Low Cost Robotic Furniture Module for Micro-Apartments

G. Chandra Mohan Reddy, Nihal Kasam, Mohammed Irfan Ahmed, and Kushwaha Jayant Mohan
Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad, India
Email: gcmreddy_mech@cbit.ac.in, kasam.nihal@gmail.com, ahmedmdirfan34@gmail.com, j.kushwaha123@gmail.com

***Abstract*—Multifunctional transforming furniture can accommodate a variety of increasingly common household formation types that are underserved by current housing options. Transforming furniture can add function and square footage to any space, large or small. However, existing models are completely manual and many of the adjustments to space require both time and labor-intensive work, which can further add to the stress of the individual. To reduce the effort and increase the efficiency of these systems, these processes are to be automated using robotics and controlled through the application of IoT (Internet of things).**

***Index Terms*—IoT, transforming space, robotics, architecture, automation**

I. Introduction

India occupies 2.41% of the world's land area but supports over 18% of the world's population. According to the 2017 revision of the World Population Prospects, the population stood at 1.3 billion and is expected to be the most populous country by 2024. However, the area available for the population to live in is very limited due to the small size of the nation and with an ever-increasing population, the living space is expected to decrease at a drastic rate, especially in large cities like Mumbai, Hyderabad, Delhi, and Bangalore. As these are hotspots with large employment opportunities and therefore expected to see a growth in population density at a much higher rate when compared to the overall growth of the country. Take the example of Hyderabad; according to the Indian Population Census - 2011 conducted by the Government of Telangana there has been a 264% increase in the population in and around the city. It has also been observed that 24% of the total people were migrants. The city has expanded over 5 times to accommodate the increase in population growth as it nearly doubled between the years 2001 and 2017.

Although similar situations are appearing in other cities around the nation, nothing has changed about the design of living spaces to combat this problem. Indications of a shortage of land are the increase in the prices for houses, rents, and other necessities. This is forcing people to adjust in small living spaces, even going down to 40 sq. m for a family of five people.

In this paper, we will discuss how the available space can be used efficiently using transforming automated furniture and smart housing.

II. Currently Applied Solutions

Many methods have been used to combat the limited space available, especially in European countries. The most successful method is the construction of micro-apartments (apartments about the size of 350 sq. feet) that integrate transforming furniture and spaces to provide complete functionality. Multifunctional transforming furniture can accommodate a variety of increasingly common household formation types that are underserved by current housing options. Transforming furniture can add function and square footage to any space, large or small. Transforming furniture offers a smarter way to live more comfortably in the space available. However, this method has resulted in its own set of problems. According to Dak Kopec, director of design for human health at Boston Architectural College and author of Environmental Psychology for Design, highlights the following challenge for architectural elements requiring an easy - but not effortless transformation ritual [1]

"For all of us, daily life is a sequence of events. But most people don't like adding extra steps to everyday tasks. Because micro-apartments are too small to hold basic furniture like a bed, table, and couch at the same time, residents must reconfigure their quarters throughout the day: folding down a Murphy bed or hanging up a dining table on the wall. What might seem novel at the beginning ends up including a lot of little inconveniences, just to go to sleep or make breakfast before work. In this case, residents might eventually stop folding up their furniture every day and the space will start feeling even more constrained. "

To deal with this problem, the MIT media lab has proposed integrating robotic systems into transforming furniture to make it much effortless. They have introduced an amalgamation of transforming space incorporating robotics and IoT for remote control. Controlling this system through either an app or voice control the effort required becomes minimal. The entire process would require a simple tap of a button or a voice command and by adding IoT to the control system one could even modify

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their house on their way back from work thereby improving efficiency even further. They have proposed "ARKits" (architectural robotics kits) which integrate all these elements and allow any designer to use these elements to create their customized furniture. This kit consists of 4 main components. The first is the brain or robotic components consisting of a brain (control unit i.e. microcontroller, motor control systems, etc.), locomotive system (motors, actuators, etc.) nervous system (the input IoT, sensor, etc.) and the architectural elements.

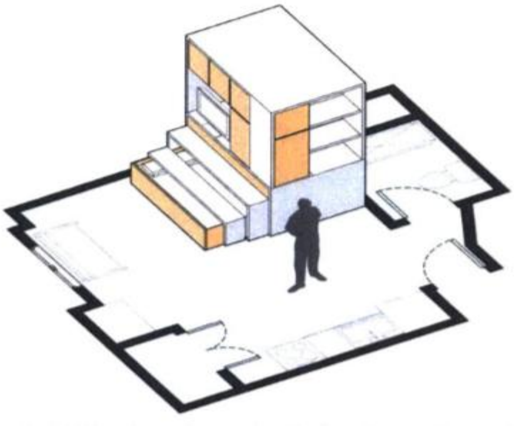

Figure 1. ORI systems design [2]

These kits were to be made using off the shelf parts that could be easily accessed by everyone. However, they use a customized actuator to move the wall that is the main part responsible for the linear motion of this setup. This actuator is made to order and is available only from their organization. As a result, the price of the kit is driven by up to nearly $10000. This is equivalent to about 7 lakhs INR in India which is approximately the price to construct a newly furnished room. Another consideration is that this kit is designed for a sliding bed, so the size of the system increases as the size of the bed increase, thereby reducing the amount of space saved by the system as floor space is generally limited. When it comes to vertical beds or wall beds, existing samples either require that the frame be fixed to the wall or that an attachment is present at the front of the frame. Regardless of the type of wall bed, its frame cannot be moved, thereby reducing the purpose of transforming living. Hence, this prevents widespread usage (in India where there is a large demand for space saving architecture). It is intended to use the same principles in the design of a unit that is composed entirely of off the shelf parts.

III. Design of the Module

In India, floor space is a premium it is planned to modify the design to use a Murphy bed as which will result in lesser floor space being used by the system. This design can be divided into two separate parts; one that consists of the Murphy bed also having a wardrobe; and the other integrating cupboard space, a multifunction table and space for an entertainment system. The resultant product is expected to have the same functionality as the work done by MIT but with lesser floor space used and using off the shelf parts. The direct drive DC motor (used for moving the module) which is the most expensive type of DC motor costing around 26000 INR will be replaced with a brushless dc which will be slightly louder (may be reduced by providing a wooden casing) but the component is cheaper and repair is easier in comparison. Most of the moving parts are designed to undergo linear horizontal motion in both forward and backward directions, these parts are provided with wheels on tracks to provide ease only in the intended direction because of this the parts to be moved can only operate only in the limited space.

First, the bed section design: the standard dimensions of a single bed was found by doing a market survey. A standard single bed is 3 feet wide and 6 feet 3 inches long (91cm x 190cm), the bed was designed with dimensions 6ft 10in x 3ft 3in x 6in its mass turned out to be about 20 kilograms for as well as modified the frame to 7ft x 3ft 4in x 7ft 7in to allow it to fit in the assembly. The frame's height turned out to be higher than usual to accommodate the bed properly along with the necessary shelving. After analysing several different mechanisms, it was decided to go with a linear actuator and pivot hinge as it had the least number of parts and it is very easy to control with a microcontroller. After finding the mass of the bed as well as the average weight of a mattress, the required properties of the actuator were calculated required by using the concept of "Moments at a Point." The actuator applies constant force with gradual motion in linear direction on the clevis pin and fork joint and the resultant moment lifts the bed (closing motion) or puts it down (opening motion). The cupboard was designed as per the popular models in the industry. However, this design can be modified as per customer requirements.

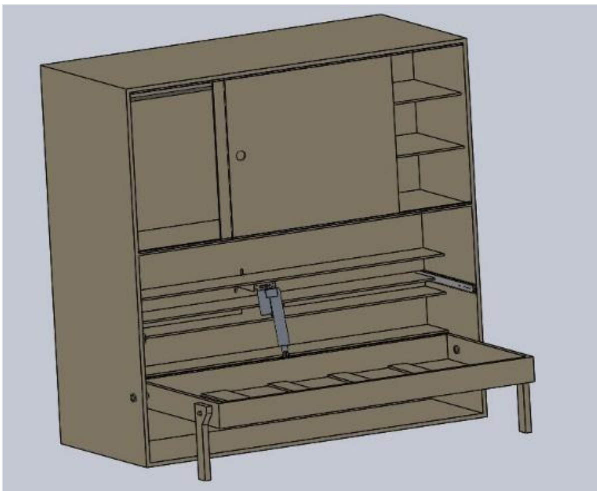

Figure 2. Bed section of frame

The second section consists of a multipurpose table, electronic items for entertainment, and shelves for the storage of small items such as books. A lead screw and stepper motor mechanism were used as it would serve two purposes: first, it allows us to easily move a table of required dimensions, and second, it allows us to control the amount of the table that is present for use. This will increase the aesthetics and space utilization factor. The entertainment area was designed for a 64”TV as well as speakers, with shelves for books and other items. Apart from the table, everything on the front side can be customised like the wardrobe on the other side. For example, one column of the lower shelves depicted below could be removed and replaced with a fridge, and a second column could similarly be replaced with a second freezer unit or a dishwasher. If induction stoves are used this would become a kitchen. Those lower shelves could similarly be altered to become bookshelves if a small library is desired.

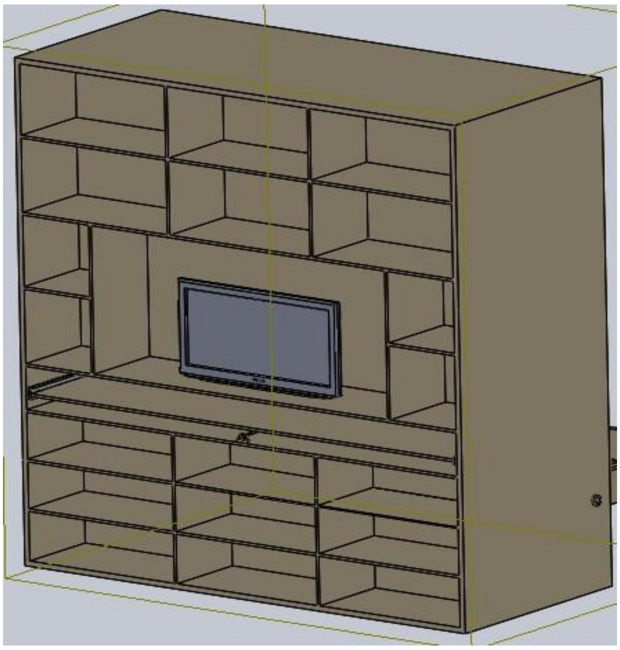

Figure 3. Front section of frame

IV. Design of the Control System

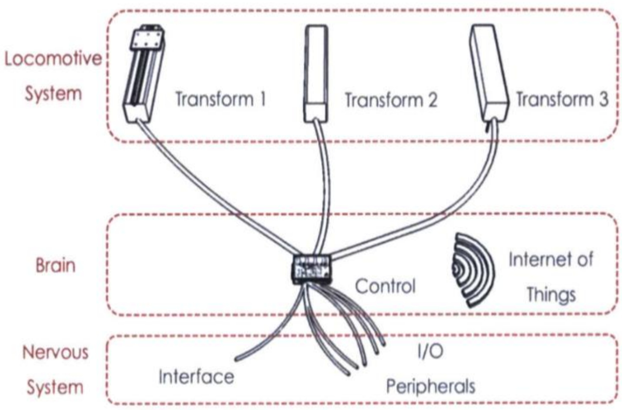

Figure 4. Components of control system [3]

The electronic control system has three main parts:

A. *The Locomotive System*

This system is responsible for the motion of the various moving components of the project. In this project, the moving components are the Murphy bed which folds into the frame and the sliding table which slides into the frame. It can be observed that one of the motions involves linear translation while the other utilises rotational movement (which has been converted to linear using pivot hinges for bed frame). As this has been discussed in detail earlier it shall not be repeated here.

B. *The Brain*

The brain of this project is a NodeMCU (Node Microcontroller Unit). The MCU is Wi-Fi enabled due to the built-in esp8266 chip which also allows us to use generic Arduino programming to control the chip. As it is Wi-Fi enabled, this chip is very easy to use in IoT applications thereby allowing us to easily implement mobile app control This chip is also commonly available in India and as such is very cheap.

C. *The Nervous System*

The Nervous System consists of basically the input and output of signals that result in activation and motion of the system. Here, the output signals are sent to a 4-channel relay, and an L298N motor controller. The relays act as switches and can provide both forward and backward motion to the motors. The motor controller, meanwhile, works on an H-bridge architecture and allows us to control not only the direction of rotation of motor but also allows us to send precise signals so that the rotation of the motor is modified to suit our requirements. Input signals are sent to the controller from the phone using relevant programming and apps.

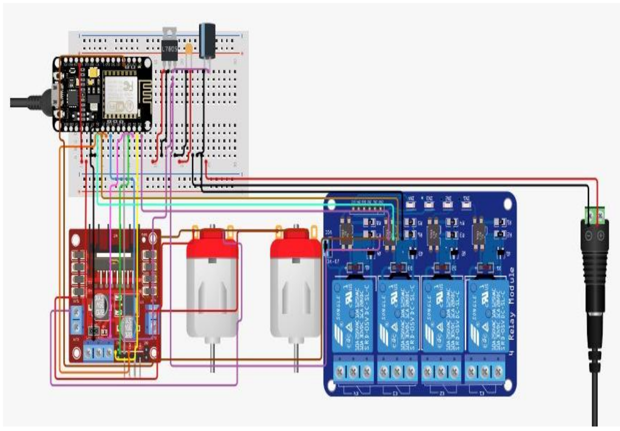

Figure 5. Design of electronic circuit

V. Cost Analysis

As the second objective for this project was to reduce the cost of the project so that it can be easily afforded by the average Indian a cost analysis was conducted to obtain the least price for which this model can be built. The system built in the U.S. costs about 7 lakh rupees. From the survey, our design would cost about 43680 rupees which is far cheaper and hence, more accessible. Another consideration is that the costs from the survey don't consider the case of mass production; in that case, the cost would decrease because of relevant discounts due to bulk purchases.

TABLE I. COST ANALYSIS OF PROJECT

S.no	Name	Qty	Dimensions/ Specifications	Cost (INR)
1	Plywood	10 sheets	4x8 ft	30000
2	Actuator	1	25cm stroke, 1500N force	4500
3	MS rod	2	25cm	800
4	Square metal plate	2	5x5cm	900
5	Lead screw	1	8mm dia 300 mm length	250
6	Hexagonal Nut	1	8mm internal dia	250
7	Stepper Motor	1	12v, 1.8degree step, 5.4kgcm	900
8	Bearings	2	8mm Dia	500
9	Flexible Coupling	1	4mm-8mm Dia	130
10	Motor Mount	1	L-shaped	450
11	Actuator Bracket	2	56 x 65 x 25mm	900
12	Breadboard	1	220 pins	130
13	Male to Male cables	15		20
14	male to female cables	10		20
15	4 channel relay	1	12vdc/220vac	250
16	NodeMCU	1	ESP8266 Wi-Fi enabled	380
17	Adapter	1	220vac-12vdc	50
18	L298N Motor Controller	1		220
19	Assorted Capacitors	2	Electrolytic Capacitor - 1uF/50V Capacitor Ceramic 100nF	10
20	Voltage Regulator	1	5V	10
21	Female DC Power adapter - 2.1mm jack to screw terminal block	1		10
22	Manufacture and Assembly			3000

Total Cost=43,680 INR

VI. METHODOLOGY OF ANALYSIS

Modal analysis of frame in ANSYS software was required to be done to calculate the maximum stress each shelf can take along with its weight. This analysis would show how much uniformly distributed loads each section may take. Apart from this, the analysis would find out the stresses at critical sections which are supposed to be the failure point in the assembly which are the point of contact between the bed and the actuator piston, and the links connecting the bed with the frame, mid-portion of the sliding table. These critical sections have been highlighted below in the pictures for one's understanding.

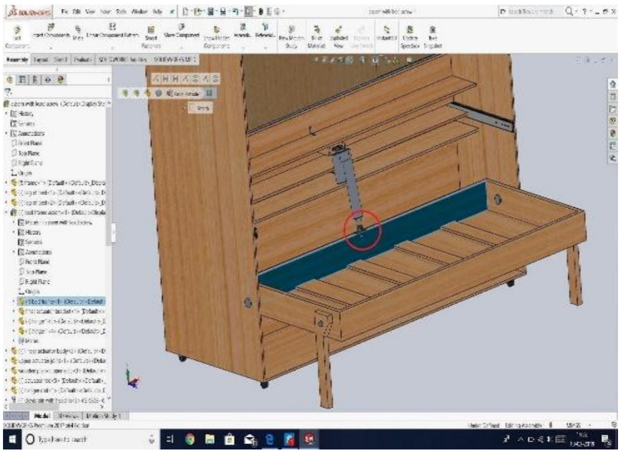

Figure 6. Critical section between actuator joint and bed between bed and frame

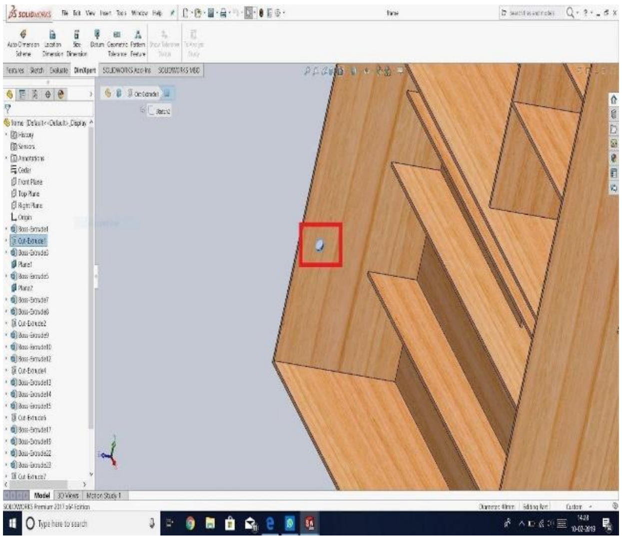

Figure 7. The hole highlighted is a Critical section with these stresses, it is aimed to calculate the maximum load that each section of the structure may take to see if it would serve its intended purposes in practical conditions in a longer run.

Another consideration taken was to do rigid body dynamic analysis of the assembly to ensure that the motion of the bed is carried out with the given force of 1500N and stroke length of actuator of 12”.

A total load of about 3500N was applied on the various shelves of the frame in order to simulate the actual weight of objects placed.

VII. Results

A. Static Structural Analysis of Bed

The following boundary conditions were given to the bed frame; a 1500N load was applied at actuator mount as that is the standard force applied by actuator of required stroke length that is readily available in market. The hinges are fixed and contact between hinge and bed allows rotation. The results have been displayed in a table.

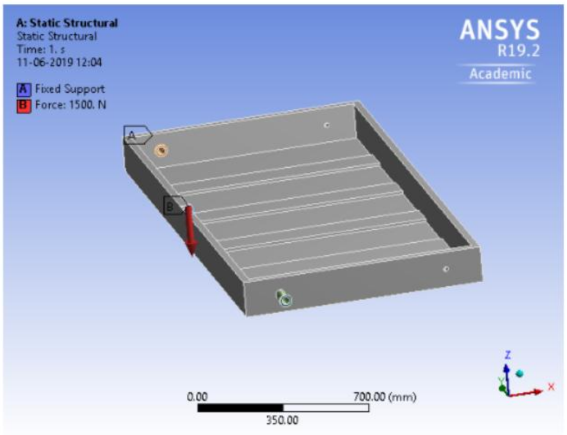

Figure 8. The image shows Load(s) and constraints (boundary conditions) on the bed frame

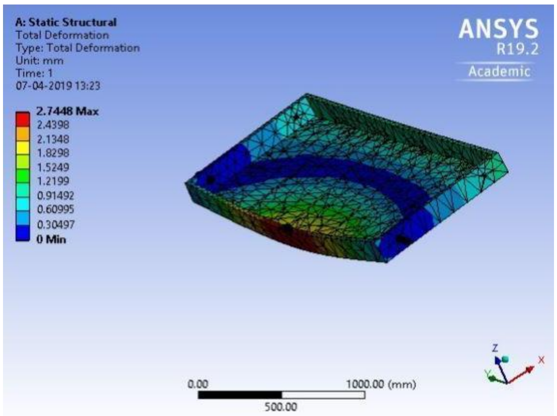

Figure 9. Static structural deformation

TABLE II. Results of Analysis of Bed

Type	Total Deformation	Equivalent (von-Mises) Stress
Results…		
Minimum	0. mm	9.811e-003 MPa
Maximum	2.7448 mm	75.174 MPa
Average	0.95402 mm	10.174 MPa
Minimum Occurs On	hinge 1	bed frame
Maximum Occurs On	Final actuator bracket copy	hinge 1

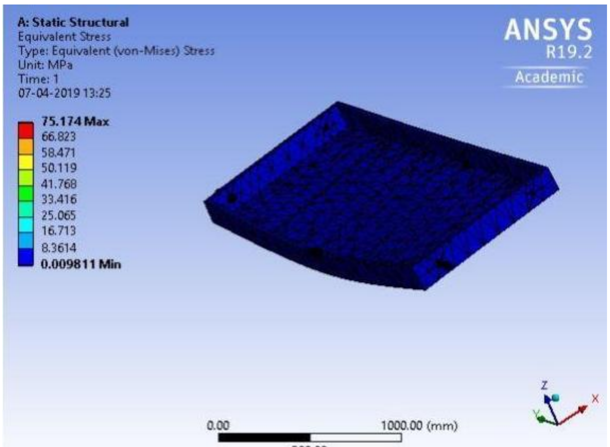

Figure 10. Von-mises stress

B. Static Structural Analysis of the Frame

A load of 1500N was distributed on all the shelves on each side of the frame giving a total load of 3000N. Apart from this another load of 80N was place on TV shelf. There is also a load of 1000N was place on hinge contacts to depict actuator load. The results are depicted in Table II below.

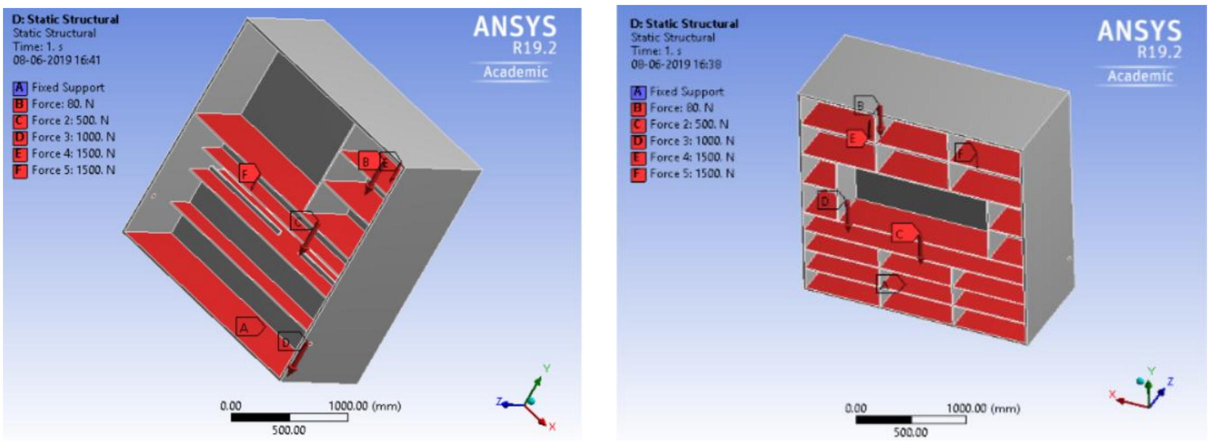

Figure 11. Loading conditions of the frame; left is bed side and right is front module

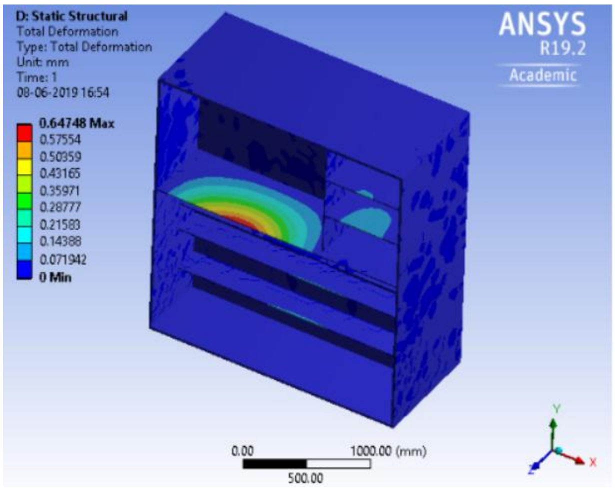

Figure 12. Static structural deformation of bed side

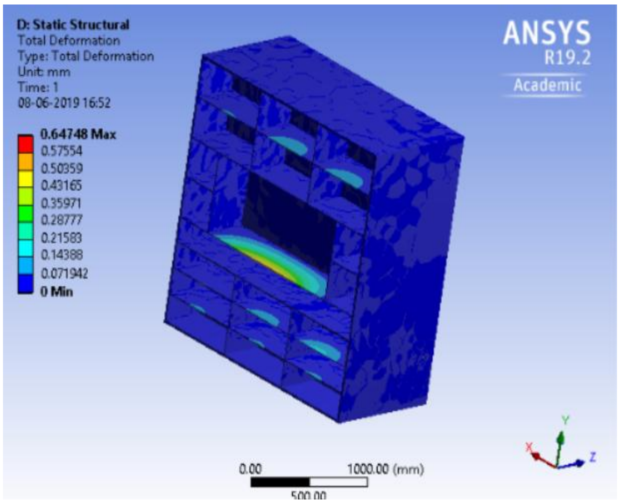

Figure 13. Static structural deformation of front

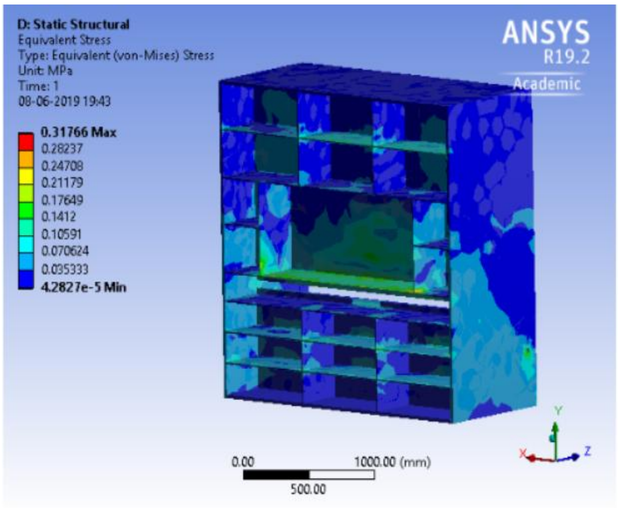

Figure 14. Von-mises stress on front side

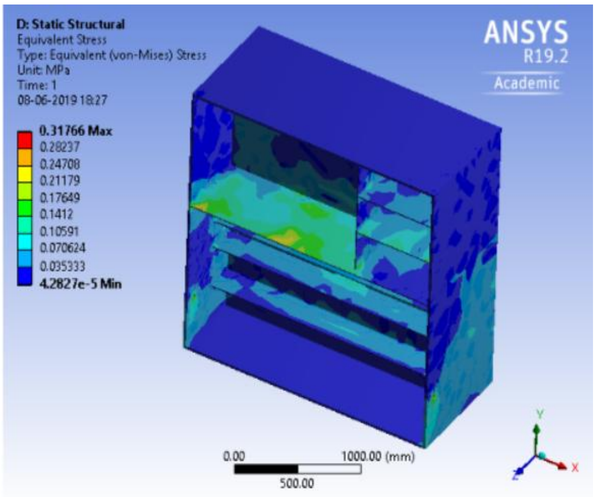

Figure 15. Von-mises stress on bed side

TABLE III. RESULTS OF ANALYSIS OF FRAME

Type	Deformation	Equivalent (von-Mises) Stress
Results		
Minimum	0. mm	4.2827e-005 MPa
Maximum	0.64748 mm	0.31766 MPa
Average	2.1832e-002 mm	3.5768e-002 MPa
Minimum Occurs On	frame	frame
Maximum Occurs On	Bed side main shelf	TV shelf and bed side main shelf

VIII. CONCLUSION

The conclusions of the present work are enumerated and presented as shown here under:

1. The frame can carry objects up to a maximum load of about 400kilograms which is about the same as that built by other similar manufacturers
2. The total cost of the manufacture is about 43000 INR which is about 684 USD; a cost that is more acceptable to lower income countries.
3. The frame saves about 40sqft of space as it compresses a bed, wardrobe, living, and dining areas into a unit of about 18sqft.

Even though the available solutions like Ori Systems and Clei seem to have their benefits, the limited movements and customised parts expenses add to the problem in some situations especially in countries with dense population like India and China where the floor space for each house is very small in metropolitan cities and the per capita income is far less than in western countries. This problem can be solved by the suggested modifications as well as choosing to use readily available parts so that this modern edge automated housing solution is accessible and economical for everyone.

Conflict of Interest

The authors declare no conflict of interest

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Dr. Chandramohanreddy Gangireddy is presently working as a Professor of Mechanical Engineering at CBIT. He started his career as an Assistant Professor in Muffakamjah College of Engineering and Technology in 1991 and joined Chaitanya Bharathi Institute of Technology in 1992. He served as the Principal of Mahatma Gandhi Institute of Technology during the years 2009-2018. He has rich experience in teaching, training, research, and administration. He has published 115 research papers in National and International Journals and Conferences. He has guided 8 students to the completion of their Ph.Ds.' and currently has 11 in progress. He has been Coordinator/Chairman/Organizing-secretary for 49 Conferences, Seminars, STTPs, Workshops, FDPs, and Conventions and delivered 58 guest-lectures at various venues around the world. He is Chief Investigator of 4 Research and Consultancy Projects.

He is the recipient of Young Engineer of the Year award-1999; Best Principal Investigator-Excellent-Grade-A-AICTE-2002; Distinguished Alumnus award-KITS-Warangal-2007; Best Technical paper presentation award-IEI-2008;Engineer of the Year Award-2009;Jewel of India-2011;Eminent Educationist-2011;Railway Board's 1st Prize for best paper-2012; ISTE Best Chapter Award 2012;Best Engineering College Principal Award-2012;ISTE Best Student Chapter Award 2014;Felicitated by Lions Club-Sept-2015; Best Paper award-ASAR IC2016; Felicitated by MED-NIT-Warangal-Oct-2016; IEI-Sept 2017.

Dr Reddy is Fellow of IEI and Member-ASME, IEEE, AeSI, ISTE, ISME & TSI. Currently working on a research consultancy project for DRDO on product development using Additive Manufacturing Technologies.

Nihal Kasam graduated with a bachelors in mechanical engineering from Chaitanya Bharathi Institute of Technology in the year 2019. He is currently continuing with this research under the guidance of Dr. Chandramohanreddy. His main research interest is in the application of robotics to interior design and smart living.

Irfan Ahmed. Mohammed completed his bachelor's in engineering in mechanical engineering from Chaitanya Bharathi Institute of Technology, Hyderabad, Telangana, India in the year 2019. He has previously worked as an Intern at Bharat Heavy Electricals Limited. He is currently working as an Apprentice at Akzo Noble India Limited in Hyderabad, India.

Mr. Mohammed is a member of SAE. His current research interests are to implementation of automation in everyday activities by combining the use of Robotics and Internet of Things along with his knowledge of mechanical engineering.

Kushwaha Jayant Mohan completed his Bachelors in Engineering in mechanical engineering from Chaitanya Bharathi Institute of Technology, Hyderabad, Telangana, India in the year 2019. He has previously worked as an Intern at Nuclear Fuel Complex in Maula Ali, Hyderabad. He is currently continuing his research in Energy Studies and automation of routine manual tasks using robotics and Internet of Things.