

Architecture for Smart Cities' Sustainable Modular Houses

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Abstract—Smart cities are a framework of technologies along with sustainable infrastructure to provide their citizens an improved quality of life, safer environment, affordability, and more, which in turn helps with the society's economic growth. The proposed research will focus on the primary building block of the smart city; the infrastructure of the house itself. The traditional method of building houses has been, for a long time, nothing but a costly manufacturing process, and consequently, buying a house becomes not an option for everyone anymore. The smart cities' Modular Houses are not using traditional building construction materials; the design reduces the common lengthy construction times and associated high costs. The Modular Houses are technological homes, low-cost and customizable based on a family's requirements. In addition, the Modular Houses are environmentally friendly and healthy enough to assist with the pandemic situation.

Keywords—Smart cities, modular houses, single-unit property, multi-unit property, mobility features, chain-supply, livable environment, carbon footprint.

I. INTRODUCTION

THE research begins with a business analysis of today's housing market. The next part of the research presents five primary key factors to assess with understating the innovative and enhanced features of the Modular Houses as one of the fundamental corners of smart cities. The primary key factors are first, the design of the Modular Houses itself, the mobility, the construction materials and chain-supply effect, the Modular Houses' technology readiness, and lastly, the health and environmental awareness.

The research shows the appealing features of the new proposed design the Modular Houses such as customization, convenience, functionality, affordability, mobility, day one technology compatibility, size adaptability, and contribution to health safety. Considering everything, it provides families with inexpensive houses and affordable to a broad range of consumers, healthy and environmentally friendly, and indirectly fixes both housing supply and low incomes.

II. BUSINESS ANALYSIS

The World Health Organization has really done a great job with regard to the pandemic situation and has produced vaccination to reduce the effect of COVID-19 that has raised the hope for anticipation of stabilization of the world

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economically. However, the new challenge; the disruption of the Russia-Ukraine crisis did not let us enjoy the recovery. Instead, it took the whole world back to another economical dip that affected the global supply chain of the construction materials that is expected to continue such as steel, copper, cement, and lumber. It is very important to remind everyone that before the COVID-19 situation, there was and still the tension when it comes to trade between the two major suppliers and buyer for construction materials — the United States and China — that has caused the prices to rise [1], [2].

According to Construction Commodity Report, by the end of Q1, 2022, the lumber prices have gone up 79.5%, steel prices also had a significant increase of 4.7% for rebar steel and 8.9% for flat steel, lastly, cement reached an increase of 3% [3], [4]. Increased demand for infrastructure is considered one of the key players that drives the prices up. A supply-demand mismatch is not only an unaffordability problem for home buyers but also for renters, and not to mention the fluctuation in construction material prices will likely remain few more years to come [5].

More environmental regulations have increased lately for a healthier human's life and these regulations are appreciated across the world however business's owner have another take on these regulations. For example, the proper way to waste materials costs businesses tens of millions of dollars each year in potential profit and it is expected to double by 2025 to nearly 2.2 billion tons worldwide [6].

The consequences have led to a reduction of buyer activity that has locked out many home buyers and has left the housing market with unresolved challenges. It is important to know that renting a house or an apartment comes with its own challenges too [6].

The pandemic situation has pushed for more people to work from home, that has encouraged many to relocate to less expensive locations which directly increased the demands for rent as quicker method to adapt to. Rents rose a record 11.3% as of 2021, according to real estate research firm CoStar Group [7]. In short, higher rents, housing market difficulties, and construction material supply and demand, all related and cannot be separated as one collateral damage problem and if there is a possible solution, it must deal with it all and not partially [7].

III. SMART CITIES' MODULAR HOUSES

Today, houses around the globe are made of wood or cement, both have a higher cost and a possibility of shortage of the materials and the different hazard risk that comes with it in addition to the inefficient healthy ventilation system that

was crucial during the pandemic situation, all have been raising concerns exponentially for years to come. As of today, the house does not have a mobility feature, which means it does not have the ability to be packed and moved to another place as people do with their furniture for example. Lastly, the responsibility and the cost of turning the house to be a smart home fall on the homeowner that is in turn will cost a fortune.

The research is proposing a realistic solution for most of the issues mentioned previously, building modern technological houses in significantly reduced time, compatible and support future innovations, affordable to a broad range of consumers, and with adaptable size on demand, which means it could be expanded and reduced. The rooms of the houses are manufactured in standard sizes and ready-made to assemble together and shape the whole house and sold online or at any hardware store or else. The Modular Houses have the ability to rotate to support natural energy sources such as solar or wind.

This section lists the five primary key factors that explain the innovative aspects of the proposed Modular Houses' design for smart cities.

A. The Design

The vast majority of homeowners around the globe do not have the option to customize how the house is built, whether it is made of cement or wood, all come in standard styles for massive production, only the 1% wealthy can customize the built to any details required simply because they can afford it. For example, if the house is three bedrooms and two bathrooms, it will stay as it is for decades or destroyed due to natural disasters such as a hurricane, a tornado, an earthquake or a fire.

Adding to or customizing an existed house is not impossible but it costs a significant amount of money. On the contrary, shrinking a house from four bedrooms and three bathrooms to two bedrooms and one bathroom is not feasible nor desirable. Changing the room's size is not an option either, the only possibility that exists today is to sell the house and buy another one.

In general, the typical ordinary house has some rooms that face the street along with the noise that comes with it from the cars passing by. The opposite side of the house has the attractive view, the rooms face a golf course or a freeway. In short, there is zero flexibility when it comes to the house's design.

The concept of the Modular Houses for the smart cities is a concept of offering residential rooms in modular form, specific to individual user needs, without the need for custom construction plans, extended building timeframes, and related high costs. The rooms would be provided in standard sizes and ready-made to be put together to comprise the whole house. The individual rooms, as well as the entire house, could be rotated on a central mechanical axis to support natural energy sources such as changing solar or wind conditions. The rooms would be sold online, at hardware stores, and through other potential avenues, Fig. 1 shows a generic 3D architecture overview of the Modular Houses for the smart cities.

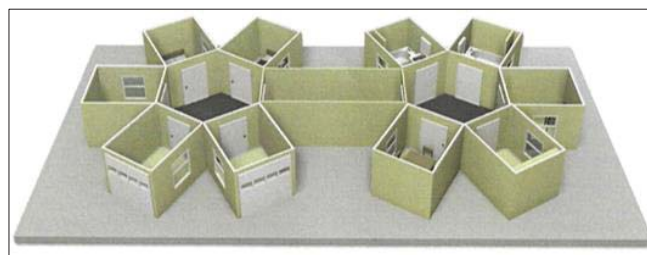


Fig. 1 (3D) Architecture overview

The proposed design would provide the means of building modern technological homes in a significantly reduced amount of time, compatible to support future innovative development, affordable to a broad range of consumers, adaptable in sizing on demand, and could also be expanded and reduced. The Modular Houses would be offered in independent cubic and cylindrical forms. Cubic units would have the dimensions of 8 feet in height x 10 feet in length x 8 feet in width. Cylindrical units would have a height of 8 feet and a diameter of 12 feet. All units could be produced of various plastic, fiberglass, and/or glass elements, with accompanying operational mechanical and electronic technology componentry including various hardware/fastener items. Consumers could choose the individual rooms to be configured into a final home composition to accommodate their own needs. Figs. 2 and 3 depict the modular houses with a single-unit property and a multi-unit property respectively.

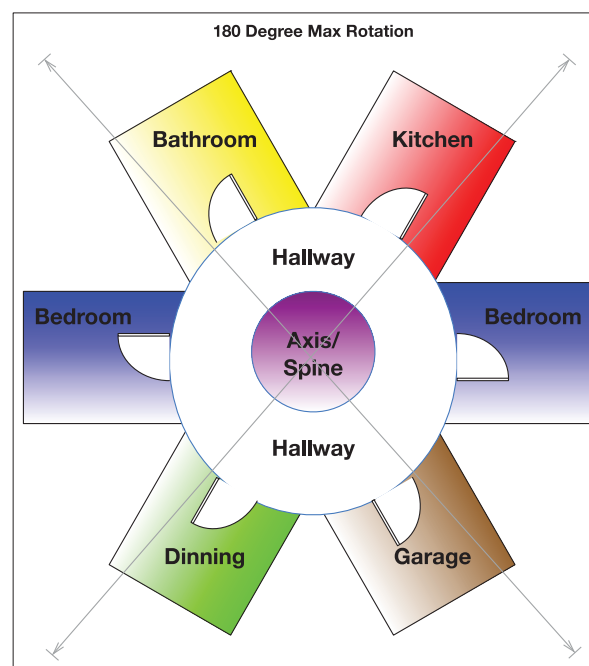


Fig. 2 Modular House-Single-unit Property

The entire cluster of rooms would be set upon a foundation, central shaft, and gear-driven mechanism which included levitation to allow the outer rooms to be rotated to compensate for optimum usage of changing solar and wind energy on a daily basis, Fig. 4. The overall room shapes/sizes, all parts and

componentry sizes, shapes, configuration, material composition, dimensions, and foundational mechanism-interface applications would be developed during the design and engineering phases, prior to manufacture. This could include producing the rooms in cubes, cylinders, or other shapes in the future, including optional accessories such as solar cells, wind power generators, etc.

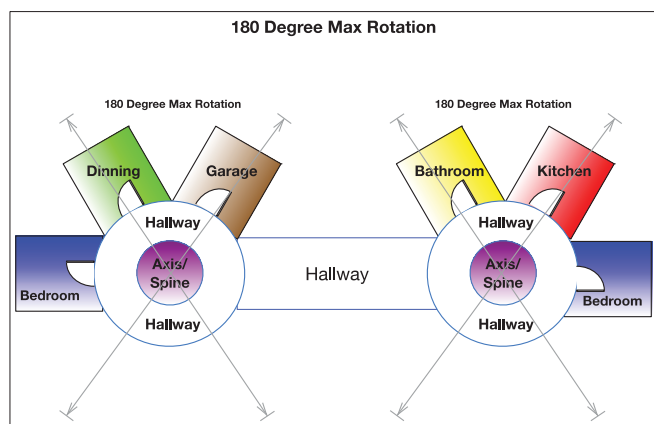


Fig. 3 Modular House-Multi-unit Property

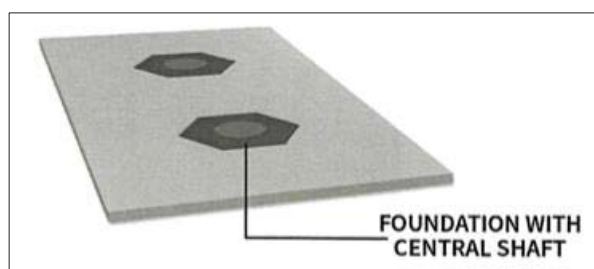


Fig. 4 Slab Platform

B. Mobility

Most people during their lifetime have to move from one place to another, a city to another, a state to another, or even from one country to another. The nightmare that comes with moving is selling one house and buying another one. It is noted that it gets harder on the families that have spent many years in a house they become very comfortable with, they organized it, painted it, decorated it, and furnished it the way they like it. Also, buying new furniture in case it does not fit the new house adds to the expenses. All in all, there is no easy mobility mechanism and nothing but pain and cost come with moving from any place to another one.

Since the Modular Houses basically are comprised of rooms as building blocks and each room could be separated and folded, it could be sold separately, rented, or used as expansion or reduction of the house size, based on that, the whole house could be packed, folded and transferred to another location. With smart cities being built in many places, this is the time to start standardizing the house architecture to provide mobility features as explained, that in turn makes it economically and comfortable to move from one place to another and follow the job or career opportunities the

individual might have.

Relocating furniture in simple terms is nothing but disassembling it, packing it, and assembling it back at the new place. The Modular Houses' mobility feature has inherited the same methodology, the only cost of moving to a new place is going only to be the relocation cost.

C. Material and Chain-Supply

Success in life and owning a house are the two fundamental goals of every individual on the planet. Success provides financial comfort to our life, also owning a house provides the stability to the individual and his family in turn. The house conventionally to be built of concrete or wood, the cost varies depending on supply and demand, and the country's economic circumstances.

Today's houses all over the world either made of wood as in United States and western hemisphere or made of metal and cement as in China, India and eastern hemisphere. Both methods have a long and costly manufacturing process and not available to everyone in turn. Houses built of concrete and wood have advantages and disadvantage when it comes to energy efficiency, fire, construction build, and other consideration [8]. The average cost of a house in the United States is \$485,000 for a 2,600 square-foot, and this price is increasing, which poses an affordability concern for many people [9], [10].

Glass and plastic are the materials used to build off the Modular Houses. Glass and plastic are made of sand or disposal plastic products. Both materials are friendly to the environment, and to the consumer to manipulate and handle. The last few years have witnessed technological development in glass or plastic manufacturing, the quality has been improved, the manufacturing cost has declined, and the delivery time has been significantly reduced as well.

The plastic components of the Modular Houses could be produced through the injection molding, rotational molding, blow molding, or extrusion processes in a variety of hard plastics including a thermoplastic polymer such as ABS, a recycled composite material, or high-density polyethylene (HDPE). Colors would be included in this manufacturing molding procedure. All fiberglass parts could be made through conventional fiberglass molding production and finishing techniques. All glass items could be produced through traditional glass fabrication and glazing methods. All components could include ultraviolet (UV) inhibitors to resist fading and cracking over time due to any prolonged outdoor water and sunlight exposure.

D. Technology Readiness

Humans have gone to the Moon, they have invented the Quantum computer, and conquered every possible scientific field. One would think that by the 21st Century, the house we live in should be monitored by cameras everywhere for security and safety purposes. It should be voice-activated everywhere, specifically for the people with disability. It should have intelligent sensors for temperature, humidity, carbon monoxide, etc. The house entertainment system from

sound to smart TVs should be everywhere, it should be connected to the cloud all the time along with people's calendars, reminders, and appointments even for grocery shopping. Also, the lighting system, heaters and air-conditioning, water sprinkle system should be intelligently embedded as well. It is worth mentioning that all the above should be cohesively integrated with and an advanced AI system to be able to cope and understand the needs of mankind.

Luckily, all these technological features exist today and they are provided by different manufacturers. Sadly, the manufacturers are not usually working together to adhere to specific standards. As a result of that, the burden of making all those features and gadgets to work together falls on the consumer.

The Modular Houses on the contrary are technologically ready day one with fiber connected to the internet with high bandwidth capacity or Internet satellite LEO (such as Starlink, OneWEB, or Amazon Kuiper) to provide internet access and open link to one of the global cloud providers (AWS, GCP, or Azure). The house's utilities, lights, power, and appliances are all connected to the AI system in the cloud.

The folding walls of each room are technologically manufactured with Dim/Block LCD to enable transparency or blocking vision on demand. The whole house is voice-activated, the sound system is wirelessly centralized and it is connected to folded rolling entertainment TV system.

Another important feature that could add a significant value is analyzing telemetry data real-time such as the security and surveillance cameras' feed, intelligent motion and temperature sensors, carbon monoxide and smart fire detectors, and the human body temperature as well. Since the whole house is intelligently IoT ready and with the connection to the cloud, all telemetry data gets analyzed instantaneously and be available for the homeowner live stream, and with the capability of the cloud AI, it can predict what could happen before it happens with the purpose of avoiding fatal consequences.

The Modular Houses foundation has only electricity as the sole source of energy along with natural sources such as solar cells, wind turbines, and power walls that connect the house to the power grid for energy conservation. In turn, using only electricity eliminates all the hazard risks that come with using the gas lines and the carbon monoxide danger as well, also eliminating the high-cost maintenance that comes with gas lines.

E. Health and Environmental Awareness

For the house to be a livable environment, it is powered by either gas, electricity, or both. Both gas and electricity have its own advantages and hazard conditions as well. The electric heating system has low-cost upfront but it gets pricy long-term, while gas is cheaper and more economical long term but very pricy and very dangerous when it comes to a gas leak, maintenance, or replacement.

Carbon monoxide due to the nonefficient combustion and exhaust system or wood burning stove or fireplace, represents

a dangerous threat to people's life than fire because no one can see it or feel it until a disaster happens. The vast majority of houses come with the standard smoke detector and it is up to the owner or the tenant to add what possibly can save life such as a fire extinguisher or carbon monoxide detector. Excessive exposure to the carbon monoxide for many hours during sleep time could cause a severe damage to the human brain or a life loss in some cases, even though taking all the possible precautions into consideration.

The recent pandemic disease COVID-19 that affected the whole world was eye-opening for new considerations with regard to the house ventilation system. The typical ventilation system is based on recirculating the indoor air that consequently could accelerate the infection with respiratory diseases. However, bringing outdoor fresh-air inside and letting indoor air outside along with air filters can certainly improve the air quality.

Manufacturing the healthier ventilating method of HVAC (Heating, Ventilation, and Air-Conditioning) systems to pull outside air inside is not difficult and does not cost much at all, however doing so is easy said than done, because replacing the existing one will cost labor which makes many homeowners very reluctant. Consequently, during the pandemic situation, the hospitals were packed with patients because they were not equipped and ready for this unprecedented situation.

As discussed previously, the latest pandemic situation had pointed to the flaws in the ventilation systems at home, at work, and at hospitals as well. The Modular Houses' ventilation system supports the outside-in mechanism by default along with the option of an advanced air filter that helps the patient at home and reduces the possibility to move to a hospital if the medical condition allows it.

According to the latest statistical studies that were done during and after the pandemic, it was found that numerous pandemic cases were mild, therefore, an appropriate ventilation system could have helped avoiding the burden on hospitals with those cases, helping the hospitals personnel to focus on the severe cases, and more importantly saving lives [11].

The pandemic situation was definitely a devastating event but it also had some positive consequences. It helped to accelerate the development and deployment of new technologies. For example, today we can have a doctor consultation on a mobile device, the doctor can see the patient, analyze infections and diseases virtually, and can read the vital information live from the app that the patient is using on the mobile device.

IV. CONCLUSION

The two most dominant types of houses all over the globe are the one made of wood and the one made of cement. Both have advantages and disadvantages with regard to material availability and cost, energy consumption, hazard, and design.

Even though with the COVID-19 vaccination has helped significantly with the pandemic situation, its side effect is still in place such as the instability of the economy and job steadiness, which led to unaffordability to buy a house.

The research has covered today's technology when it comes to building houses along with the drawbacks that cause the prices to rise and make the house unaffordable for a broad range of individuals across the globe.

The smart cities' Modular Houses design is discussed from an architectural aspect to the materials that are used and how it is capable to overcome the drawbacks of today. The Modular Houses offer customers a solution that would allow them to choose their rooms based on their particular family requirements. It also provides the option of mechanically rotating the entire house structure to utilize optimal solar and wind conditions as they change daily. The consumer could easily purchase the rooms individually and assemble them to form their particular house cluster through online sources, at hardware stores, etc.

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