TEAM SHUNYA
Building a sustainable future

Market Analysis

U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON

Jury Documentation

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Market Potential

Our net-zero house - Project Vivaan, is a single-family detached home designed for a family of 4 (a couple and their two children). The family has moved to Navi Mumbai from a Tier 2 city for better job opportunities, inspired by the statistical data for households surveyed in Navi Mumbai [1]. The design of Vivaan aims to address the sense of disconnect and alienation felt by inhabitants of Navi Mumbai's rising culture of modular and apartment houses using the framework of phenomenology. The design seeks to create spaces tailored to the needs and perceptions of inhabitants to provide a sense of belonging and transform houses into homes. The report also identifies families with a gross income of approximately INR 18 lakhs ($22,000) annually as a target market for sustainable living and net-zero houses, and notes that effective marketing strategies, such as emphasizing long-term cost savings and environmental benefits, can appeal to a broader market. The report also highlights potential marketing opportunities for businesses, such as energy-efficient appliances, home automation systems, and sustainable building materials. Understanding the specific needs and preferences of this target market is crucial in marketing sustainable housing solutions and building sustainable cities.

Needs of the Target Client

The needs of our target client - a family of four interested in sustainable living and net-zero houses may include a desire for a high quality of life and a healthy living environment. Navi Mumbai is known for its spatial openness and high quality of infrastructure, which can provide a better quality of life than other parts of Greater Mumbai [2]. The city also ranks high regarding social indicators like literacy rate and social and civic infrastructure [2].

Regarding their house, our target client is expected to prioritize features that support sustainable living and reduce their environmental impact. This could include eco-friendly elements such as rooftop rainwater harvesting systems, solar panels, and efficient ventilation systems [3]. They may also prioritize energy-efficient designs and materials to reduce their energy consumption and save on utility bills in the long run.

A survey conducted among 200 recently shifted households in Navi Mumbai found that 69.2% and 78% of the households availed non-motorized modes for using facilities like banks/post offices and leisure facilities with 85% satisfaction response rates from female household members [4]. Around 70-80% of the households perceived higher satisfaction after shifting to the new community [4]. Thus, we have chosen Navi Mumbai as our site due to its multiple benefits.

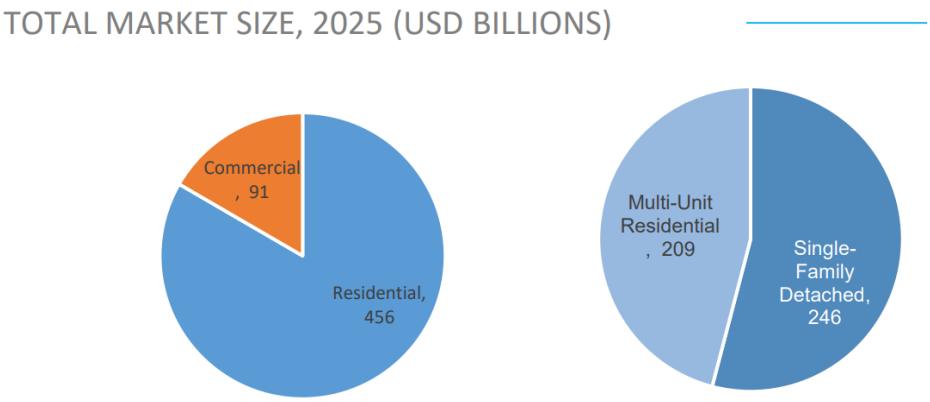
Site Location

Mumbai is a city that has reached its saturation level. Any further development there is an additional burden on the already stretched infrastructure and services like sewerage, road, water, and electricity. There is a dearth of space in Mumbai, with only possible vertical development, which is out of reach for most residents [5]. As a result, buyers are increasingly looking for alternatives that offer a better balance of affordability and quality of living.

Navi Mumbai has transformed itself from an alternate city to a first-choice destination for people looking for a permanent place to live a quality life [5]. The improved social infrastructure, upgraded modes of connectivity, and commercial development have increased the popularity of Navi Mumbai as an ideal location to live [6]. The well-planned city with wide roads, basic amenities, gardens, schools, and colleges, and an overall quality of life that is missing in neighboring cities like Mumbai have made Navi Mumbai an attractive choice for residence [5].

As per the Socio-Economic Survey of Households in Planned Nodes, about 48% of the households surveyed in Navi Mumbai have migrated from Greater Mumbai [1]. Kharghar in Navi Mumbai is the node with the highest customer satisfaction rating based on qualitative points, such as the availability of houses, better living conditions, a planned city, and proximity to their workplace. The availability of housing units in Kharghar makes it an attractive option for families looking for a balance of quality of living and affordability. Overall, Kharghar is a valuable investment for buyers looking for a comfortable and convenient place to call home.

Addressing Functional Needs through Design



The Indian market is dominated by residential buildings, with single-family detached homes being the most in number. We have built our design on top of this particular market and decided to design Vivaan as a single-family detached house, to maximize the impact potential.

A two-story house offers flexibility in design and future expansion while utilizing a lower building footprint than a single-story house. Additionally, it provides greater privacy and separation of living areas from sleeping areas. We have identified the functional and spatial needs of the target client and developed the space syntax in the following manner:

- The Ground Floor comprises the Living Room, Kitchen + Dining Room, 1 Master Bedroom for Parents, and a Common Washroom. The Living Room is a spacious area for relaxation and entertainment. The Kitchen + Dining Room is designed to provide a comfortable space for family meals and gatherings. The Master Bedroom for Parents is a convenient addition for the elderly or those with mobility issues, offering easy access to the ground floor facilities. The Common Washroom adds to the convenience of the residents while reflecting on traditional Indian layouts, where washrooms are not attached to bedrooms.
- The First Floor consists of 1 Bedroom for Children, a possible location for a new bedroom in future expansion, and an Open Space with natural ventilation and light, which can be used as a Study room. The Bedroom for Children can be converted into a master bedroom, providing flexibility for the residents. The possible location for a new bedroom in future expansion adds to the property's value. The Open Space with natural ventilation and light is a valuable addition, providing an ideal environment for a study or work area.

Affordability & Cost Effectiveness

For a similar floor area, compared to traditional houses that cost around INR 30 lakhs ($ 36,000), our design costs about five times more, i.e., about INR 1.5 crore ($ 182,000). However, it is to be noted that this amount includes additional features like EV car (INR 16 lakhs), cost of construction (INR 14 lakhs), land acquisition (INR 40 lakhs), end-of-life demolition, and the entire costs of interior furnishings (INR 10 lakhs). Thus, if only the building

envelope is considered, Vivaan will cost a buyer about INR 70 lakhs ($ 85,000), about twice that of a conventional house.

None of the additional costs mentioned above are considered in the stated price of a conventional house, which today is mainly sold as a semi-furnished flat in mid-rise apartments (as per the existing housing stock data mentioned in [1]). Also, Vivaan is designed for a 50-year life cycle. At the same time, houses in India usually last about 30 years, by the end of which they usually become unsafe to live in and have very little recyclable or scrap value. Furthermore, many financing options have come up in recent years, along with a few government initiatives, such as tax rebates [7, pp. 2, 4] that might help reduce the brunt of the up-front costs of our design.

Our design decisions were driven by optimization for life cycle cost. Hence, we considered maximizing our solar energy generation potential while selecting site building orientation. Compared to conventional brick-mortar construction, our passive design features and building envelope details reduce our annual heating and cooling demand by 18% as per energy simulations. Optimizing daylight usage and using energy-efficient lighting and HVAC further reduced energy demand, bringing it down to about 12 MWh annually. On the other hand, a conventional house's annual energy demand is estimated to be around 13.5 MWh, with certain assumptions mentioned in the Appendix.

During the financial year 2020, the average cost of state electricity supplied in India was 6.15 Indian rupees per kWh [8]. The tariff for supplied water in Mumbai is about INR 5 per 1000 liters [9].

Our design results in 40% lesser overall emissions than a conventional house with similar aspects. Project Vivaan has considerably lower emissions due to reduced energy demand. The intake from the grid is reduced by 56%. Moreover, the export of electricity to the grid offsets up to 85% of the total emissions in the project's life cycle. The materials selection has fostered a reduction of 34%.

The difference in cost between Vivaan and a conventional house is INR 1.2 crore (1.5 crore - 30 lakhs). Though, project is expected to provide a positive return of at least $ 60,000 over 50 years, while the conventional house is expected to have a negative return of $ 50,000 over 30 years. The details of the calculations are listed in the Appendix.

Livability

Due to India’s modern developing economy, there is a growing demand for sustainable, net-zero houses that provide high livability and convenience compared to the past decades. By creating a livable net-zero house that meets the needs of the modern homeowner while promoting sustainable living, we aim to help reduce the environmental impact of residential construction. This is essential as the world faces increasing environmental challenges such as climate change, water scarcity, and air pollution.

Market Expectations

There is a growing trend among millennials in India to opt for eco-friendly and sustainable homes. Millennials are redefining the Indian housing sector by opting for homes that are not only affordable but also environmentally friendly [11]. Another article by Times Property states that more and more millennials are going for eco-friendly homes [12]. These trends suggest a market expectation for sustainable housing in Navi Mumbai, driven by the preferences of upcoming generations who value environmental sustainability.

Mumbai has announced detailed plans to zero out carbon emissions by 2050, a target that puts it two decades ahead of India's national goal and makes it the first city in South Asia to set such a timeline [13].

Net-zero energy residences can uniquely deliver affordable and healthy housing solutions given their low cost of ownership over a long period [3] (owners or tenants have little to no utility bills) and their high quality of construction [15]. However, there are data and research gaps on market expectations for livability and convenience for general net-zero houses in Mumbai or India.

As more and more homeowners become aware of the benefits of sustainable living, the market expectations are primarily driven by the need to address the country's growing energy demands and environmental concerns. Additionally, homebuyers in India also place a high value on homes that are designed to provide a high level of comfort and convenience, with features such as innovative home technology, efficient HVAC systems, and modern amenities, along with added features such as solar panels, rainwater harvesting, and energy-efficient appliances. To meet these market expectations, we carefully considered the homeowner's needs and lifestyle, as discussed earlier.

Buildability

Construction Details

The house design incorporates materials and construction techniques commonly found in India and worldwide, including steel framing and an RCC raft foundation. The drywall construction method using recycled agricultural products and glass wool provides cost-effective insulation. Solar panels, energy-efficient lighting, plumbing, and HVAC systems are incorporated to reduce energy consumption and lower utility costs. The design carefully chooses appropriate materials and sustainable construction methods to ensure minimal environmental impact. Additionally, Vivaan is code compliant with the National Building Code [16] of India and local code compliant with the General Development Control Regulations [17]. This ensures that local developers can quickly execute the design in the city.

Documentation

Documentation is a critical aspect of any construction project. Vivaan's design has been extensively documented to ensure smooth collaboration between architects, engineers, and everyone involved. BIM allowed hassle-free information management through Autodesk construction cloud as CDE during the project. Training and visualization of critical structural

and MEP connections for designers and engineers enabled a clash-free coordinated model resulting in lean construction through less material and time wastage.

We have done cash-flow forecasting and derived material procurement schedule from 5D BIM. It also helped with dynamic generation BOQs as per the requirement and timeline of the project. Material properties and sun path derived from the BIM model for Energy, Lighting, and Life Cycle Analysis helped the team remove duplication of work and resulted in integrated project delivery.

In addition to using BIM authoring software, we have added an extra step of simplifying the architectural drawings to make them more understandable for clients and construction labor. This is particularly important in India, where construction labor is often unskilled to understand complex drawings and relies more on heuristics from their experience. Simplified drawings ensure everyone understands the design intent clearly, minimizing errors and miscommunications during construction.

Design Efficiency

Design efficiency refers to the effectiveness of the design in terms of the construction process. It involves selecting construction methods and materials to make work on-site faster, safer, and more efficient. For Vivaan, we asked industry partners to consider some customization so that heavy-duty procedures could be carried out off-site, reducing the amount of work needed on-site for our design. This approach also helped us ensure that the construction process was less disruptive to the surrounding properties and the environment.

Vivaan incorporates a disassemble structure, meaning the building can be taken apart and its components reused or recycled at the end of its life cycle. This approach promotes circular economy principles, reduces waste, and saves resources in the long run.

The design efficiency of Vivaan involves selecting construction methods and materials that make work on-site faster, safer, and more efficient. This includes customization of heavy-duty procedures off-site, disassemble structure for circular economy principles, and an Integrated Project Delivery approach for collaboration between stakeholders. Prefabrication of entire building sections like window assemblies and staircases reduces construction time and labor, and optimizing the design for energy efficiency and incorporating renewable energy systems allow Vivaan to operate efficiently with reduced reliance on grid electricity.

Scalability

India's Green Building market was underdeveloped as of 2020, with the certified floor space representing only about 2% of the formal newly built area [7]. India's green building market is

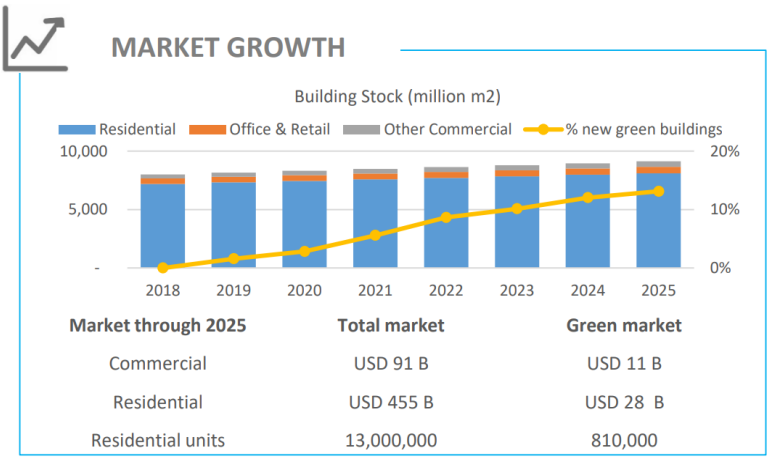


Figure 1 - Building Stock and Green Building Share in India

expected to reach 10 billion ft^2 by 2030, valued at $ 35-50 billion [18]. This growth is driven by increasing consumer awareness about the benefits of environmentally conscious living and the government's focus on developing eco-friendly infrastructure.

In addition to the environmental benefits of sustainable housing, it can also provide economic benefits to homeowners by reducing energy consumption and saving on utility bills in the long run. This can make them affordable and accessible to a broader range of potential buyers.

India has a mix of codes and standards that promote green building practices. These include the National Building Code, the Energy Conservation Building Code (ECBC), and norms set by rating programs such as Leadership in Energy and Environmental Design-India (LEED-India), the Indian Green Building Council (IGBC), TERI-GRIHA, and others (Commercial Design India 2021). As per our assessment, Vivaan is compliant with the ECBC, GRIHA, and the Eco-Nivas Samhita (ENS), which is a green rating manual for residential buildings in India.

While these codes and standards are voluntary, their adoption increases as awareness grows about the benefits of sustainable building practices. The government of India has also introduced various incentives to promote the development of green buildings. For example, the Global Housing Technology.

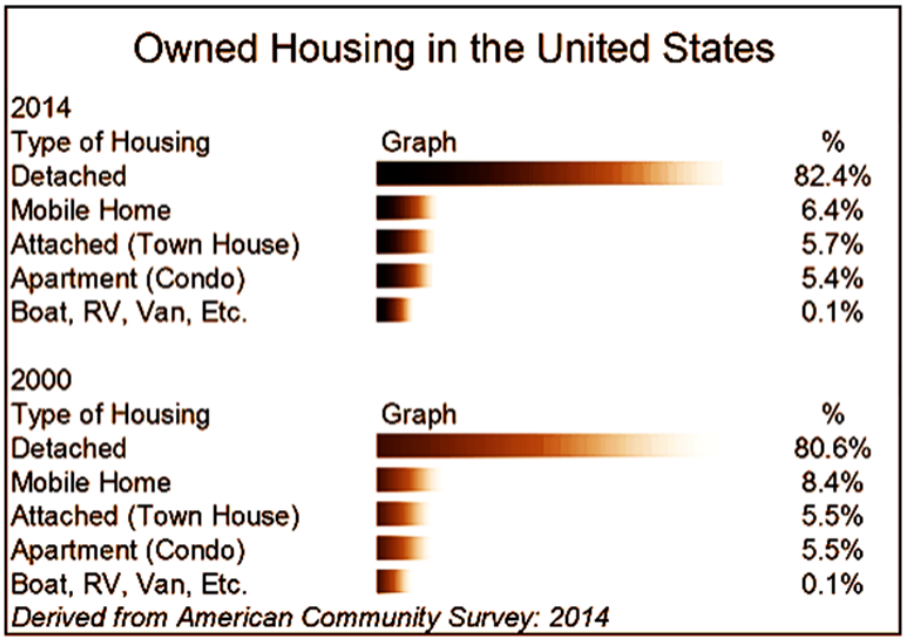
Challenge - India (GHTC-India) aims to identify and promote innovative and sustainable housing technologies that can be used to construct affordable housing in India [19].

The adoption of green building codes and standards has the potential to impact the Indian market in the long run significantly. By promoting sustainable building practices, these codes can help to reduce energy consumption, conserve resources, and improve the quality of life for building occupants.

US Market Impact Potential

We focused on scalable and easily replicable off-site construction techniques with the aid of 3D modeling software. The US housing market provides diverse options of housing types, with single-family detached homes accounting for about 82% of homes owned. The preferred housing type depends on factors like lifestyle, family size, and location, with single-family homes being popular among families with children and townhouses/condos being popular among urban dwellers and empty-nesters. Although there's a recent trend towards smaller and more eco-friendly housing options, it's mainly observed in major urban centers with higher living costs.

Our Vivaan design, a single-family detached home similar to suburban houses in the US, is a perfect match for US homebuyers' preferences for spacious living areas, large kitchens, and



outdoor spaces like patios and yards. The architectural typology of Vivaan, a single-family detached home similar to suburban houses in the US, is particularly suitable for the US market. We have considered US homebuyers' preferences, including the desire for spacious living areas, large kitchens, and outdoor spaces like patios and yards. Our design's scalability and easy reproduction have significant commercial potential, reducing construction time and costs and making our designs more affordable and efficient for homebuyers. This can help address the growing demand for housing in the US market, particularly in suburban areas with high demand for single-family homes.

Innovation

Considering the new and growing market of sustainable residential buildings in India, the following points highlight the innovative measures in terms of livability and buildability that Vivaan incorporates:

1. Net-Zero Energy, Water & Carbon
2. Universal Design: The net-zero house design incorporates universal design principles to make the house accessible to all, regardless of age or ability. This approach to livability promotes inclusivity and inspires the public to consider how design can improve the quality of life for everyone.
3. Modular Design: The use of modular design allows for flexible and customizable floor plans, which can be easily adapted to suit the changing needs of occupants. This approach to livability promotes adaptability and inspires the public to consider how design can accommodate changing lifestyles and needs.
4. Collaboration and Technology: BIM software and other collaboration tools ensure that all stakeholders can easily collaborate and communicate during the design and construction process. This approach to buildability sets an example for effective teamwork and inspires the public to consider the role of technology in improving the construction process.

By incorporating innovative approaches to livability and buildability, the net-zero house design sets a new standard for sustainable and accessible future housing. These features inspire the public to consider how design can improve their quality of life while reducing their environmental impact, making it an attractive investment opportunity for forward-thinking developers and investors.

Appendix

Cost Comparison to a Conventional House

The difference in cost between Vivaan and a conventional house is INR 1.2 crore (1.5 crore - 30 lakhs). The annual savings on electricity for our house compared to a conventional house would be

(16 MWh - 12 MWh) * INR 6/kWh = INR 24,000.

Additionally, Vivaan generates 13.5 MWh of electricity using rooftop solar panels, which could result in additional savings of

17 MWh * INR 6/kWh = INR 102,000 annually ($ 1,200).

The efficient water fixtures of our house reduce the intake from 668 liters per day to 395 liters per day for the four-person house. Furthermore, the gray water recycling system saves around 60 liters daily that could be reused in the toilets and gardening. This reduction in water consumption results in an annual saving of

(668 - 395 + 60) * 365 * INR 5 / 1000 = INR 3,011

along with a 61% reduction in CO2 emissions from the water supply and consumption.

The total annual savings for Vivaan, compared to a conventional house, would be

INR 24,000 + INR 102,000 + INR 3,011 = INR 129,011 ($ 1,570).

Breakeven period = Initial cost of Vivaan house / Total annual savings = INR 1.5 crore / INR 129,011

Breakeven period = 11.63 years

Therefore, it would take approximately 12 years to recover the initial cost of the Vivaan house through electricity and water consumption savings alone. After that, the homeowner's annual savings would be a net gain.

The maintenance cost for a typical Mumbai house is around INR 5-7,000 per month [10]. This can be estimated as INR 80,000 ($ 1000) annually, amounting to about INR 10 lakhs plus additional costs for every decade. However, no such study could help estimate the maintenance costs of a house like Vivaan or prefabricated housing in India in general. Thus, assuming constant savings and a 15% maintenance cost every ten years for both houses, we can calculate the estimated returns for Vivaan and a conventional house over their respective life cycles.

Maintenance cost after 10 years = 0.15 * INR 1.5 crore = INR 22.5 lakhs

Total return after 10 years = Total annual savings - Maintenance cost = INR 1,29,011 * 10 - INR 22,50,000 = INR 10,14,110

Total return after 50 years = INR 10,14,110 * 5 = INR 50 lakhs ($ 62,000)

For a conventional house:

Total annual savings = INR 0 (assuming no energy or water savings)

Maintenance cost after 10 years = 0.15 * INR 1 crore = INR 15 lakhs

Total return after 30 years = - INR 45 lakhs (- $ 50,000)

Electricity Demand Comparison Conventional House in Mumbai, India

For the calculation of annual electricity demand for a conventional house in India with similar utilities as Vivaan, the following assumptions were taken:

Three split ACs running for 8 hours daily for 6 months:

- Energy consumed by 1 AC in 8 hours = (1.5 ton * 1,500 watts) * 8 hours = 18,000 watt-hours = 18 kWh
- Total energy consumed by 3 ACs in 8 hours = 18 kWh * 3 = 54 kWh
- Total energy consumed by 3 ACs in 6 months = 54 kWh * 30 * 6 = 9,720 kWh

Four fans running for 20 hours daily for 12 months:

- Energy consumed by 1 fan in 20 hours = 75 watts * 20 hours = 1,500 watt-hours = 1.5 kWh
- Total energy consumed by 4 fans in 20 hours = 1.5 kWh * 4 = 6 kWh
- Total energy consumed by 4 fans in 12 months = 6 kWh * 30 * 12 = 2,160 kWh

Four tube lights running for 6 hours daily for 12 months:

- Energy consumed by 1 tube light in 6 hours = 20 watts * 6 hours = 120 watt-hours = 0.12 kWh
- Total energy consumed by 4 tube lights in 6 hours = 0.12 kWh * 4 = 0.48 kWh
- Total energy consumed by 4 tube lights in 12 months = 0.48 kWh * 30 * 12 = 172.8 kWh

One refrigerator running for 24 hours daily for 12 months:

- Energy consumed by the refrigerator in 24 hours = 200 watts * 24 hours = 4,800 watt-hours = 4.8 kWh
- Total energy consumed by the refrigerator in 12 months = 4.8 kWh * 30 * 12 = 1,728 kWh

One microwave oven running for 1 hour daily for 12 months:

- Energy consumed by the microwave oven in 1 hour = 1.2 kWh

- Total energy consumed by the microwave oven in 12 months = 1.2 kWh * 30 * 12 = 432 kWh

One dehumidifier running for 4 hours daily for 3 months:

- Energy consumed by the dehumidifier in 4 hours = 500 watts * 4 hours = 2,000 watt-hours = 2 kWh
- Total energy consumed by the dehumidifier in 3 months = 2 kWh * 30 * 3 = 180 kWh

Ten LEDs running for 14 hours daily for 12 months:

- Energy consumed by 1 LED in 14 hours = 10 watts * 14 hours = 140 watt-hours = 0.14 kWh
- Total energy consumed by 10 LEDs in 14 hours = 0.14 kWh * 10 = 1.4 kWh
- Total energy consumed by 10 LEDs in 12 months = 1.4 kWh * 30 * 12 = 504 kWh

Adding 20% for additional appliances, the total daily energy consumption would be:

Total energy consumption

= 9,720 kWh + 2,160 kWh + 172.8 kWh + 1,728 kWh + 432 kWh + 180 kWh + 504 kWh = 15,896.8 kWh Annual electricity demand =15,896.8 kWh = 16 MWh

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