

Design And Fabrication Of Shape Shifting Cuboid

Abhishek Garg¹, Sandeep Udayasingh², Kundan Kumar³, Dhruv Kumar⁴,
Ashutosh Singh⁵, Manash Dey⁶

^{1,2,3}Student, Department of mechanical engineering, JIMS engineering management technical campus, Greater Noida, UP

^{4,5,6}Assistant Professor, Department of mechanical engineering, JIMS engineering management technical campus, Greater Noida, Uttar Pradesh, India
corresponding author: Abhishek Garg

Abstract: Recognition of essential household utilities with respect to the space and environment plays a crucial role in obtaining an advanced and compact design. Our work aims to create a structure that can fulfill various necessities including furniture and storage facilities. To create such a structure, processes those are involved in our work emphasis on applications of Mechatronics, Machine design and robotics.

A shape shifting structure has the ability to be used as a chair, a table, a sofa and a bed. These facilities are the basic demands for a household. Our work focuses on reduction of space for all necessities and easy accessibility. In addition to that some special attention towards the disabled personals emphasizes to help that section of society.

To obtain such a structure a study that mainly aims on the design of the structure keeping all aspects that includes forces and stresses from all directions. For that purpose, suitable material selection is done. A study from many sources and including crucial aspects emphasizes to reduce all the expenses involved in the structure and economical for people in the market.

Keywords - design, furniture, household, material, structure.

Date of Submission: 12-11-2018

Date of acceptance: 26-11-2018

I. INTRODUCTION

Now a days we can see advancement in the technology with new-coming discoveries. If we talk about space utilization in big cities there are a lot of problems people are facing in their daily lives. People with middle income are unable to afford big houses, so they are bound to live in small rooms. Since everyone has desires to maintain a good lifestyle, lack of space and economical factors are responsible for creating problems for all these purposes. A small room is not sufficient enough to occupy a sofa set, a chair, table and a bed separately within a given area.

Our work aims to create a structure that is all in one object that can support various necessities. It is easy to handle, movable with the help of supports, low maintenance requirement, compact size, economical to people, light in weight, good strength and long life span.

The study includes applications of mechanical energy utilization and sensors. Fields of studies of mechatronics, machine designing, robotics and some applications of electronics helps to develop the structure.

The shape shifting cuboid is the structure that is capable of changing shape whether it's a table that can be formed by lifting a part of surface from the top with the help of supporting column powered by mechanical power input for load lifting, and providing space to sit at the sides of the remaining parts as chair, or into a sofa that is obtained by lifting some part of the rear end at some angle and supported with joints powered by mechanical inputs.

The structure can be used as a bed by extending from the front with mechanical power input and providing good strength to the structure with the help of support across the edges.

After all these uses there is some space remaining in the structure that would be used to create storages in forms of racks.

In society, the citizens having some disabilities face a lot of troubles in daily life and they always need some assistance or some kind of help form others. One of the special feature of our structure is to design in accordance to the disabled personals as well. The structure provides a wheelchair for those who are not able to walk properly and Braille language writing system is adapted to support blind personals by providing instructions. That is helpful in way that they are no longer need to rely on others every time.

In our work an approach for obtaining the structure include sustainable material selection and design according to it. Designing is completed with the help of design software that include all parts of structure,

calculations includes strength of material, the stress factors, tension on parts and overall forces from all directions.

II. RELATED WORK

2.1 Sustainable material selection

The basic idea of selecting material is necessary for the environmental factor affecting the performance of products. Generally, we categorize the materials on the basis of some crucial factors. These factors require the team knowledge, environmental acceptance of material, reliability, quality attributes, research and innovations to increase performance.

For choosing an appropriate material for our project, the evidence is taken from a case study done at Orange box, which is a sustainability led furniture design company. They are working on consecutive New Product developments (NPDs) in the furniture sector. [1]

2.2 Material selection factors

The Research and Innovation department of the European commission in the year 2001 estimated that about 70% of the innovations are based on materials with new properties. [2]

This case study focuses on an in-house design team working in the furniture section.

Factors influencing material selection:

Internal factors –

- 1). Cost
- 2). Availability
- 3). Performance
- 4). Manufacturability
- 5). Supply source
- 6). Internal knowledge

External factors –

- 1). New technologies
- 2). Advanced materials
- 3). Industrial and technical infrastructures
- 4). Expenditure involved
- 5). Ethical and style changes
- 6). Social and geo-political factors

Design is, at basis, a decision- making, and problem solving activity [3]

2.3 Furniture

Structure of furniture is made mainly from elements cut from timber and wood based material. In our work we decided to use plywood as the material for the furniture. This plywood we are using is hardwood timber made plywood that is comfortable in handling heavy loads and long lasting. The work consists a study about the characteristics of the furniture. According to the theory given by J. Smardzewskion the topic “classification and characteristics of furniture” published in 2015 –Furniture is of applied arts intended for permanent furnishing of residential interiors and it serves for storage, work, eating, sleeping and relaxing. A set of storage can consist of bookcase, dressers etc. Table and desk for offices usually have a fixed geometry of work surface but they have step adjustment of its position height.

[4]

2.4 Mechanism Theory

2.4.1 “Folding chair” as given in U.S. patent: 5,984,406 By Howard Lee, 1325 Oakhill Pl, SouthPasadena, Calif. 91030.

A lawn seat having: an edge comprising of a couple of front crossed legs, a couple of back crossed legs, and two sets of Side crossed legs, each combine of crossed legs urgently associated together where they cross. The lower closures of the front legs and the lower, front finishes of the Side legs are significantly Associated with first and second lower, front cushions. The lower closures of the back legs and the lower, back finishes of the Side legs are vitally associated with first and Second lower, back cushions. The upper finishes of the back legs and the upper, back closures of the Side legs are essentially associated with first and Second upper, back cushions. The upper closures of the front legs and the upper, front finishes of the Side legs are crucially associated with first and Second upper, front cushions. The upper finishes of the front legs slidably [15] go through the first and Second upper front cushions, the upper closures twisted to frame hand rests over the upper front cushions. The upper, front, closures of the Side legs are crucially associated with the upper front cushions. Adaptable seat implies are associated with the casing with the corners at the four upper cushions.

The lower ends of the front legs and the lower, front ends of the Side legs are pivotally connected to

first and Second lower, front pads. The upper ends of the back legs and the upper, back ends of the Side legs are pivotally connected to first and Second upper, back pads[15]. The upper ends of the front legs and the upper, front ends of the Side legs are connected to first and Second upper, front pads. The upper ends of the front legs Slidably[15] pass through the first and Second upper front pads, the upper ends bent to form hand rests above the upper front pads.

[15]

2.4.2 “Folding Sofa Lounge and Knockdown Furniture” as given in U.S. Patent 3,001,822 By Paul Pagliaro, Whitestone, and Nethan Friedman, Brooklyn, N.Y., assignors to Nu Era wood products.

Collapsible seats are organized with the twin goals of comfort and effortlessness of limit. They are generally folded for limit when not being utilized, so the Smaller and more insignificant the seat can be in its disintegrated express, the better it is overall seen to be by the customer. Right when being utilized, nevertheless, a greater setup is much of the time alluring, and arm rests are a positive development to comfort. Some collapsible seats have used material reached out between edge people to give arm rests, while others use hard arm people from inflexible material, for instance, wood or plastic to give Solid arm rests. These Solid arm rests may be viewed as more liberal by customers. In particular, when a customer raises himself from the seat, it may be more pleasant to have a solid part to push against than a versatile one, while expanding one's parity.

[18]

2.4.3 “Hospital bed convertible to chair” as given in U.S. Patent 4,862,529 By Peck, W.H., Hill-Rom Co Inc, 1989.

A bed that is convertible to a seat. The bed has a pulling back diagram mounted on a settled packaging. A patient help is molded by successively related head, arrange, thigh, calf and foot sheets, with the seat board being settled to the pulling back layout. Improvement of the pulling back diagram toward the foot end of the bed causes the go to rise and the leg board to drop, along these lines making a seat.

[23]

2.4.4 “Sofa-bed” as given in U.S. patent 1,127,874 By Dyke DF, inventor; Pullman Couch Company, assignee.

convertible furniture of the class in which a progression of foldable related bed segments are masterminded to unfurl to frame a bed, and all the more especially to couch beds in which implies are accommodated anchoring some portion of the areas in divided collapsed connection while being unfurled or collapsed concerning the staying sectional' segments. Beds of this character have been made in various courses, for the most part with the bed partition turned straightforwardly to the front of the couch outline, or conveyed by a rotatable mounted empty seat outline taking a load off part for the couch framed specifically upon or conveyed by one side, and having the bed divide critically associated with and conveyed by the switch side, the bed in either case being extensible transversely of the couch and being foldable one segment over another a similar way for capacity under the seat part when the bed isn't being used.

[25]

III. RESEARCH AND THEORY OF SHAPE SHIFTING CUBOID

3.1 Objective of shape shifting

The theory given by Jane Francis Apthorpemphasizes on the research made by the author expresses the characters of habitats and tourists in relation to furniture and its arrangement within the interior.

The research mainly explains the changing in shape of furniture by several arrangements. [5]

Our work mainly gives a structural idea of shape conversion. The research work is focused on converting the cuboid into a sofa and a convertible bed.

The convertible shape shifting of structure is derived from various studies and research for shape shifting of objects.

One of the researches is related to improvements in convertible couch beds and converted in such a way that it becomes a full size twin beds spaced from each other. This study is given by Martin Shankman on the topic “Convertible bed couch “. [6]

The compensation element use significantly improves the strength, durability and reliability.

Mattress type cushion acting a bed, the mattress can have one, two, or more parts.

3.2 Assembly Hardware

Exceptional gear required to gather transformable space saving furniture is not ordinarily used on standard furniture since they have unmistakable limits. The principal components of the uncommon gear are to

ensure the transformable parts can be moved effortlessly and safely, and it in like manner ought to be enough sable to restrict the forces drew in with its standard use.

In the orange float of Figure 1(a) is one of the models of exceptional gear that have been used on transformable space saving furniture. This sort of hardware is mounted on the sides of bed plots with the true objective to relate the rack and bed layout. The specialty of this hardware is the things on the rack can be remaining set up when the rack is climbed or down. The rack can in like manner be used as legs when the bed is being utilized.



Figure 1(a)

<http://www.baraldiarreda.it/altri-mobili-trasformabili/rete-cf97/>

Moreover, in the orange circles of Figure 1(b), it shows another sort of extraordinary equipment. It is an auto-bolt framework which is set between the holes of the edge and the bed, with the end goal to give the whole household item a spotless look. The capacity of this extraordinary equipment is to give wellbeing after changes. At the point when the client needs to put the bed once more into the casing, the little handle will be naturally bolted on the edge. In view of these capacities, this sort of equipment not just should have the capacity to encourage smooth congregations and changes, yet in addition should be adequately steady to oppose the powers associated with its normal utilize.



Figure 1(b)

http://www.baraldiarreda.it/letti-singoli-a-scomparsa/altea-book_cabrio/

Transformable space saving table arrives in an extensive variety of structures. This structure is generally kept up by a sliding system which makes it useful for the table to be extended and pulled back. The sliding structure is normally concealed under or inside the table, with the objective that the table still has an unblemished appearance. Figure 1(b) is an instance of a sliding structure. With the true objective to impact the table to connect very far, the maker combines different sliding pieces. The concept of shape shifting in this figure is explained by Konstantin Grcic given by the name “panorama” viewed in “Vitra Design Museum“ in Germany.



Figure 1(c)

<https://www.wmagazine.com/story/konstantin-grcic-vitra-design-museum>

3.3 Elevating the Top

- We have studied that by elevating a surface from the top with the support of a stainless steel rod. This rod enables the table to lift upward with the help of worm gear mechanism for mechanical power input. Such an operation can lessen the efforts to a limited amount and self locking properties.
- A study given on the topic “Multi-function and Automatic stick” invented by Young- Feng Hung, Pei Pin E.Rd, says the mechanical type adjusting mechanism can only provide an elevating adjustment and the cost is low compared with hydraulic type mechanism. [7]
- Worm gear mechanism** helps to lift a heavy load with low effort. Using this effect can reduce various loads acting on other part of structure. By doing this a major portion of stress analysis can be completed.
- A study based on the topic “Worm gear performance “by Henry E Merritt performed a study on worm gear design.
- The load- carrying capacity and efficiency of worm gear may be predicted.
- The requirements of worm thread profile are briefly considered and use of the involute helicoids as a basis of worm thread design is recommended.

On a theorem on the curvature of tooth profiles as basis, the relative curvature of worm threads and wheel teeth is determined. [8]

3.4 Wheel chair

The study in the field of shape shifting also focused on helping disabled by providing a **wheel chair** that can be placed on the right side towards the rear of the structure.

A **wheel chair** is made up with a simple mechanism. This enables the personals those are not able to walk can move freely with the help of wheel chair.

To further analyze its structure a study done from the research work in this field.

The research work done by Bhaskar Vitthal Patwardhan on the title “Wheel chair with a commode that converts into a bed “provides some ideas. The main aspects of this study consists a chair converts from bed to

chair. This improved wheel chair can be used by anyone like patient which will overcome all the problems of the wheel chair or bed or lifting and shifting apparatus.[9]

- The means of making movement of frames to convert chair into bed by comprise a gear- box along with gears or cables.
- The multipurpose wheel chair of the present invention can be used as chair and bed. This wheel chair is useful for the aged, permanently or temporary disabled or patients. This wheel chair with bed is useful in hospitals.
- The movement of inner frame is controlled by the threaded rods, which are attached to the frame by the means of nut bolts, rivets. [9]

3.5 Equations

3.5.1 Gear Design and Terminologies:

3.5.1.1 Terminology of Worm gears: -

Four quantities of a pair of worm gears is specified and designated in the following manner.

$$Z_1/Z_2/q/m$$

Where,

- number of starts on the worm = Z_1
- number of teeth on the worm wheel = Z_2
- diametrical quotient = q
- module = m (in mm)
- Diametrical quotient is given by, $q = d_i/m$

(i) Axial pitch (p_x)

(ii) Lead, $l = p_x * x_1$

Lead of worm = l

Internal diameter = d_i

- Pitch circle diameter of worm wheel is given by

$$d_2 = m * Z_2$$

[10]

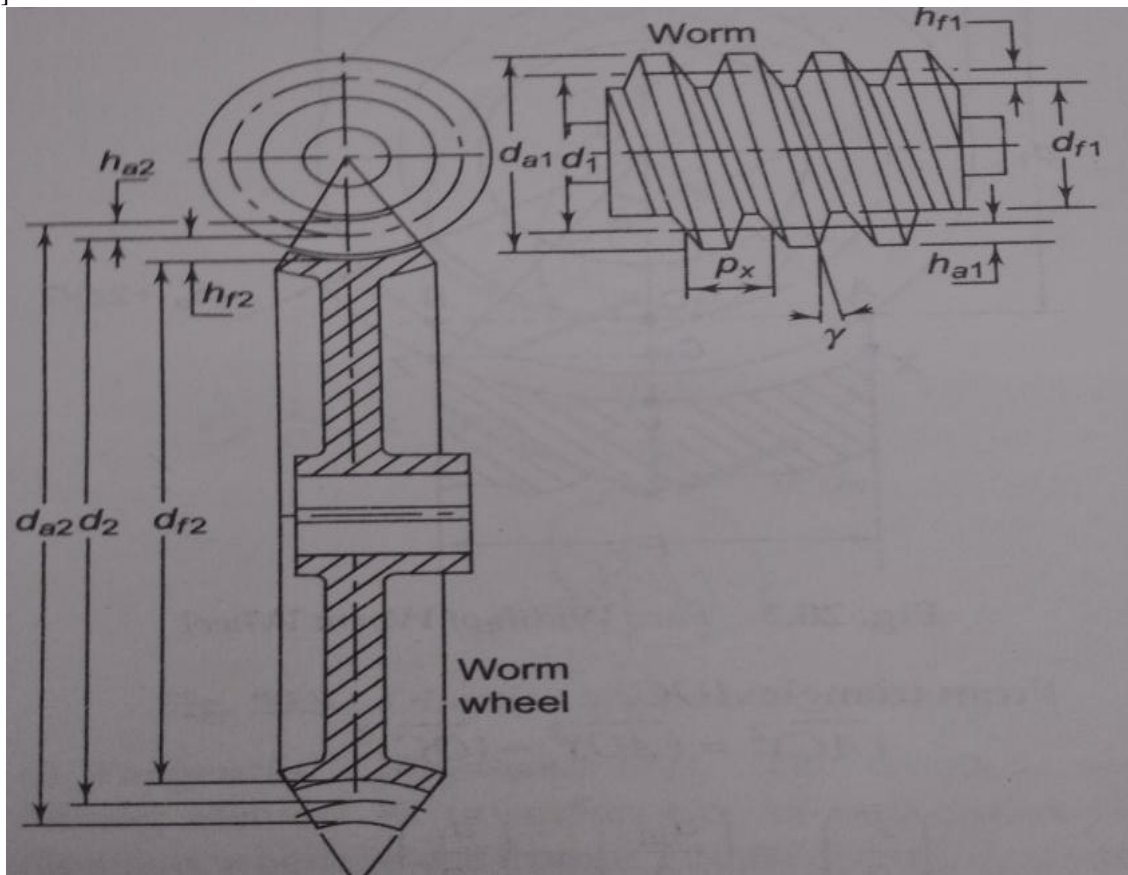


Figure 2 (V.B Bhandari, 2017)

The above figure 2, is from the reference [10], provide the dimensional aspects of worm gear.

In our work we emphasize on the dimensional aspects of the worm gear. The above equation helps to determine the meshing of worm and worm gear appropriately.

3.5.1.2 Strength rating of worm gears:-

$$(M_t)_1 = 17.65 * X_{b1} * S_{b1} * m * l_r * d_2 * \cos \Psi$$

$$(M_t)_2 = 17.65 * X_{b2} * S_{b2} * m * l_r * d_2 * \cos \Psi$$

Where,

- permissible torque on the worm wheel is given by $(M_t)_1, (M_t)_2$
- speed factors for strength of worm and worm wheel = X_{b1}, X_{b2}
- bending stress factors of worm and worm wheel = S_{b1}, S_{b2}
- module = m
- length of the root of worm wheel teeth given by l_r
- pitch circle diameter of worm wheel is given by d_2
- lead angle of the worm is given by Ψ

[10]

$$\text{Power, kW} = (2 * \pi * n * M_t) / 60 * 10^6$$

The above equations are for determining the bending strength of the gears being used. [10]

3.5.1.3 Wear rating of worm gears :-

$$(M_t)_3 = 18.64 * X_{c1} * S_{c1} * Y_2 * (d_2)^{1.8} * m$$

$$(M_t)_4 = 18.64 * X_{c2} * S_{c2} * Y_2 * (d_2)^{1.8} * m$$

Where,

- permissible torque on the worm wheel is given by $(M_t)_3, (M_t)_4$
- speed factors for the wear of worm and worm wheel is given by X_{c1}, X_{c2}
- surface stress factors of worm and worm wheel = S_{c1}, S_{c2}
- zone factor = Y_2

[10]

The above equations are stated for determining the wear strength of the gear.

[10]

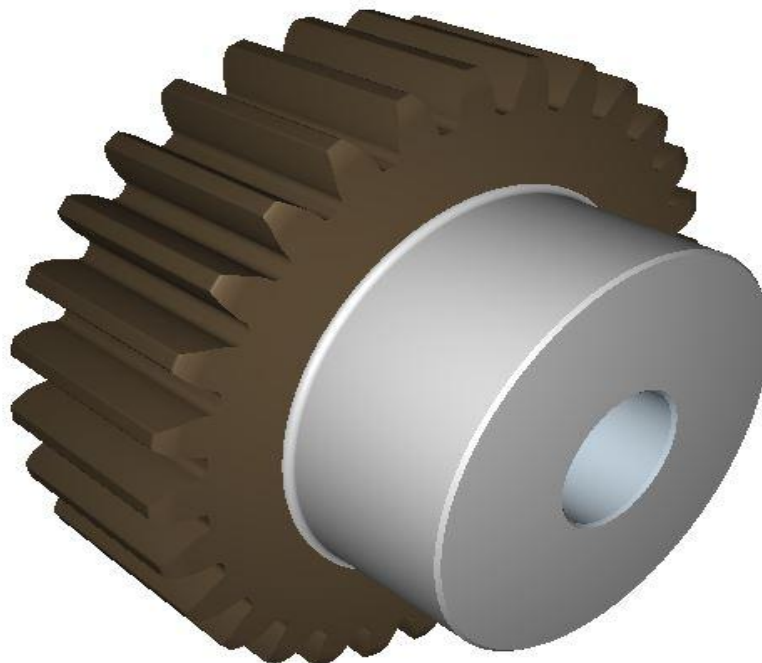


Figure 3

3.5.2 Figures

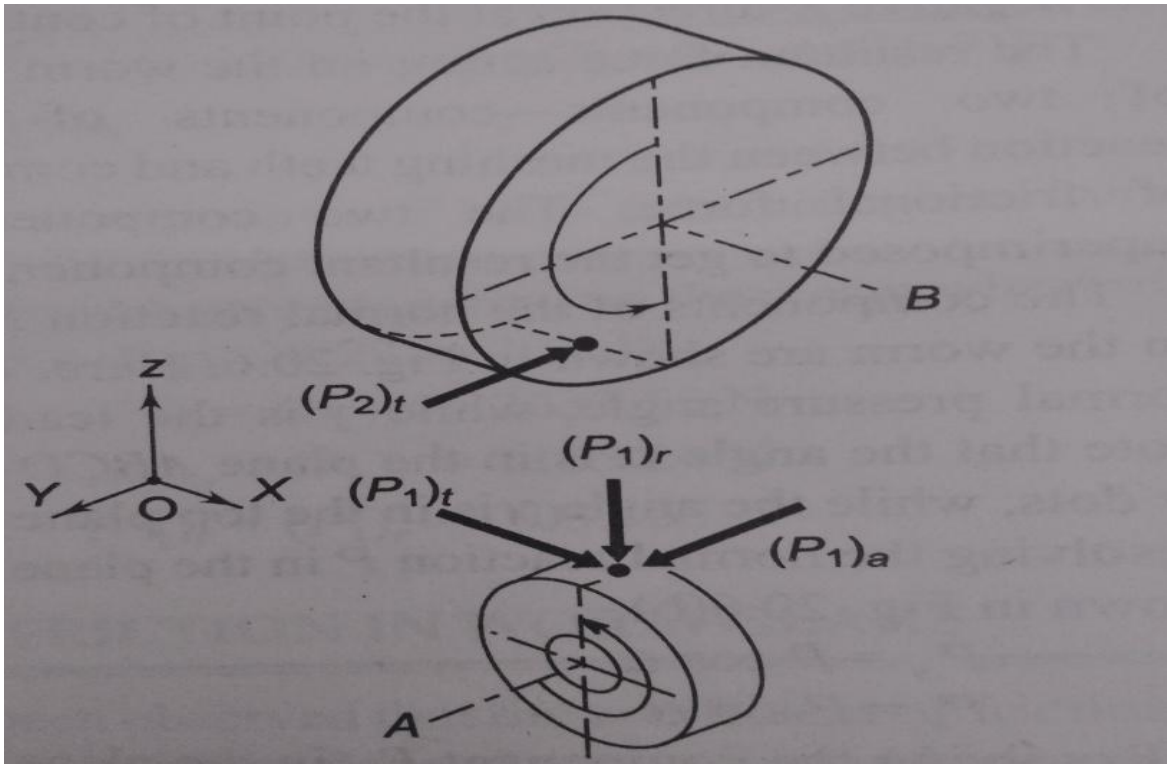


Figure 4 (V.B Bhandari, 2017)

The above figure 4 taken from reference [10], describes the direction of force components in 3-D view.

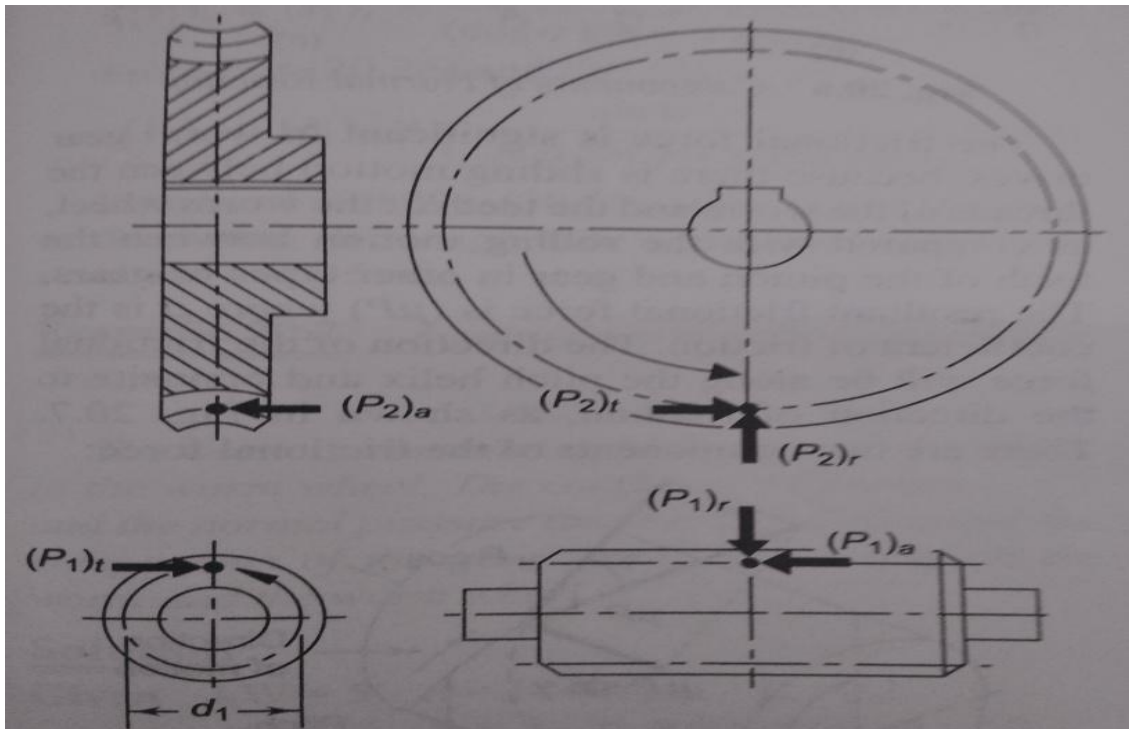


Figure 5 (V.B Bhandari)

Figure 5 is taken from the reference [10], it describes the loads acting at the points at which gears are in mesh to each other. These are the components of tooth force.

3.6 Stress, strain and failure factors

3.6.1 Column section

Since, the column made of steel undergoes various stresses. These stresses are the loads acting on the vertical column. These loads are crushing and buckling loads.

This figure 6(a, b) is from reference [11], explains the crushing load (a) and buckling load (b) acting on the column section.

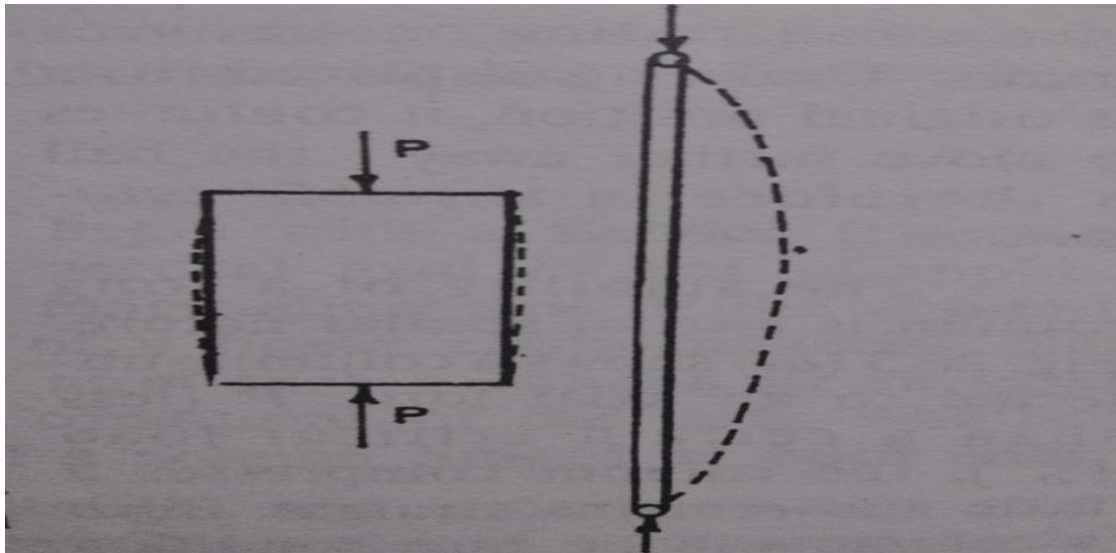


Figure 6 (a, b)

3.6.2 Stress and strain

When we discuss about table and bed, a compressive load is acting on the structure. That load factor can be explained using some theories and formulas.

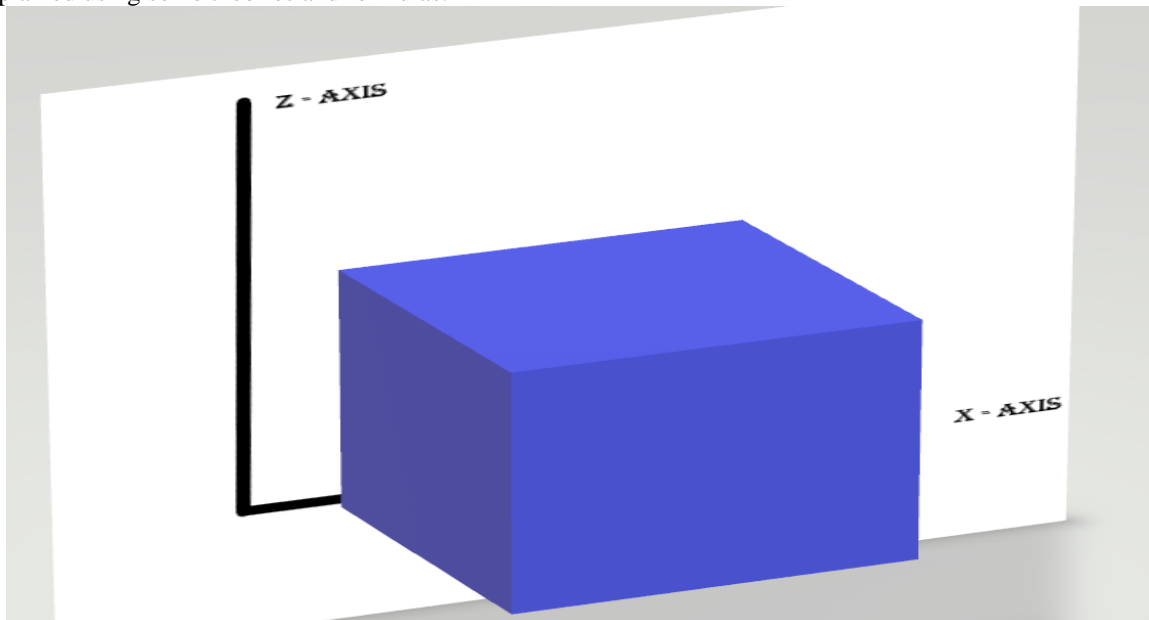


Figure 7

The compressive stress can be given by -

$$\sigma_3 = f_y'$$

Where,

f_y' = yield point stress in simple compression

σ_3 = maximum principle stress in z-axis.

[11]

3.6.3 Failure factor

Now, consider the failure theory of “Maximum principle stress theory”, gives the equation –

$$f_y' = \sigma_3 - (1/m) (\sigma_1 + \sigma_2)$$

Where,

σ_1 = maximum principle stress in x-axis

σ_2 = maximum principle stress in y-axis

1/m = Poisson’s ratio

[11]

for steel	Values
Modulus of Elasticity (E)	190 – 210
Poisson’s ratio (1/m)	0.27 – 0.30

Table 1

3.7 Units

- Permissible torques in “N-mm”
- Power in “kW”
- Module in “mm”
- Diameter in “mm”
- Modulus of Elasticity in “Giga Pascal”

All the above theories and equations are taken from [10][11]. Considering the necessary factors affecting the structure, we can say that these theories are applicable when the structure is realistic in future. For further details, refer to [10][11].

IV. WORK PROPOSED ON SHAPE SHIFTING CUBOID

The work we proposed here has an objective to view a structure that is able of fulfilling all the aspect discussed earlier contains different views for various aspects of use.

4.1 3-D view of table

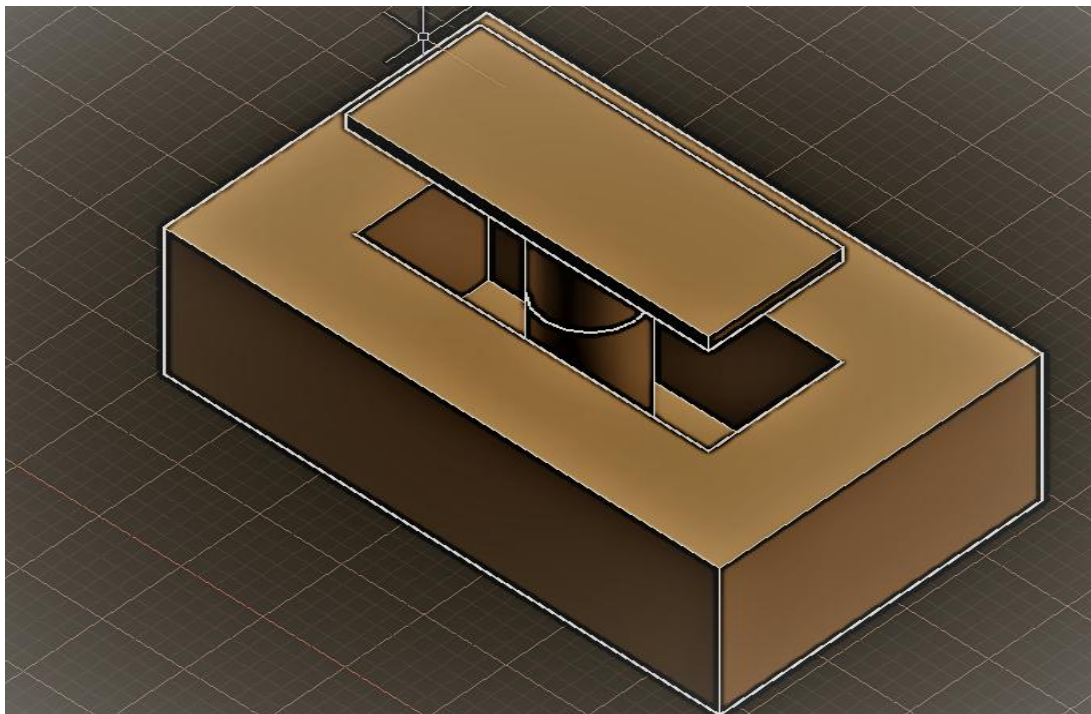


Figure 8

The above design provides a realistic idea of the table used in software. In the above Figure 8, it can be seen that there is some space vacant to sit between the remaining part after extrusion of table and the vertical column.

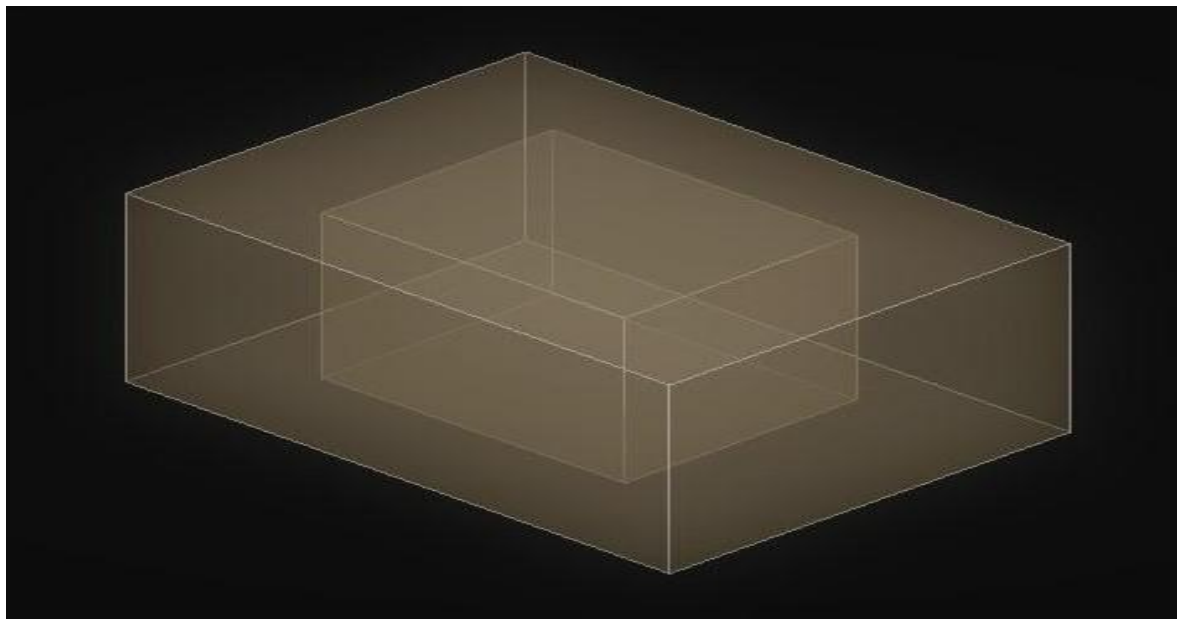


Figure 9

This is a view of bed when structure is closed from all the sides and only the cuboid is being viewed.

4.2 3-D view of sofa

The theories and research work we have discussed earlier provides us a view of a structure being used as a sofa.

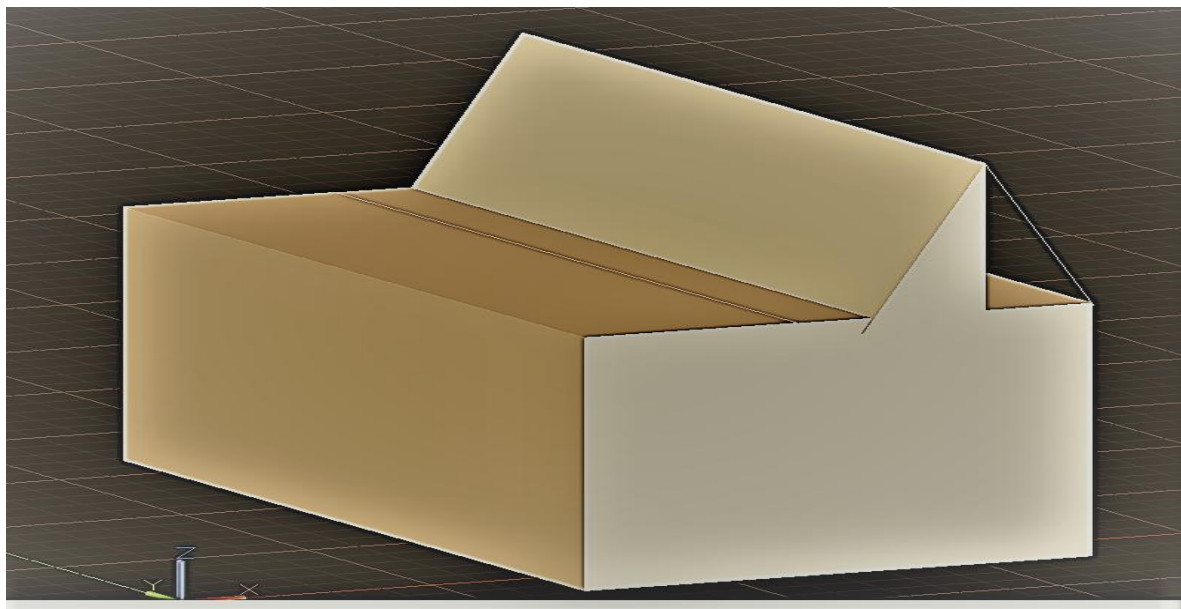


Figure 10

4.3 2-D view of sofa

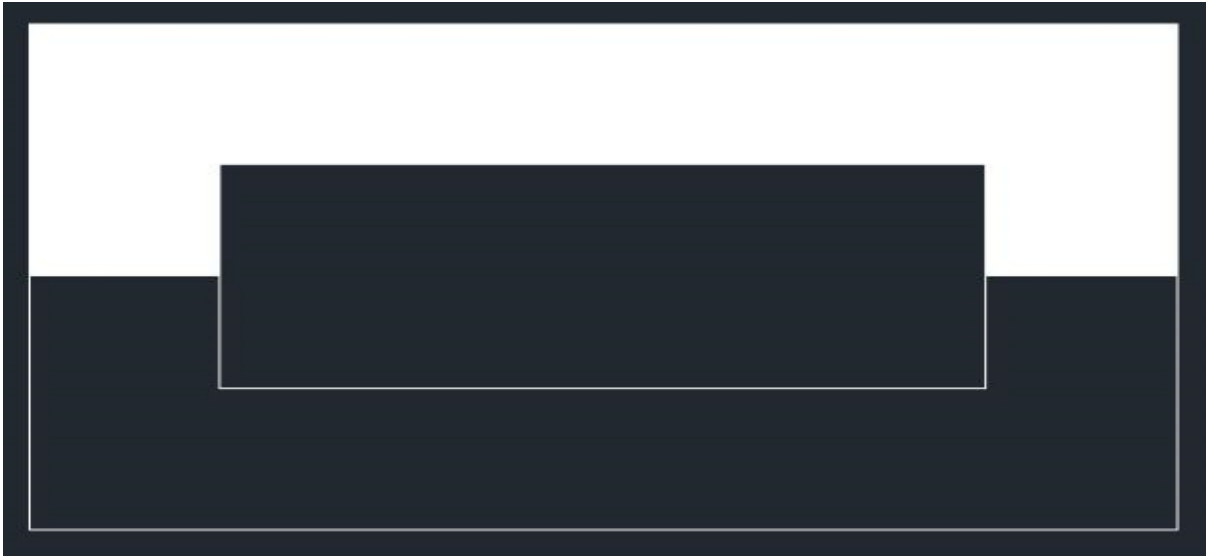


Figure 11

The above figures describe the realistic views of sofa that is emphasized on the work we have done before. Figure 10, gives a three dimensional view of the sofa. Figure 11, is the two dimensional view.

4.4 2-D and 3-D view of back of sofa

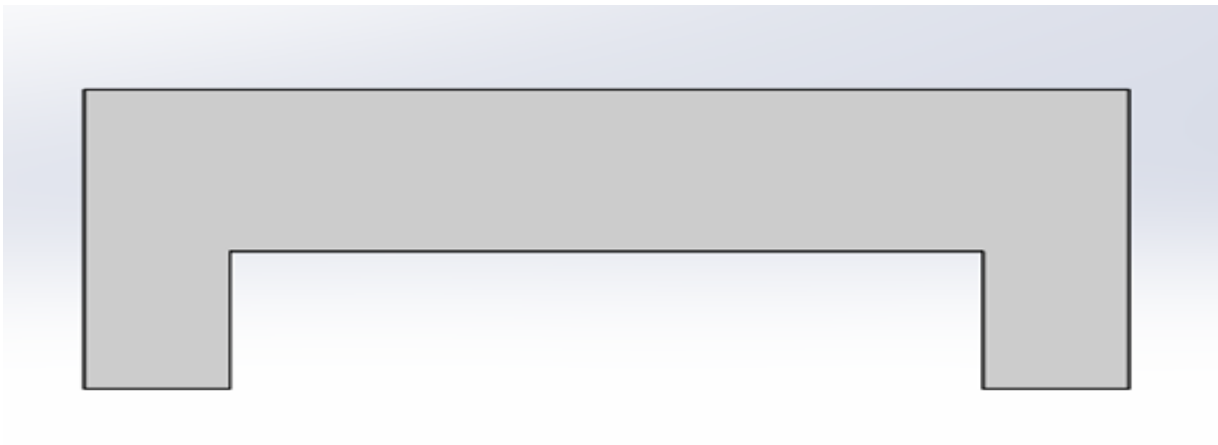


Figure 12

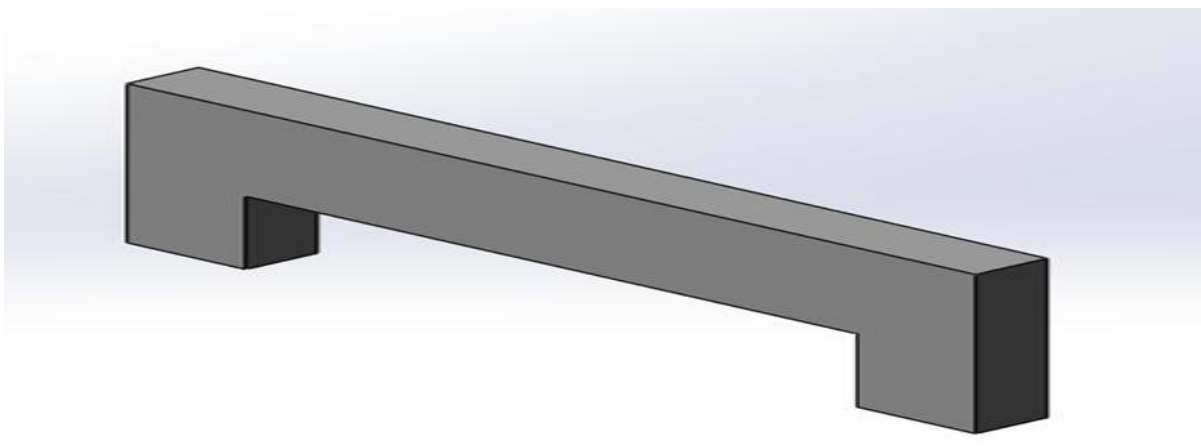


Figure 13

The half portion of the bed on right hand side is pulled upwards manually which forms the back of the sofa upon which the person can rest his back while sitting. Figure 12 is the 2D view of back of sofa and Figure 13 is the 3D view of back of sofa.

V. MOTIVATION

a. Related values and attribute

Shape Shifting Cuboid is a Shape Shifting Furniture which uses less space and provides many function and shapes like sofa, table, etc.

Huge urban areas, for example, Delhi and Bombay have vast populaces, expansive holes among rich and poor and an extensive part of little space lofts. Shape moving gives a decent chance to the improvement of transformable space sparing furniture. Transformable space sparing furniture is a transformation and advancement. For individuals who have little spending plans for furniture consumption and who live in constrained spaces, transformable space sparing furniture may be their solitary choice. One of the difficulties for fashioners of transformable space sparing furniture is that the furniture should be both stylish and functional. Most individuals who live in little room at lease in expansive urban communities that originates from far towns for studies or work or live are from the center or lower classes; they may either be youngsters or new representatives. These individuals regularly need adequate assets to pay for or contract huge flats or extravagant furniture. The appearance, cost and capacity of transformable space sparing furniture makes it the best choice for such kinds of individuals.

In our work, we will investigate transformable space sparing furniture both mechanically and monetarily.

Mechanically, the vital parts of transformable space sparing furniture will be portrayed in detail, and some prominent plans will be given. To cover this current furniture's money related angles, we will break down some vital markets for this item dependent on numerical information. In addition, the expense and the cost of the transformable space sparing furniture will be contrasted and typical furniture.

In our society most of the people see people with disabilities as liabilities, they sometimes underestimate the strength of that section of society which creates a sense of disbelief among the disabled personals.

Keeping these values and ethics in mind our work is focused on helping this people. The aspects we have discussed earlier contain a wheel chair for the disabled people.

Apart from this we are also planning to use Braille language system plates for blind personals. By doing this we can maintain balance in the society and can give a hope or motivation, so that they could help themselves and bring self belief in life.

b. Cost factor

The material we are using is timber plywood in table, bed and sofa which has maximum strength and low cost. The support we are using for the table is made up of HSS (high speed steel). By doing this a large cost can be reduced.

c. Additional feature –

- Lighting systems
- Braille language system
- Safe storage facilities
- Wireless charging ports

The above features are possible with addition of new equipments and systems.

VI. CONCLUSION

The study focuses on building a structure recognizing essential household utilities according to the space available. The work aims to create structure that can fulfill various necessities including furniture and storage facilities. A study from many sources and including crucial aspects emphasizes to reduce all the expenses involved in the structure and economical in market.

VII. FUTURE ASPECTS

In future we can see robotics being used in these sectors also, a structure can be developed in such a way that it changes its shape and move in all directions automatically on command. Sensors may be developed for the safety of people.

ACKNOWLEDGMENT

We express our deep gratitude to Mr. Dhruv Kumar, Assistant Professor, Department of Mechanical Engineering for his valuable guidance and suggestion throughout my project work. We are thankful to the Mr. Ashutosh Singh, for his valuable guidance.

We would like to extend our sincere thanks to Dr. Devender Jha, Professor & Head of the Department, for his time to time suggestions to complete our project work. We are also thankful to Dr. R. KRaghuvanshi, Professor, Department of Mechanical Engineering for providing us the facilities to carry out our project work.

REFERENCES

- [1]. Sharon Prendeville, Dr Frank O'Connor, Simon O'Rafferty "Material selection and design for sustainable Material Innovation", eco design centre, Cardiff Metropolitan University, Cardiff. Published in April, 2013.
- [2]. Research and innovation department, European Commission, 2011.
- [3]. Design commission, Kuttii 2009.
- [4]. J Smardzewski, "classification of characteristics of furniture", furniture design, Springer international publishing, Switzerland, 2015.
- [5]. Aphorpe, J.F., 2008. The furniture tourist: escaping the habitue: an exegesis presented in partial fulfillment of the requirements for a degree of Masters of Design at Massey University, Wellington, New Zealand (Doctoral dissertation, Massey University).
- [6]. Martin, S., 1957. Convertible bed couch. U.S. Patent 2,783,480.
- [7]. Young – Feng hung " Multi-function and Automatic stick ", 3 Fl.2, No.28, Pei Pin E.Rd, Taipei, Taiwan. Patent in 19 April, 1994.
- [8]. Merritt, H.E., 1935. Worm gear performance. Proceedings of the Institution of Mechanical Engineers, 129(1), pp.127-194..
- [9]. Patwardhan, B.V., 2013. Wheelchair with a commode that converts into a bed. U.S. Patent 8,359,685.
- [10]. V.B Bhandari " Design of Machine elements ", published by Mc Graw Hill Education Private Limited . as per V.B Bhandari 2017
- [11]. B.C Punmia , E R Ashok Kumar Jain, " Machines of Materials", published by Laxmi Publication. In year 2014
- [12]. Angland, C.A., 2003. Mattress support device for a sofa sleeper. U.S. Patent 6,618,883.
- [13]. Bly, R.R. and Wysocki, K.S., Invacare Corp, 2012. Bed lift mechanism. U.S. Patent 8,256,048.
- [14]. Thompson, A.S., 1932. Folding bed and table structure. U.S. Patent 1,841,992.
- [15]. "Folding chair" United States Patent Lee, Patent number is 5,984,406 by Howard Lee, 1325 Oakhill Pl., South Pasadena, Calif. 91030, Date of patent is Nov. 16, 1999.
- [16]. "Adjustable, Multi-Purpose Type of sick bed convertible to Wheelchair", United States Patent Chen et al. Patent Number is 4,771,489 by Liang T. Chen; Liang H. Chen, both of No. 1, Lane 57, Ling Chou E. Street, Tainan City, Taiwan. Date of Patent is Sep. 20, 1998.
- [17]. "Convertible bed and wheelchair unit", U.S. Patent 4,717,169 by Willis G. Shaffer, Westminster, Colo. Date of Patent is Jan. 5, 1988.
- [18]. "Folding Sofa Lounge and Knockdown Furniture", U.S. Patent 3,001,822 by Paul Pagliaro, Whitestone, and Nathan Friedman, Brooklyn, N.Y., assignors to Nu Era wood products, Date of Patent is Sept. 26, 1961.
- [19]. "Bed-Type Chair", U.S. Patent 2,411,278 By Lillie M. Leavitt, Lakeport, N.H. Date of Patent is Nov. 19, 1946.
- [20]. "Bed Tray Table" U.S. Patent 2,003,241 By Alexander Brown. Date of Patent is May 28, 1935.
- [21]. Thompson, A.S., 1932. Folding bed and table structure. U.S. Patent 1,841,992.
- [22]. Foster, L.D. and Peck, W.H., Hill-Rom Co Inc, 1986. Hospital bed. U.S. Patent 4,592,104.
- [23]. Peck, W.H., Hill-Rom Co Inc, 1989. Hospital bed convertible to chair. U.S. Patent 4,862,529.
- [24]. Choi, H., North Pole Ltd, 2006. Hard arm chair with sliding arm mechanisms. U.S. Patent 7,066,534.
- [25]. Dyke DF, inventor; Pullman Couch Company, assignee. "Sofa-bed". U.S. patent 1,127,874 in 1915 Feb 9.
- [26]. Chen Liang T, Chen Liang H, Adjustable, "Multi-purpose type of sick bed convertible to wheel-chair". U.S. patent 4,771,489 in 1988.

Abhishek Garg "Design And Fabrication Of Shape Shifting Cuboid" International Journal of Engineering Science Invention (IJESI), vol. 07, no. 11, 2018, pp 25-37