive values, which is harmful to nature. Furthermore, they have yielded how much greenhouse gas is absorbed or is stopped from the emission as negative values, which is harmless to nature. The result has indicated the obvious difference of the three materials. The value of the potential environmental impact of timber has been -110,497.2. On the other hand, the values of concrete and steel have been 405,568.1 and 7,526,530.9, respectively. It has appeared that concrete and steel produce carbon dioxide during the product stage when the materials are manufactured, according to the tables (Tables 1,2,3).

To sum up, timber which has shown a negative value would be the least harmful material of the three. Even if the volume of the three used materials differ from each other, the timber will be the most harmless material of the three, since the steel and the concrete would always show the positive values during the production stage by LCAQuick, whereas producing timber which would be growing trees will absorb carbon dioxide so as to results in yielding the negative values by LCAQuick. Thus, timber has been chosen as the primary material straightforwardly, according to the LCAQuick. As long as timber could comply with the acceptable safety or service of the proposed building, timber will be utilized for this project. This has meant that if timber could not provide acceptable functions of a building, steel or concrete could be partially utilized for the construction as Frank Gehry designed Louis Vuitton Foundation (fig.39).

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Fig.39. Doreen Carvajal, Louis Vuitton Foundation Designed by Frank Gehry, Indicating the Combination of Steel and Timber Structures, The New York Times, (The New York Times Company, Oct 2014), https://www.nytimes.com/2014/10/18/arts/design/lvmh-flaunts-its-billowing-gehry-trophy-in-paris.html. Copyright 2014 by The New York Times Company.

Table 1
The Table Indicating How Much The Timber Model Will Be Harmless to the Environment.

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Source: *LCAQuick: Life Cycle Assessment Tool*, LCAQuickV3.4.2, https://www.branz.co.nz/environment-zero-carbon-research/framework/lcaquick/. Copyright 2016 by Jarred Butler. Reprinted with permission.

Table 2
The Table Indicating How Much The Concrete Model Will Be Harmful to the Environment.

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Source: *LCAQuick: Life Cycle Assessment Tool*, LCAQuickV3.4.2, https://www.branz.co.nz/environment-zero-carbon-research/framework/lcaquick/. Copyright 2016 by Jarred Butler. Reprinted with permission.

Table 3
The Table Indicating How Much The Steel Model Will Be Harmful to the Environment.

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Source: *LCAQuick: Life Cycle Assessment Tool*, LCAQuickV3.4.2, https://www.branz.co.nz/environment-zero-carbon-research/framework/lcaquick/. Copyright 2016 by Jarred Butler. Reprinted with permission.

The Preliminary Design (the Iterative Process)

1. The 1st phase (Using clay to describe “trickling water”)

Three models were created out of clay to experiment on whether or not sculptural forms could describe water. This was because the proposed architecture would need to symbolize the meanings of Waiheke island as “beauty” of Vitruvius’s principle. Several words of fluidity, puddle, liquid, water, flow, stream, trickle, drip and wiggle occurred to me since those words could be relevant to “island of trickling waters, or descending waters”. Clay was stretched and bent into different directions, so that viewers could imagine and feel “trickling waters or descending waters” easily by looking at the clay forms. Furthermore, the three models were made to look as if they were long shelters. The experimentation of making such forms were rather successful because it turned out that such sculptural forms could represent such movements of water (fig.40).

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Fig.40. Akito Kamiya, *The Three Conceptual Clay Models Symbolizing “Trickling Water”,* 2020,

However, those models needed to be developed further or another architectural form had to be conceived due to the problem of their views. Buildings are normally seen from the street, which could be the worm’s eye view. However, the problem was that the clay models did not appear as anything special in the worm’s eye view, though they look like meaningful sculptural forms in the bird’s-eye view (fig.41, 42, 43). Furthermore, the forms did not contain actual functional or sustainable elements. Thus, a different approach was taken on the 2nd phase.

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Fig.41. Akito Kamiya, *The Bird’s-eye View of One of The Three Models,* 2020, Wellington.

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Fig.42. Akito Kamiya, *The Bird’s-eye View of One of The Three Models,* 2020, Wellington.

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Fig.43. Akito Kamiya, *The Bird’s-eye View of One of The Three Models,* 2020, Wellington.

2. The 2nd phase (Using wire to describe “trickling water”)

The topography of the site and sustainability were integrated into another conceptual architectural forms at the 2nd phase. Firstly, the slope of the hill of the proposed site was exploited for making an architectural form since the slope could be utilized for symbolizing “descending trickling water” of Waiheke island (fig.44). Secondly, the proposed building should be linear for the three reasons, which are for passive solar heating, cross ventilation and the meaning of “the long sheltering island”. Because of the passive solar heating, the majority of the wall- surfaces of the building should be oriented to the north, so that heat would be obtained by the walls from the sun. Furthermore, because of the efficiency of the cross ventilation, the floor plans of the building should be narrow. Moreover, one of the meanings of Waiheke island was “long sheltering island”, so that the buildings could be linear objects which protect people from the environment.

The several rough sketches were drawn in order to symbolize fluidity of “descending trickling water” as well as a long form. Something linear on the slope of the site was drawn, but the linear object would have to symbolize the fluidity of water (fig.45). In order to symbolize the fluidity of descending water from the upper part of the hill, a series of narrow objects which were parallel to east-west axis were drawn. The series of the narrow objects could show a rhythm, so that the drawing could show the fluidity of water (fig.45). The series of the linear objects could be constructed of an appropriate material for thermal mass effect. In order to let the sketch symbolize more fluidity of water, something which looked like lightweight cloth over the series of the linear objects was drawn in this image (fig.46). The lightweight cloth sort of thing could be constructed of glass, and the glass would be supported by structures below. Those things have been indicated as the 3 layers in the image. Thus, the large glass roof would enclose the series of the linear buildings. The glass roof was to keep warm air in itself in winter. The three layers have seemed to provide more fluidity in the image. Furthermore, the drawing at the bottom has seemed to be most fluent and most interesting (fig.46). This aesthetic notion might be identified in Ludwig Mies van der Rohe’s works. For instance, the S. R. Crown Hall has a series of columns, transparent walls of glass, and other objects such as the mullions, the window blinds and the lightings. The columns were constructed evenly, so that the arrangement of the vertical structures has created the rhythm and the glazed wall has provided an atmosphere of smoothness of the light material. Furthermore, those other objects are arranged evenly so that other types of rhythm are created. As a result, the S. R. Crown Hall seems to show several rhythmical layers and a smooth transparent layer, so that some people might identify that the building has created fluidity as its entire view (fig.47). The sketches created at the 2nd phase show the curvy forms rather than a boxy shape so that the fluidity could be identified more straightforwardly in the sketches than in the S. R. Crown Hall.

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Fig.44. The Hillside of the Proposed Site, Indicated with the Red Square, *Google Maps,*(Google, 2021), https://www.google.com/maps/place/Waiheke+Island/@-36.7759385, 174.9888436,708a,35y,132.69h,43.23t/data=!3m1!1e3!4m5!3m4!1s0x-6d72c882cf34cebd:0xcb6ce79667d0cc2c!8m2!3d-36.8000487!4d175.1009721. Copyright 2021 by Maxar Technologies, CNES/Airbus-,Planet.com, Waikato District Council.

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Fig.45. Akito Kamiya, *The Sketch with the Dimension in the Middle, Indicating the Fluidity by Rhythm on the Slope,* 2020, Wellington.

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Fig.46. Akito Kamiya, *The Sketch Indicating the Fluidity by Rhythm on the Slope,* 2020,Wellington.

This content has been redacted.

Fig.47. The S. R. Crown Hall's Facade Indicating the Rhythm, *Nomada*, https://nomada.uy/guide/view/attractions/1197. Accessed 6 Dec. 2020.

However, the notions of the two designs conceived differently could originate from the same idea coincidentally. With regards to the proposed design, the drawing has indicated an enlarged view of the series of the linear buildings (fig.48). The spaces between the linear objects could be filled with water for cooling the building in summer. The spaces of the water would also be drained in winter. Subsequent to developing the conceptual form by sketch, a conceptual model was created out of wire by the inspiration from the fluidity and the complexity of an existing stream on Waiheke island (fig.33). The wire model was made with considering the slope of the site and the sustainable features (fig.49,50,51).
Unfortunately, the conceived form had to be given up on, as the form was simpler than the form of the Guggenheim Museum Bilbao. If the form was not complex enough, a Bilbao effect might not occur with the form. Another problem of the 2nd phase was that the actual habitable spaces of the building were only series of simple conventional linear objects which would be able to ventilate themselves and obtain the solar heat efficiently. On the other hand, the exterior curvy shell actually would not provide any habitable spaces. However, the positive side of the 2nd phase was the fact that wire had still been utilized well for making an architectural form with its meaning and some degree of the function and the sustainability. However, the scheme of this wire conceptual model needed to be abandoned for the reasons mentioned above.

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Fig.48. Akito Kamiya, *The enlarged view of the series of the linear buildings,* 2020,Wellington.

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Fig.49. Akito Kamiya, *The Conceptual Wire Model Indicating the Fluidity and the complexity on the Slope,* 2020,Wellington.

This content has been redacted.

Fig.50. Akito Kamiya, *The Conceptual Wire Model Indicating the Fluidity and the complexity on the Slope,* 2020,Wellington.

This content has been redacted.

Fig.51. Akito Kamiya, *The Conceptual Wire Model Indicating the Fluidity and the complexity on the Slope,* 2020,Wellington.

3. The 3rd phase (Using wire to describe "trickling water" with more complexity)

The very primitive form which would become the final design of the proposed building was conceived out of cardboard at the 3rd phase. In the first review of the thesis before the 2nd phase, it was actually advised that I should have a more playful approach to make architectural forms and that Frank Gehry's way to design buildings could be referred to. As the architect used to develop Guggenheim Museum Bilbao's primitive form, thin carboard (paper) was used, but each geometry of the primitive form was a diamond rather than a rectangle or a square which the architect had utilized (fig.52). That was because a designer could sometimes obtain an inspiration by the texture, the color or the geometry of materials. In this case, it was thought that the reflective dark diamond shape could inspire me to conceive a complex form which represents the fluidity of water (fig.53). Complexity and fluidity were prioritized and the concept of the form being as a linear for the thermal mass effect was considered at a smaller degree than before. In such a way, the very primitive form of the proposed building was conceived out of cardboard.

The way to represent the fluidity by wire was still useful so that the method was integrated after using cardboard. The created primitive cardboard form was utilized as a reference, so that the developing new model that was created of wire covered the referenced model, as the image indicates (fig.54).

While the new wire model was created, the concept of the fluidity was focused on, so that the wire model could show an atmosphere of the fluidity, as the image indicates (fig.54). As the second wire model was being developed, the new design appeared to have twin linear objects which could look like scissors in its plan view. In comparison, Guggenheim Museum Bilbao has one long continuous form in one direction with other divided sections in several directions its plan view (fig.55). However, when the two different designs were captured in their elevation views, a fault of the developing design of this thesis-project was identified.

The long part of Guggenheim Museum Bilbao appeared as bananas or elegant swords with the tallest part of the atrium which has supplemented the entire elevation view of the building (fig.56). It was speculated that this elevation could be one of the factors to have invoked the Bilbao effect. On the other hand, the developing design of the thesis contains its two long objects, but the elevation view did not produce any aesthetic value. It was intuitively noticed that the elevation of the new design did not contain its highest place, so that it looked as mere long flat forms (fig.57). The Bilbao Guggenheim museum would also have a similar poor appearance without its high atrium.
Thus, a high place which could enhance the elevation view of the proposed design was added with considering the fluidity, so that the form seemed as complex as Bilbao Guggenheim Museum (fig. 58,59,60,61).
As a result, the conceptual wire model which would evolve to the final design directly was made.

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Fig. 52. Frank Gehry. "The Conceptual Model of Guggenheim Museum Bilbao Created by Frank Gehry"; Van Bruggen, Frank O. Gehry Guggenheim Museum Bilbao, (Guggenheim Museum, 1998), p. 174. Copyright 1997 by The Solomon R. Guggenheim Foundation.

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Fig.53. Akito Kamiya, *The Conceptual Cardboard Model* , 2020, Wellington.

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Fig.54. Akito Kamiya, *The Another Conceptual Wire Model Was Being Created, Indicating the Fluidity,* 2020, Wellington.

This content has been redacted.

Fig. 55. Guggenheim Museum Bilbao, Plan, *Rethinking The Future*, [Rethinking Internet Media Pvt Ltd], https://www.re-thinkingthefuture.com/architects-lounge/a1598-places-to-visit-in-bilbao-for-the-travelling-architect/. Copyright by blogspot.com.

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Fig. 56. The Elevation of Guggenheim Museum Bilbao, *Guggenheim Bilbao*, [FMGB Guggenheim Bilbao Museoa], https://www.guggenheim-bilbao.eus/en/the-building, Copyright 2021 by FMGB Guggenheim Bilbao Museoa.

This content has been redacted.

Fig.57 Akito Kamiya, *The Conceptual Wire Model Appearing Flat,* 2020, Wellington.

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Fig.58 Akito Kamiya, *The Conceptual Wire Model which would evolve to the final design directly,* 2020, Wellington.

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Fig.59 Akito Kamiya, *The Conceptual Wire Model which would evolve to the final design directly,* 2020, Wellington.

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Fig.60. Akito Kamiya, *The Conceptual Wire Model which would evolve to the final design directly,* 2020, Wellington.

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Fig.61. Akito Kamiya, *The Conceptual Wire Model which would evolve to the final design directly,* 2020, Wellington.

The Digitization

1. 3D scanners

<u>The advantages</u>

3D scanners have had their potential to digitize a physical model although there have still been its limits. This is because a physical object could be scanned in order to obtain data of the physical object by computer, so that a digital form of the physical object could be modeled within a few hours. In fact, when a container of glue was scanned experimentally, a three-dimensional model of the container appeared in a computer (fig.62, 63). As a result, the geometry of such a digital model could be measured accurately by computer and the exactly same geometry could also be printed out, which means that 3D scanners could be utilized to duplicate an appearance of a physical object as well as record its digital data. For instance, a designer creates a primitive form of a building manually, and they could digitize the physical model by using the 3D scanner. Furthermore, it could not take a long time to model a digital form if a physical object is scanned appropriately. Thus, using a 3D scanner is a potential method in architecture, as the architect, Frank Gehry uses.

<u>The limits and the result</u>

However, there have been limits of 3D scanners. This is because 3D scanners are sometimes unable to obtain data of a physical model appropriately due to the geometry or the reflectiveness of the physical object. This has been an actual failure of 3D-scanning a physical object. When I attempted to 3D-scan the wire conceptual model made at the 3rd phase, the wire model was roughly digitized on a flat surface only as two dimensional without its volume, which has meant that only the flat outline of my wire conceptual model appeared in the computer. The technician of 3D scanners explained that the wire model contained a lot of fine parts which had been made of thin wire. Furthermore, he continued explaining that the steel wire was really reflective whereas 3D scanners are able to scan physical objects which are in dull colors. Therefore, those limits of the 3D scanners hindered the wire model from being 3D- scanned appropriately. Thus, such a cutting edge machine has still had its faults.

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Fig.62. Akito Kamiya, *The Rhinocero-model digitized by 3D Scanner, in the Shaded View,* 2020, Wellington.

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Fig.63. Akito Kamiya, *The Rhinocero-model digitized by 3D scanner, in the Rendered view,* 2020, Wellington.

2. The 4th phase

A solution to digitize the wire conceptual model was discovered after the 3D scanning method had failed due to the used material. The process was to measure each coordinate of the geometry by using a ruler, a piece of tracing paper and a green craft cutting mat that has 1 cm x 1 cm grid. A piece of tracing paper was taped on the mat and the wire model which was placed on the tracing paper was tied to the mat with strings tightly (fig.64). If the horizontal lines of the mat are X axis, the vertical lines of it are Y axis, and the imaginary lines perpendicular to the mat are Z axis, the coordinates of the wire model will be able to be measured, theoretically. The coordinates of some points on each used piece of wire were measured and recorded on the tracing paper. Even if the measured points floated above the mat, a skinny ruler or a Staedtler Mars 780 Technical Mechanical Pencil by which a lead can be extended perpendicularly to the mat from the points are used to measure the height of the points. If the Technical Mechanical Pencil is used, the length of the extended part of the lead will become the coordinate of Z axis of the points (fig.65). If the mat has 1 cm x 1 cm grid, it will help to measure the coordinates of X and Y axes of the points. This way was not applied to all the points on the used piece of wire but some points on it. Then the geometry of the measured piece of wire could be digitized by putting the values of the coordinates in order to add each point in Rhinoceros with referring to the measured coordinates. Then the command of "Interpolate points" was used to draw lines which go through the added points in Rhinoceros . When a digitized model that did not show the same geometry of the original hand-made model, the coordinates of the points on the geometry were measured again. The previous measurement of the coordinates might have contained big errors which caused the failure of the digitization. Furthermore, when measuring the same points did not satisfy the digitization, the coordinates of more points on the geometry were measured. For instance, if measuring the coordinates of three points did not satisfy the digitization, it was helpful to try to measure the coordinates of four points precisely. This method was applied to all the pieces of wire of the conceptual model. Thus, most parts of the geometry of the wire model were able to be digitized quite accurately, which meant that the digitized model seemed satisfactory in appearance, compared to the original physical model. Subsequently, each surface was created as the roof by using the curvy lines which had been digitized by measuring the wire conceptual model.

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Fig.64. Akito Kamiya, *The Conceptual Wire Model Tied to the Craft Mat for the Measurement,* 2020, Wellington.

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Fig.65. Akito Kamiya, *Using the Mechanical Pencil for the Measurement,* 2020, Wellington.

The digitized model was refined by Grasshopper and Kangaroo plug-ins. This was because the digitized model contained some faults in its architectural form, although a digital model might have been modeled accurately by the measuring method established for this project. When one section of the model was digitized accurately, it turned out that the part appeared flat and lacking volume, which could not represent an ample of fluent water as “beauty” (fig.66,67). Generally, a simple surface which faces upwards could be swelled vertically by Grasshopper and Kangaroo plug-ins so that the surface looks like a jellyfish, and this has been commonly known as a basic feature of Kangaroo plug-in (fig.68). However, it was considered if the movement of the swelling model could be controlled mathematically. Thus, a further modification was made to the commonly known script. The problem was that when the script was assigned to a part of the proposed model, the part could not be swelled in any other directions except in the vertical directions. During the digitization, it was considered that if the three vectors along x, y and z axes are manipulated mathematically, any points in the three dimensional space of Rhinoceros can be located, so that a line from the origin to a point located specifically will be a determined vector. Thus, if any point can be located in such a way, any directions will be specified mathematically. In fact, the coordinate of any point can generally be specified as $k\vec{x}+l\vec{y}+m\vec{z}$, where $\vec{x}$ is a unit vector (1,0,0), $\vec{y}$ is a unit vector (0,1,0), $\vec{z}$ is a unit vector (0,0,1) and k, l and m are any real numbers. For instance, a point A whose coordinate is described as (X, Y, Z) can be described as $(X, Y, Z) = k\vec{x}+l\vec{y}+m\vec{z}$. In such a way, mathematical addition was made to the commonly known script of Grasshopper plug-in. It has been common that a desired architectural form is determined by using sliders of Grasshopper plug-in. Likewise, the direction of the swelling part was controlled by changing the real numbers k, l and m of the sliders, although the direction had been limited as vertical at the beginning of this digitization. As a result, a suitable shape was discovered by swelling the particular section in many directions experimentally (fig.69). As a result, the aesthtetic default of the conceptual model was fixed, so that the form represented a volume of fluent water architecturally, finally. The architectural form of the digitized model was improved by Grasshopper and Kangaroo plug-ins (fig.70,71).

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Fig.66. Akito Kamiya,T*he Digitized Blue Section and the Original Same Section,* 2020, Wellington.

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Fig.67. Akito Kamiya, *The Blue Section Appearing Flat,* 2020, Wellington.

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Fig. 68. Daniel Christev, “Grasshopper - Kangaroo 1 vs. Kangaroo 2,” Youtube, (Jawed Karim, Steve Chen, Chad Hurley, Feb 2017), https://www.youtube.com/watch?v=R_Bfmm8y-Ms&t=1166s. Copyright 2017 by Daniel Christev.

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Fig.69. Akito Kamiya, *The Blue Section Being Manipulated by X, Y, and Z Vectors by Grasshopper Plug-in to Determine a Desire Form,* 2020, Wellington.

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Fig.70. Akito Kamiya, *The Determined Form Indicated in Cyan,* 2020, Wellington.

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Fig.71. Akito Kamiya, *The Script Originally Created for a Surface to Be Manipulated by X,Y and Z Vectors,* 2020, Wellington.

The walls which had not been modeled out of wire were added to the digitized model. The edges of the conceptual architectural clay forms were manipulated in order to represent the fluidity of water at the 1st phase, and the same way was applied at this stage (fig.40). As a result, the curved surfaces were added as walls to the model digitized by Rhinoceros and Grasshopper through the measurement, in order to finalize the architectural form representing "trickling water" (fig.72,73,74,75).

Overall, the digitization by the method invented for this thesis was very successful. The digitized model might not have been as accurate in geometry as the 3D-scanned digital model which Frank Gehry had obtained for the Guggenheim Museum Bilbao. However, the degree of the errors about the accuracy was minimized well, so that the digitized model did not reveal so much difference between the original conceptual wire model and itself. That was the moment when the digitization turned out to have succeeded (fig.72,73,74,75)

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Fig.72. Akito Kamiya, *The Curved Surfaces Added as the Walls and the Comparison Indicating the Successful Digitization,* 2020, Wellington.

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Fig.73. Akito Kamiya, *The Curved Surfaces Added as the Walls and the Comparison Indicating the Successful Digitization,* 2020, Wellington.

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Fig.74. Akito Kamiya, *The Curved Surfaces Added as the Walls and the Comparison Indicating the Successful Digitization,* 2020, Wellington.

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Fig.75 Akito Kamiya, *The Curved Surfaces Added as the Walls and the Comparison Indicating the Successful Digitization,* 2020, Wellington.

The Developed Design

The 5th phase (Determining the final form)

Since sustainable design has been one aspect of my design, a large amount of excavation of the hill on the proposed site should be avoided. It could also be considered that the proposed building would be erected on the flat site next to the hill, so that no vegetation or land of the hill should be eliminated (fig.76). However, if the proposed building were simply built on the totally flat site, the architectural design would have limited integration of the site-topography into the architectural design which could lead to an attractive composition. Thus, it was needed that the proposed building would gracefully be connected to the near green area of the hill without destroying the nature drastically.

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Fig.76 Akito Kamiya, *The Flat Area and the Hillside of the Proposed Site,* 2020, Waiheke Island Auckland.

The junction of the architectural form and the surrounding nature had to be resolved physically and atmospherically. This was because the topography of the proposed site had not been taken into consideration so precisely when the primitive model was created with the paper diamond-shapes. Thus a precise physical site model was created on this phase. When the wire model created at the 3rd phase was laid on the carved site model, an awkward and unsmooth physical relationship became apparent. Furthermore, when the most previously upgraded digital model was placed on the accurate digital site model in Rhinoceros, it was apparent that the two models crushed each other obviously (fig.77, 78). The physical wire model was stuck to the physical site model, which was an attempt to force the wire model to be fitted on the site model. However, some modifications needed to be undertaken in order to make the entire view of the building and the site look integrated. Thus, the developing architectural form had to be connected to the earth of the site firmly in the construction and naturally in the architectural design.

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Fig.77 Akito Kamiya, *The Digitized Model and the Site Model* Crushing Each Other*, Indicated with the Circles,* 2020, Wellington.

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Fig.78 Akito Kamiya, *The Digitized Model and the Site Model Crushing Each Other, Indicated with the Circles,* 2020, Wellington.

It was actually necessary to re-design how the proposed building is connected to the surrounding green on the slope. Several strings of wire were attached to the physical site model as if the new joint floated gradually above the earth so that the joint smoothly leaded to the actual building-model itself. When the additional wire was attached, the forms of the junctions were reformed with an awareness of the fluidity as the project's meaning. The forms of the junction would not only improve the appearance of the connection but also improve the entire proposed building-appearance and the entire view of the proposed building and the site seen as one. Thus, the connection between the proposed architecture and the proposed site was re-conceived (fig.79, 80, 81).

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Fig.79 Akito Kamiya, *The entire view of the proposed Building Model and the Site Model with the Resolved Junction,* 2020, Wellington.

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Fig.80. Akito Kamiya, *The entire view of the proposed Building Model and the Site Model with the Resolved Junction,* 2020, Wellington.

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Fig.81. Akito Kamiya, *The entire view of the proposed Building Model and the Site Model with the Resolved Junction,* 2020, Wellington.

The proposed architectural form was completed after the multiple experimentations and variations of the form with integrating the sustainable design and Vitruvius's principle. A series of the concrete footing would be embodied into the ground as the very junction between the proposed building and the near hill of the proposed site. The concrete footings would be the only portion of excavating the earth of the hill. Since the hill would not be excavated for creating spaces underground but for embodying the concrete footings, the wooden floor frames would be constructed with following the gradient of the site. Furthermore, the internal spaces above the ground of the hill would possess a small amount of space which would be utilized as a machine rooms or storages. Such a sector would appear as gently covering the small portion of the hill rather than colliding with it (fig.82, 83). Thus, the form of the proposed model has been finalized in such a way, with a number of alterations and additions undertaken due to the many restrictions through the iterative process.

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Fig.82 Akito Kamiya, *The Redesigned Junction between the Proposed Design and the Site,* 2020, Wellington.

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Fig.83 Akito Kamiya, *"Wireframe" Which Is the Transparent View Showing the Finalized Form Covering the Hillside,* 2020, Wellington.

Plug-ins Honeybee and Ladybug

Further modifications of the latest proposed digital model were required for Ladybug and Honeybee plug-ins which are utilized for the environmental and building-thermal performance simulations. This was because very complex round geometries of the proposed design could not be utilized by Ladybug and Honeybee plug-ins. In fact, the proposed model had a number of three dimensionally round surfaces. Therefore, all the surfaces of the model's envelope except a few flat surfaces had to be altered to planar surfaces in order to utilize by the two plug-ins for the evaluations.

Though a round object could be constructed with a numerous number of flat surfaces in reality, such a method of making the planar surfaces look like the curved surfaces was applied to only the environmental and building-thermal performance simulations. Other two plug-ins which are called Kangaroo and LunchBox generally enable designers to create planar surfaces for round surfaces. It could be assumed that the difference between a result of the simulation of an actual geometry and that of the simplified geometry with flat surfaces in such a way could be approximated as zero. Thus, the round surfaces of the proposed upgraded model have been transformed into the flat ones, so that environmental and building-thermal performance simulations could possibly be conducted with the proposed design. In addition, it was considered that the proposed building could be designed by using flat panels rather than curvy panels, so that the construction cost could decrease. In fact, 30 St Mary Axe (The Gherkin) designed by Norman Foster has consisted of flat surfaces except its apex, so that the viewers might as well think that the glazed façade constructed with flat panels look round. However, the true curvy surfaces would represent the fluidity more atmospherically, so that such a scheme of using the flat panels in the actual design was not approved, but it was decided that such a method was utilized for only the environmental and building-thermal performance simulations. Thus, the plug-ins, Kangaroo and Lunchbox were able to create the curved surfaces with only flat surfaces (fig. 84,85,86). However, the plug-ins simulations failed with the simplified model, unfortunately due to the too complexy geometry.

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Fig.84. Akito Kamiya, *The original model to be transformed into the one that consist of the flat surfaces,* 2020, Wellington.

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Fig.85. Akito Kamiya, *The chosen curved surfaces to be transformed to the flat surfaces,* 2020, Wellington.

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Fig.86. Akito Kamiya, *The flat surfaces transformed by Kangaroo and LunchBox,* 2020, Wellington.

The 2nd attempt by reducing the mesh of the model

An alternative method to transform the round surfaces to planar ones was discovered, and the mean worked successfully. The method used mesh of surfaces in Rhinoceros. A similar geometry to a model could usually be made by the command "Mesh". in Rhinoceros. The geometry produced by "Mesh" consists of triangles and quadrilaterals, and the number of triangles and quadrilaterals could be regulated. For instance, if "Mesh" is applied to a sphere, the similar geometries to the original true sphere will be created, and the degree of the similarity can be controlled. One of the similar geometries can look like a really rough sphere so that it has lost the surface of the true sphere. However, it has had less information, in which case the geometry is easy to control. On the other hand, a similar sphere with the dense surface can still be yielded, but the geometry could still be difficult to handle due to its much information. Furthermore, the number of mesh could be reduced further by the command of "Reduce Mesh", although the geometry of the model is sometimes deformed severely. In fact, due to the reducing the mesh by 10 % of the proposed design, some parts of the model collapsed partially (fig.87). Moreover, there was a further option of "Planar only" that transformed all the pieces of the mesh to planar ones as a part of "Reduce Mesh" command, and which worked satisfactory to reduce the number of the mesh without losing any sections of the geometry of the proposed design. As a result, this method was selected to let the simulation of the solar radiation study run by Ladybug, as follows (fig. 87).

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Fig.87. Akito Kamiya, *From the left to the right, the original proposed model, the mesh model by "Mesh", the mesh model by reducing the mesh by 10%, the mesh model by "Planar only",* 2020, Wellington.

The solar radiation study

It was possible to evaluate the amount of the radiation to be positively and negatively gained by the proposed building envelope. The model simplified by "Mesh" of the proposed design was assigned to a script of such a solar study. The script that has been provided online was able to produce scientific data of how much of the solar energy could be beneficial or harmful to the proposed design. For example, the solar heat could warm a building-envelope and make the internal spaces comfortable in winter, whereas it could increase the temperatures of the building, so that the occupants could suffer the heat in summer. The script was able to produce the two types of data, which would be useful for this proposed design (fig. 88). The data has indicated the green areas and the red areas which represent the comfortable zones with the temperatures below 12 degree Celsius and the uncomfortable zones with the temperatures above 18 degree Celsius, respectably. The unit of the two types of data has been kWh/m2, so that it has been indicated how much beneficial and harmful solar radiation could be obtained per square meters, when the temperatures are below 12 degree Celsius and above 18 degree Celsius, respectively. Thus, it could be summarized that the model colored in green has indicated comfortable areas due to the solar radiation especially in winter and the model colored in red has indicated uncomfortable areas due to the solar radiation especially in summer.

The colored sections could determine the type of the internal spaces and the required architectural features. It could be identified that the red zones and the green zones almost match each other (fig. 88). As a result, the more vivid red or green parts indicate the areas which could catch the solar radiation more owing to the orientation and the geometry of the proposed building. Therefore, those red and green zones could indicate the positions of solar panels, since the vivid colored area could allow the solar panels obtain the heat efficiently, whereas some white sectors would not allow the solar panels to generate the electricity so well. Furthermore, the solar panels could prevent overheating the roof cladding in the red zones. Finally, the red area could be ventilated flexibly naturally or mechanically if it is necessary. On the other hand, there have been less red zones due to the orientation of the roof and wall surfaces. The atriums (the voids) and the openable windows could be provided in the less red areas but close to the very red areas in order to let the natural ventilation occur in hot summer.

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Fig.88. Akito Kamiya, *The Green Areas Indicating the Comfortable Areas Due to the Solar Radiation Especially in Winter and the Red Areas Indicating the Uncomfortable Areas Due to the Solar Radiation Especially in Summer,* 2020, Wellington.

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This is because if the atriums are provided in the very red zones, the internal spaces could become too hot and the artworks could be damaged. However, the atriums slightly adjacent to the very red zones could contribute regulating the thermal comfort in the very red zone obliquely. Unfortunately, providing the atriums would also make the spaces cold unnecessarily during the nights in winter. Thus, the exhibition spaces where people do not usually exist during the cold winter night time have been assigned to the atriums-spaces, so that few people will suffer the unnecessary coldness. On the other hand, the area of the similar ventilation-risers (the lightwells) of the accommodation-zone would be minimized to reserve the warmness during the cold winter night. Thus, this solar study could help to specify how the spaces are used and the sustainable design.

The results of the solar study have shown an oddness which needed to be investigated further. The strange matter was some very white parts appearing very next to vivid green or vivid red colors. For instance, the white sector of the top of the proposed model was one of the weird sections, as the surface should suffer the solar radiation due to the position and the orientation. (fig. 88). The colors of the surface could normally be altered gradually as gradations by the used script, unless the surfaces are angled suddenly between themselves or covered partially. For example, the simple model created for "the psychrometric chart" of the site analysis, was assigned to this script of the solar study. Then the walls of the simple model have indicated gradation of red and white, which appeared to be a natural change between white and red (fig. 89). Thus, it was speculated that the appropriate results of the used script could be produced in such a mean.

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Fig.89. Akito Kamiya, *The Natural Gradation Shown on the Simple Model. (The Model Exists in the Southern Hemisphere. The Characters of the Legend Are Oriented to the North, and the Surfaces Oriented to the Sun Are Shown in Red. If the Surfaces Are Oriented to the Ground Even Though Those Are on the Northern Wall, the Surfaces Are Shown as Whiter.* , 2020,Wellington.

However, although some gradations could be identified on the proposed model due to the positions and the orientations, it could be speculated that the simulation lapsed partially for the parts colored oddly (fig.90). The lapses might have been caused by the too complex geometry of the proposed design. However, it could be hypothesized that if the surfaces are oriented to the sun, those will certainly gain the heat and then the parts will be displayed in colors on the model. Therefore, some walls hidden by other near parts of the building from the sun or walls oriented in the different directions from the sun will naturally become rather whiter, whereas the parts directly exposed to the sun are displayed in vivid colors, and the way would sound sensible. Thus, the parts abnormally indicated in white against the sensible way needed to be investigated.

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Fig.90. Akito Kamiya, *The model showing the natural gradation and the odd white sectors. The characters and the numbers of the legend are oriented to the north,* 2020,Wellington.

The different script of the solar radiation was created and the simplified proposed model was split into multiple parts for the energy simulation. This second script required creating a Honeybee energy model for the building-thermal performance simulation, although the first solar radiation study had been conducted with a Ladybug script for the environmental simulation. Furthermore, the psychrometric chart could be created with a Ladybug script for the environmental simulation, but once a Honeybee energy model is linked to the psychrometric chart, the entire script can be labelled a Ladybug- Honeybee script. The Honeybee energy model of the simplified proposed design was created. The entire simplified model was assigned to the alternative script of the solar radiation once. However, the model was still too complex and too large, although the model could not be simplified further since it needed to preserve the authentic appearance of the proposed design. Thus, the entire geometry of the proposed design needed to be divided into multiple smaller zones, with some of them selected to run the energy simulations (fig. 91).

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Fig.91. Akito Kamiya, *The selected sections are shown in green. One of them is assigned to the alternative script and shown in the multiple colors for the simulation,* 2020,Wellington.

The second script made it clear that the surfaces of the building would straightforwardly obtain the solar radiation unless they are oriented to the different vectors from the sun or other objects block the sun. The time could be regulated in the second script. For instance, the simulation could be run for 12:00 pm, 1 January and for 12:00 pm, 1 July at Auckland Airport. The difference has indicated that the warm sectors and the cool sections of the building did not alter so much at 12:00 pm, but the values of the radiation rate differed since January is in summer, whereas July is in winter (fig. 92, 93). When the simulation was run for 7:00 am 1 January at Auckland Airport, the eastern side of the partial Honeybee model was colored in red and orange, but the walls oriented to the west turned to blue (fig. 94). When the simulation was run for 5:00 pm 1 January in Auckland Airport, the western part of the partial model became red, orange and yellow, whereas the eastern side was just blue (fig. 95). Therefore, it could be identified that the surfaces oriented to the sun without obstacles would straightforwardly gain solar radiation. Finally, if the time is 5pm 1 July in winter, the partial model shows blue, which indicates the model would not obtain the solar radiation at that time (fig. 96). In addition, when the top of the building was sliced as a partial model, the top of the building indicated the actual red,

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Fig.92. Akito Kamiya, *The Simulation Indicating How Much Solar Radiation Is Obtained at 12:00 pm, 1 January in Colors,* 2020,Wellington.

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Fig.93. Akito Kamiya, *The Simulation Indicating How Much Solar Radiation Is Obtained at 12:00 pm, 1 July in Colors,* 2020,Wellington.

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Fig.94. Akito Kamiya, *The Simulation Indicating How Much Solar Radiation Is Obtained at 7:00 am, 1 January in Colors,* 2020,Wellington.

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Fig.95. Akito Kamiya, *The Simulation Indicating How Much Solar Radiation Is Obtained at 5:00 pm, 1 January in Colors,* 2020, Wellington.

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Fig.96. Akito Kamiya, *The Simulation Indicating How Much Solar Radiation Is Obtained at 5:00 pm, 1 July in Colors,* 2020, Wellington.

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Fig.97. Akito Kamiya, *The Simulation Indicating* No Odd Part, 2020, Wellington.

but there was no odd color change as identified in the first solar study (fig. 97).

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Fig.98. Akito Kamiya, *The Simulation Indicating* the Clear Gradation, 2020, Wellington.

Overall, the gradation could be identified entirely, so that this alternative method of the solar radiation appeared to be a more trustworthy one (fig. 98). In conclusion, as hypothesized, if the coverings of the building face the sun directly without any interruption, the surfaces will certainly obtain solar heat.

To sum up, the positions of the solar panels could be specified, and the surfaces unexposed to the sun would remain as the specified roof cladding painted in the same blue as the solar panels without the solar panels. Furthermore, some sectors which are rather near the red zones in the simulations could house the atriums (the voids) and include the openable windows to ventilate the red area. Those strategies indicated above are the outcome yielded by the two scripts of the solar radiation study of Ladybug and Honeybee.

The potentials of the Honeybee and Ladybug

The plug-ins Ladybug and Honeybee have developed in the architectural industry and will develop further in the future. Future plug-ins might be able to handle larger and more complex building for the sustainable design, then. The plug-ins would allow the designers to evaluate the surface temperatures of the building, the indoor temperatures of the buildings and other types of data besides the solar radiation. Thus, there would be more options in order to obtain the sustainable strategies. Thus, the sustainable study would continue and make progress with developing plug-ins in the future.

The Internal Spaces

1. The auditorium

A large auditorium usually requires its large space for its appropriate acoustic performance. This is because sounds of a performance need to be transmitted to the audiences clearly, and the volume of the auditorium could affect the acoustic performance. Wallace C. Sabine established a formula of the reverberation time before 20th century. The reverberation time (RT) has been defined as "a measure of the amount of reverberation in a space and equal to the time required for the level of a steady sound to decay by 60 dB after the sound has stopped"(Sengpie ; par. 3). Such a reverberation time could alter, depending on the area of sound absorption existing in a room, the geometry of the room and the frequency of sounds in the room (par. 3). In fact, a music concert hall could frequently have its more than 20 m height in order to let all the sounds be heard by audiences well and the height has been calculated based on Sabine's formula. Therefore, the height of a large auditorium could tend to be large for the acoustic performance.

Such a large auditorium was going to be designed as the underground acoustic space below the flat field-area of the proposed site, but the proposal was turned down (fig. 76). That was because it was considered that a deep underground space would cost a considerable amount of finance. Thus, only 5 m underground space was allowed since such a space has frequently been utilized as a car parking area in reality. For instance, the building built near Lambton harbour has had a 5m deep car parking below the sea level (appendix E). In fact, that compromise of a more than 20 m deep underground auditorium could sound reasonable in reality. This is because if a new building has a large complex form as a museum and a large auditorium underground, the project could be counted as two large projects. As a result, such a project could straightforwardly go over its budget. Furthermore, even if the two large facilities have successfully been erected, there would be no guarantee that the businesses of the new building would succeed. In the worst-case scenario, the investor of the project could suffer a bankruptcy, if the new businesses were not conducted well. It has been true that the owners of some existing buildings have undergone such circumstances due to the failures of their businesses or the architectural design such as the Gherkin. For those practical and economical reasons, the scheme for a more than 20 m deep underground auditorium was not pursued.

However, a scheme for an auditorium whose volume was similar to the volume of the Walt Disney Concert Hall which is approximately, 42m long, 30m wide, and from 18m to 24 m high has been conceived. The proposed auditorium would be constructed on the underground floor, but most of the auditorium space would be situated above the ground (fig. 99). Various precedents were looked up in terms of their capacity of the audiences and their actual volumes of the auditoriums. Due to the narrow shapes of the proposed design, the size of the compact auditorium of the Walt Disney Concert whose capacity has been 2265 audiences and the pipe organ has been selected. Thus, the size that has been identified as suitable for the proposed design has a proposed auditorium for 2366 people in three layers of the seating with a pipe organ.

The proposed acoustic ceiling was designed by using the plug-ins of Grasshopper, Pachyderm Acoustical Simulation and Pufferfish. The sounds reflected on the ceiling panels were considered so that sounds made on the stage will be heard to all the seats of the room within two reflections. Pachyderm Acoustical Simulation and Pufferfish allowed the simulations of how the sounds are reflected on the surfaces (fig. 100,101,102). Thus, the shape of the ceiling panels was not determined by aesthetic but by the acoustic simulation.

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Fig.100. Akito Kamiya, *The Proposed Acoustic Ceiling,* 2020, Wellington.

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Fig.101. Akito Kamiya, *The Simulation by Grasshopper, Pachyderm Acoustical Simulation and Pufferfish,* 2020, Wellington.

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Fig.99. Akito Kamiya, *1:700 The Longitudinal Section of the Proposed Design,* 2020, Wellington.

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Fig.102. Akito Kamiya, *The Script to Design Acoustic Ceilings*, 2020, Wellington.

2. The orthogonal exhibition spaces

The twelve underground orthogonal exhibitions have been conceived owing to the efficiency of displaying the art works in the proposed design (fig. 103). Furthermore, as Frank Lloyd Wright conceived the spiral as an efficient one -way route for the visitors to visit each artwork, one-way continuous route has been conceived by orthogonal plan, so that the visitors would automatically come back to the lobby which they started their visiting the orthogonal exhibition space. To sum up, the visitors could also appreciate the artworks in a traditional way underground, though the entire museum would be shaped as curvature.

The rehearsal room has been remote from the auditorium, since if performers cannot rehearse well because the sounds created in the rehearsal room can be heard in the auditorium, the function of the rehearsal room would be reduced. Thus, the room has been situated in an isolated space.

Furthermore, several . escape routes have been conceived based on New Zealand Building Code (Ministry of Business, Innovation & Employment; p.60).

<u>The atriums (the voids)</u>

The proposed building would possess various void spaces as its atriums for the sustainable design. This was because the proposed building should be narrow and linear for enhancing natural cross ventilation and passive solar systems. However, each branch of the proposed design was still as wide as approximately 50 m, as the floor plans have indicated (fig. 104,105). Therefore, each branch had to be subdivided by providing a void space, so that the natural ventilation system and the passive solar systems would be enhanced in each zone. Chimney effects would be expected because of the atrium, so that lower floors would become cool and the upper floors which tend to become warm will be ventilated by openable windows existing on the top of the building in hot summer. The walls, roofs and floors are to be constructed out of timber which could operate for thermal mass effect to improve comfort of the internal spaces in cold winter. Finally, the skylights of the atriums could distribute the natural daylight. Thus, the conventional method of the atriums would still realize the strategies specified by the psychrometric chart in the proposed design.

<u>The residential area</u>

A pool would be provided on the top of the residential zone of the building, since providing a pool has been common on Waiheke island. In fact, the residential house that I investigated for its sustainable design and the accommodation where I stayed during the site-visit were facilitated with pools (appendix D). Thus, it would be natural that the accommodation of the proposed design should contain a pool, and the existence of such a pool could be justified by the fact that people cannot swim in Matiatia bay which is adjacent to the proposed site. Furthermore, the pool could cool the upper floor of the building although the building could also be cooled due to the evaporative cooling effect by the adjacent sea. Overall, the proposed building would possess a pool at its upper level.

The residential zone would provide 306 bedrooms from the 2nd floor to the 7th floor. Each bedroom would contain its approximately 25m2 floor area and a window or a skylight to obtain the natural daylight. The bedrooms located at the two central sectors would have each lightwell which is connected to the bottom of the pool on the roof top (fig. 99). In addition, the third lightwell located in the south is connected to the roof. This means that some parts of the bottom of the pool and the part of the roof would be constructed of glass, so that the daylight could be sent from the sky to each bedroom below through the glass. Dark roller blinds would be attached to each window of each room and the layout of each room has been conceived for the privacy. Such a lightwell has been identified in an existing hostel, where privacy and daylight have been provided in the way. It is feasible that the bedrooms in an accommodation-building could obtain natural daylight at the central part of the building in this way. Otherwise, the central bedrooms of the accommodation would gain no natural daylight. In addition, each window of the central bedrooms would open partially, so that each room could be ventilated through the shafts of the lightwells in the proposed design. The shafts except the most southern one would be led to the 8th floor before going up to the rooftop, and the rising air will be extracted from the northern part of the 8th floor. The most southern shaft would extract the air from the glass roof which is openable. Furthermore, not only the ventilation route but also the changing room of the pool would be provided on the 8th floor. The other bedrooms would directly be positioned near the external walls with the windows or the other skylights. Furthermore, some bedrooms near the external walls would look unusually angled in the plan view. That was because the bedrooms were to be parallel to the 2 m deep roof structural beams, so that the rooms would be inserted between the 2 m deep roof structure. Otherwise, the 2 m deep structures will penetrate the bedrooms. This means that such a layout was conceived as angled because the bedrooms would need to avoid the roof structures (fig. 106). In such means, 306 bedrooms would be provided in the residential section of the proposed design.

This content has been redacted.

Fig.103. Akito Kamiya, *1:700 The Underground Floor Plan of the Proposed Design*, 2020, Wellington.

This content has been redacted.

Fig.104. Akito Kamiya, *1:700 The Ground Floor Plan of the Proposed Design,* 2020, Wellington.

This content has been redacted.

Fig.105. Akito Kamiya, *1:700 The First Floor Plan of the Proposed Design,* 2020, Wellington.

This content has been redacted.

Fig. 106. Akito Kamiya, *1:700 The Second Floor Plan of the Proposed Design* 2020, Wellington.

<u>The construction</u>

The specifications

The manufacturer of the timber has been specified as a company Hess Timber Limitless in Germany, since the company has produced timber structures which could form eccentric shapes flexibly. The products have been used all over the world such as the UK, the USA and Australia, so that using such products in New Zealand would be achievable. In addition, a long spanning beam of Hess Timber Limitless has consisted of a series of short beams which could be connected on a project-site. In fact, 55m long beams could be identified in Tennis and bowling center in Petange,Luxembourg (Hess Timber Limitless 20). Furthermore, a timber column provided by Hess Timber Limitless could form a curvy, spiral or twisted shape, and its diameter could be from 150mm to 1000mm (23). Furthermore, there has been a product called "Hess Hybrid" which has a few centimeters-coating of another type of timber on the actual timber structure. In terms of the types of coating, the firm is openminded, so that the coating with different materials such as Rimu on the main structure could be achieved. Therefore, this corporation has been chosen, as it could contribute to the proposed design in such a flexible way.

In terms of the timber-coating of the structures, "whitewood" which almost looks white would be used, in order to match the atmosphere of the fluidity as "beauty" of the principle."

Siberian larch shingles have been selected as the main timber exterior cladding system for this project. This is because the material could last for a long period for the sustainable design. Furthermore, larch has generally been utilized for architecture as aesthetic and durability. Larch could become dark grey from pale yellow/golden brown, as it ages (NORclad; par. 6). In terms of the cladding system, the type of shingles has been selected rather than the type of weather boards, since a complete appearance with shingles could yield an atmosphere of roundness or fluidity, as the image of Chesa Futura that Norman Foster designed with Siberian larch shingles has indicated (fig. 107). This has meant that the cladding of shingles could be useful to fulfill the one of the aspects of Vitruvius's principle. In fact, the shingles of larch would last for approximately 80 years with less maintenance (TPC Siberia, "Larch Roofing"; par. 1). The proposed building's finish could be expected to be the similar one to that of Chesa Futura's exterior. Overall, the exterior walls and roofs of the proposed architecture would be constructed with Siberian larch shingles.

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Fig. 107. Foster+Partners, "Chesa Futura", Pinterest, (Ben Silbermann, 2010), https://www.pinterest.nz/pin/chesa-futura-by-fosterpartners--266908715385959670/. Copyright 2012 by enochliew.

The RESIST structures against the lateral forces

RESIST established by Victoria University in Wellington is a software which is generally utilized for the seismic design of a building at a preliminary design stage of a project. RESIST has also been used to determine the quantity, the size and the position of the structures against the lateral forces for the proposed design, though a different software, Catia was utilized for Guggenheim Museum Bilbao. The structures determined by RESIST should be erected from the bottom of the building and reach the top of the building. It should be avoided to remove a cross brace from each bay or to create any openings on any shear walls ideally. Thus, there have been some restrictions of the structures against the lateral forces. Moreover, RESIST models are created by stretching the floor-boundary upwards, as normal buildings (appendix F). Furthermore, RESIST could assess only eight storeyed buildings. Therefore, if there are any large differences between a RESIST model and an actual more complex design, it will need to make an appropriate adjustment and a proper assumption on the RESIST model. The proposed design was too complex for RESIST to access its seismic design. Thus, the proposed design was divided into five parts and each sector was assessed separately (fig. 108). When the RESIST models were created, the boundaries of the floor plans were simplified slightly, but still followed the original proposed design, so there were zigzag sectors. The actual total volume of the complex proposed building was calculated by Rhinoceros and the yielded value was divided by the ground floor area which had also been calculated by Autocad. As a result, the value of the height of the RESIST model was produced, since a RESIST model usually forms a prism whose volume is calculated by multiplying the ground floor area by the height. However, the calculated value of the height of the RESIST model differed from the true height of the actual proposed design, and it was assumed that such a simplified RESIST model could suffice for the RESIST assessment. The height of the RESIST model was divided by eight which was the maximum of the number of floors in RESIST, and the produced value for each floor height was put in RESIST. Moreover, the profile of the timber braces has been decided as a circular one. RESIST has suggested 600 x 600 mm timber square braces or 600mm diameter braces for the proposed design. However, smooth surfaces of the round structures could symbolize the architectural meaning of the fluidity of streams more properly, compared to the boxy structures. Thus, 600 mm diameter circular braces have been utilized. Then, 600mm diameter timber braced frames spaced three meters apart were applied in RESIST. Thanks to the location which has been Waiheke Island in Auckland, it has turned out that some 600mm diameter timber braced frames constructed in the building could suffice against the lateral force (fig. 108, appendix F). If the location were in Wellington, more braced frames would be required. Thus, the software, RESIST was utilized with regards to the lateral forces which are different from the gravity forces.

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Fig. 108. Akito Kamiya, *RESIST Joined Five Floor Plans for the Proposed Design, (Avoiding the Positions of the Final Exits, the RISIST structures Were Placed.)* 2020, Wellington.

Modeling the complex structures digitally

The software of Grasshopper enables a designer to model structures for complex buildings. The complex form of Guggenheim Museum Bilbao has been supported by the structures which literally form the actual complex building shape. The same structural method was applied and all the bays of the structures which form the shell of the proposed design were modeled by Grasshopper. Various scripts of Grasshopper for modeling structures were discovered online, but the different scripts had their different faults, so that none of them was a perfect script or an absolutely correct script. This was because, even if the method of the script seemed geometrically correct, some complex geometries were still difficult to model. Therefore, different scripts were prepared for each different particular case, and the geometries that were modeled with some compromises needed to be approximated to the true geometries as much as they could. To sum up, the scripts used for the proposed design were the ones developed from the online introduced scripts and unique scripts that were set up during this project, and those were utilized for modeling the complex structures (fig. 109).

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Fig. 109. Akito Kamiya, *One of the Used Structural Scripts*, 2020, Wellington.

The load bearing walls

The sizes of the vertical and horizontal structures of the load bearing walls of the proposed design have been determined by referring to the RESIST outcome and the structural reference books written by Francis D.K. CHING. The proposed museum would possess timber load bearings walls which contain timber columns and timber horizontal structures of walls (fig. 110). Due to the RESIST result, the diameter of the braces was 600 mm. Thus, it was assumed that the circular columns' diameter could be 600 mm, so that the long side of the section profile of such horizontal timber structures could measure 600 mm. The short side of that has been calculated by the ratio shown in the section profile of Glue Laminated Timber according to one structural book (Ching et al. 127). Then, the size of the horizontal structures ended up being 600 x 258 mm. However, another structural book has introduced the ratio of 3:1 for the long side to the short side of section profile of Glue Laminated Timber beam in which case 600 x 200 mm might possibly suffice for the horizontal structures (Ching 4.35). However, 600 x 258 mm has been applied to this proposed design, and it would be specified by the structural engineers. Finally, 600mm diameter cross braces were added to the positions specified by RESIST (fig. 110). The structural braced bays would be continuous from the underground bottom of the building to the top of the building. The braces suggested by RESIST could not usually be removed through the continuous bays in order for the proposed building to endure the lateral forces. In fact, the RESIST structural plan has indicated that the braced frames have been modeled with avoiding the positions of the final exits (fig. 108). Guggenheim Museum Bilbao has indicated as though all of the bays had been braced, and the method to brace all the bay could provide a securer building. However, the number of the positions was minimized for the proposed design as RESIST suggested, unless the structural engineers would recommend bracing more bays. Thus, the positions and sizes of the braces against the lateral force were specified by RESIST and the sizes of the load bearing walls were determined along with the braces.

The wall claddings

The details of the proposed wall structures have been specified at this phase. Normally the horizontal and vertical structures of the exterior wall cladding system could be applied as the secondary and tertiary structures, and those structures are different from the load bearing structures, but those support only the wall cladding. Guggenheim Museum Bilbao has possessed its secondary and tertiary structures of the titanium wall cladding besides the load bearing columns and beams (Center for Design Informatics 10, 11) (fig. 111). The proposed design could have the same cladding structures. However, 10 cm plywood panels are applied with considering 3 m spacing of the primary structural columns and beams of the walls, instead of the exactly same method. Thus the 10 cm plywood panels would be attached to the primary structures and Siberian larch wall shingles and its shingle felt underlayment would be nailed to the plywood panels. The thermal insulation would be inserted between the plywood panels and the interior wall linings. Those have been the proposed details of the wall cladding system for the proposed design, and other components could be added by the manufacturer, if those are necessary.

This content has been redacted.

Fig. 110. Akito Kamiya, *Grasshopper Indicating the Horizontal and Vertical Structures and the Braces of the Curved Wall. (In This Case, the Braces Were Not Modeled Due to the RESIST Floor Plan)*, 2020, Wellington.

This content has been redacted.

Fig. 111. The Tertiary Vertical Structures Attached to the Secondary Horizontal Structures of the Guggenheim Museum Bilbao, Managing the Construction of the Museo Guggenheim Bilbao (B). [Center for Design Informatics, Harvard Design School], p. 10, Didactia database, University of Rome, https://didattica-2000.archived.uniroma2.it//ACALAB2/deposito/case_Guggenheim.pdf. Copyright 1999-2002 by the President and the Fellows of Harvard College.

The load bearing ceiling (roof)

The proposed roof structural system has consisted of 240mm wide 2000mm deep timber beams manufactured by Hess Limitless previously and roof timber decks (Hess Timber Limitless 22). The 240mm wide 2000mm deep timber beams would span each section of the proposed building, so that the exhibition spaces of the proposed building would provide their column-free spaces inside. The spacing of such deep beams has been approximately 3 m as equivalent as the spacing of the 600 mm diameter timber columns (fig. 120). Normally, purlins are traditionally used for constructing a roof structure, but if the loadbearing ceilings of Guggenheim Museum Bilbao are refer purlins red to, purlins have not been utilized but roof metal decks and beams in the one-way system, and some additional blocking where that is necessary have been applied to the museum (fig.23). Therefore, wood decks have been utilized on 240mm wide 2000mm deep timber beams, with timber cross braces or blocking to be added partially by the structural engineers if those are necessary in the proposed design.

Likewise, some details of the proposed roof structures have been specified at this phase. The span of the wooden decks has been 3 m which is the spacing of the 240 mm wide 2000 mm deep timber beams. The timber deck would be 100 mm deep due to the ratio of 1/30 for depth to length cited from "Building Construction Illustrated" (Ching 4.40). Thermal insulation and its vapor barrier would be added between the timber decks and the 240 mm wide 2000 mm deep beams, and the insulation would be covered with another vapor barrier and wooden ceilings, so that the insulation would not be visible inside of the proposed building. Finally, Siberian larch roof shingles and its shingle felt underlayment would be nailed to the timber decks as the exterior roof covering. Those have been the proposed details of the roof cladding system for this project, and other components could be added by the manufacturer, if those are necessary.

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Fig. 112. Akito Kamiya, *The Roof Primary Structures (240 mm Wide 2000 mm Deep) and the Braced Wall Structures (100mm Deep Timber Decks and Blocking are to Be Placed on the Primary Roof Beams)*, 2020, Wellington.

The flexible solar panels and collectors

In order to generate electricity from the sun, flexible solar panels that could be bent or curved would be screwed to the shingles of the proposed roofs and walls (fig.113). The details of the flexible solar panels would be provided by its manufacturers. Likewise, the flexible solar collectors would be installed on the curved surfaces of the proposed architecture. Furthermore, it has been identified that several parts of the walls and roofs would not been oriented to the sun, so that those sections would not gain so much solar heat, according to the Ladybug solar radiation study. Therefore, those parts would have no solar panels or collectors on themselves and remain as shingles, but those claddings would be painted in blue. Then, a continuity between the solar panels, the solar collectors and the blue shingles would be identified on the roofs and some portion of the walls. This treatment of the finish could provide an atmosphere of the fluidity. Overall, the flexible solar panels and collectors would be utilized to generate the electricity on the curved surfaces.

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Fig. 113. Flexible lightweight solar panels, Solar Constructions, [Solar Constructions], http://www.solar-constructions.com/wordpress/flexible-solar-panel/#, Copyright by Solar Constructions.

The structures of the residential area

A different structural system has been applied to the residential section of the proposed building. The 600 mm diameter circular timber columns would be internally constructed every 10 m for the residential zone, whereas other exhibition spaces would have column free spaces. This has been because if the residential area had the same structural arrangement which provides column free spaces, the depth of the beams which support each floor would be as large as 2 meters. In such a situation, each floor would need to have an adequate height in order to accommodate the deep beams and the ducts of the HVAC system. However, the height of the residential zone would be 4 m whereas that of the exhibition spaces would be 9 m. Therefore, the solution has been to erect the internal columns in order to minimize the depth of the beams and the height of each floor. Furthermore, the size of the timber beams which would support each floor with spanning approximately 10 m has been 500 mm deep and 167 mm wide, due to the ratio introduced in a reference book (Ching 4.35). Those beams would be supported by the internal 600mm diameter timber columns spaced 10 m apart and the external 600mm diameter timber columns spaced at 3 m (fig. 105, 106). The sizes of the timber structures could vary, as the structural engineers suggest. To sum up, the structural system for the proposed residential zone has differed owing to the 4 m height of each residential floor.

The structures of the underground floor

In terms of the underground construction, steel and concrete have been utilized besides timber. In this proposed design, open web steel joists have been selected in order to minimize the depth of the beams supporting the ground floor. In a comparison, the depth of a timber beam would usually be larger than that of a steel beam in order to support a same load, due to the durability of the materials. Furthermore, the open web steel joists could let the ducts of the HVAC system go through themselves, so that if the open web steel joists are used, the 5 m deep underground space can still have the ample space. Such open web steel joists could span 18 m with the 750 mm depth, due to the ratio of 1:24 for the depth to the span (fig. 114) (Ching et al. 117). The size of the joist has been 194 mm wide and 750 mm deep due to the ratio of the cross section introduced in the book. In addition, external underground walls would be constructed of concrete, as the walls of a basement are normally constructed of concrete. Thus, those material-selections have been made based on constructing an underground space with considering the depth of the space and the durability of the materials.

In this proposed design, it would be distinctive how to transfer the load above the ground to the underground structures. Normally load bearing columns should penetrate underground space all the way through from the top of the building to the very bottom of the underground space. However, some of the columns would not penetrate the underground space, since the totally different orthogonal underground exhibition spaces have been conceived. However, all the internal walls underground would be 600 mm thick walls which contain 600mm diameter load bearing timber columns in order to compensate for the columns not penetrating the underground space. However, the only structures that have been set up by RESIST would penetrate the underground space due to the seismic design. Thus, the only structures specified by RESIST would be braced continuously from the top of the building to the bottom of the underground space (fig. 103). This has meant that the other structural bays could have no cross braces unless the structural engineers recommend adding the cross braces. Furthermore, the other load bearing columns that have no cross braces to themselves would need to transfer the load to the very bottom of the underground space without such a penetration. The open web steel joists just below the boundary of the ground floor had to be designed, because the parameter of the ground floor would indicate the positions of the loadbearing columns (fig. 104, 115). Thus, in order to transfer the load obtained above the ground floor, such open web steel joists will transfer the load to any columns or structural walls to which the joists are connected. Such columns would be embodied in the 600 mm internal loadbearing walls underground. Thus, the way to transfer the load to the underground space has been rather eccentric except where the structure specified by RESIST has been incorporated in the proposed design.

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Fig. 114 Akito Kamiya, *Schematic Underground Structural Plan Indicating the Open Web Steel Joists and the Walls,* 2020, Wellington.

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Fig. 115. Akito Kamiya, *One Sector of the Open Web Steel Joists Just below the Boundary of the Ground Floor,* 2020, Wellington.

Conclusion

In conclusion, to answer the research question, “How could a work of architecture that is designed to evoke a Bilbao effect be designed sustainably and in accordance with Vitruvius’s principle?”, the site and the program choices for the project would be very crucial to evoke a Bilbao effect. The site should be linked to other tourism which could attract a number of travelers who could gather in hostels. For instance, with respect to Waiheke Island, Auckland is the site that could potentially evoke a Bilbao effect due to New Zealand depending on the tourism industry and the tourism of Waiheke island and Auckland. The suitable program would be a museum, a venue of art activities and sight-seeing besides hostels which travelers almost always utilize. Furthermore, the architectural form should be designed well so as to attract the visitors. Therefore, the experimentation of the architectural forms would be essential and the form would develop through the iterative process. Moreover, in order to resolve the construction issues of such complex architecture, it would be necessary to integrate using software into the design-method.

In terms of the sustainability, timber has been the most sustainable material of the three materials which are steel, concrete and timber, according to LCAQuick. The sustainable strategy would need to be specified by psychrometric chart with an awareness of precedent. The low energy consumption building could be achieved by manipulating the natural and mechanical sustainable features flexibly. For example, providing water area around the proposed building could lower the temperatures in hot summer and orienting the long facade of the building to the sun could positively warm the entire building naturally and passively in winter. The voids of the atriums and the openable windows would also contribute for the natural ventilation, although the thermal comfort could be adjusted mechanically. The flexible solar panels and collectors, the CCHP system and the UV sterilization unit would be integrated. Moreover, the grid is to be connected to those sustainable features.

Finally, the architecture would need to combine a rigid structural system and provide the required functions, while achieving its architectural expression with its meaning. For instance, this proposed design has been designed with considering the proper structures and the acceptable utility of the programs. The meanings of the Waiheke island “trickling water” and “long sheltering island” have been embodied into the form of the architecture. Those three layers have been the essential elements in order to fulfill Vitruvius’s principle.

In addition, my thesis has been devised to allow me to explore current design software. This includes acquiring expertise of how to digitize a complex hand-made architectural model, how to model the complex structures digitally with understanding the existing structures of a complex building such as Guggenheim Museum Bilbao, how to utilize the plug-ins Ladybug and Honeybee which possess the potential in the sustainable design and how to manipulate several other plug-ins such as Pachyderm Acoustical Simulation and Pufferfish for the acoustic performance of a functional building. The expertise has enabled me to design the proposed architecture in order to address the research question.

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The works on P. 51,52 and 53 have been created by Akito Kamiya.

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Appendix A. Akito Kamiya, *The investigated residential house on Waiheke island,* 2020,Aukland.

Appendix B. Dominic Glamuzina, *The Ground Floor Plan of the Residential House (the North Being Up),* 2006, Glamuzina Architets, Auckland.

This content has been redacted.

Appendix C. Dominic Glamuzina, *The First Floor Plan of the Residential House (the North Being Up),* 2006, Glamuzina Architets, Auckland.

This content has been redacted.

Appendix D. Dominic Glamuzina, *The Section of the Residential House Indicating the Void,* 2006, Glamuzina Architets, Auckland.

This content has been redacted.

Appendix E. Athfield Architects Limited, *The Section Indicating the 5 meter Deep Underground Space Near Lambton Harbour*, 2014, Wellington.

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Appendix F. RESIST Reports. ARCI 591 1/5-5/5, New Zealand Society for Earthquake Engineering, 2021.

RESIST 4.0.0.2475

RESIST(NZ) - Preliminary Lateral Load Design Architectural Report

RESIST is an application for the simplified evaluation of the structural performance of lateral load-resisting systems in a building under seismic and wind loads. It is designed to be used in educational settings as a guide for the sizing of lateral load resisting systems for Architectural and Civil Engineering students. RESIST should not be used as a final preliminary design; a full, complete preliminary design should be carried out by a structural engineer.

Project: **ARCI 591 1/5**
Modeller: **Akito Kamiya**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	7%	28%	31%
Brace	3%	79%	12%

Y-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	7%	26%	27%
Brace	3%	68%	9%

Wind Vibrations

The building does not appear to be susceptible to wind vibrations or other serviceablility problems caused by wind. $H^{1.3}/M$ = 0.0975 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Contains crowds/high-value contents
Number of storeys	8
Total height	22.32 m
Floor plan points	(38.86, -4.72), (32.71, -23.93), (15.47, -17.49), (0, 0), (0.58, 27.48), (31.55, 45.06), (60.57, 41.05), (80.34, 51.44), (98.34, 55.72), (96.23, 64.38), (103.9, 72.02), (112.8, 98.74), (122.9, 46.56), (101.9, 3.92), (64.35, -8.28), (54.9, -14.3)
Floor plan properties	Area: 6541 m^2; Perimeter length: 413.1 m; Centroid: (62.3, 23.56) m; Bound lengths: (122.9, 122.7) m
Inter-storey height	2.79 m
Floor	Weight type: light, Dead load: 0.66 kPa, Live load: office (3.00 kPa)

Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)
External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: light, Weight type: light, Height: 0 m, Dead load: 0.40 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Timber Cross Braced Frame (x 20) Locations: (42.52, -4.785), (30.45, -23.45), (25.31, -19.83), (47.95, -10.18), (35.58, -13.19), (53.54, -14.28), (59.49, -8.574), (65.58, -8.448), (71.66, -5.301), (77.53, -3.791), (83.45, -2.113), (89.83, 0.7815), (95.78, 2.501), (101.8, 4.096), (108.6, 14.75), (114.7, 26.83), (118.8, 33.63), (120.7, 53.26), (116.9, 64.21), (113.5, 76.67)
Structure in Y direction	Timber Cross Braced Frame (x 20) Locations: (39.07, -7.398), (86.74, 1.049), (33.23, -19.84), (21.92, -20.26), (50.81, -13.1), (56.85, -11.47), (68.6, -5.889), (45.15, -7.609), (102.5, 7.41), (105.7, 12.19), (109.4, 17.77), (112, 23.06), (120, 37.03), (116.2, 29.85), (122.2, 42.69), (122.2, 49.11), (121.1, 55.91), (118.8, 61.57), (118.1, 67.23), (116.9, 74.03)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	A6
Terrain category	Open
Lee effect zone	None
Site elevation	0 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	1000	25
Regional 3s gust wind speed, V_R (m/s)	46	37

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.13
Soil:	Very soft soil (E)
Recurrence interval years:	1000 (U) ; 25 (SLS1)
Return Period factor, R:	1.3 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	20
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 10.30 m, pad depth: 2.00 m To anchor the lateral resisting component against tensile uplift, provide 1100 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1500 mm; Width=1500 mm
Beam Design	Depth=350 mm ; Width=250 mm

Lateral Load Structure, Y Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	20
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 9.60 m, pad depth: 1.93 m To anchor the lateral resisting component against tensile uplift, provide 1050 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1400 mm; Width=1400 mm
Beam Design	Depth=350 mm ; Width=250 mm

RESIST Limitations

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- The design of Steel Eccentric Braced Frames (EBF) requires careful design to ensure they behave as expected. RESIST only carries out an initial assessment of the design of the EBF; there are many other aspects to the design of EBF that will require design by the Structural Engineer.
- RESIST uses an elastic approach for evaluating torsion effects. Generally torsion effects should be evaluated by taking into account inelastic deformations.
- RESIST does not carry out a design of gravity load support system, e.g. columns and beams, floor system.
- The lateral resisting systems provided by RESIST are only representative of the possible choices currently available. New technologies such as buckling restrained braced frames, base isolation, and other systems may be a suitable choice for a building. The Structural Engineer will provide guidance.
- Fire protection of members is not accounted for by RESIST. If required this may require an increase in the overall size of the members.
- RESIST does not analyse hybrid resisting systems where different resisting systems are used in the same direction, e.g. walls and frames.
- RESIST allows only resisting systems aligned to X and Y axes.

This content has been redacted.

RESIST 4.0.0.2475

RESIST(NZ) - Preliminary Lateral Load Design Architectural Report

RESIST is an application for the simplified evaluation of the structural performance of lateral load-resisting systems in a building under seismic and wind loads. It is designed to be used in educational settings as a guide for the sizing of lateral load resisting systems for Architectural and Civil Engineering students. RESIST should not be used as a final preliminary design; a full, complete preliminary design should be carried out by a structural engineer.

Project: **ARCI 591 2/5**
Modeller: **Akito Kamiya**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	11%	26%	26%
Brace	5%	67%	9%

Y-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	9%	24%	26%
Brace	3%	57%	8%

Wind Vibrations

The building does not appear to be susceptible to wind vibrations or other serviceablility problems caused by wind. $H^{1.3}/M$ = 0.163 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Contains crowds/high-value contents
Number of storeys	8
Total height	22.32 m
Floor plan points	(15.24, 15.12), (25.02, 28.45), (45.89, 32.57), (69.09, 61.17), (63.42, 76.88), (67.29, 91.82), (55.43, 87.95), (54.66, 75.07), (41.25, 58.07), (25.79, 109.1), (18.1, 93.93), (-5.88, 71.25), (4.59, 55.33), (-15.05, 47.77), (-16.83, 38.71), (0, 0)
Floor plan properties	Area: 4188 m^2; Perimeter length: 370.1 m; Centroid: (22.7, 52.85) m; Bound lengths: (85.92, 109.1) m
Inter-storey height	2.79 m
Floor	Weight type: light, Dead load: 0.66 kPa, Live load: office (3.00 kPa)

Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)
External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: light, Weight type: light, Height: 0 m, Dead load: 0.40 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Timber Cross Braced Frame (x 12) Locations: (3.188, 6.045), (23.57, 105.1), (9.403, 11.43), (15.08, 17.01), (20.45, 22.64), (-14.03, 44.88), (-12.26, 49.91), (-3.151, 53.24), (2.702, 55.26), (2.57, 61.87), (-3.181, 67.91), (18.62, 101.2)
Structure in Y direction	Timber Cross Braced Frame (x 12) Locations: (6.163, 8.623), (11.84, 14.33), (0.2031, 3.085), (17.55, 19.96), (22.97, 25.74), (-16.82, 41.74), (-14.96, 48), (24.6, 106.5), (-5.515, 53.6), (2.862, 58.74), (-2.957, 64.41), (-5.419, 71.01)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	A6
Terrain category	Open
Lee effect zone	None
Site elevation	3 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	1000	25
Regional 3s gust wind speed, V_R (m/s)	46	37

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.13
Soil:	Very soft soil (E)
Recurrence interval years:	1000 (U) ; 25 (SLS1)
Return Period factor, R:	1.3 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Timber Cross Braced Frame
Design method	Limit-state

Number of frame-lines	12
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 9.40 m, pad depth: 1.90 m To anchor the lateral resisting component against tensile uplift, provide 1000 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1375 mm; Width=1375 mm
Beam Design	Depth=350 mm ; Width=250 mm

Lateral Load Structure, Y Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	12
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 8.80 m, pad depth: 1.78 m To anchor the lateral resisting component against tensile uplift, provide 925 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1275 mm; Width=1275 mm
Beam Design	Depth=350 mm ; Width=250 mm

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RESIST 4.0.0.2475

RESIST(NZ) - Preliminary Lateral Load Design Architectural Report

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Project: **ARCI 591 3/5**
Modeller: **Akito Kamiya**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	5%	18%	19%
Brace	4%	89%	13%

Y-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	7%	19%	20%
Brace	6%	100%	14%

Wind Vibrations

The building does not appear to be susceptible to wind vibrations or other serviceablility problems caused by wind. $H^{1.3}/M$ = 0.144 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Contains crowds/high-value contents
Number of storeys	8
Total height	22.32 m
Floor plan points	(-42.94, 48.37), (-40.56, 30.49), (-16.83, 38.71), (0, 0), (-43.78, -7.16), (-83.78, -17.7), (-96.17, -11.43), (-90.83, 46.91), (-62.02, 31.18), (-53.68, 41.62), (-72.81, 43), (-51.71, 64.16), (-66.15, 73.69), (-60.32, 87.55), (-45.96, 79.27), (-36.5, 62.1)
Floor plan properties	Area: 4905 m^2; Perimeter length: 422.5 m; Centroid: (-53.93, 21.79) m; Bound lengths: (96.17, 105.2) m
Inter-storey height	2.79 m
Floor	Weight type: light, Dead load: 0.66 kPa, Live load: office (3.00 kPa)

Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)
External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: light, Weight type: light, Height: 0 m, Dead load: 0.40 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Timber Cross Braced Frame (x 12) Locations: (-79.48, -15.79), (-73.12, -14.42), (-87.19, -15.49), (-93.04, -12.31), (-66.01, -13.22), (-60.11, -11.14), (-47.45, -7.313), (-31.95, 32.89), (-26.2, 35.61), (-20.08, 38.96), (-37.4, 31.29), (-41.37, 36.9)
Structure in Y direction	Timber Cross Braced Frame (x 7) Locations: (-90.27, -15.21), (-69.65, -14.58), (-57.38, -9.678), (-33.13, 33.11), (-22.82, 35.83), (-41.37, 33.61), (-41.84, 39.49)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	A6
Terrain category	Open
Lee effect zone	None
Site elevation	3 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	1000	25
Regional 3s gust wind speed, V_R (m/s)	46	37

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.13
Soil:	Soft soil (D)
Recurrence interval years:	1000 (U) ; 25 (SLS1)
Return Period factor, R:	1.3 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Timber Cross Braced Frame
Design method	Limit-state

Number of frame-lines	12
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 9.50 m, pad depth: 1.90 m To anchor the lateral resisting component against tensile uplift, provide 1200 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1600 mm; Width=1600 mm
Beam Design	Depth=400 mm ; Width=300 mm

Lateral Load Structure, Y Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	7
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 10.00 m, pad depth: 2.00 m To anchor the lateral resisting component against tensile uplift, provide 1250 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1700 mm; Width=1700 mm
Beam Design	Depth=400 mm ; Width=300 mm

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Project: **ARCI 591 4/5**
Modeller: **Akito Kamiya**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	8%	26%	29%
Brace	3%	73%	10%

Y-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	8%	28%	28%
Brace	4%	80%	11%

Wind Vibrations

The building does not appear to be susceptible to wind vibrations or other serviceablility problems caused by wind. $H^{1.3}/M$ = 0.147 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Contains crowds/high-value contents
Number of storeys	8
Total height	22.32 m
Floor plan points	(-80.49, -83.67), (-51.22, -54.14), (-11.9, -37.26), (-37.17, -55.45), (-51.95, -77.89), (-74.12, -84.96), (-61.09, -90.36), (-13.98, -84.96), (3.16, -59.02), (0, 0), (-11.42, -13.38), (-39.38, -13.17), (-44.72, -20.67), (-63.16, -23.7)
Floor plan properties	Area: 4387 m^2; Perimeter length: 453.2 m; Centroid: (-32.39, -49.32) m; Bound lengths: (83.65, 90.36) m
Inter-storey height	2.79 m
Floor	Weight type: light, Dead load: 0.66 kPa, Live load: office (3.00 kPa)

Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)
External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: light, Weight type: light, Height: 0 m, Dead load: 0.40 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Timber Cross Braced Frame (x 14) Locations: (-28.68, -51.17), (-14.32, -37.91), (-24.54, -47.85), (-19.95, -43.24), (-33.38, -53.93), (-14.87, -41.22), (-41.45, -61.68), (-46.17, -68.36), (-52.43, -75.59), (-59.11, -80.22), (-70.23, -84.67), (-64.11, -81.34), (-19.43, -39.62), (-10.53, -77.44)
Structure in Y direction	Timber Cross Braced Frame (x 10) Locations: (-25.07, -46.95), (-34.76, -52.82), (-17.08, -39.57), (-43.02, -65.39), (-38.57, -58.44), (-49.65, -72.06), (-56.33, -78), (-66.71, -82.45), (-11.64, -81.71), (-8.675, -73.73)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	A6
Terrain category	Open
Lee effect zone	None
Site elevation	3 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	1000	25
Regional 3s gust wind speed, V_R (m/s)	46	37

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.13
Soil:	Very soft soil (E)
Recurrence interval years:	1000 (U) ; 25 (SLS1)
Return Period factor, R:	1.3 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Timber Cross Braced Frame

Design method	Limit-state
Number of frame-lines	14
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 9.90 m, pad depth: 2.00 m To anchor the lateral resisting component against tensile uplift, provide 1050 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1475 mm; Width=1475 mm
Beam Design	Depth=400 mm ; Width=300 mm

Lateral Load Structure, Y Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	10
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 10.40 m, pad depth: 2.00 m To anchor the lateral resisting component against tensile uplift, provide 1100 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.79 m; Depth=1525 mm; Width=1525 mm
Beam Design	Depth=400 mm ; Width=300 mm

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RESIST 4.0.0.2475

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Project: **ARCI 591 5/5**
Modeller: **Akito Kamiya**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	11%	23%	32%
Brace	3%	47%	9%

Y-Direction: Timber Cross Braced Frame

	Wind	Seismic (U)	Seismic (S)
Drift	9%	30%	39%
Brace	4%	99%	17%

Wind Vibrations

The building does not appear to be susceptible to wind vibrations or other serviceablility problems caused by wind. $H^{1.3}/M$ = 0.158 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Normal structures
Number of storeys	8
Total height	22.24 m
Floor plan points	(2.96, -59.33), (7.41, -74.2), (27.48, -75.73), (47.48, -83.4), (67.96, -72.96), (88.4, -56.38), (76.83, -50.46), (52.73, -56.14), (58.18, -37.88), (42.11, -20.19), (43.78, 7.16), (0, 0)
Floor plan properties	Area: 4458 m^2; Perimeter length: 318.3 m; Centroid: (32.32, -41.53) m; Bound lengths: (88.4, 90.56) m
Inter-storey height	2.78 m
Floor	Weight type: light, Dead load: 0.66 kPa, Live load: office (3.00 kPa)

Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)
External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: light, Weight type: light, Height: 0 m, Dead load: 0.40 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Timber Cross Braced Frame (x 13) Locations: (11.08, -74.72), (17.64, -74.92), (23.31, -75.12), (6.747, -65.8), (60.17, -76.24), (35.28, -78.12), (30.54, -75.61), (40.86, -80.07), (54.23, -80.07), (46.71, -83.41), (66.22, -72.26), (73.75, -67.53), (79.32, -63.07)
Structure in Y direction	Timber Cross Braced Frame (x 9) Locations: (52.69, -80.21), (82.63, -61.18), (6.291, -68.15), (40.51, -81.46), (33.61, -78.4), (62.32, -75.33), (70.12, -69.76), (75.98, -65.85), (8.522, -73.66)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	A6
Terrain category	Open
Lee effect zone	None
Site elevation	100 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	500	25
Regional 3s gust wind speed, V_R (m/s)	45	37

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.13
Soil:	Very soft soil (E)
Recurrence interval years:	500 (U) ; 25 (SLS1)
Return Period factor, R:	1.0 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	13

Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 7.90 m, pad depth: 1.60 m To anchor the lateral resisting component against tensile uplift, provide 850 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.78 m; Depth=1125 mm; Width=1125 mm
Beam Design	Depth=300 mm ; Width=250 mm

Lateral Load Structure, Y Direction

Type	Timber Cross Braced Frame
Design method	Limit-state
Number of frame-lines	9
Total No. bays/frame-line	2
No. braced bays/frame-line	2
Max No. adjacent bays/frame-line	2
Bay length	3 m
Floor width supported by braced-bay beam	3 m
Brace	Depth: 600 mm; Width: 600 mm; Area: 360000 mm^2
Foundations	Foundation beam: centre-line distance between pads: 6.00 m, square pad width: 11.50 m, pad depth: 2.00 m To anchor the lateral resisting component against tensile uplift, provide 1250 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Column Design(Each end of bay(s) with braces)	Column Length=2.78 m; Depth=1700 mm; Width=1700 mm
Beam Design	Depth=400 mm ; Width=300 mm

RESIST Limitations

RESIST has been designed as an education tool, primarily for Architecture students, as a means for initial sizing of lateral resisting elements for wind and earthquake loading.

RESIST may be used as a small part of the overall design process:

1. Initial preliminary design. RESIST can be used as a way of initial sizing and testing options, providing a point of discussion between architects and engineers.
2. Once a conceptual design has been formulated, the Structural Engineer will carry out another preliminary design, where ALL assumptions and initial sizes are re-evaluated for accuracy and appropriateness. RESIST cannot be used as a substitute for a complete preliminary design by a Structural Engineer.
3. Final design will follow from the structural engineer's preliminary design, and the results from RESIST should have no influence on this stage of the structural design.

RESIST does not analyse or design the following:

- Floor diaphragms are not evaluated by RESIST. It is assumed that the floor diaphragms have sufficient rigidity and strength to transfer loads to all the resisting elements. They are assumed to be rigid. The floor plan editor allows non-rectangular floor diaphragms, which if highly irregular will require careful design by the Structural Engineer.
- Connections within the resisting elements and the rest of the building are not analysed or designed by RESIST. Such connections are critical to the performance of the building, and are assumed by RESIST to be have sufficient strength to ensure the expected performance of the resisting elements.
- RESIST assumes the lateral structure to be uniform for the full height of the building. In practise section sizes will reduce with height, but this requires careful design by the Structural Engineer.
- The design of Steel Eccentric Braced Frames (EBF) requires careful design to ensure they behave as expected. RESIST only carries out an initial assessment of the design of the EBF; there are many other aspects to the design of EBF that will require design by the Structural Engineer.
- RESIST uses an elastic approach for evaluating torsion effects. Generally torsion effects should be evaluated by taking into account inelastic deformations.
- RESIST does not carry out a design of gravity load support system, e.g. columns and beams, floor system.
- The lateral resisting systems provided by RESIST are only representative of the possible choices currently available. New technologies such as buckling restrained braced frames, base isolation, and other systems may be a suitable choice for a building. The Structural Engineer will provide guidance.
- Fire protection of members is not accounted for by RESIST. If required this may require an increase in the overall size of the members.
- RESIST does not analyse hybrid resisting systems where different resisting systems are used in the same direction, e.g. walls and frames.
- RESIST allows only resisting systems aligned to X and Y axes.

This content has been redacted.

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