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“Design of a universal mounting system for flat panel TV screens”

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Master’s thesis in Engineering Design…END-3900-24V…May 2024

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ABSTRACT

In compact living spaces like micro-houses and apartments, there is a growing interest in décor and furnishing that utilize multi-functional systems and furniture. Of particular interest is the ability to facilitate the transformation of room setups, allowing for changes in the viewing positions of TVs regardless of alterations in room orientation.

A thorough examination of the problem area uncovered several shortcomings in current market designs. These include limited adjustability, where fixed TV mounts mounted on walls or ceilings lack flexibility, making it difficult to achieve desired viewing angles without dismantling and reassembling the setup.

Additionally, there are issues with limited compatibility, as some TV mounts fail to adhere to established VESA standards, a universal mounting standard for flat panel displays. Furthermore, many modern TV mounts lack additional functionality, such as cable management, resulting in cluttered and unsightly cable arrangements.

The objective of the master thesis project is to develop a full-motion universal mounting system for flat panel displays that addresses these challenges. The system will be designed to be easily mountable and capable of supporting large and heavy television sizes.

Utilizing 3D modeling software, such as SolidWorks, the product was meticulously designed to meet all design requirements.

Additionally, Granta EduPack was employed to select the optimal material for the TV mount that is light, cheap and strong ensuring durability and safety.

An extensive analysis of the product was performed on the compound beam of the product to validate whether the product is strong enough to withstand the design load of 55” – 70” flat display. The section modulus was identified as the contributing factor to the higher stiffness of the beam produce reduced deflections.

With the aim of a minimizing weight, the minimum design cross-section of the beam was obtained by means of the safety analysis criterion. The cross section of the beam was optimized to accommodate the design load and also help reduce manufacturing and material cost and usage.

NOMENCLATURE

TV – Television

FD – Flat Displays

VESA – Video Electronics Standards Association

DOF – Degree of Freedom

FOS – Factor of Safety

FDMI – Flat Display Mounting Interface

MIS – Mounting Interface Standard

FOS – Factor of Safety

1 PROBLEM DESCRIPTION

1.1 Introduction

In small houses and apartments, décor and furnishing by using multi-functional systems and furniture are of great interest. This is a way to keep the layout and devices in rooms in orderly fashion, for example placing TV and microwaves on tables, wardrobes for clothes etc., brought about innovative carpentry designs to provide stools and cabinets for the placements of televisions and other devices.

The flexibility of changing the viewing positions and angles of TVs by either rotating it to a angle or extending its distance from the wall at different places in a living room and being able to also move it out of the area in the room when not in use by retracting it to the ceiling top or along the wall etc. using remote controller or manual means. The ability to aid the transformation of a room setup by allowing the change of the viewing positions of the TV regardless of a change in the direction of the room the TV is set up.

The need to be able to rotate TV to different positions for more viewing angles depending on the setup of the room led to the manufacturing of first version of the most TV mounts we have today. A lot has changed as times changed and different versions has been brought forward depending on the weight capacity of the Television and specified mounting style, whether on the table, wall, ceiling etc.

1.2 Historical Review

With the invention of household television in the early years also known as the Cathode Ray Tube (CRT), due to its heavy aesthetics was placed on heavy wood table or block compartments and others being placed on the floor due to the nature of the room, the furniture available or the preference of the household (*Figure 1*).

With the improvement in the TV mount design, the original way of mounting TV was overthrown by a new style of mounting( *Figure 2*) which is an early version of the modern designs we have today.

Figure 1:CRT placed on a solid wood stand, (2022), by Avery. (Source: Reddit) Available from (https://www.reddit.com/r/crtgaming/comments/x1cysc/the_back_breaker_9000_sony_kv34hs420_is_finally/) [Cited on Feb. 9, 2024].

Figure 2: CRT monitor on wall mount. Available from (https://goodshoppin.top/ProductDetail.aspx?iid=540223833&pr=69.88) [Cited on Feb. 9, 2024].

The introduction of flat panel displays by manufacturers also led to improvements in previous designs and developments that have improved the flexibility of TV mounting styles and adjustable viewing positions and angles. Developments such as TV-lifts (*Figure 3*), mobile tv mounts (*Figure 4*), wall mounts (*Figure 5*), ceiling mounts (*Figure 6*) and table mounts (*Figure 7*).

Figure 3: Motorized TV Lift (Drop down). Posted by Firgelli Automations (Source: Pinterest). Available from (https://www.pinterest.com/pin/676314069029627199/) [Cited on Feb. 9,2024].

Figure 4: Mobile TV Stand. (Source: Amazon). Available from (https://www.amazon.com/Mount-Mobile-Wheels-Adjustable-Rolling/dp/B01N4KNOTM) [Cited on Feb 9,2024].

Figure 5: TV wall mount. (Source: StarTech.com). Available from (https://www.startech.com/en-eu/display-mounting-ergonomics/fha-tv-wall-mount) [Cited on Feb 9,2024].

Figure 6: Ceiling TV mount (Source: IndiaMart). Available from (https://www.indiamart.com/proddetail/ceiling-tv-mount-bracket-21446507091.html) [Cited on Feb. 9, 2024]

Figure 7: Dual monitor table mount. (Source: Target). Available from (Dual Monitor Mount – Clamp-on Monitor Arm With 2 Adjustable Vesa Mounts – Black – Stand Steady : Target) [Cited on Feb. 9, 2024]

Figure 8: Flat display with custom stand. (Source: Amazon). Available from (https://www.amazon.com/Acer-UM-FV6AA-003-24-Inch-Screen-Monitor/dp/B00BI37RNG) [Cited on Feb. 9,2024]

1.3 Identifying Opportunities

1.3.1 State-of-the-Art

Extensive work has been done in the area of TV mounting systems over the years. The device has seen some changes in the designs and improvements by major manufacturing companies such as Ergotron, Samsung, TLC etc., producing several TV mounts for different TV sizes and mounting style. The literature by Jaeheon Chung, Byung-Ju Yi and Sung Oh also describes the development of a three degree of freedom (DOF) parallel mechanism model having two rotational and one translational motion that utilizes an asymmetrical parallel structure that has three kinematic chains with internal four bar linkage to support the heavy weight of flat panel TV.(Jaeheon et al., 2009)

The Flat Panel TV screen frame system invented by Steve Sanchez, Walnut Creek, CA (US) is a wall mountable flat panel TV screen by connector structure. The connector structure connects the frame to the flat panel TV screen with the frame surrounding the flat panel TV screen and the flat panel TV screen is observable through the frame opening.(Sanchez, 2004)

The universal mounting system for flat panel display invented by Christopher Petrick, Robert Coon, Bjorn Gunderson, Jimmy-Quang Viet Doan and Clifford Krapfl includes a plurality of angularly disposed telescoping arms that are interconnected to a central hub. The arms are intermeshed to provide a synchronized movement relative to each other. By properly adjusting the angle of the arms, connection points on the arms may be positioned adjacent a plurality of different hole placements to thereby allow the mounting system to connect to flat panel displays in different VESA (Video Electronics Standards Association) categories or to flat displays that do not conform the VESA standard.(Petrick et al., 2009)

The article(Chung et al.) by Jaecheon Chung, Sang Heon Lee, Byung-Ju Yi and Whee Kuk Kim describes a 3-DOF mounting system with the task of fitting a large glass window panel at a construction site. It also implements a folding mechanism such the Scott-Russell mechanism with optimally designed link lengths which effectively control a construction robot handling of the large and heavy glass plate. Other linkage mechanisms could have been used to implement the foldability of parts of the mounting system which will be explored in much detail in this master thesis.

Other examples of inventions include the TV mount bracket (Pei, 2020a) (Pei, 2020b)by Xubo Pei, Shenzhen (CN) which aid the fixed mounting of Flat panel screen displays on the wall.

In several applications of the TV mounts in modern households, hotels and offices, the placement of the TVs has been an integral part of the setup of a room and how accommodating it is going to be. To devise a solution, a deep dive into the problem area gave light into the drawbacks in most current designs needing some design improvements. The identified opportunities in the market that needs to be satisfied are as follows:

- **Limited Adjustability:** Some examples of mounts such as the full motion wall mount (*Figure 5*) and ceiling mount (*Figure 6*) offer a great number of advantages in terms of the tilt angles, extension and rotation, but are fixed to either the wall or ceiling and do not allow for movement of mount from fixed position. In a case of change in room setup or viewing direction, the fixed mounting position must be changed by dismantling and assembling the mounting setup at the new position making it challenging to achieve a number of desired viewing angles.

- **Limited compatibility:** Some TV mounts are designed for some particular Flat panel displays ((*Figure 8*) for example) without adhering to the VESA standards and other TV mounts are made for few flat panel display sizes. Other TV mount cannot be used in certain room layouts which brings about the need for a new TV or new set of mounting system compatible with the TV.

- **Limited functionality:** Many modern TV mounts lack additional functionality such as cable management (*Figure 9*), leaving the cables to hang out at the back of the TV resulting in a cluttered and unsightly appearance.

Figure 9: Dangling TV cables, (2019). Posted by Josh Soupir. (Source: ECHOGEAR), Available from https://www.echogear.com/blog/how-to-hide-tv-wires-in-or-on-the-wall/ [Cited on Feb. 9,2024].

1.4 Product Character

Goal

A universal mounting system for flat panel screens.

Context

In small houses and apartments, people desire to be able to transform their room setup where they get to watch TV at different positions and in different rooms when they want to and be able to pack it away (out of way) after use. A mobile TV mounting system that aids the transformation of a room setup with the flexibility of varying the TV viewing angles or positions regardless of a change in the direction of the room the TV is setup. A universal product that can be used with a wide range of standard TVs and adaptable to a range of room layouts.

Constraints

1. It should be easy to mount.
2. It should be durable.
3. It should be robust.
4. It should be reliable.
5. It should be safe.
6. Can withstand and support a range of TVs from 55 – 70 inches.

Criteria

1. It should be user-friendly.
2. It should be flexible.
3. Nice appearance
4. Ease of assembling and disassembling.

The constraints listed above for the product set the targets within which the design must be achieved, and the criteria will be used for evaluating between different design proposals, each of which meets the constraint targets.

The *rational methods approach* (Cross, 2008) used in the design process will help generate a solution that is easy to mount, has added functionalities and compatible with different room layouts and Flat panel displays.

Problem Thesis: *"Design a universal mounting system for flat panel TV screens."*

2 CLARIFYING OBJECTIVES

Based on the design brief and deep dive into the problem area, the aim of this thesis is to design a universal mounting system that is:

- Easy to mount, can be placed in different angles (flexible), can be move from one position in a room to another (movable) and should be nice.

- Able to withstand the weight of the TV and carry TVs from size 55 inch to 70 inch.

To describe the list of objectives, the method known as the objective tree (Cross, 2008) was used to sort them into ordered sets of higher order and lower order objectives. The aim of the objective tree is to expand and clarify the general objectives into more specific and simpler ones, which implies a "Means-End" relationship; that is, a lower-level objective is a means to achieving a higher-level one. The type of questions such as 'why?' and 'how?' are useful to expanding and clarifying objectives.

The first set of objectives describes the adjustability, aesthetics and ergonomic factors of the design grouped under the general objective which relates to the convenience of the product. The second set of objectives describes the compatibility, safety, functions and performance factors of the design grouped under the general objective of how reliable the product is to perform its functions. The objectives are based upon the compartmentalization of the product character, character of context, constraints, criteria, materials, personality, and usability.

The objectives for the end-product or solution are mainly based on design, function, and operation. Some sub-objectives may emerge as means for achieving or meeting the higher-level objective. The objectives are clarified by generating an objective tree as shown below.

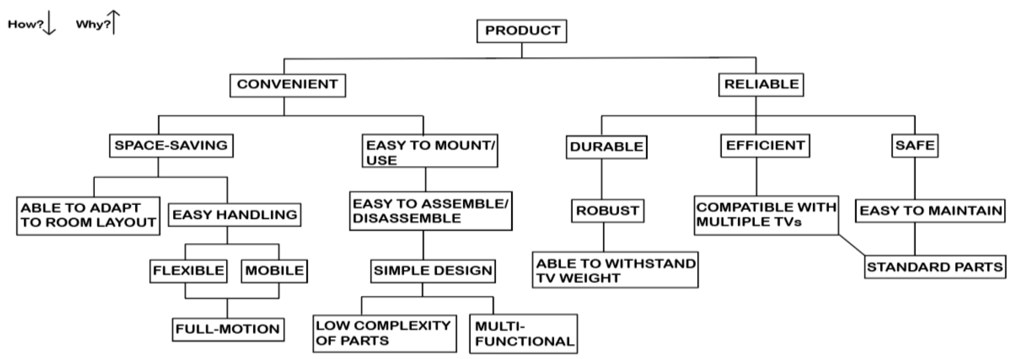


Figure 10: Objective Tree.

2.1 Product Physiology

Materials

Due to the frequent usage of the product, the material must have high wear resistance properties in order prevent damage to the structural integrity and durability of the product. For the product to hold the heavy weight of the TV sizes 55"-70", the product must be stiff enough and strong enough to be able to withstand the loading without causing large deflections or damage to the product. Specification for the material in terms of stiffness and strength shall be specified in more detail in the *material selection* stage. A material selection process will be followed to find the best material for the product.

To ensure maximum flexibility of the product, the mass of the product is essential for easy handling of the product. The mass of the product shall be optimized in different aspects of the design process such as selecting a light, strong material, and optimizing the design such that the product is easy to move with or without the TV mounted.

2.2 Product Psychology

Personality

As the product will be used in households, hotels, apartments etc., the product should have an aesthetically pleasing appearance and can be perceived as a high-end product.

Usability

The product must have simple and obvious operations to ensure easy usage of product. It is also important that the product is adaptable and can easily be mounted or used in several room setups.

3 SETTING REQUIREMENTS

To set the requirements for the product, the *performance specification method* is used. The aim of the performance specification method is to make an accurate specification of the performance required of the design solution.

The list of performance attributes derived from the constraints and some criteria that the design should satisfy was used to generate the product's specifications. The matrix below shows the specification demands and wishes with D and W.

To ensure the mounting system can be supported in many ways by many different flat panels displays marketed by different manufacturers, the placement of connection locations on the back surface of flat panel displays has been specified in a standard known as the VESA standard.(VESA, 2006)

3.1 VESA Standard

VESA defines standards for mounting interfaces on monitors and TVs. The VESA standard provides that particular connection hole placements that should be used for particular ranges of flat panel display sizes, as measured on the diagonal. Flat Display Mounting Interface Standard (VESA, 2006) specifies individual categories for flat panel displays based on the diagonal dimensions of the display. Over the years, the VESA pattern has been modified to accommodate differently sized screens and monitors as they've become popular on the consumer electronics market. The categories are divided into the following groups: 4-inch to 7.9-inch diagonal flat displays (Part B), 8-inch to 11.9-inch diagonal flat displays (Part C), 12-inch to 22.9-inch diagonal flat displays (Part D), 23-inch to 30.9-inch diagonal flat displays (Part E), and 31-inch to larger diagonal flat displays (Part F). The focus of this project will be on Part F of the standard (Mounting Interface Standard for 31" and Larger Diagonal Flat Displays).

The VESA Standard allows low-cost installation of displays into a broad range of applications while positioning screens for increased flexibility and ergonomic benefit.

3.2 List of Requirements

D or W	Specifications
W	Simple design
W	Simple, obvious operation and convenient handling
W	Low mass
D	Support TV sizes 55"-70"
W	Mounting Interface Standard for 31" or larger diagonal Flat displays (Part F (VESA, 2006))
W	Stiff and strong enough
D	Swivel Mechanism
D	Strong wear resistance
W	Maximum swivel range (-57 to 57) degrees
D	Tilt Mechanism
W	Maximum tilt range (-7 to +15) degrees
D	Extension and retraction [Foldable] mechanism
W	Maximum extension distance (1.5 to 2) meters
W	Maximum retractable distance: 20cm to 35cm
D	Easy replacement of parts
D	Reliable
D	Robust
W	No sharp edges

D	Durable
W	Maximum supported Load (15-40kg)

Table 1: Design Requirements

Detailed specifications of the product's material will be explored in the *material selection* chapter to obtain the best materials for the product.

4 DETERMINING CHARACTERISTICS

To generate the engineering characteristics, a comprehensive method known as the *Quality Function Deployment (QFD) method* is used to match customer requirements to engineering characteristics. The identified product attributes from the objectives are used and are carefully translated into specifications of the appropriate engineering characteristics.

The aim of the QFD method is to set targets to be achieved for the engineering characteristics of the product, such that they satisfy customer requirements.

4.1 House of Quality (HOQ)

The House of Quality or Quality Functional Deployment (QFD) for this project ranks a small list of customer needs against the few engineering requirements developed thus far.

Figure 11 shows a 'house of quality' developed for the universal TV mounting system design. In the main body, the customer attributes (CA) and their relative weights are vertically down the edge of matrix and the engineering characteristics (EC) are placed horizontally along the top edge. The CAs form the rows of the matrix and ECs form the columns of the matrix. Each cell of the matrix represents a potential interaction or relationship between EC and CA. The strengths of the relationship between CAs and ECs have been assessed as strong, medium, or weak. These relationships that occur have been assigned a value, i.e., 3 for strong relationship, 2 for a medium-strength relationship and 1 for a weak relationship.

In the "roof" of the matrix, the interactions between ECs have also been identified, again using strong, medium, or weak relationships.

The right edge of the matrix shows the results of the evaluation of the competing products as shown in *Figure 12* (labelled as competitor A, B and C respectively) which is achieved against the customer attributes.

The important ratings for the engineering characteristics have been determined by multiplying the scores of the relationships by the important ratings for the CAs, totalled and normalized to indicate EC importance ratings. Although these figures are self-assigned and thus have limited mathematical validity, they do roughly indicate the relative importance of the ECs in determining the product characteristics. The targets set for the engineering characteristics can be seen at the bottom of the matrix and changes in the design concepts will result in changes in these values and EC interactions.

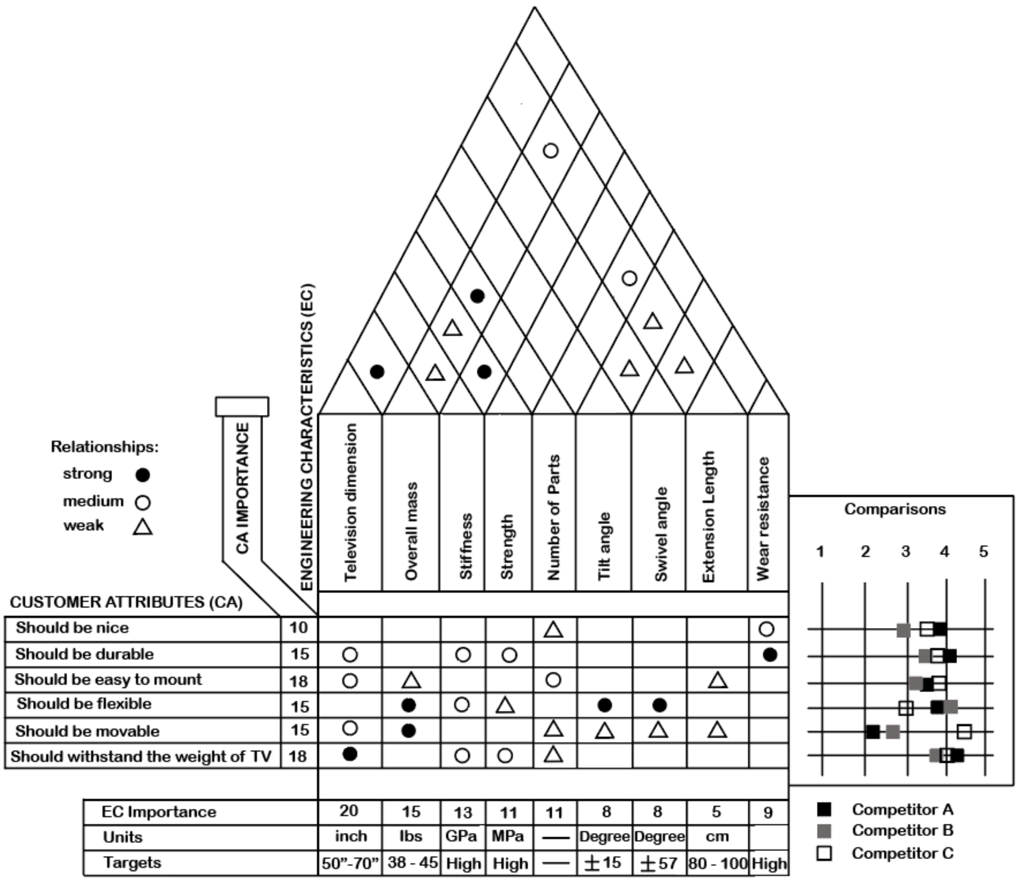


Figure 11: House of Quality.

Based on the results from the HOQ, more value shall be placed on the design’s capacity to withstand the weight of the set dimensions for TV.

*(a)**Competitor A** (Full motion TV*

*(b)**Competitor B** (Flat panel black TV ceiling mount for TV’s 37”-70” [Cited on*

*(c)**Competitor C** (Floor mounting mobile TV stand for TV’s 32”-75”*

wall mount for TV's 42"-90" [Cited on Feb 9, 2024]. Available from https://www.sanus.com/en_us/products/tv-mounts/vlf728/	*Feb 9,2024]. Available from https://www.abt.com/Sanus-37-70-Flat-Panel-Black-TV-Ceiling-Mount-LC1AB1/p/33374.html*	*[Cited on Feb 9,2024]. Available from https://no.rs-online.com/web/p/monitor-arms-wall-mounts/1862023*

Figure 12: Listed competitions on the market that was used for the HOQ.

5 GENERATING ALTERNATIVES

In order to address the problem, the product was segmented into compartments, listing the essential functions or features to the product to come up with the means each function can be achieved to help generate alternatives for evaluation. Various mounting supports and scenarios for the viewing positions is considered in *Figure 13* and *Figure 14* to help generate design concepts to problem. The morphological chart method is used at this stage to analyze the shape or form the product might take. It encourages novel combinations from each function to obtain a complete set of different concepts.

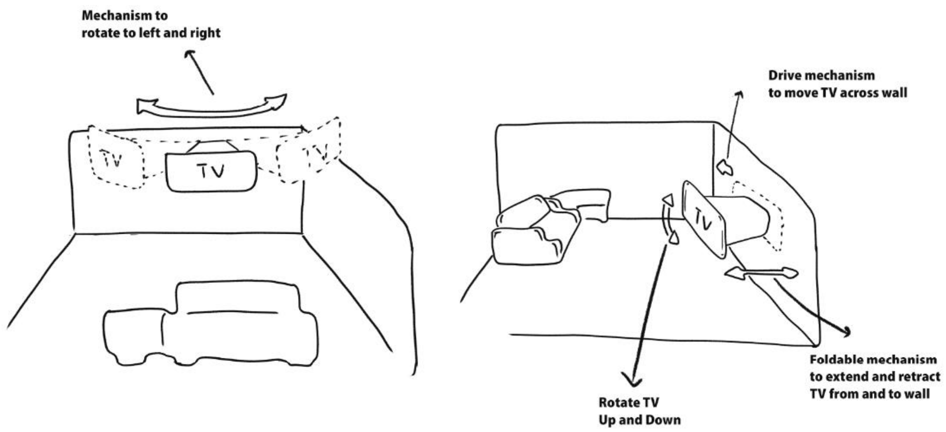


Figure 13: Wall mounting design concept.

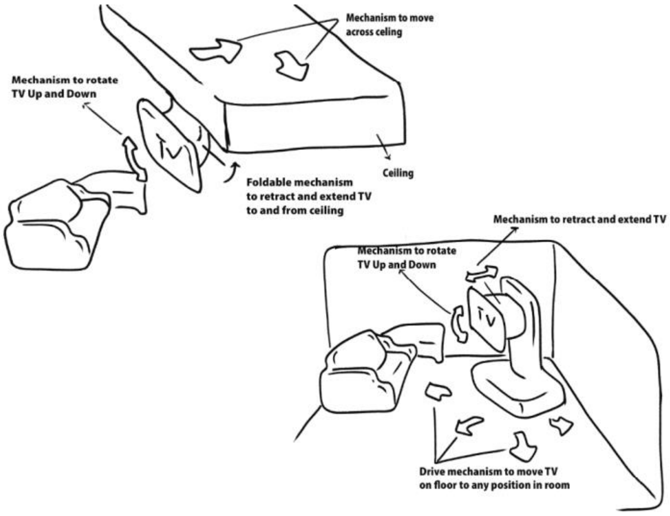


Figure 14: Ceiling and Cart mounting design concept.

When the specification of the concept is in hand, different sketches often suggest form, size or key-features. Since form follows function, *Figure 15* describes the form the design alternatives will take.

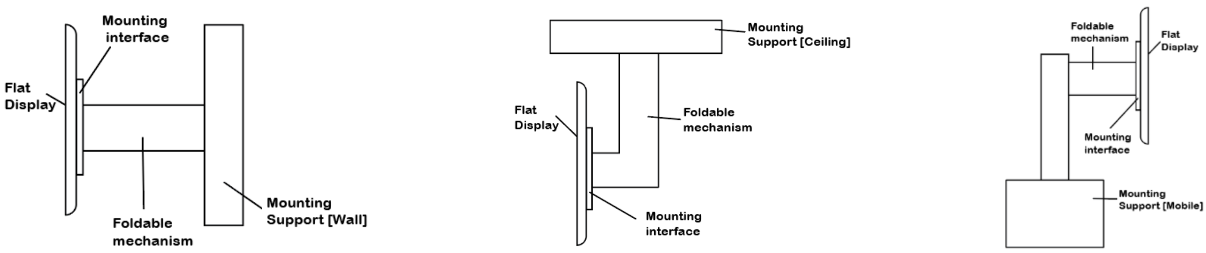


Figure 15: Side view of 2D illustrations of design concepts.

To generate the design alternatives, the product was divided into compartments which includes the main functions as shown in the *Figure 16* below.

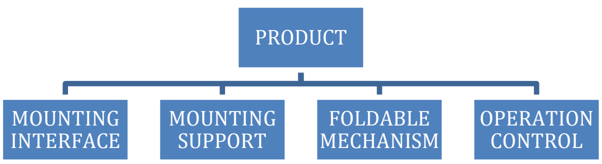


Figure 16: Compartmentalization of the design concept.

5.1 Mounting Interface

In order to design a mounting interface to be placed on the back of TV, part F of the VESA standard (VESA, 2006) was selected which defines dimensions of the four-hole attachment interface on the back of displays with a viewing area ranging in size from 785mm (31”) and larger diagonal displays, and the screws used to fit those holes. To explore alternative mounting interfaces, the key considerations revolve around adhering to the specifications for screw mounting interface dimensions and mounting profiles.

5.1.1 Screw Mounting Interface dimensions.

The dimensions of the screw mounting are crucial for ensuring the structural integrity and stability of the TV when mounted. The dimensions may vary based on the weight distribution and load-bearing capacity of the TV to provide adequate support. The mounting interface should align centrally (C) with the center line (C/L) of the display, as depicted in *Figure 17*. A center-positioned pattern minimizes torquing forces applied to the mount, allowing it to hold a heavier load. According to the part F of the standard(VESA, 2006), all hole pattern spacing dimensions must be in 100mm increments and cannot be less than 200mm, that is 200mm, 300mm, 400mm, 500mm, 600mm, etc..

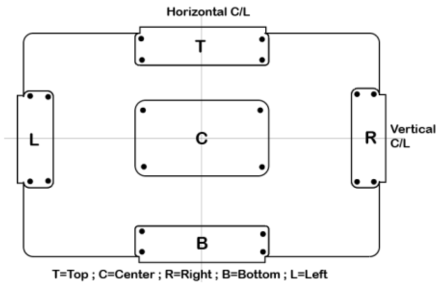


Figure 17: Mounting positions on the back of flat screens.

For compatibility purposes, the mounting interface position shall be at the center (C) as shown in *Figure 17* and designed for both symmetric and unsymmetric hole patterns of flat displays. i.e. (200mm x 200mm, 400mm x 400mm, 600mm x 600mm) and (300mm x 200mm, 400mm x 200mm, 600mm x 400mm) respectively. The hole pattern dimensions are distributed across the horizontal and vertical outline at the back of the flat display as rectangles as shown in *Figure 18*.

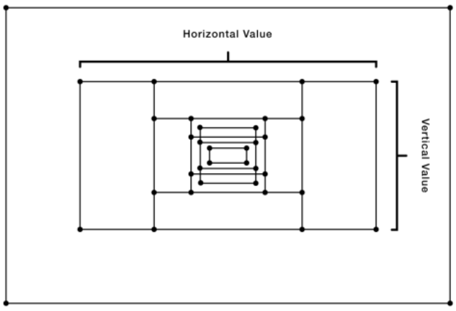


Figure 18: An illustration of the center hole patterns on the back of TV's. (Source: Oeveo) Available from (https://www.oeveo.com/content/320-all-about-the-vesa-pattern) [Cited on Mar 30, 2024]

5.1.2 Mounting Interface Profiles

To ensure the mounting system's compliance to part F of the VESA standard and compatibility with various large flat screens, two mounting profile alternatives were devised to accommodate both VESA and non-VESA sizes. A depiction of these two alternatives is provided below.

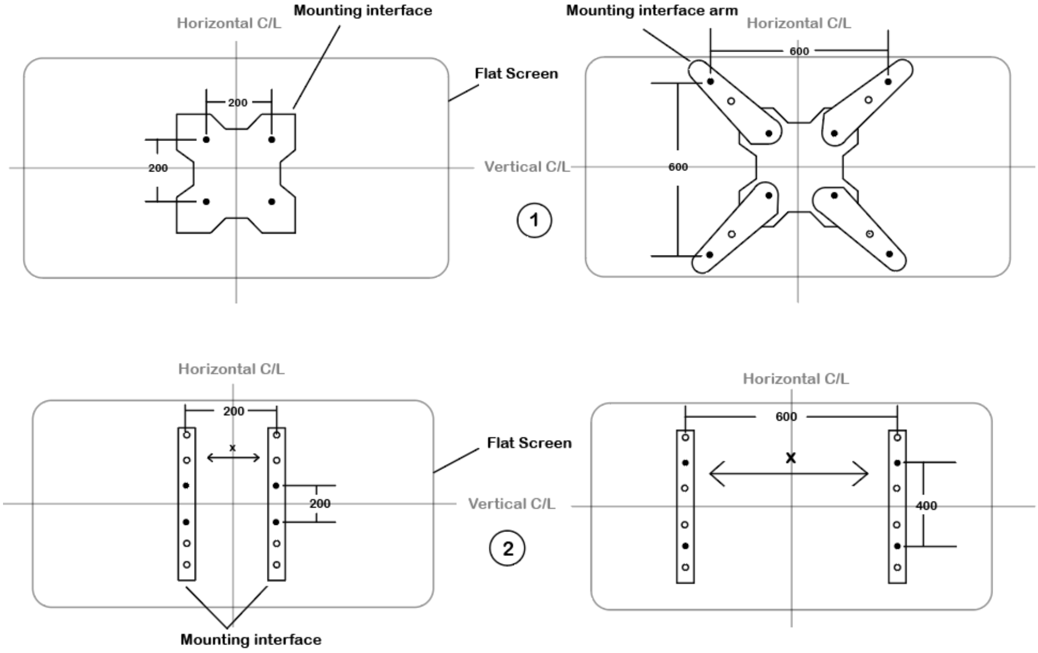


Figure 19: An illustration of the Mounting Interface Profile alternatives on the back of TV.

NOTE: From *Figure 19*, the black dots indicate the point of attachment of the mounting interface to the back of TV and as in the case of Alternative 1 the inner black dots at the right hand side of the sketch could be a point of attachment of the mounting interface to the mounting interface arms. Alternative Profile 2 consists of two separate strips that can be placed at any distance from the Horizontal center line (C/L). Alternative Profile 1 consists of extra arms to aid adjustments to different hole patterns at the back of the TV.

5.2 Foldable mechanism for extension and retraction

To meet the flexibility specifications for extension and retraction functions of the mounting system, a foldable mechanism is suggested. To streamline the possible higher number of combinations, three foldable mechanisms, including the hinged-joint mechanism and several configurations of the parallelogram mechanism, will be employed to accomplish the swing arms' extension and retraction functions. Multiple alternatives were created for each mechanism, as illustrated below.

5.2.1 Hinged-joint or “Knee-joint” mechanism.

The hinged joint mechanism is a mechanical device facilitating rotational movement between interconnected components. Operating primarily in one plane, hinge joints permit flexion and extension, with limited motion in other planes. It consists of two or more parts, joined together by a pivot point or axis, allowing them to rotate relative to each other along a single axis.

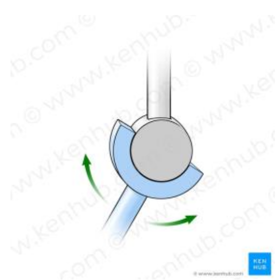
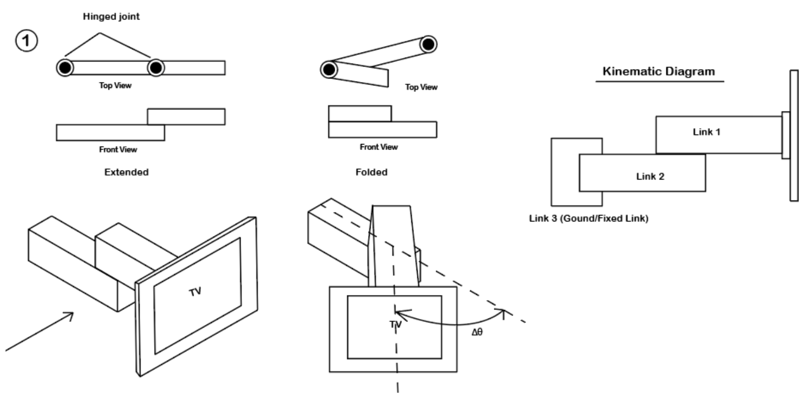
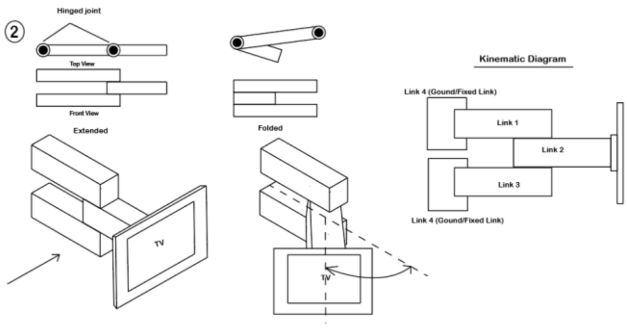


Figure 20: An illustration of the knee joint. (Source: Kenhub). Available from (https://www.kenhub.com/en/library/anatomy/hinge-joint) [Cited on Mar 21,2024]

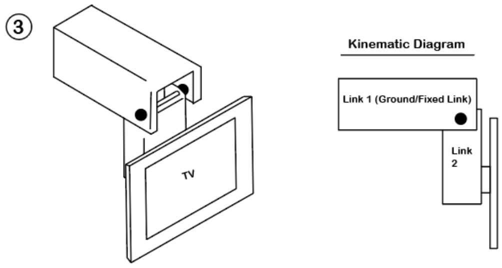
The alternatives of the foldable mechanism generated that uses the hinge joint are shown below. These three alternatives allow one degree of freedom at each pin joint.



(a) Alternative 1



(b) Alternative 2



(c) Alternative 3

Figure 21: Illustration of foldable mechanisms that utilizes the hinge joint.

From (Myszka, 2010), the degree of freedom (DOF) or Mobility (M) of the mechanism is

$$M = 3(n-1) - 2j_p - j_h \qquad 5.1$$

where n=total number of links in the mechanism; j_p=total number of primary joints (pins or sliding joints); j_h=total number of higher-order joints (cam or gear joints)

From the first alternative (1), $n = 3; j_p = (2\ pins) = 2; j_h = 0$

$$\rightarrow M = 3(3-1) - 2(2) - 0 = 6 - 4 = 2$$

Therefore, the alternative 1 allows one degree of freedom each in each pin joint.

From the first alternative (2), $n = 4; j_p = (3\ pins) = 3; j_h = 0$

$$\rightarrow M = 3(4-1) - 2(3) - 0 = 9 - 6 = 3$$

Therefore, the alternative 2 allows one degree of freedom each in each pin joint.

From the first alternative (3), $n = 2; j_p = (1\ pin) = 1; j_h = 0$

$$\rightarrow M = 3(2-1) - 2(1) - 0 = 3 - 2 = 1$$

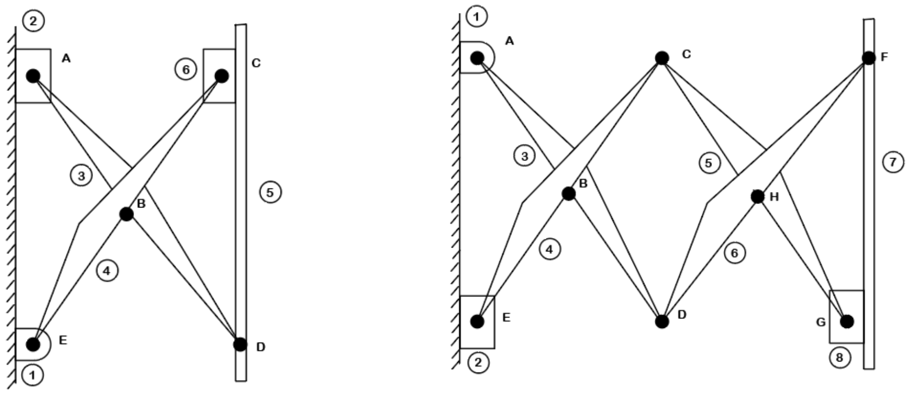
Therefore, the alternative 3 allows one degree of freedom in the pin joint.

5.2.2 Parallelogram mechanism

The mechanism consists of interconnected links arranged in parallelograms. This configuration allows for controlled movement of components in a way that maintains their orientation without altering their pitch or angle, thus creating a parallel motion. For this project, two types of parallelogram linkages were selected. *Figure 22* illustrates the scissor linkage, while *Figure 23* depicts alternative configurations of the parallel mechanism.

5.2.2.1 Scissor-linkage mechanism.

The scissor mechanism employs interconnected folding structural support elements arranged in an angled or "criss-cross" pattern, resembling the movement of a pair of scissors, to facilitate horizontal translational motion. (Tao et al., 2009)



(a) (b)

Figure 22: Scissor linkage mechanism.

From the above mechanism (a), the labelled numbers from indicate linkages and the labelled alphabets indicate joints, i.e. $n = 6; j_p = (5\, pins + 2\, sliders) = 7; j_h = 0$

$$\rightarrow M = 3(6-1) - 2(7) - 0 = 15 - 14 = 1$$

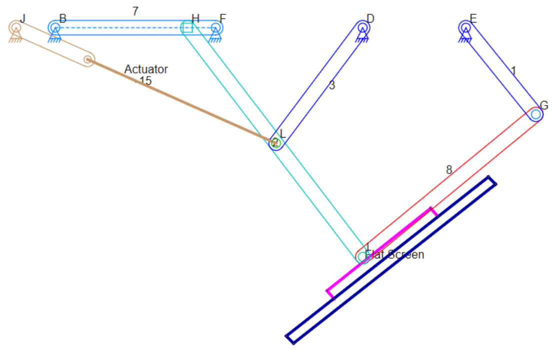
With one degree of freedom, the mechanism has constrained motion, moving the mechanism in the left-right horizontal motion.

From the above mechanism (b), $n = 8; j_p = (8\, pins + 2\, sliders) = 10; j_h = 0$

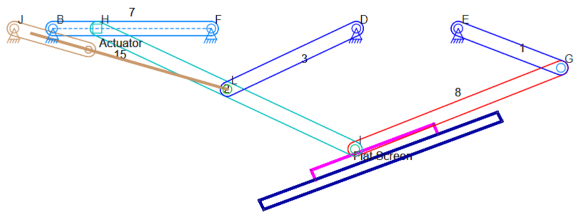
$$\rightarrow M = 3(8-1) - 2(10) - 0 = 21 - 20 = 1$$

With one degree of freedom, the mechanism has constrained motion, moving the mechanism in the left-right horizontal motion, same as (a).

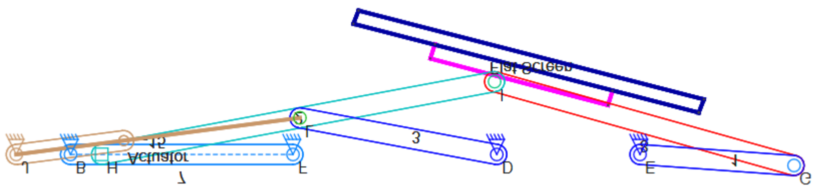
5.2.2.2 Other configuration of parallelogram mechanism



(a) Start of mechanism



(b) Transition

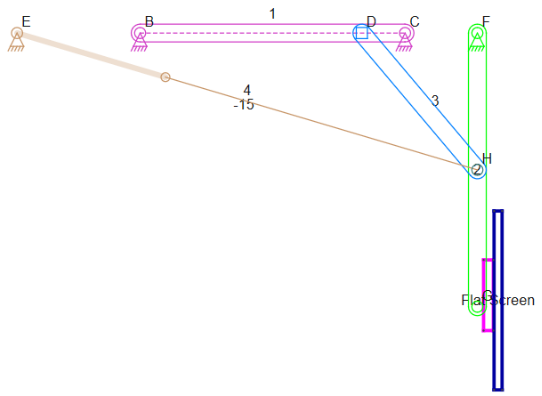


(c) End of mechanism

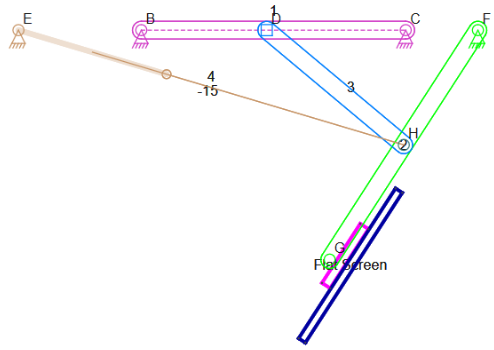
Figure 23: An illustration of the parallel mechanism designed with the Linkage software.

From the above mechanism, the labelled numbers from indicate linkages and the labelled alphabets indicate joints. The actuator is assumed as a slider and $n = 8; j_p = (8\ pins + 2\ sliders) = 10; j_h = 0; \rightarrow M = 3(8-1) - 2(10) - 0 = 21 - 20 = 1$

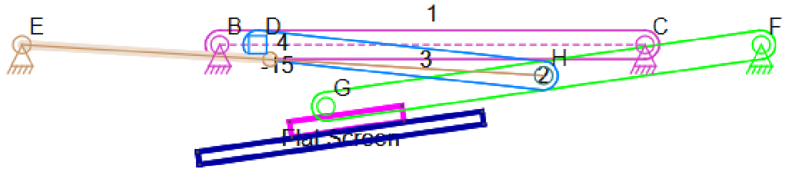
With one degree of freedom, the mechanism has constrained motion, moving the mechanism in an angular motion.



(a) Initial position of mechanism



(b) Transition



(c) End of mechanism

Figure 24: An illustration of the third mechanism using the Linkage software.

From the above mechanism, the labelled numbers from indicate linkages and the labelled alphabets indicate joints. The actuator is assumed as a slider and $n = 6; j_p = (5\,pins + 2\,sliders) = 4; j_h = 0; \rightarrow M = 3(6-1) - 2(7) - 0 = 15 - 14 = 1$

The morphological chart method is summarized in the matrix provided below, featuring a grid of squares. The left-hand column enumerates the core features of the product, while each row delineates the corresponding secondary lists of sub-solutions or methods for achieving these functions. Each square serves as a space for distinct alternative options.

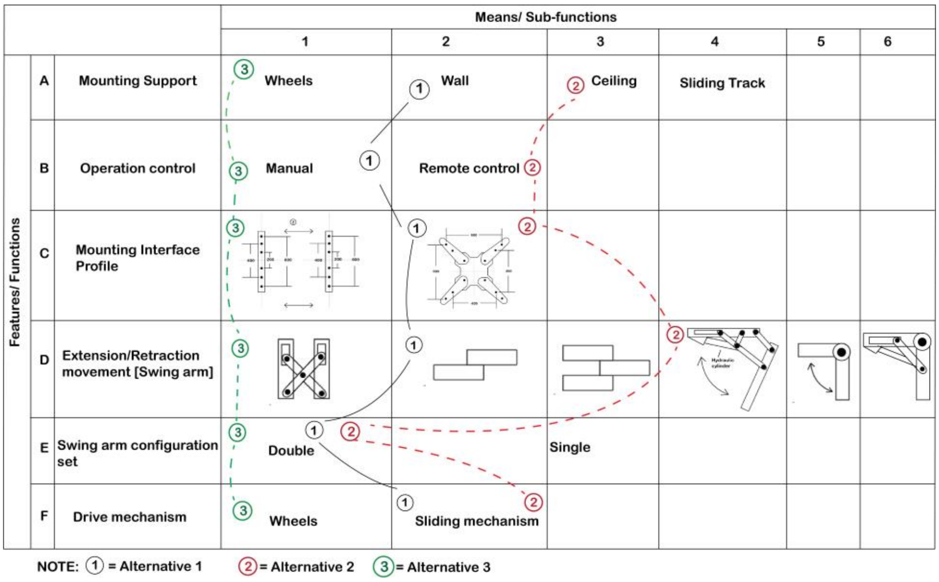


Figure 25: Morphological chart.

NOTE: From the above morphological chart, Cells D2, D3, and D5 represent alternatives of the hinge mechanism of *Figure 21*, Cell D1 represents mechanism (a) of *Figure 22*, D4 represent mechanism in *Figure 23* and D6 represent the mechanism in *Figure 24.*

Selection of A Foldable Mechanism For Each Design Concept

These foldable mechanisms are compatible with some mount supports, such as D4, D5 and D6 for Ceiling mounting, D1, D2 and D3 for wall and wheel/Sliding track support.To select the various alternatives for evaluation, an evaluation of D2 and D3 was made to select the best foldable mechanism for the wall mounting support.

Hinge Joint Evaluation	D2	D3
Level of flexibility	+	+
Weight	+	0
TOTAL SCORE	2	1

Table 2: Evaluation of Hinge Joint Concepts.

In *Table 2,* the alternatives are evaluated based on which one best satisfies the design objectives of flexibility and weight. i.e. (+) sign for better and zero (0) for worse. Even though the additional arm of D3 provides extra stability and support to the system, it also adds additional weight to the system. The extension distance of the wheel support mounting is not much of a concern, since the system can be moved to the preferred position, D1 is selected for the wheel support mounting system to allow for shorter extension distance of TV.

5.3 Concept Drawings

Once the specifications of the concept are established, various hand-drawn sketches can offer insights into form, size, and key features. The objective is to explore multiple options that can be evaluated against the specifications. The matrix above illustrates the combinations for each alternative.

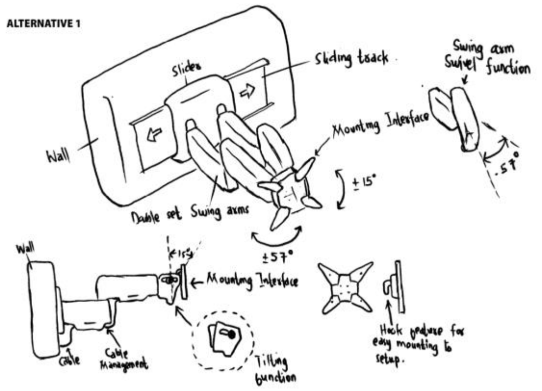


Figure 26: Alternative 1

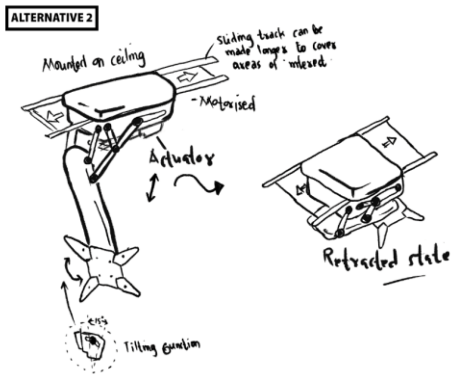


Figure 27: Alternative 2.

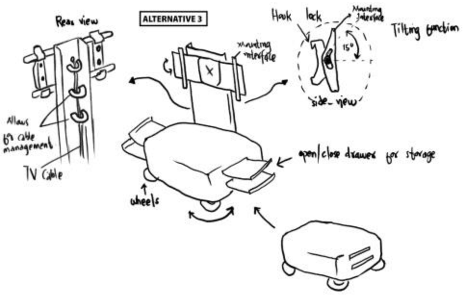


Figure 28: Alternative 3.

6 EVALUATING ALTERNATIVES

The next step is to evaluate the selected alternatives against the design objectives to ascertain which design concept is best suited to be the final design. The weighted Objective method is used to compare the utility values of alternative design proposals, based on performance against differentially weighted objectives. The evaluation matrix can be seen below,

6.1 Evaluation matrix

			PRINCIPLE OF EVALUATION	Weight factor, W (%)	Alternative 1 S	Alternative 1 U	Alternative 2 S	Alternative 2 U	Alternative 3 S	Alternative 3 U
DESIGN CRITERIA	1	Level of flexibility	Multifunctionality	12	4	0.48	3	0.36	4	0.48
			Portability	8	4	0.32	2	0.16	3	0.24
	2	Cost	Compatibility with other flat TV's (55"-70")	25	4	1	4	1	4	1
			Number of parts	5	3	0.15	3	0.15	2	0.10
	3	Simple design	Ease of mounting/attaching TV	20	4	0.8	3	0.6	4	0.8
			Ease of assembling/disassembling	12	4	0.48	3	0.36	3	0.36
	4	User-friendly	Ease of handling/Operation control	8	4	0.32	4	0.32	3	0.24
			Adaptability to room layout	10	3	0.3	3	0.3	4	0.4
OVERALL UTILITY					3.85		3.25		3.62	
RANK					1		3		2	
Continue?					Develop		No		No	

Table 3: Final evaluation chart for alternatives.

NOTE: From the above table, W=*Percentage weight of each criterion (from 100)*; S=*Score of the quality of each design, which was assigned to each alternative on a scale of 1 to 5*, i.e. 1 for *Poor* and 5 for *best* and U=*Weighted score of design*=W x S. From the evaluation matrix *Table 3*, alternative 1 had the best score overall and was selected for further CAD modelling of parts.

7 MATERIAL SELECTION

The material selection of a wall TV mount plays a vital role to provide the strength needed for the TV mount. This stage involves translating of the design requirements into some material properties to select the best possible materials for the design. The four main steps of material selection from (Ashby, 2005). i.e. translation, screening, ranking and documentation will be utilized to first translate the design requirements into a clear statement of *function*, *constraints*, *objectives*; screen or eliminate the materials that cannot meet the set constraints and order the remaining materials based on the optimization criteria also known as the material indices. The selection procedure is demonstrated below.

The *function* of the final design concept is simplified into a cantilever beam that is fixed a one end and loaded at the free end.

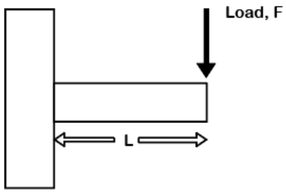


Figure 29: Cantilever Beam

Design Requirements.

Function: Beam - light, stiff and strong.

Constraints:

1. Toughness, $G_C > 1KJ/m^2$
2. Length, L specified
3. Corrosion resistant
4. Wear resistant
5. Stiffness: Must not deflect too much under design loads.
6. Strength: Must not fail under design loads.

Objective:

1. Minimum mass to withstand the weight of TV and not damage support (wall).
2. Cheap as possible

Free Variable:

1. Choice of materials
2. Cross-section area of beam, A

To assign a material to this design by using the software Granta EduPack, the materials will be determined by finding the material index. The governing equation for the combination of the objectives of product, The cost of the member from (Ashby, 2005), is given by

$$C = m\ x\ C_m \quad 7.1$$

where m= mass; C = Cost, C_m= Cost per mass; the mass is given by

$$m = AL\rho \quad 7.2$$

where A=cross-sectional area; ρ=density; L=length. Substituting equation *7.2* into equation gives *7.1* to obtain the objective function which yields;

$$C = AL\rho\ x\ C_m \quad 7.3$$

As the beam is assumed to be a solid bar, it is possible to use the calculations for a solid beam to solve for the material index.

<u>Applying the constraints of stiffness</u>

The bending stiffness, S formulae is given by;

$$S = \frac{F}{\delta}$$

Where F, is the applied load and δ is the deflection of the beam.

From the appendix text of (Ashby, 2005), the deflection of a beam, δ is given by.

$$\delta = \frac{FL^3}{C_1 EI}$$

Substituting it into the stiffness equation gives;

$$S = \frac{C_1 EI}{L^3} \qquad 7.4$$

Taking the cross-section of the beam to be a square; Therefore, the moment of inertia, I is given by;

$$I = \frac{bh^3}{12} = \frac{b \cdot (b)^3}{12} = \frac{(b \cdot b)^2}{12} = \frac{A^2}{12}$$

Substituting into the stiffness equation gives; and for a simple supported beam, $C_1 = 3$

$$S = \frac{3 \cdot E \cdot \left(\frac{A^2}{12}\right)}{L^3} = \frac{E \cdot A^2}{4 \cdot L^3}$$

For the beam not to deflect too much, the stiffness, S must not be less than the critical stiffness, S_{cr}. Which implies that;

$$S_{cr} \leq S; \rightarrow S_{cr} \leq \frac{E \cdot A^2}{4 \cdot L^3} \qquad 7.5$$

Making the free variable, A the subject in equation *7.5* yields;

$$A^2 \geq \frac{4 \cdot S_{cr} L^3}{E};\ A \geq \left(\frac{4 \cdot S_{cr} L^3}{E}\right)^{\frac{1}{2}} \qquad 7.6$$

Substituting the equation *7.6* into equation *7.2* yields;

$$m \geq \left(\frac{4 \cdot S_{cr} L^3}{E}\right)^{\frac{1}{2}} \rho L$$

And finally, re-arranging the above expression for the mass (m), we obtain;

$$m \geq (4 \cdot S_{cr})^{\frac{1}{2}} \cdot L^{\frac{3}{2}} \cdot L \cdot \frac{\rho}{E^{\frac{1}{2}}} = (4 \cdot S_{cr} L^3)^{\frac{1}{2}} \cdot (L) \cdot \left(\frac{\rho}{E^{\frac{1}{2}}}\right) \qquad 7.7$$

To obtain the performance equation from (Ashby, 2005), substitute *equation 7.7* into *equation 7.1* gives;

$$c_1 = \underbrace{(4 \cdot S_{cr} \cdot L^3)^{\frac{1}{2}}}_{\substack{Functional \\ Constraint}} \cdot \underbrace{(L)}_{\substack{Geometric \\ Constraint}} \cdot \underbrace{\left(\frac{\rho C_m}{E^{\frac{1}{2}}}\right)}_{\substack{Material \\ Properties}} \qquad 7.8$$

Therefore, to obtain the cheap and light material, the material index $M_1 = \rho C_m / E^{\frac{1}{2}}$ from *equation 7.8* is minimized.

Applying the strength constraints.

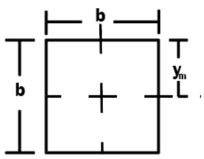


Figure 30: Cross-section of beam.

From the appendix of (Ashby, 2005), The force that the beam can bear before it will failure (failure load, F_f) is given by;

$$F_f = C_2 \frac{I \sigma_f}{y_m l} = \frac{C_2 (Z) \sigma_f}{l} \qquad 7.9$$

Where Z= section modulus; I= moment of inertia; y_m= distance between the neutral axis of the bending and the outer surface of the beam as shown above in *Figure 30*. The expressions for y_m, and Z are given by;

$$y_m = \frac{b}{2} \text{ and } Z = \frac{I}{y_m}$$

To compute the failure load (F_f), the variables y_m and Z are calculated and substituted into equation *7.9* in the following way;

$$I = \frac{b^4}{12} = \frac{A^2}{12} \qquad 7.10$$

and;

$$Z = \frac{\left(\frac{A^2}{12}\right)}{\frac{b}{2}} = \frac{A^2}{6b} = \frac{b^4}{6b} = \frac{b^3}{6} \qquad 7.11$$

From the appendix of (Ashby, 2005), the constant C_2 for a cantilever beam is 1, and substituting the rest of the variables into *equation 7.9* gives,

$$\rightarrow F_f = 1 \cdot (Z)\frac{\sigma_f}{l} = \left(\frac{b^3}{6}\right)\frac{\sigma_f}{L} \qquad 7.12$$

For the beam not to fail under design loads, the design load, F must not be greater than the failure load, F_f. Which implies that;

$$F \leq F_f \qquad 7.13$$

Substituting equation into equation gives;

$$\rightarrow F \leq \left(\frac{b^3}{6}\right)\frac{\sigma_f}{L}$$

Making the free variable, b the subject in the above expression gives;

$$\frac{b^3}{6} \geq \frac{L \cdot F}{\sigma_f};\ b \geq \left(\frac{6 \cdot L \cdot F}{\sigma_f}\right)^{1/3} \qquad 7.14$$

Substituting *equation 7.14* into *equation 7.2*, we obtain;

$$m \geq A\rho L = (b^2)\rho L = \left(\left(\frac{6 \cdot L \cdot F}{\sigma_f}\right)^{1/3}\right)^2 \rho L = 6^{\frac{2}{3}} \cdot L \cdot (L)^{\frac{2}{3}} \cdot F^{\frac{2}{3}} \cdot \left(\frac{\rho}{\sigma_f^{2/3}}\right) \qquad 7.15$$

And finally, substituting *equation 7.15* into the objective function (*equation 7.1*) we obtain;

$$c_2 = (6 \cdot F \cdot L)^{2/3} \cdot (L) \cdot \left(\frac{\rho C_m}{\sigma_f^{2/3}}\right) \qquad 7.16$$

Similarly, as in *equation 7.8*, to obtain the cheap and light material, the material index $M_2 = \rho C_m / \sigma_f^{2/3}$ is minimized.

Therefore, the material indices *7.17* and *7.18* below are to be minimized to obtain the best materials that are light and cheap.

$$M_1 = \frac{\rho C_m}{E^{\frac{1}{2}}} \qquad 7.17$$

$$M_2 = \frac{\rho C_m}{\sigma_f^{2/3}} \qquad 7.18$$

Applying Toughness, G_{1C} constraints.

To eliminate brittle materials from the selection process, the toughness, G_{1C} constraint is applied in Level 2 of the Granta EduPack Database, the relation for toughness from (Ashby, 2005) is used, and the relation is given by;

$$G_{1C} = \frac{K_{1C}^2}{E(1+v)}$$

where E=Young's modulus, v=Poisson's ratio, K_{1C}=Fracture toughness is used to generate the y-axis for the graph in Granta EduPack as shown below.

The obtained materials illustrated as small rectangular boxes in the bigger box as shown in *Figure 31* below, are the materials that satisfy the toughness constraint of $G_{1C} > 1000 J/m^2$.

Figure 31: Toughness G_{1C} constraint.

Plotting M_1 and M_2

To obtain the cheap and light materials that satisfy the constraints of stiffness and strength, the *coupling line* method as described in (Ashby, 2005) is utilized to obtain the best materials. The method requires plotting a graph of the material index M_2 against M_1 as shown in *Figure 32,* where the best materials are obtained on the slope (coupling line) .i.e. at the intersection of the two performance equations *7.8* and *7.16*.

It implies that;

$$c_2 = c_1$$

$$(4 \cdot S_{cr} L^3)^{\frac{1}{2}} \cdot (L) \cdot \left(\frac{\rho C_m}{E^{\frac{1}{2}}} \right) = (6 \cdot F \cdot L)^{2/3} \cdot (L) \cdot \left(\frac{\rho C_m}{\sigma_f^{2/3}} \right) \tag{7.19}$$

Substituting equation *7.17* and *7.18* into equation *7.19* yields;

$$(6 \cdot F \cdot L)^{2/3} \cdot (L) \cdot M_2 = (4 \cdot S_{cr} L^3)^{\frac{1}{2}} \cdot (L) \cdot M_1 \tag{7.20}$$

Making M_2 the subject of the equation *7.20;*

$$M_2 = \frac{(4 \cdot S_{cr} L^3)^{\frac{1}{2}} \cdot (L)}{(6 \cdot F \cdot L)^{2/3} \cdot (L)} \cdot M_1 = \underbrace{\left(\frac{2}{6^{2/3}} \times \frac{{S_{cr}}^{1/2}}{F^{2/3}} \times L^{5/6} \right)}_{C_c = Coupling\ Constant} \cdot M_1 \tag{7.21}$$

$$\rightarrow M_2 = C_c \cdot M_1$$

For extremely large or small values of the material properties of materials included in the graph of M_2 against M_1 in Granta EduPack, the logarithmic scale is applied to above equation to accommodate these materials. The result yields,

$$\underbrace{log(M_2)}_{y} = \underbrace{log(M_1)}_{x} + \underbrace{log(C_c)}_{c} \tag{7.22}$$

To plot the graph of M_2 against M_1, *equation 7.22* can be likened to the straight-line equation *7.23*.

$$y = \left(\underbrace{m}_{\substack{Slope\ of \\ the\ Line}} \right) \cdot x + c \tag{7.23}$$

Equating *equation 7.22* to the straight-line *equation 7.23* implies that the slope of the straight-line *equation 7.22*, m is 1. *Equation 7.22* represents the couple lines in the graph of M_2 against M_1 shown below in *Figure 32.*

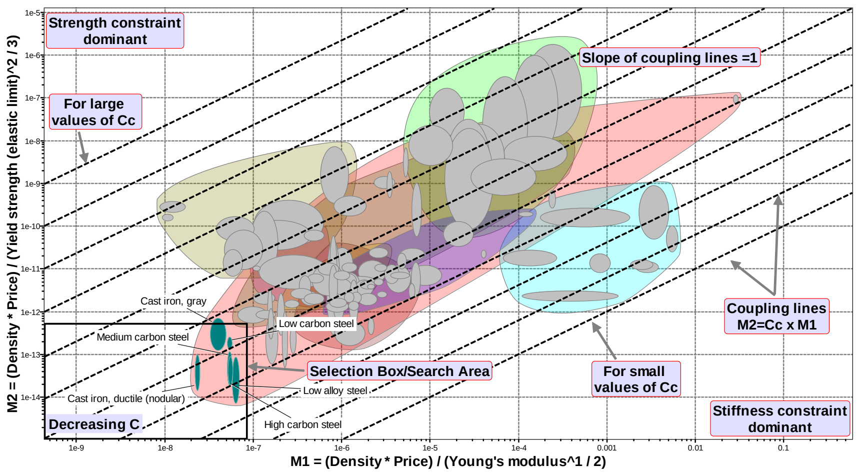


Figure 32: A graph of M2 against M1.

The best materials that satisfy the objective of both minimum mass and cost can be found at the bottom-left corner of the graph *Figure 32* below. The multiple dashed lines in *Figure 32* illustrate the various intercept positions the slope line will take in the event that the coupling constant, C_c is specified. The chart *Figure 32* is more general, covering all values of S_{cr}, F, and L. Level 2 Database of the selection data in Granta EduPack was used in the material selection to obtain the best materials shown in *Figure 33* below.

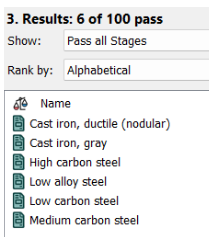


Figure 33: Best materials.

The properties of the materials in *Figure 33* obtained from the Granta EduPack software database level 2 are listed in Table 4.

Material	$\rho[\frac{kg}{m^3}]$	$E[GPa]$	$\sigma_y[MPa]$	$C_m[USD/kg]$
High carbon steel	7800	200 – 220	433 - 924	0.71 – 0.749
Cast Iron, gray	6940 - 7230	94 - 140	97.4 - 228	0.31 – 0.334
Cast Iron, ductile (nodular)	7050 - 7150	170 - 180	246 - 630	0.284
Low alloy steel	7800	200 - 210	469 - 1600	0.753 – 0.902
Low carbon steel	7800 - 7820	200 - 220	255 - 355	0.698 – 0.735
Medium carbon steel	7800	200 -220	376 – 929	0.698 – 0.735

Table 4: Material Properties.

To determine which material satisfies both design objectives of minimum mass and minimum cost, the material indices M_1 and M_2 is computed for each material in *Figure 33* with material properties listed in *Table 4* to obtain the table below.

Material	$M_1 = \frac{\rho C_m}{E^{\frac{1}{2}}}$	$M_2 = \frac{\rho C_m}{\sigma_f^{2/3}}$	Comments
High carbon steel	0.0124 – 0.0125	0.00616 - 0.00967	High M_1 and Low M_2
Cast Iron, gray.	0.00645 - 0.00702	0.00647 - 0.0102	Low M_1 and M_2 values
Cast Iron, ductile (nodular)	0.00479 - 0.00486	0.00276 – 0.0051	Lowest M_1 and M_2 values
Low alloy steel	0.0131 – 0.0154	0.00514 – 0.00973	Highest M_1 and M_2 values
Low carbon steel	0.0122 – 0.01225	0.0115 - 0.0135	Higher M_2 values than medium carbon steel
Medium carbon steel	0.0122 – 0.01222	0.00602 – 0.0105	Lower M_2 values than low carbon steel

Table 5: Materials for the swing arm.

8 CAD Modelling

Solidworks will be used as the design modeler in this project. Solidworks can also visualize key-functions and moving parts as well as rendering images and videos of the product.

<u>Swing arm [x 4]</u>

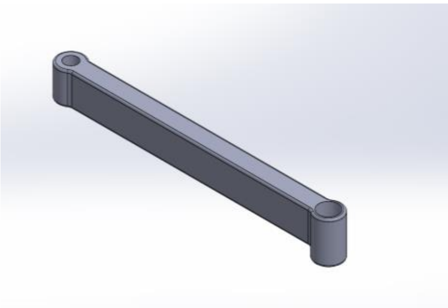


Figure 34:3D isometric View of Swing arm.

<u>Mounting Interface Profile</u>

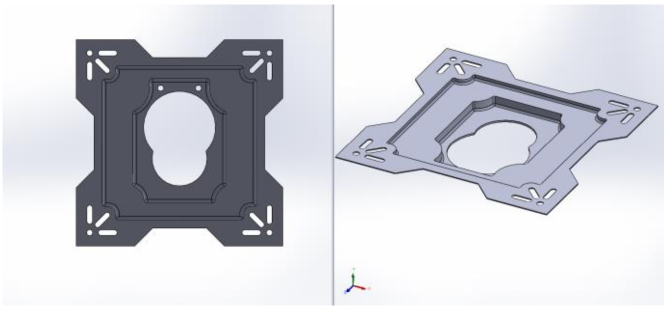


Figure 35: Mounting Interface Profile.

Material Selection

According to the VESA Standard (VESA, 2006), the screw mounting interface shall be flat within 1mm +/- over the entire mounting interface surface. To ensure the design part can withstand the design loading, the dimensionless material parameter known as the *shape factor* is introduced in the material selection which is the measure of the efficiency of material usage, to select the best material and shape combination.

<u>Applying the Shape factor to the Performance Equation *7.1*</u>

For the elastic bending of beams, the bending stiffness(S) of the shaped section differs from that of a square one (reference shape) with the same area by the factor ϕ_B^e which is given by (Ashby, 2005) as

$$\phi_B^e = \frac{S}{S_0} = \frac{EI}{EI_0} = \frac{I}{I_0} = \frac{12I}{A^2} \qquad 8.1$$

where ϕ_B^e=shape factor for elastic bending; A=cross-sectional area of section; E= Young's modulus of the material of the section; I=second moment of area of the section; I_0= second moment of area of the square reference section; S_0=bending stiffness of square reference section. Making I the subject of *equation 8.1* and substituting it into the bending stiffness *equation 7.4* gives,

$$S_B = \frac{C_1 EI}{L^3} = \frac{3 \cdot E \cdot \phi_B^e \cdot A^2}{12 \cdot L^3}$$

For the beam not to deflect too much, the stiffness, S_B must not be less than the critical stiffness, S_{cr}. Which implies that,

$$S_B \geq S_{cr} = \frac{3 \cdot E \cdot \phi_B^e \cdot A^2}{12 \cdot L^3} \geq S_{cr} \qquad 8.2$$

Making A the subject of equation *8.2* gives,

$$A \geq \left(\frac{S_{cr} \cdot 4 \cdot L^3}{E \cdot \phi_B^e}\right)^{1/2} \qquad 8.3$$

Substituting *equation 8.3* into performance equation *7.3* gives

$$c_3 = \underbrace{(4 \cdot S_{cr} \cdot L^3)^{\frac{1}{2}}}_{\substack{Functional \\ Constraint}} \cdot \underbrace{(L)}_{\substack{Geometric \\ Constraint}} \cdot \underbrace{\left(\frac{\rho C_m}{(E \cdot \phi_B^e)^{\frac{1}{2}}}\right)}_{\substack{Material \\ Properties}} \qquad 8.4$$

Therefore, to obtain the best materials that are cheap, light and with shape efficiency the material index, $M_3 = \rho C_m / (E \cdot \phi_B^e)^{\frac{1}{2}}$ from *equation 8.4* is minimized. Similarly for the failure in bending, the strength-efficiency of the shaped section, ϕ_B^f is given by,

$$\phi_B^f = \frac{Z}{Z_0} \quad 8.5$$

where Z_0, section modulus of a reference square section is given by $Z_0 = A^{3/2}/6$. Thus, substituting the relation of Z_0 into *equation 8.5*, it yields

$$\phi_B^f = \frac{6Z}{A^{3/2}} \quad 8.6$$

Failure occurs if the bending moment exceeds,

$$M = Z\sigma_f \quad 8.7$$

where Z=section modulus; σ_f=the stress at which failure occurs. Making Z the subject of equation *8.6* and substituting into *equation 8.7* yields,

$$M = \frac{\phi_B^f \cdot A^{3/2}}{6}\sigma_f \quad 8.8$$

Making A the subject of the *equation 8.8* gives,

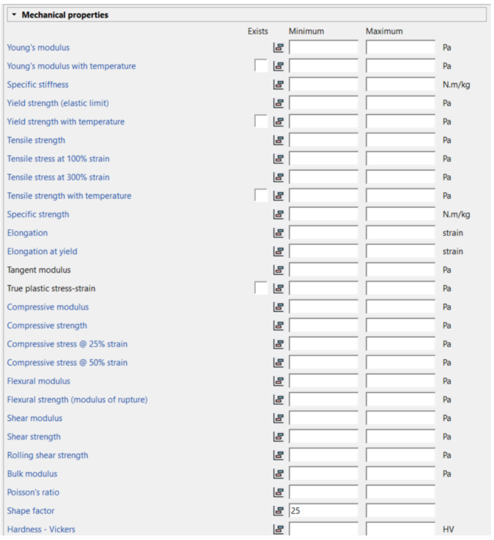
$$A = \left(\frac{6 \cdot M}{\phi_B^f \cdot \sigma_f}\right)^{2/3} \quad 8.9$$

Substituting *equation 8.9* into the performance *equation 7.3* gives,

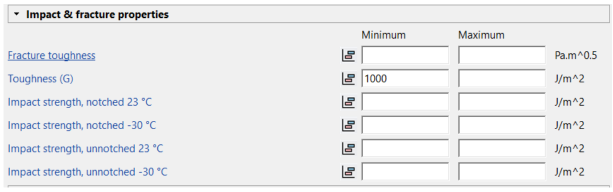
$$c_4 = (6 \cdot M)^{2/3} \cdot L \cdot \left(\frac{\rho C_m}{\left(\phi_B^f \cdot \sigma_f\right)^{2/3}}\right) \quad 8.10$$

Therefore, to obtain the best materials that are cheap, light and with shape efficiency the material index, $M_4 = \rho C_m/\left(\phi_B^f \cdot \sigma_f\right)^{2/3}$ from *equation 8.10* is minimized.

Using the Granta EduPack with level 3 database to plot the graph M_2 against M_1 including the shape factors, the toughness and the shape factor are applied as constraints in the selection process with a value of $1000J/m^2$ and 25 respectively as shown in *Figure 36* to obtain the best materials with shape combinations.



(a) Shape factor constraint.



(b) Toughness constraint

Figure 36: Design Constraints.

The results after applying the design constraint can be seen in *Figure 37*, *Figure 38* and. *Figure 39.*

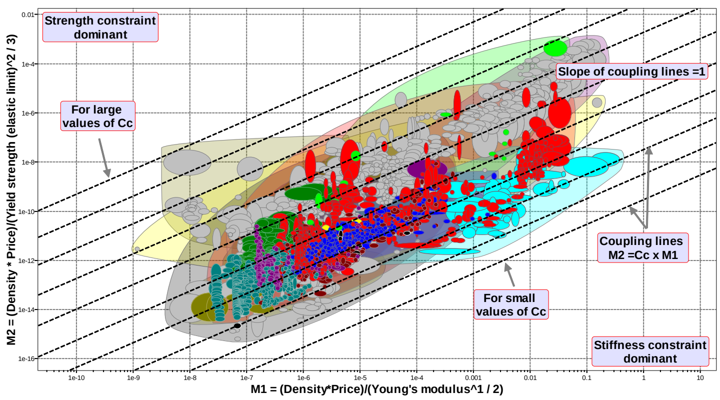


Figure 37: A graph of M2 against M1 [After Toughness constraint]

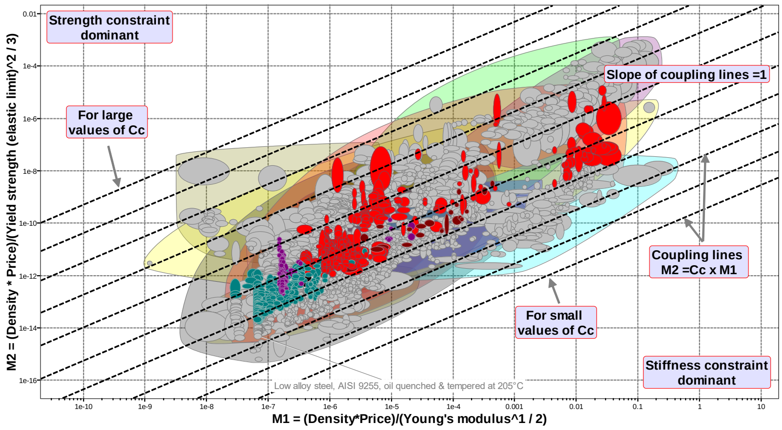


Figure 38: A graph of M2 against M1 [After shape factor + Toughness constraints]

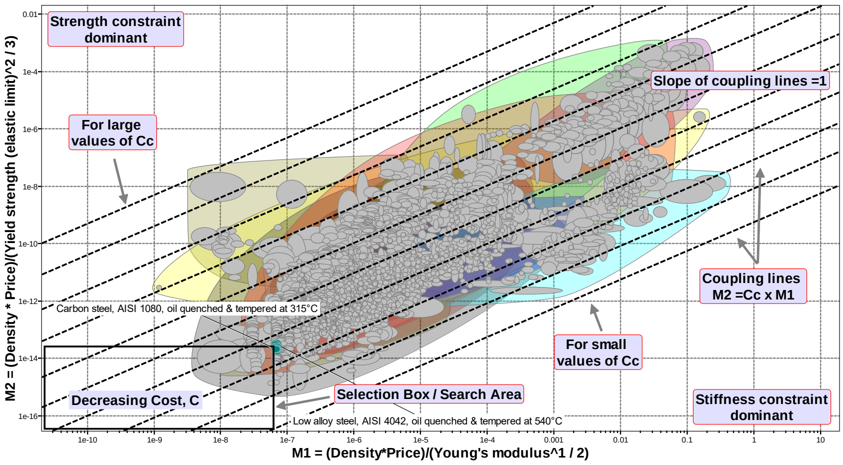


Figure 39: A graph of M2 against M1 [Final selection]

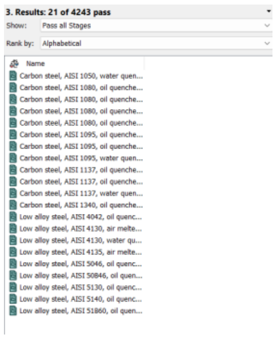


Figure 40:Best materials at Level 3

Table 6 below lists some material properties of the selected material obtained from the Level 3 database of Granta EduPack.

Material	Shape Factor	Density(kg/m^3)	Young's Modulus (GPa)	Yield Strength (MPa)	Price (USD/Kg)
Low alloy steel, AISI 4130	27	7800 – 7900	201 - 216	820 – 1000	0.794 – 1.05

Carbon steel, AISI 1080	31	7800 – 7900	200 - 215	725 – 890	0.762 – 1
Carbon steel, AISI 1095	30	7800 – 7900	200 - 215	730 – 895	0.762 – 1
Carbon steel, AISI 1137	29	7800 – 7900	200 - 215	755 – 930	0.765 – 1.01
Carbon steel, AISI 1050	31	7800 – 7900	208 – 216	725 – 890	0.763 – 1
Low alloy steel, AISI 5140	29	7800 – 7900	209 – 217	770 – 955	0.769 – 1.01
Low alloy steel, AISI 4042	28	7800 – 7900	201 – 212	790 – 980	0.797 – 1.05

Table 6: Material Properties of the selected materials.

The optimal materials obtained based on boundary conditions are shown in *Figure 40*. Based on the specified thickness for some parts of the design, the Carbon steel AISI 1080 that is also corrosion and abrasive wear resistant will be used for the design and structural analysis of the product. To maintain consistent material properties throughout the mounting structure, same material will be applied for the rest of the parts of the mounting system. The rest of the 3D design of the parts are shown below.

.

Mounting Interface Profile Arm(x4)

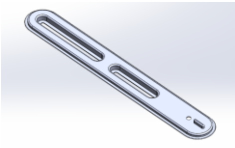


Figure 41: 3D isometric View of Mounting Interface Profile Arm

Sliding Track(x2)

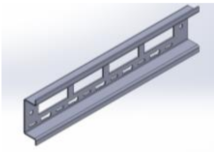


Figure 42: 3D isometric View of Sliding Track.

Assembly of Mounting System

Figure 43: 3D isometric View of Mounting System Assembly.

Casing Unit(x4)

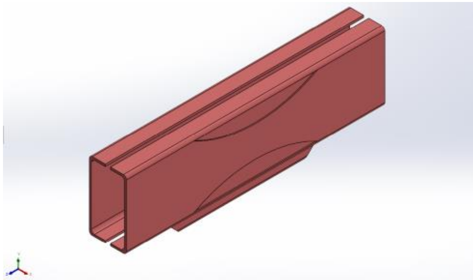


Figure 44: 3D isometric view of thermoplastic casing unit

The materials chosen for the lightweight casing unit are Acrylonitrile Butadiene Styrene (ABS), Polystyrene (PS), and Poly methyl methacrylate (PMMA) – also known as acrylic. The *material* and *process* selection for the casing unit is demonstrated in the *Appendix.*

8.1 Prototyping

Figure 45: 3D printing of design.

8.2 Production Drawings

When CAD-modelling of the parts are finished, production drawings can easily be developed in the same software and sent to a production-line for manufacturing. All production drawings are listed in the *Appendix*.

9 ANALYTICAL AND NUMERICAL ANALYSIS

9.1 FINITE ELEMENT ANALYSIS

The most important structural member of the design is the compound beam that is attached to other members of the assembly, so its structural integrity is relevant and most crucial to the design as it determines the overall strength, stability, and functionality of the product. The next aspect is to determine the structural strength of the beam by performing the finite element analysis of the beam with the finite element software, Ansys Workbench.

9.1.1 Model

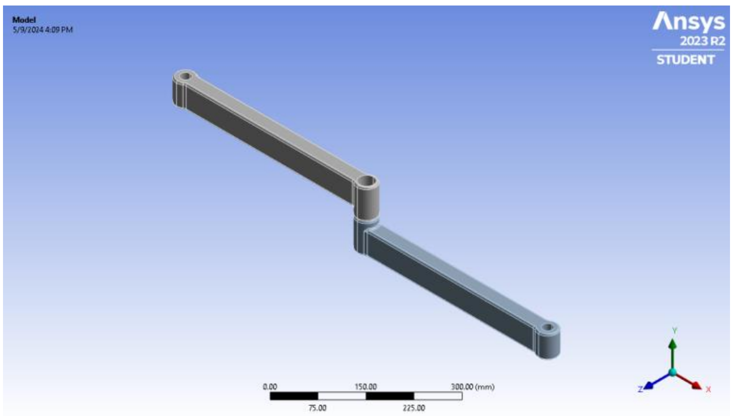


Figure 46: Model of one compound beam.

9.1.2 Material

The material selected from the material selection for the beam in *chapter7* will be used for the analysis. The outcome of the analysis is dependent on the properties of the material stated in *Table 7* below.

Carbon steel AISI 1080	
Young's Modulus	207.5GPa
Yield strength	807.5MPa
Poisson ratio	0.29

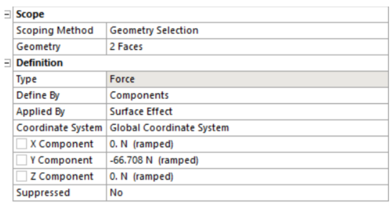
Table 7: Properties of Carbon steel AISI 1080.

NOTE: The values of the material properties used in *Table 7* are average values of the material properties from Granta EduPack Level 3 as stated in *Table 6*.

9.1.3 Static Structural

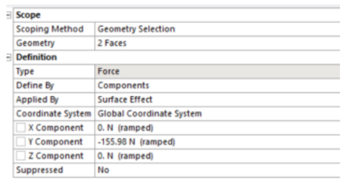
The analysis of the dual swing arms focuses on only one of the compound beams comprising the design with half of the design load applied. To obtain consistent results, boundary conditions are applied to the compound beam together with the applied load in Ansys Workbench to yield an approximate solution with the analytical results of the cantilever beam.

For the boundary conditions, the right end of the lower arm is fixed, and hole on the left end of the upper arm is subjected to the force in the negative y-direction illustrated in *Figure 47* and *Figure 48* respectively as shown below.



Scope	
Scoping Method	Geometry Selection
Geometry	2 Faces
Definition	
Type	Force
Define By	Components
Applied By	Surface Effect
Coordinate System	Global Coordinate System
X Component	0. N (ramped)
Y Component	-66.708 N (ramped)
Z Component	0. N (ramped)
Suppressed	No

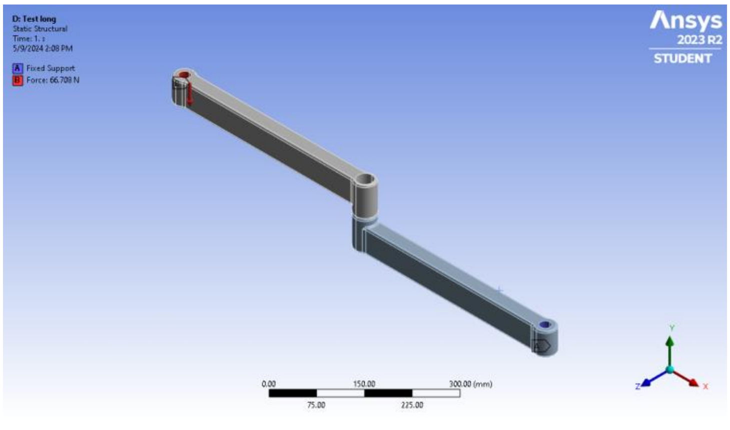
(a) 55" TV



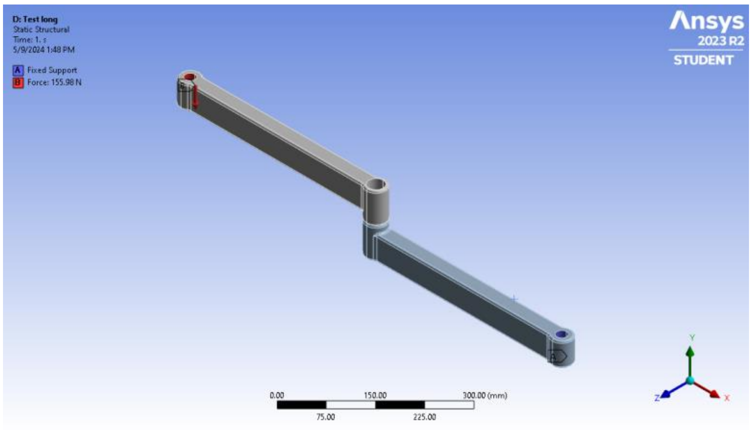
Scope	
Scoping Method	Geometry Selection
Geometry	2 Faces
Definition	
Type	Force
Define By	Components
Applied By	Surface Effect
Coordinate System	Global Coordinate System
X Component	0. N (ramped)
Y Component	-155.98 N (ramped)
Z Component	0. N (ramped)
Suppressed	No

(b) 70" TV

Figure 47: Force Scope.



(a) Weight of 55" TV in the negative y-direction



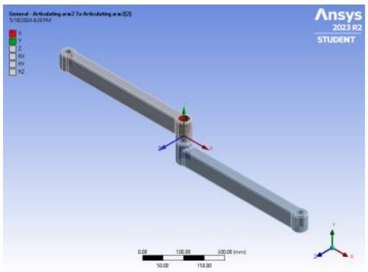
(b) Weight of 70" TV in the negative y-direction.

Figure 48: An illustration of the applied boundary conditions.

In the free body diagram, the reaction expression of the static force at the hinge joint indicates no moment at the joint. Therefore, a general connection (joint) is applied at the contact region between the two arms of the compound beam, with rotation fixed in all directions. The analysis is conducted in the x-y plane, assuming that all rotation and translation in the z-axis are negligible. The joint variables are illustrated in *Figure 49* below.

Definition	
Connection Type	Body-Body
Type	General
Primitive Type	None
Translation X	Free
Translation Y	Free
Translation Z	Fixed
Rotations	Fix All
Element APDL Name	
Suppressed	No
Reference	
Scoping Method	Geometry Selection
Applied By	Remote Attachment
Scope	5 Faces
Body	Articulating arm2
Coordinate System	Reference Coordinate System
Behavior	Rigid
Formulation	MPC
Relaxation Method	No
Pinball Region	All
Mobile	
Scoping Method	Geometry Selection
Applied By	Remote Attachment
Scope	5 Faces
Body	Articulating arm2[2]
Initial Position	Unchanged
Behavior	Rigid
Formulation	MPC
Relaxation Method	No
Pinball Region	All
Stops	

(a) Joint Scope



(b) Illustration of the Joint

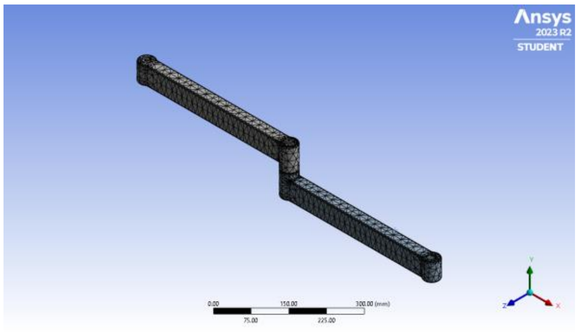
Figure 49: An illustration of the applied boundary conditions to the joint

9.1.4 Mesh

The model must be meshed before the simulation can take place. Meshing takes the model and cut it into finite elements and calculate each element piece by piece where the final solution is the sum of all calculated elements. For the solid structure, the mesh size of 20mm and the tetrahedrons mesh type are applied to the model to better approximate the surface contours. The number of elements and element size used for the analysis is shown in *Figure 50* below.

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	20.0 mm
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
Nodes	19608
Elements	10504
Show Detailed Statistics	No

(a) Number of mesh elements



(a) An illustration of applied mesh

Figure 50: Mesh of beam with element size of 20mm.

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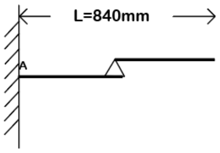
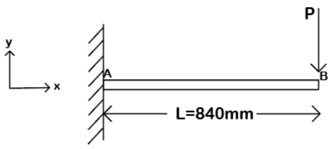
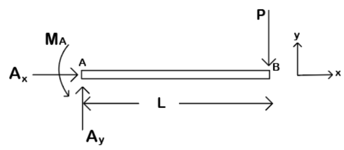
9.1.5 Analytical Computations of the cantilever beam.



(a) Schematic Diagram of Member interaction



(b) Cantilever Beam (Assumption)



(c) Free Body Diagram

To compute the reaction forces in (b) at the fixed support, the equilibrium equations is applied to sum up the moment and forces in the x and y axes. i.e. $\sum F_x = 0; \sum F_y = 0; \sum M_A = 0.$

Taking the direction to the right as positive and summing up forces in the x-direction;

$$\sum F_x = 0; \rightarrow A_x = 0 \qquad 9.1$$

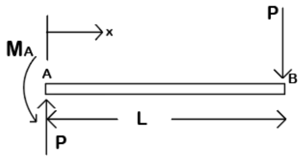
Taking the upward direction to be positive and summing up forces in the y-direction;

$$\sum F_y = 0; \rightarrow A_y - P = 0; \ \rightarrow A_y = P \qquad 9.2$$

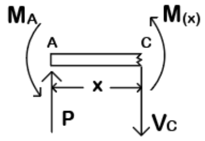
Taking the clockwise direction as positive and the moment of point A;

$$\sum M_A = 0; \rightarrow M_A - P \times L = 0; \ \rightarrow M_A = P \times L \qquad 9.3$$

To calculate the deflection of the cantilever beam, the double moment method from (Hibbeler, 2017) is utilized, where the moment is expressed as a function of the position(x) in (e) below, then successive integration will yield the beam's slope.



(d)



(e)

(f) Predicted elastic curve

Performing the analysis of a small section of beam in (e) as follows;

Moment Function: Taking the moment of point C and the clockwise direction as positive.

$$\sum M_C = 0; \rightarrow M_A + M(x) - P \times x = 0 \tag{9.4}$$

Making $M(x)$ the subject in *equation 9.4* gives;

$$M(x) = Px - M_A \tag{9.5}$$

Substituting *equation 9.3* into *equation 9.5* gives,

$$M(x) = Px - PL \tag{9.6}$$

Slope and elastic curve:

$$EI\frac{d^2y}{dx^2} = M(x) \tag{9.7}$$

where E=Young's Modulus and I=Moment of Inertia. Substituting *equation 9.6* into *equation 9.7* gives;

$$EI\frac{d^2y}{dx^2} = Px - PL \tag{9.8}$$

Integrating twice gives;

$$EI\frac{dy}{dx} = P\frac{x^2}{2} - PLx + C_1 \tag{9.9}$$

$$EIy = P\frac{x^3}{6} - PL\frac{x^2}{2} + C_1x + C_2; \rightarrow y = \frac{1}{EI}\left(P\frac{x^3}{6} - PL\frac{x^2}{2} + C_1x + C_2\right) \tag{9.10}$$

Applying the boundary conditions to *equation 9.9* and *equation 9.10*

At x=0 in (a); y=0

$$\rightarrow 0 = \frac{1}{EI}\left(P\frac{0^3}{6} - PL\frac{0^2}{2} + C_1 \times 0 + C_2\right); \rightarrow C_2 = 0 \tag{9.11}$$

At x=0, dy/dx=0

$$0 = \frac{1}{EI}\left(P\frac{0^2}{2} - PL \times 0 + C_1\right); \rightarrow C_1 = 0 \qquad 9.12$$

The deflection *equation 9.10* becomes,

$$y = \frac{1}{EI}\left(P\frac{x^3}{6} - PL\frac{x^2}{2}\right) = \frac{P}{EI}\left(\frac{x^3}{6} - L\frac{x^2}{2}\right) = \frac{P}{EI}\left(\frac{x^3 - 3Lx^2}{6}\right) \qquad 9.13$$

Applying the beam material properties in *Table 7* and load to *equation 9.13*.

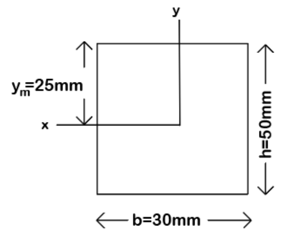


Figure 51: Cross- section of beam.

The moment of inertia, *I* of the rectangular cross-section of the beam gives,

$$I = \frac{1}{12}bh^3 = \frac{1}{12} \times 30 \times 10^{-3} \times (50 \times 10^{-3})^3 = 3.125 \times 10^{-7} m^4$$

The mass of the 55" – 70" flat displays is assumed to be in the range of 30Ibs – 70Ibs (13.8kg -31.8kg). Therefore, it implies that;

<u>For a 55" TV</u>

The required weight of the TV can be computed as; Weight(P) =mass x acceleration due to gravity =13.6 x 9.81m/s^2=133.416N. For a single beam analysis, half of the load is used for the analysis. i.e. 133.416/2 = 66.708N. The deflection is at its greatest when x=L

$$\rightarrow y = \frac{P}{EI}\left(\frac{L^3 - 3L^3}{6}\right) = -\frac{PL^3}{3EI} \qquad 9.14$$

$$y = -\frac{PL^3}{3EI} = -\frac{66.708 \times (840 \times 10^{-3})^3}{3 \times 207.5 \times 10^9 \times 3.125 \times 10^{-7}} = 0.2032mm$$

The maximum bending stress;

$$\sigma_b = \frac{M_{max}}{I} \times y_m \qquad 9.15$$

$$M_{max} = M_A = P \times L = 66.708 \times 840 \times 10^{-3} = 56.03472Nm$$

$$\sigma_b = \frac{M_{max}}{I} \times y_m = \frac{56.03472}{3.125 \times 10^{-7}} \times \frac{50 \times 10^{-3}}{2} = 0.44827776 \times 10^{7} = 4.4828MPa$$

<u>For a 70” TV</u>

The mass of the TV is assumed to be 31.8kg, which implies that the required weight of the TV can be computed as; Weight(P) =mass x acceleration due to gravity =31.8 x 9.81m/s^2=311.958N.For a single beam analysis, half of the load is used for the analysis. i.e 311.958/2 = 155.979N.

The maximum deflection occurs at x=L as in *equation 9.14*

$$\rightarrow y = -\frac{PL^3}{3EI} = -\frac{155.979 \times (840 \times 10^{-3})^3}{3 \times 207.5 \times 10^{9} \times 3.125 \times 10^{-7}} = 0.4752mm$$

The maximum bending stress occurs at x=0 as in *equation 9.15*

$$M_{max} = M_A = P \times L = 155.979 \times 840 \times 10^{-3} = 131.02236Nm$$

$$\sigma_b = \frac{M_{max}}{I} \times y_m = \frac{131.02236}{3.125 \times 10^{-7}} \times \frac{50 \times 10^{-3}}{2} = 1.04818 \times 10^{7} = 10.4818MPa$$

9.1.6 Numerical Results

9.1.6.1 For 55” Flat display

<u>Total Deformation</u>

The total deflection generated by the mesh size was calculated to be 0.17736mm as shown in *Figure 52* below.

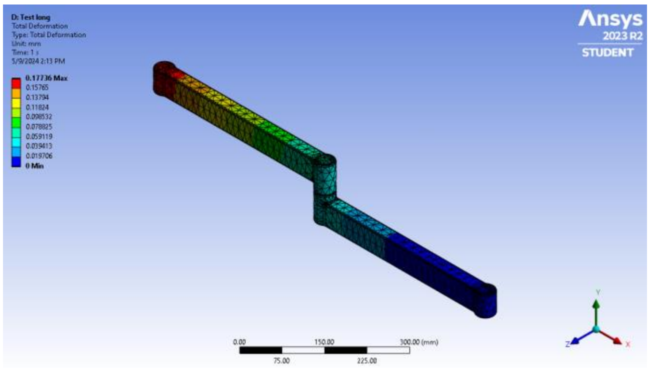


Figure 52: Total deformation of the 55" TV load.

Equivalent Stress

The von-Mises stress is calculated as 5.8751MPa as shown in *Figure 53* below.

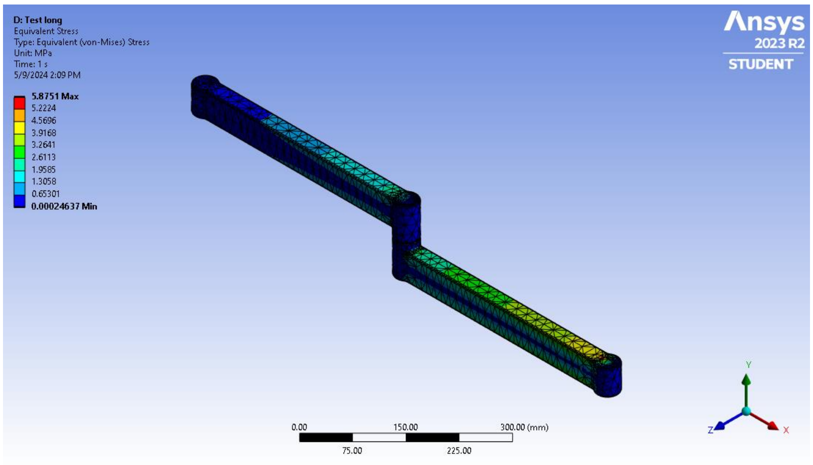


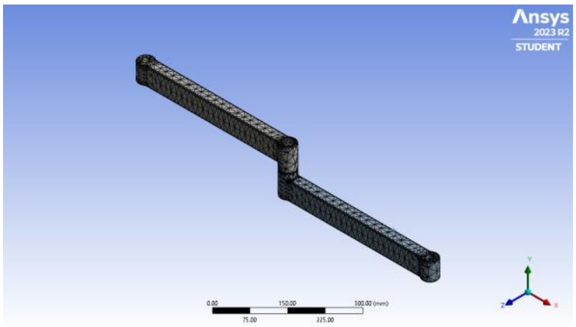
Figure 53: von-Mises stress from the 55" TV load.

9.1.7 Refined Mesh

To obtain a more accurate results of the finite element model to the analytical calculations, The number of elements and element size is refined from 2cm to 1cm for the analysis as illustrated in *Figure 54* below.

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	10.0 mm
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
Nodes	19864
Elements	10652
Show Detailed Statistics	No

(a) Number of elements



(b) An illustration of the applied mesh

Figure 54: Mesh with smaller element size.

9.1.7.1 For 55” Flat Display

Total Deformation

The total deformation generated by the mesh size was calculated to be 0.17741mm as shown in *Figure 55* below.

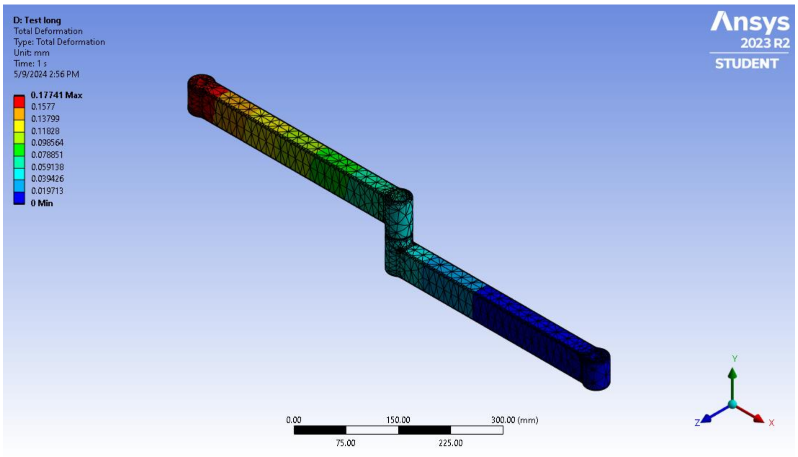


Figure 55: Total deformation of the 55" TV load with a finer mesh.

Von-Mises stress

The von-Mises stress is calculated as 5.6806MPa as shown in *Figure 56* below.

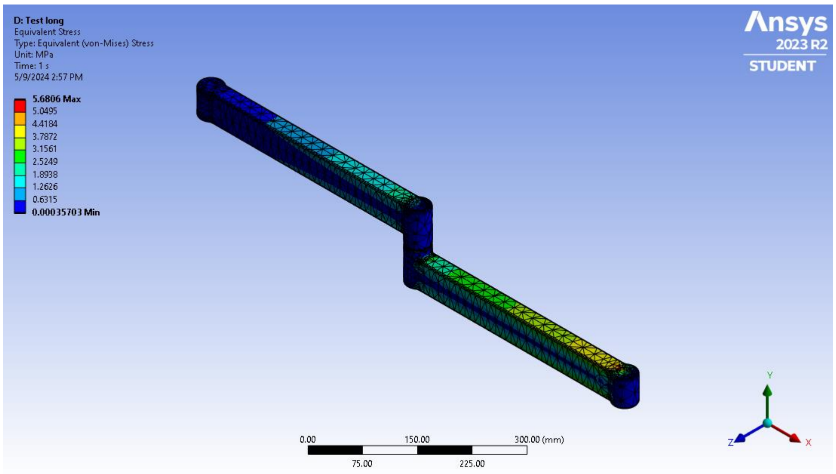


Figure 56: von-Mises stress from the 55" TV load with finer mesh.

Similar analysis of the numerical computations is performed for 70" TV for both mesh sizes and the illustrations can be found in the appendix. Comparison of the numerical results of the design member to the analytical results of the cantilever beam is shown in *Table 8* below.

Element size		Deflection[mm]		von-Mises Stress [MPa]	
		55"	70"	55"	70"
	Analytical Results	0.2032	0.4752	4.4828	10.4818
0.02m	Numerical Results	0.17736	0.41472	5.8751	13.738
0.01m	Numerical Results (Refined mesh)	0.17741	0.41485	5.6808	13.283

Table 8: Comparison of numerical and analytical results.

9.1.8 Discussion of Results

The obtained result from the numerical analysis is likened to the cantilever beam from the analytical calculations due to the type of loading and support conditions applied in the numerical analysis with Ansys Workbench. Small deflection values in both cases indicate the beam's ability to handle the loads from the 55"-70" flat displays. The numerical results (*Table 8*) obtained after mesh refinement did not produce significant change in the previous results with mesh size of 2cm. Solid elements sometimes produce inaccurate results as compared to the line beam element, so the results were expected. A more complex and refined mesh size will produce an even consistent results compared with analytical solution. Another comparison is made with the numerical analysis of the cantilever using Ansys APDL with beam elements, and design load of the 55" Flat display to obtain an approximate solution and validate results to the analytical calculations. Similar analysis was made with workbench to test the accuracy of results from both platforms as shown in *Table 9* below.

Element size		Deflection[mm]	Von-Mises stress [MPa]
	Analytical results	0.2032	4.4828
0.05m	Numerical Results (1D Beam 188 element type)	0.20364	4.34
0.05m	Numerical Results (3D solid 185 element)	0.25491	5.4

Table 9: Numerical results of the cantilever beam obtained using Ansys APDL.

NOTE: The illustrations from the results of cantilever beam from Ansys APDL and Ansys Workbench that be found in the appendix.

<u>Results Validation</u>

The results from of the cantilever beam from APDL is juxtaposed to that from workbench to verify the accuracy using the error formula which is;

$$\text{The percentage error}(\%E) = \left|\frac{Analytical - Numerical}{Analytical}\right| \times 100 \tag{9.16}$$

Using the error formula in *equation 9.16*, the deflection and stress error is evaluated *below*.

	Deflection error (%)	Stress error (%)
Analytical		
Numerical (APDL beam 188 element)	0.217	3.19
Numerical (Workbench beam)	188.55	

Table 10: The deflection and stress error.

From Table 10, it can be seen that the error margin for both cases under the same boundary conditions, the results from APDL have the least error margin and the more accurate platform with consistent results. Hence, the results for the model in *Table 8* is expected. The illustrations of the cantilever beam analysis in workbench can be found in the appendix.

9.2 Design Optimization and Safety calculation.

From the results of both the cantilever beam and the design model, it can be observed that, the deflections are very small. The section modulus, Z of the beam is very high which makes the beam stiffer and less susceptible to bending under the applied design load. The increased stiffness is a contributing factor to the reduced deflections in both case studies of the varied design load. Since other components other than the TV would be attached to the beam in the assembly, it must be designed with a high factor of safety to account for these loads from the other members. Using the maximum-distortion-energy criterion for failure from (Davies, 2006) to determine the factor of safety of the beam, to verify the margin of safety of the beam and to make informed decision on its design.

$$Factor\ of\ Safety(FOS), n = \frac{Yield\ Strength, \sigma_Y}{von - Mises\ stress, \sigma_e} = \frac{807.5 \times 10^6}{13.283 \times 10^6} = 60.791 \qquad 9.17$$

The FOS of 60 indicates that the structure or component can withstand the design load or stress level that is 60 times lower than its ultimate capacity or failure point. The obtained FOS value means that the material selected for the product provides an unnecessary large factor of safety and a wide buffer between the expected operating conditions and the point at which failure might occur. The FOS of 60 is very large which is expected due to the beam having a higher section modulus being subjected to a small design load. The section modulus used for the analysis is rather large and unnecessary considering the design load. To help design a beam with a lower section modulus that can also provide the needed structural integrity of the design at a cheaper cost and less material usage, a factor of safety of 5 is first chosen as a guide to account for uncertainties manufacturing processes and operating conditions and also select the optimum cross-section that will be suitable for the design.

NOTE: The calculations for the suitable cross-section and material optimization can be found in the appendix.

9.2.1.1 Improving details

For a lower material cost and safe design, the optimum cross-section of the beam with a factor of safety of 5 can be chosen to be b=20mm=0.02m and h=16mm=0.016m as it satisfies the structural requirements of the beam under the design load(P) as demonstrated in *equation 10.6.* Based on the numerical and analytical results in the previous section, the idea was to use a new cross-sectional area or remove material for the beam. With the same material and cross-section selected, the beam design was improved by removing some material from the beam to reduce the overall weight of the beam and also help reduce material and manufacturing cost. The optimized design can be viewed in the appendix.

10 FUTURE WORK

There is a lot of desire for improvement, and much more work is needed to enhance the handling of the product by implementing remote control capabilities. The next step will involve a comprehensive study of the kinematic model of the design, providing analytical analysis of the transformation of each kinematic member to determine the full extent of the model's workspace. Additionally, the analytical model will be used to develop a motorized mounting system that can further improve the handling and control of the mounting system. In terms of enhancing the flexibility of the product, the design of the sliding track could be improved to allow for corner wall mounting of the mounting system. The determination of all possible and feasible sets of joint variables, which would achieve the specified position and orientation of the manipulator’s end-effector with respect to the base/reference frame.

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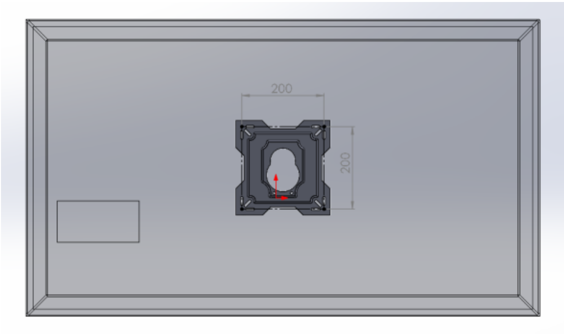
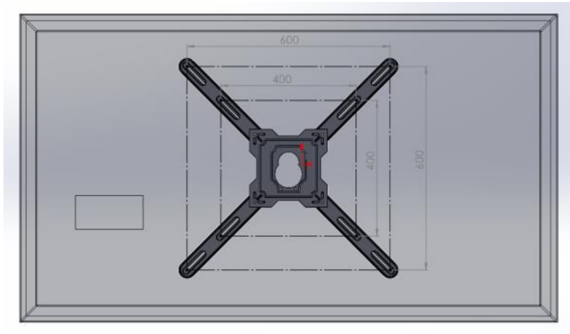
Appendix A

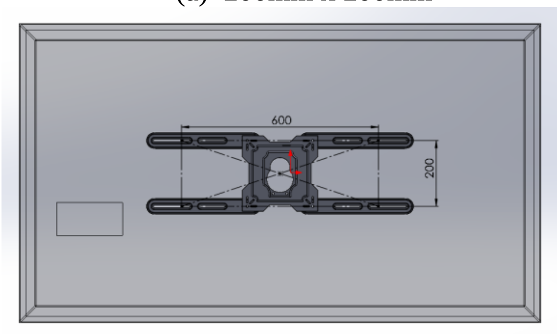
Various configurations of the mounting interface



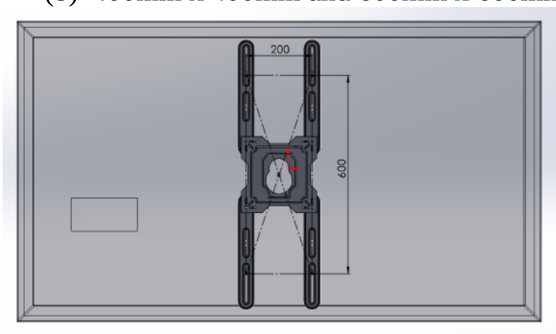
(a) 200mm x 200mm



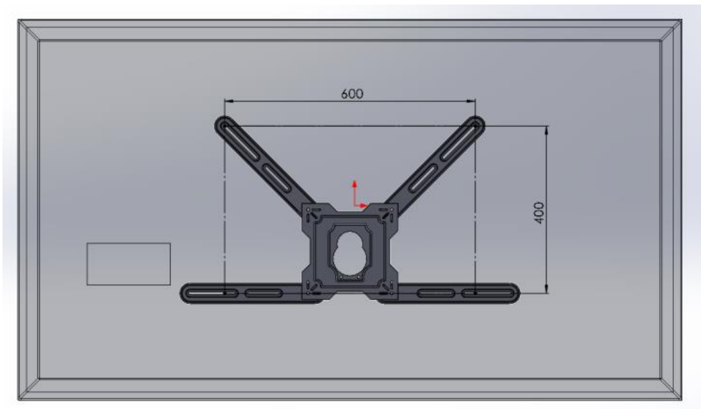
(b) 400mm x 400mm and 600mm x 600mm



(c) 600mm x 200mm



(d) 200mm x 600mm



(e) 600mm x 400mm

Appendix B

Material and Process selection of casing unit

The casing unit is chosen to be a lightweight and made up of a thermoplastic material. The process requirements to select the best process to manufacture the casing unit is translated below.

<u>Process Selection Requirements</u>

Function: Shaping of a casing material.

Objective: Minimize cost.

Constraints.

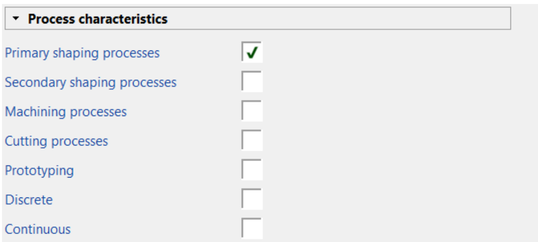
- Material: Thermoplastic
- Shape: 3D Solid
- Minimum section: 0.4mm
- Estimated mass: 0.01 – 0.05kg
- Batch size: 10^4 to 10^6

Free Variable:

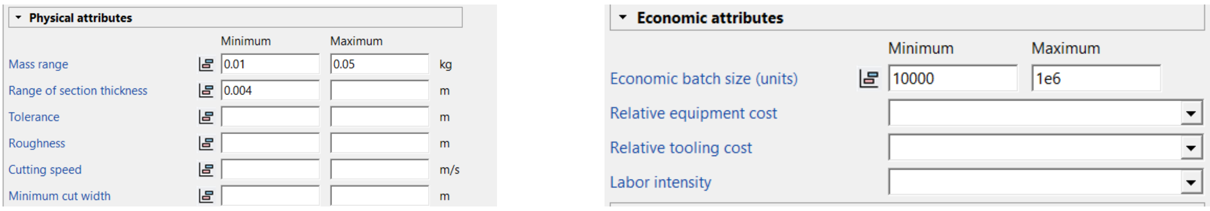
- Choice of Process and process operating conditions

The selection method for the shaping process of the casing unit is done with Granta EduPack, whereby the process constraints for the casing unit (*Figure 44*) are specified in Granta EduPack with Level 3 Database as shown in *Figure 57*.

(a) Shape constraints



(b) Process Characteristics



(c) Mass and Thickness constraints (d) Batch size

Figure 57: Process constraints.

The obtained result of the processes based on the process constraints is shown in *Figure 58* below.

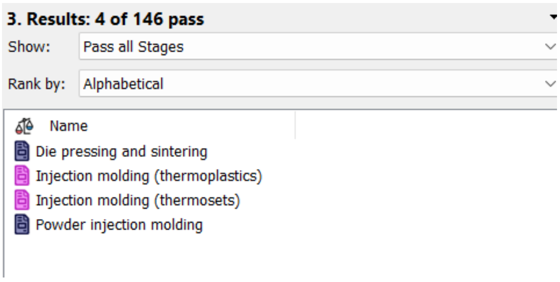


Figure 58: Results of Processes at Level 3

Table 11 below describes the compatibility of the obtained results in *Figure 58* with thermoplastics (Fig 7.3 - Chapter 7(Ashby, 2005) and the specified 3D shape.

Process	Compatibility with Thermoplastics (Fig 7.3)	Compatibility with shape	Quality Comment
Die pressing and sintering	Fails		
Injection molding		Complex shapes are possible	Meets requirement for finish and tolerance
Powder injection molding	Fails		

Table 11: Compatibility of the obtained processes.

From the Level 3 database of Granta EduPack, lightweight casing material such as Acrylonitrile Butadiene Styrene (ABS), Polystyrene (PS), and Poly methyl methacrylate (PMMA) – also known as acrylic are all suitable thermoplastic materials that can be used for the casing unit of the design which will be produced by injection molding process as indicated in *Table 11*.

Appendix C

Numerical analysis of the 70” flat display

Total Deformation

The total deformation generated by the mesh size was calculated to be 0.41472mm as shown in *Figure 59* below.

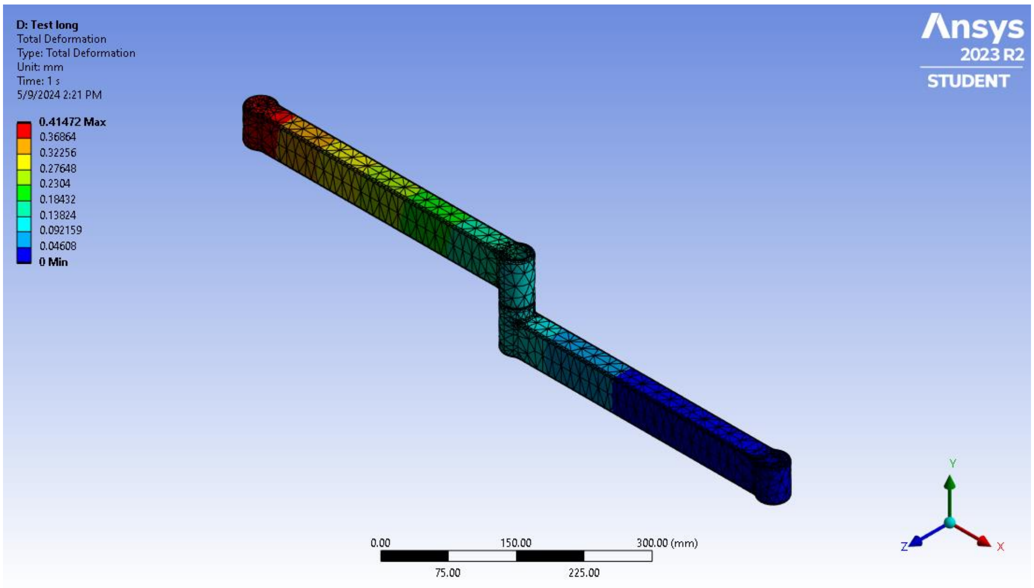


Figure 59: Total deformation of the 70" TV load.

Equivalent Stress

The von-Mises stress is calculated as 13.738MPa as shown in *Figure 60* below.

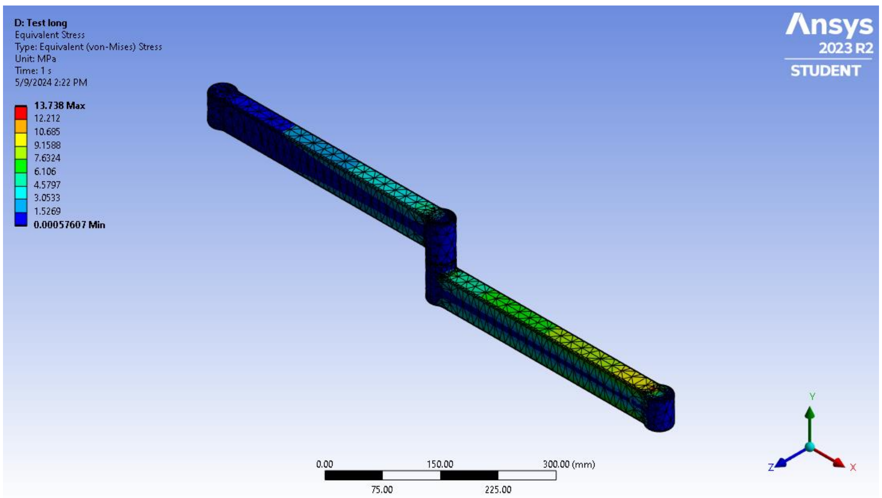


Figure 60:von-Mises stress from the 70" TV load.

For the Refined Mesh

Total Deformation

The total deformation generated by the mesh size was calculated to be 0.41485mm as shown in *Figure 61* below.

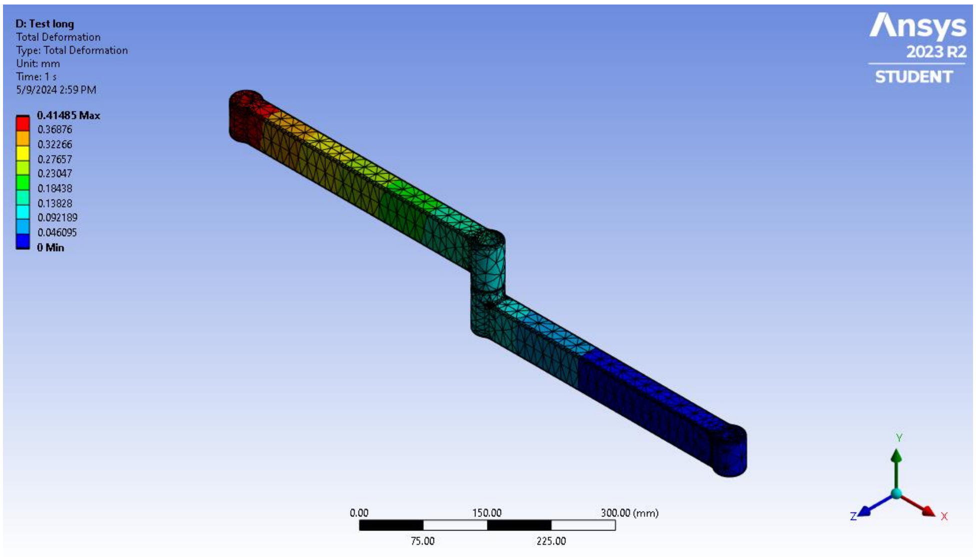


Figure 61: Total deformation of the 70" TV load with a finer mesh.

Von-Mises Stress

The von-Mises stress is calculated as 13.283MPa as shown in *Figure 62* below.

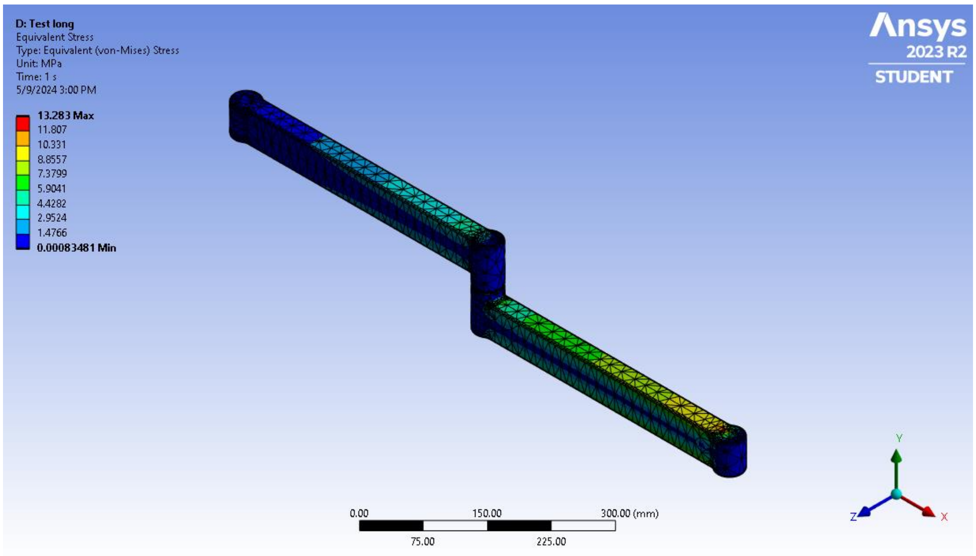


Figure 62: von-Mises stress from the 70" TV load with finer mesh.

Appendix D

Log file of the cantilever beam with end-point load analysis using APDL

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KEYW,PR_STRUC,1

KEYW,PR_THERM,0

KEYW,PR_FLUID,0

KEYW,PR_ELMAG,0

KEYW,MAGNOD,0

KEYW,MAGEDG,0

KEYW,MAGHFE,0

KEYW,MAGELC,0

KEYW,PR_MULTI,0

/PREP7

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MPTEMP,1,0

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!*

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/REPLOT

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!*

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SECOFFSET, CENT

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LPLOT

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/REPLOT,RESIZE

/UI,MESH,OFF

/REPLOT,RESIZE
```

```
LMESH,       1

LPLOT

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SOLVE

SAVE

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/POST1

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/SHRINK,0
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PRNSOL,U,Y

PRESOL,FORC

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PLNSOL, S,EQV, 0,1.0

SAVE

finish

FINISH
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Illustration for deflection and stress

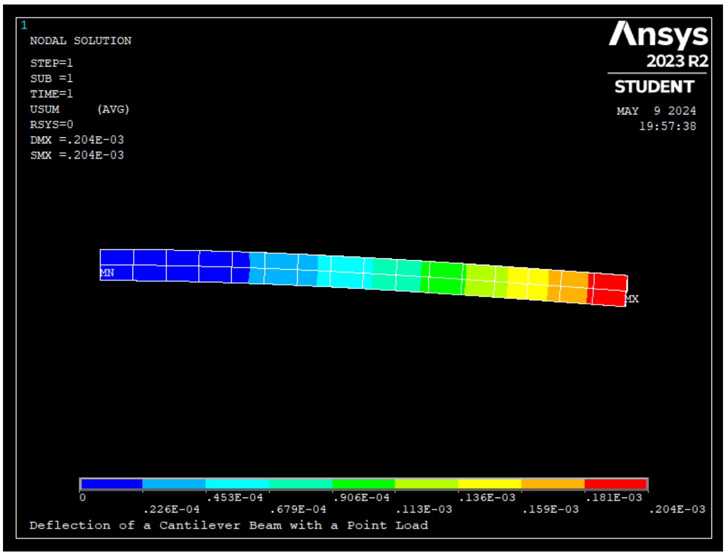


Figure 63: Displacement of cantilever beam with 1D beam element.

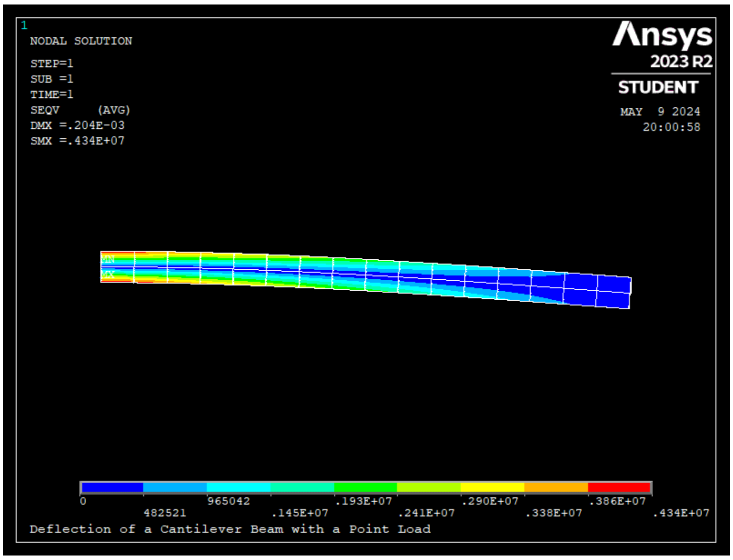


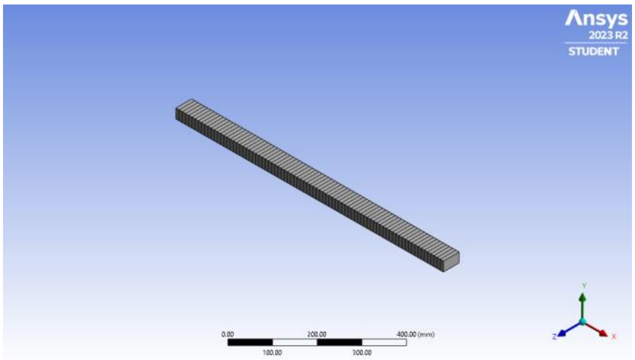
Figure 64: von-Mises stress of cantilever beam with 1D beam element.

Appendix E

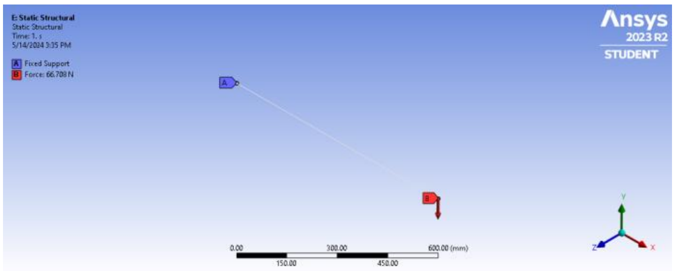
Cantilever beam analysis with end-point load using workbench.

Mesh

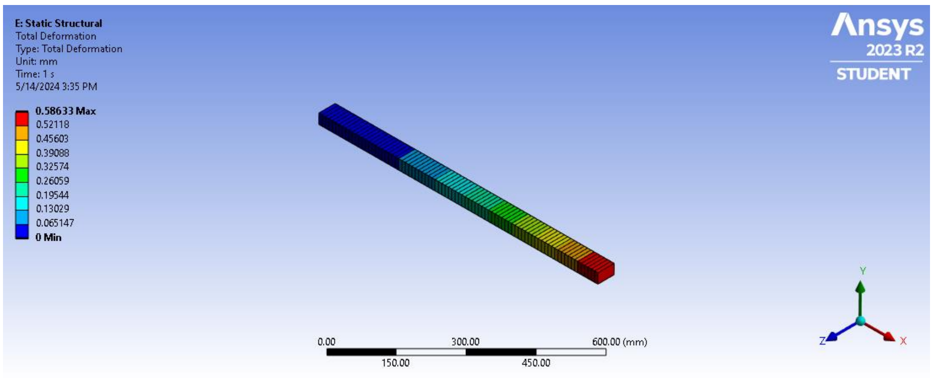
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	10.0 mm
Sizing	
Quality	
Inflation	
Batch Connections	
Advanced	
Statistics	
Nodes	169
Elements	84
Show Detailed St...	No



Boundary Conditions



Deflection



Calculation for the suitable cross-section of the design

Making σ_e the subject of *equation 9.17* yields;

$$\sigma_e \leq \frac{\sigma_Y}{n} = \frac{807.5\,MPa}{5} = 161.5MPa \quad 10.1$$

From *equation 9.15*, the bending stress is given as;

$$\sigma_b = \frac{M_{max}}{I} \times y_m = \frac{M_{max}}{Z} = \frac{P \times L}{Z} \quad 10.2$$

where Z=section modulus; which is given by $Z = I/y_m = bh^2/6$.

The bending stress calculated was assumed to be the total stress in the beam. So, it implies that the von-Mises stress is equal to the bending stress. i.e. $\sigma_b = \sigma_e$

$$\rightarrow \sigma_b = \sigma_e \leq 161.5MPa = \frac{P \times L \times 6}{bh^2} \leq 161.5MPa \quad 10.3$$

Applying the maximum design load of 155.979N and L=840mm to *equation 10.3* yields;

$$\frac{155.979 \times 840 \times 10^{-3} \times 6}{bh^2} \leq 161.5MPa$$

Simplifying the above equation yields;

$$\frac{786.13416}{bh^2} \leq 161.5MPa \quad 10.4$$

NOTE: The beam fails if the left-hand side (LHS) is higher than the right-hand side (RHS). The optimum cross-section area is the one that will not yield under the design load(P).

Applying some iterations and few guesses of the width(b) and heigh(h) of the cross-section of the beam to *equation 10.4* to obtain the minimum cross-section of the beam that will be most suitable under the design load.

<u>For 1st iteration; b=20mm and h=15mm</u>

$$\frac{155.979 \times 840 \times 10^{-3} \times 6}{20 \times 10^{-3} \times (15 \times 10^{-3})^2} \leq 161.5MPa$$

$$174.696MPa \leq 161.5MPa \quad 10.5$$

The LHS is greater than the RHS, hence yielding will occur.

<u>For 2nd iteration; b=20mm and h=16mm</u>

$$\frac{155.979 \times 840 \times 10^{-3} \times 6}{20 \times 10^{-3} \times (16 \times 10^{-3})^2} \leq 161.5MPa$$

$$153.542MPa \leq 161.5MPa \quad 10.6$$

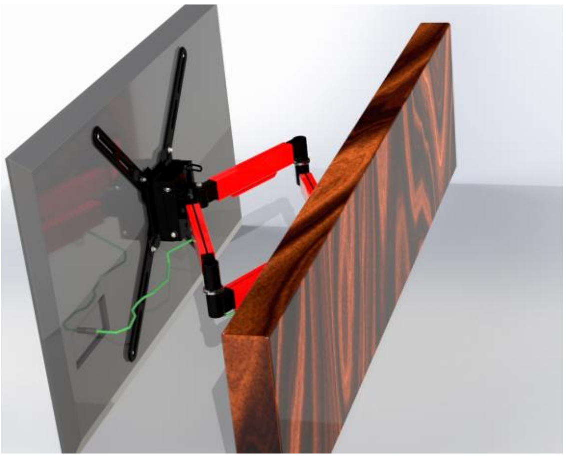
The LHS is less than the RHS, hence yielding will not occur.

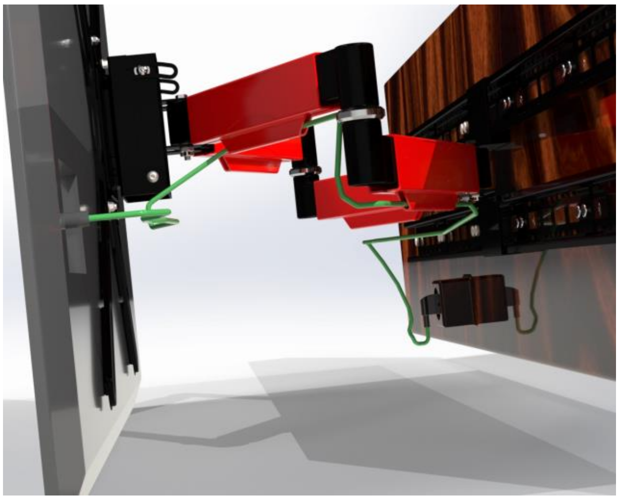
Therefore, the optimized design of the beam can be seen below;

Figure 65: Improved design of the swing arm.

Appendix F

Final Product and Renderings





Cable management

Appendix G

Thesis Task

University of Tromsø – The Arctic University of Norway
Faculty of Engineering Science and Technology
Department of Computer Science and Computational Engineering

Master of Science

Master thesis “Design of a mobile TV-frame suspension system”

—

Candidate name: Ephraim Nyarko Ebo Otsiwah
Master thesis in Engineering Design spring 2024

- Problem description

In small houses (micro-house) and apartments, décor and furnishing by using multi-functional systems and furniture are of great interest. For instance, you only need a tv for a period of time during the day, and maybe if you have friends over for watching football you need the tv to be placed in another angle or place than if you are going to relax and watch a movie for yourself. Then, a flexible suspension system for placing the TV is needed so that it can be put in different places in the living room (or at least vary with a couple of meters). When you do not want to watch TV anymore, it should be possible to place the TV in a place where it is not in the way when you move around in the living room. For instance, the tv could be placed along a wall, in the ceiling etc. so it doesn't disturb the living-room.

The system should be easy to mount, withstand the weight of the TV and be nice. It should be able to carry tv's from 55"-70".

The work shall include:

1. **A literature study** both in terms of finding state-of –the art for these types of products and solutions in the market and potential competitors, as well as literature that is necessary to solve the problem (regulations, standards for materials, algorithms etc.).
2. **Establishment of some case studies** including specifications (i.e., loading and boundary conditions, physical conditions, requirements for stiffness, strength, weight, materials, temperatures).
3. By using **systematic engineering design** and **product design process** and **materials selection process**, the system should be designed.
4. **A 3D-model** included a **3D-simulation** that shows the flexibility of the system must be performed.
5. **Analytical** and **numerical analysis of the concept.**
6. A **3D-printed scaled prototype/model** should be made.
7. **Suggestions** for future work and description of remaining work.

The solution of the task should be based on typical engineering design methods and areas of study for the Master Program Engineering Design at UiT – campus Narvik.

- General information

- This master thesis should include:

❄ Preliminary work/literature study related to actual topic
  - A state-of-the-art investigation
  - An analysis of requirement specifications, definitions, design requirements, given standards or norms, guidelines, and practical experience etc.
  - Description concerning limitations and size of the task/project
  - Estimated time schedule for the project/ thesis

❄ Selection & investigation of actual materials

❄ Development (creating a model or model concept)

❄ Experimental work (planned in the preliminary work/literature study part)

❄ Suggestion for future work/development

Limitations of the task/project
There may be information in the report that may not be open, and if so, the report should be restricted. This will be considered before the candidate submits the thesis.

- Preliminary work/literature study

After the task description has been distributed to the candidate a preliminary study should be completed within 4 weeks. It should include bullet pints 1 and 2 in “The work shall include”, and a plan of the progress. The preliminary study may be submitted as a separate report or “natural” incorporated in the main thesis report. A plan of progress and a deviation report (gap report) can be added as an appendix to the thesis.

In any case the preliminary study report/part must be accepted by the supervisor before the student can continue with the rest of the master thesis. In the evaluation of this thesis emphasis will be placed on the thorough documentation of the work performed.

- Reporting requirements

The thesis should be submitted as a research report and must include the following parts: Abstract, Introduction, Material & Methods, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References and Appendices. Choices should be well documented with evidence, references, or logical arguments.

The candidate should in this thesis strive to make the report survey-able, testable, accessible, well written, and documented.

Materials which are developed during the project (thesis) such as software/codes or physical equipment are a part of this paper (thesis). Documentation for correct use of such information should be added, as far as possible, to this paper (thesis).

The text for this task should be added as an appendix to the report (thesis).

The report (Abstract, Introduction, Material & Methods, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References) should not exceed 50 pages. Any additional material should be included in the appendix.

- General project requirements

If the tasks or the problems are performed in close cooperation with an external company, the candidate should follow the guidelines or other directives given by the management of the company.

The candidate does not have the authority to enter or access external companies' information system, production equipment or likewise. If such should be necessary for solving the task in a satisfactory way a detailed permission should be given by the management in the company before any action are made.

Any travel cost, printing and phone cost must be covered by the candidate themselves, if and only if, this is not covered by an agreement between the candidate and the management in the enterprises.

If the candidate enters some unexpected problems or challenges during the work with the tasks and these will cause changes to the work plan, it should be addressed to the supervisor at the UiT Campus Narvik or the person which is responsible, without any delay in time.

- Submission requirements

This thesis should result in a final report with an electronic copy of the report included appendices and necessary software codes, simulations, and calculations. The final report with its appendices will be the basis for the evaluation and grading of the thesis. The report with all materials should be delivered in an electronic format. The report should be in PDF format while the rest of the material should be bundled in ZIP file. A standard front page, which can be found on the UiT Campus Narvik internet site, should be used. Otherwise, refer to the "General guidelines for thesis" and the subject description for master thesis.

The final report with its appendices should be submitted no later than the decided final date. The final report should be delivered/ submitted/ uploaded to WISEflow.

Date of distributing the task:	XX.01.2024
Date for submission (deadline):	XX.05.2024

- Contact information.

Supervisors at the UiT Narvik
Professor Annette Meidell Annette.Meidell@uit.no

Appendix H

Production Drawing of the Assembly Parts