Unscrewing the climate change lightbulb with 5,000 net-zero-energy professionals

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Abstract

India's fast-growing economy accounted for 7.3 % of global emissions in 2018. Summer temperatures in many cities cross 40 °C and extreme weather events leave large sections of the population vulnerable to climate change risks. India's building sector will expand by 6 billion m^2 and cooling demand is expected to grow 15-fold in the next 20 years. For the 2 °C pathway and India's Nationally Determined Contributions, a 50 % reduction in building energy demand is needed by 2050. Solutions for net-zero energy buildings (NZEB) that are resilient need to be implemented at a large scale, going beyond the energy codes that still have to take root in India. About 500,000 students graduate every year in India from building sector-related courses, with a curriculum that does not prepare them to implement NZEBs. Out of the 450+ architecture colleges, less than 20 have coursework related to energy-efficiency or sustainable design. This is a huge capacity deficit.

This paper summarizes the structure of Solar Decathlon India and the learning from its first year. It was launched in 2020 as an annual competition where students partner with real estate entities to provide net-zero, affordable, and resilient design solutions for real projects. This program builds capacity by providing online distance learning and allows students to get hands-on experience on real projects. In its first year, the competition has been able to reach 944 students, 165 faculty members, 53 real estate partners, and 63 manufacturers who have formed an ecosystem interested in finding affordable NZEB solutions. The structure of the competition has allowed it to be included in coursework, but it has also enabled students and faculty to participate outside the curriculum in many institutions. It also highlights how the program with a pedagogy that can scale into thousands of students is well aligned with the National Education Policy, National Missions that were set up under India's National Action Plan on Climate Change, UN Sustainable Development Goals and speed up the implementation of pathways towards the 1.5 °C limit under the Paris Agreement. The paper makes a case for creative approaches to scaling up capacity building in ways that excite the students and faculty while engaging with the industry and delivering market-ready solutions.

Introduction

India is a rapidly urbanising economy with increasing per-capita emissions across sectors. Globally, the building sector alone contributes to 39 % of energy-related CO_2 emissions (UN Environment and International Energy Agency, 2017). In India, 68 % of emissions between 2005–2013 were accounted for by the energy sector which includes electricity generation and fuel combustion required by the building sector (Chakrabarty, 2018). This is bound to increase manifold over the next decade, as India plans to add over 6 million ft^2 of floor space every year. We are already beginning to face extreme weather events such as floods and heat-island effects due to climate change. Meanwhile, India's cooling energy demand is expected to double in 2027 from 2017 baseline, with 57 % contributed by cooling demand in buildings (Kumar *et al.*, 2018). To combat this, India is working towards the 1.5 °C pathway through its

Nationally Determined Contributions. Net-Zero Energy Buildings can mitigate the building sector's contribution to climate change and help in reducing India's building energy demand by 50 % by the year 2050. They are highly efficient, have a negative carbon footprint, and also give back to the grid. Furthermore, India's buildings need to be more resilient to protect the inhabitants from risk to their lives and property, in the face of climate change.

Energy efficient building design in India is still at a nascent stage. The lack of stringent policies and the misconception that sustainable buildings cost more, are major barriers to their uptake in the market. Regulatory policies such as the Energy Conservation Building Code of India (ECBC) and the Eco-Niwas Samhita provide the energy codes for commercial and residential buildings in India. However, these are not mandatory codes, and many states in India are yet to adopt them (Garg and Bhadra, 2020). Besides, there is a lack of technical expertise in implementing these regulatory requirements for efficient and high-performance buildings. Adequate capacity development in building professionals can not only inspire compliance to these regulations but also ensure greater consciousness of the energy waste produced in the building sector. Currently, the curriculum does not build capacity among professionals to design, test, and implement net-zero buildings, and monitor their performance after they are built. Existing capacity building and Accredited Professional (AP) certifications provided by the Green Rating for Integrated Habitat Assessment (GRIHA), Leadership in Energy and Environmental Design (LEED), and the Indian Green Building Council (IGBC) do not provide holistic training on net-zero using computations and simulations that can help in designing as well as evaluating the performance of the buildings, post-occupancy. Capacity building of young professionals is crucial for India in the next decade, as over 70 % of the building stock is yet to be built (Becqué *et al.*, 2015). Providing them the foundations i.e., the knowledge and skills for designing and operating NZEBs during their early education will influence the buildings they will work on over their careers, spanning at least 3 decades.

The Solar Decathlon was initiated by the United States Department of Energy in 2002 to enable students to develop net-zero building solutions. Projects from past Solar Decathlons have shown that students can produce high-quality work at par with professionals and in fact, their solutions have resulted in design and technology innovations. Over 100 students from Indian institutions have participated in Solar Decathlons held in other countries, and 92 % of them are already working in the Indian market towards net-zero. However, international Solar Decathlons do not offer the necessary training to design net-zero buildings in the Indian context. Solar Decathlon India was launched in 2020 to fill this gap and offer a platform for young professionals to innovate and combat climate change by designing net-zero buildings that suit the climatic conditions in India and comply with the Indian standards for energy-efficient construction (Vaidya and Bhadra, 2020). In the first year alone, Solar Decathlon India has built capacity among 944 students and has generated engagement opportunities for participants in the clean energy field. Unlike other programmes and trainings, Solar Decathlon India nudges students to step out of the standard practices and innovate using new technologies. It is creating a new generation of professionals who will set the course for future-proofing buildings in India.

Intent

Solar Decathlon India is a challenge-based, gamified program for undergraduate and postgraduate students, providing education, skill-building, and industry collaboration activities that give them agency of the clean energy transition and creation of climate-resilient habitats. Table 1 summarizes the theory of change of the program over an anticipated period of five years.

Structure of Solar Decathlon India

From the onset, the intention of the competition is to provide the students with a platform to learn, by doing hands-on work on real problems. The Solar Decathlon India is designed to allow students to go beyond NZEBs and to design net-zero-energy-water buildings and contribute to real projects while they partner with real estate developers.

Table 1. Theory of Change.

Inputs	Outputs	Outcomes	Impacts
• High quality online learning modules accessed within and outside the curriculum • Amplification through media and policy advocacy • Internship program for Solar Decathlon India Alumni • Management of competitive gamified environment • Access to national and international experts and mentoring	• Hands-on learning for 7,000 students with problem-solving capability related to climate change and the ability to work in large teams • The development of 700 faculty members from small and large colleges across India, enabled them to make changes for climate resilience in their curriculum • Affordable Net-Zero Energy & Water solutions for 700 real building projects • Innovation and application of scientific research in building projects	• Ripple effect change in the curriculum of colleges across India to continue the march to a Zero Emissions economy • Change in the outlook of industry manufacturers, real estate developer, and local government to start solving the climate change problem • A culture of practical innovation in the building sector collegiate education of engineering and architecture • Cascading effects from the students' learning, industry involvement, leading to net-zero policy • Demand for high-performance buildings and low/zero-carbon-centric business models	• Clean energy transition for the building sector in India and across the Global South • Green jobs and internships for professionals who can make the clean energy transition happen and protect people and property from the impacts of climate change

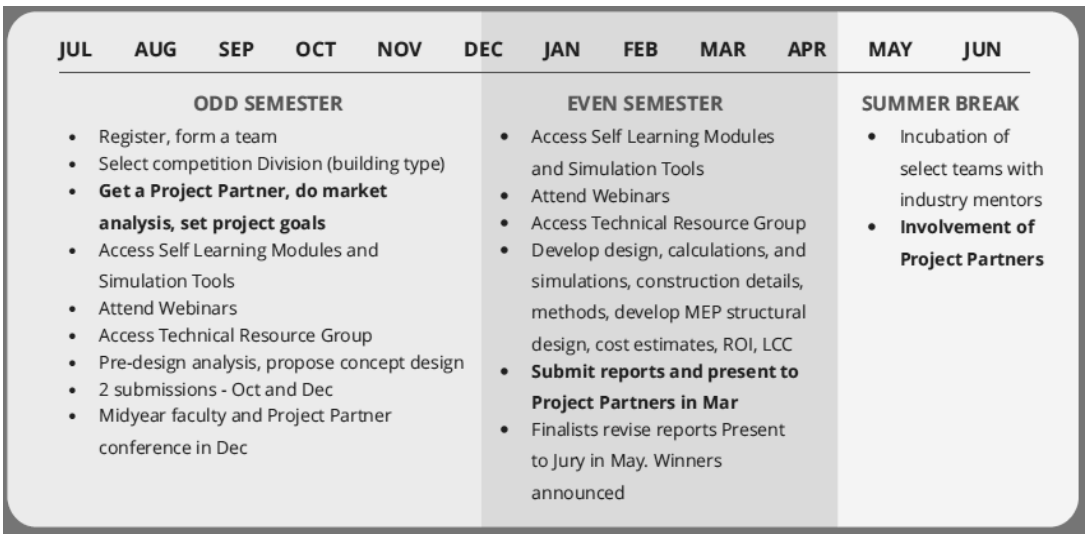

Figure 1. Solar Decathlon India annual schedule.

The challenge is open to all colleges in India. Interdisciplinary teams are encouraged to innovate and design affordable net-zero-energy-water buildings. They compete and work on real building projects by partnering with developers/clients to propose affordable market-ready solutions. Each team is guided by a faculty advisor. Developers, real estate companies, manufacturers, and professionals, partner with teams and draw benefits from the student exploration and innovations. The students work in the Solar Decathlon India provides the college and faculty members opportunities to gain recognition as leaders in addressing climate change. The competition runs over an entire year and in two stages. The teams are provided with online learning materials related to building science, energy efficiency & net-zero performance, renewable energy, water sufficiency, cost estimation, etc. They are provided with access to mentorship from experts in the industry, simulation software to test their work in different scenarios and live building projects to implement them.

Students from any postgraduate or undergraduate programs form a multidisciplinary team with at least one student from architecture/building science and one from an engineering background. Students collaborate with other colleges/institutions to form a team and each team can have a minimum of five and a maximum of fifteen students. Registrations open in July so that the 1st stage of the competition is aligned with the Monsoon semester which ends in December. In the second stage, during the even semester (i.e., January–April), the students develop their design with engineering and construction details. The teams complete their work and present it to a jury of industry professionals in May. Teams with promising work are selected for a 6-week incubation hub during the summer break (i.e., in May–June), where industry experts mentor them to take their solutions to the next level and make them market-ready. Teams with start-up potential are also be selected for a separate business incubation hub. Finalist teams have access to Solar Decathlon India's Internship Programme and get placed in prominent industry and research organizations so that they continue to work in the Climate Change space. The annual schedule of Solar Decathlon India is presented in Figure 1.

THE TEN CONTESTS

Participating teams compete in ten contests (hence, called Decathlon) and are judged equally against the evaluation criteria of each of the contest areas.

Energy Performance: This Contest evaluates the building's energy use and production, as well as its capability to interact with the electricity grid, with on-site or stored power. Teams are encouraged to take a whole building performance approach to integrate various passive/low-energy strategies, efficient systems and operation, and renewable energy technologies into the building form and design. Teams are evaluated based on their solutions to achieve net-zero energy performance in their building, integrated with renewable energy systems that are affordable and scalable.

Water Performance: This Contest emphasises on the design and management of on-site water resources towards a fully water-sufficient development. Teams are evaluated based on their building's water use, production, and its ability to manage on-site water as a resource. Teams are encouraged to use rainwater harvesting, efficient plumbing fixtures for minimizing water usage, as well as water reuse to achieve net-zero-water performance.

Resilience: Resilience is the ability to anticipate, withstand, respond to, and recover from disruptions. This Contest evaluates the building's ability to ensure long-term durability in response to local climatic conditions, to withstand and recover from prevailing disaster risks in its intended location, and to maintain critical operations during power/water supply disruptions. Teams are also encouraged to think in terms of food security and resilience at a community level.

Affordability: This Contest evaluates the building's financial costs for initial investment and ongoing operations. Strategies for rightsizing and optimization of systems help to control the potential increase in the cost of high-performance buildings. The cost of construction and financing, and the extent to which the design would cost more or less than a typical building in the target market, should be carefully considered and justified. Design strategies for achieving economies in construction, such as simplifying and integrating building assemblies and using local materials can be considered. Teams are encouraged to look at

operations and maintenance costs that determine the total cost of ownership.

Innovation: This Contest evaluates the incorporation of innovative technologies as well as business models that can be scaled up and implemented on a large scale. Teams are required to understand the problem at hand, either at the building level or community level and are expected to develop innovative solutions that meet the project intent and the target market. Teams are required to identify the challenges and strategies to scale up their ideas and anticipate their impact.

Scalability and market potential: This Contest evaluates the building's responsiveness to the target market, likely appeal to intended occupants or owners and the construction industry. It also evaluates the team's ability to demonstrate how climate change is addressed through buildings, making the solution desirable and scalable. The teams should establish their understanding of the target market, and the design should reflect its responsiveness to this target market. Scalability includes successful replication or large-scale implementation of a product, technology, assembly, business model, or approach. Teams need to engage actively with industry partners while developing and whetting their proposed solutions.

Comfort and environmental quality: This Contest evaluate the building's capability to integrate comfort and indoor environmental quality with energy-efficient performance. Thermal comfort and ventilation are the two aspects that are evaluated. Teams are encouraged to adopt the adaptive thermal comfort model from the National Building Code of India and design a resilient building that uses passive approaches to maximise thermal comfort without the need for air-conditioning equipment in the habitable areas. For hours when passive approaches are not able to achieve thermal comfort, teams can provide air-conditioning for the occupied areas. Teams need to ensure ventilation for fresh air as recommended by the National Building Code of India. For designs using natural ventilation, teams need to consider issues such as dust, noise, insects, and pollution.

Architectural design: This Contest evaluates the building's architectural design for its creativity, integration of systems, and ability to deliver desirable aesthetics and functionality along with performance. Cutting-edge energy-efficient building performance is better positioned to achieve market acceptance if integrated into architectural designs that creatively meet or exceed aesthetic and functional expectations of both industry and consumers. It also includes the effective integration of high-performance engineering systems.

Engineering design and operation: This Contest evaluates the effective integration of high-performance engineering systems and an understanding of the building operation. Structural engineering systems should be effectively integrated with natural heating and cooling opportunities and must be designed with a right-sizing approach to minimize materials, equipment, and energy waste. Building systems, appliances, and features should be thoughtfully selected and integrated into the overall design. An intelligent approach to automation and adaptive control by occupants needs to be considered.

Presentation: This Contest evaluates the team's ability to accurately and effectively convey its design and energy performance strategy to relevant audiences. The value proposition of salient aspects of the building design including energy, water, resilience, and comfort, must be conveyed to investors, developers, and the larger public. A smart design on its own is insufficient. Presentation quality can dramatically affect market perception and the likelihood of innovation adoption, and Solar Decathlon India encourages teams to address this effectively.

COMPETITION DIVISIONS

In the 2020–2021 Solar Decathlon India challenge, teams competed in any one of the four divisions (viz., Office building, Community Resilience Shelter, Multi-family housing, and Education building). Teams worked on the building typology of their choice. The team's designs were expected to comply with byelaws, codes, or standards governing ground coverage, setbacks, minimum room size, fire protection requirements, toilet locations, and quantities, and other specific requirements. Teams identified a new/upcoming project with the help of their project partner. Given the enormous amount of built-up area that is estimated to be added in the next decade, Solar Decathlon India prioritises new construction. Retrofit buildings will be included in the subsequent years.

Competition divisions (or building types) are selected on the following two key parameters:

- Potential to positively address climate change,
- Potential to improve people's quality of life (i.e., provide comfort and well-being).

The four divisions in the first year provided an opportunity for students and the industry to innovate and propose net-zero solutions for affordable homes which are expected to grow multi-fold in the next decade; efficient and cost-effective office spaces ranging from medium to large sizes; educational buildings which will pave the path for innovation in educational activities and net-zero transitions; and lastly, the community resilience shelter which is integral to promote resilient communities in the face of extreme weather events or disasters. Owing to the positive response and interest shown by both academia and the industry, we will add two more divisions i.e., 'Single-family Housing' and 'Community Cold Hubs' in the next year's challenge. The divisions are identified based on their potential to have a positive social and economic impact on people and the community, while meeting the national targets towards the SDGs and the Paris Agreement.

PROJECT PARTNERS AND INDUSTRY PARTNERS

Each team must partner with a developer or a client, whose (real) project they will work on. Project Partners get risk-free net-zero solutions proposed for their projects, and they make no financial commitments. Teams are encouraged to seek out industry partnerships to work towards market-ready solutions using the latest technologies. Industry partners help with factors like affordability, scalability, and innovation. By involving the real estate, manufacturing, and knowledge industry as Project Partners and Industry Partners, Solar Decathlon India develops and diffuses net-zero and resilient solutions in the market.

INSTITUTIONS AND STUDENTS

The institutions or colleges only commit to enabling a faculty member to be a mentor for the team of participating students. Faculty mentors are also provided with a faculty development

meet twice during the challenge. They also get opportunities to gain recognition locally and nationally as leaders in addressing climate change.

Further, colleges are encouraged to include the competition into their coursework to recognise the effort that the students put in and the learning they get. The Solar Decathlon India challenge provides colleges the platform and support to enable their students to learn about sustainability with an interdisciplinary and comprehensive problem-solving experience. This also enables the college to align itself with the National Education Policy (2020).

Participation in the competition gives the students hands-on experience in developing innovative solutions for net-zero buildings. The collaborative work results in research, publications, and patents. The experience and the exposure give them the confidence to explore and learn with interest to tackle complex socio-technical problems in the future. Working with Project Partners and Industry Partners gives them an experience that is not provided through their normal coursework. This also enables an eco-system of academia-business collaboration which exposes them to some of the best students and young professionals with innovative ideas to tackle climate change.

Integration and pedagogy

Gupta *et al.*, (2019) argue that if building performance is to be adopted widely by the industry in India, then it needs to be taught in higher education and continuing education. In a study that included a survey of faculty members from Civil Engineering departments and the prescribed model curricula from the All-India Council for Technical Education (AICTE), they found very little evidence of integration of sustainability and net-zero or carbon neutral approaches that address climate change. This integration was even less so in the post-graduate curricula. Architectural education, with curricula prescribed by the Council of Architecture similarly, includes a thin menu of electives on these topics, with almost no evidence of integration into the problem-solving cases in the design studios, where application-oriented learning happens (Manu *et al.*, 2010). Manu, Vaidya and Rawal, (2017) found that building services-related courses do not get integrated with building design subjects, hence integration between climate-responsive built forms and the energy-consuming systems such as HVAC, lighting does not take place. As a response to this lack of deeper education, CEPT University started the multidisciplinary Master of Technology in Building Energy Performance program, where the pedagogy allows the students to get hands-on learning. However, the intake of that program is 20 students a year, while there are over 60,000 students in architecture colleges and over 500,000 students in engineering courses connected with the building sector. To have any significant impact, a program with a pedagogy that can scale into thousands of students is needed.

Solar Decathlon India requires that each participating team of 5–15 students is mentored by a faculty member and that each team be multidisciplinary with a minimum of one architectural and one engineering student in the team. Teams are required to work on live, real building projects. There are 3 main parts to the pedagogy.

- Multidisciplinary problem-solving in a team supported by online distance learning and a gamified experience. This provides the fundamentals for learning concepts and best practices and applying them deeply to problems of the students' choice. while engaging the team with a gamified experience.
- Having them work on a real, live project to give them a real-life experience, develop soft skills, seek partnerships, develop a sense of responsibility and purpose, and learn the reality of tackling climate change from a mitigation and adaptation perspective.
- Providing regular feedback and support to the students and their faculty mentor, along with a faculty development program that builds capacity within the students and their faculty over a period. The faculty development program also allows the organizers to get feedback and adjust the program components to their needs.

The program aligns the pedagogy to India's National Education Policy (Ministry of Human Resource Development, 2020) in several ways as indicated in Table 2.

Results – Year 1 of Solar Decathlon India

As there is growing attention towards making the buildings sector more sustainable and energy-efficient, students and future professionals hold an important responsibility. Over a rigorous 10 months, participants of Solar Decathlon India are gaining foundational knowledge on building physics and key concepts of the net-zero energy performance of buildings, adding a completely new dimension to their university-level learning. By working on live projects along with their project partners, they are experiencing working in the industry first-hand and applying their learning into practice. Teams are comprised of an average of 12 members from diverse backgrounds including architecture, engineering, data science, management, and finance to garner a 360-degree view throughout their design process. This includes taking into consideration the climatic zone, energy consumption, costs and affordability, and market potential to innovate and design net-zero and resilient buildings. They are using simulations to consider the different complexities of the building system and achieve optimum efficiency. Students reported that their participation in the competition sharpened their technical knowledge and helped them perform better in their other university work. The participants of the 2020–2021 challenge are collectively working on designs of over 12 million ft^2 of real estate, showing how 6.3 million tonnes of CO_2 emissions can be abated from the building sector. The results from the first year of the program are illustrated in Figure 2.

On average, more than 830 participants provided feedback on the Self-Learning Modules (Figure 3) and more than 640 participants provided feedback on Technical Webinars (Figure 4), which are intended to provide them with a solid foundation of the technical concepts. This also includes students from backgrounds other than Engineering and Architecture, for whom Solar Decathlon India has provided an entry into energy efficiency in buildings. In the 2020–21 challenge, students from non-technical backgrounds such as Management and Finance also participated. The scope offered by Solar Decathlon India

Table 2. Mapping India's National Education Policy to Solar Decathlon India.

National Education Policy aspect	Solar Decathlon India pedagogy
Multidisciplinary education that enables the deep study of one or more specialized areas of interest with 21st century capabilities across a range of disciplines including sciences, social sciences, arts, humanities, languages, as well as professional, technical, and vocational subjects.	A foundational education that spans across the expertise areas of building design, building science, civil and mechanical engineering of building systems, water sufficiency, costing and finance, and resilience in building design and construction.
Increased access, equity, and inclusion through a range of measures, online education, and Open Distance Learning.	Online Self Learning Modules accessed through a Learning Management Platform along with webinars and mentorship from industry leaders provided to students from all parts of the country.
Bring together mathematics, science, vocational subjects, professional subjects, and soft skills.	The competition challenge and the design problem are structured so that students learn to apply their learning on a live-real problem, and learn to be professionals while interacting with the industry and by taking on the responsibility of a real project. They develop soft skills of communication, writing, movie-making, creating partnerships, leadership, and teamwork.
Autonomy to faculty and institutions.	By allowing several options of participation such as voluntary participation of the students, enabling the integration of the competition effort as an elective course, studio course, lab course, or even a group project, faculty members can decide how to integrate the learning into their curriculum.
Revamping curriculum, pedagogy, assessment, and student support for enhanced student experiences.	The gamification aspect and the sense of a nationwide cohort, as well as the ability to compare themselves against teams from other colleges, give the students an enhanced learning experience.
Courses and projects in the areas of community engagement and service, environmental education, and value-based education.	Working on live, real projects that have the potential to impact communities, and developing innovations that can be scaled up gives the students a purpose and a meaningful experience.
Environment education will include areas such as climate change, pollution, waste management, sanitation, conservation of biological diversity, management of biological resources and biodiversity, forest and wildlife conservation, and sustainable development and living.	This is core learning and capacity building in Solar Decathlon India.
Creation of greater employment opportunities.	Solar Decathlon India's Internship Program and Incubation Hub pathways.

Figure 2. Results of Solar Decathlon India 2020–21.

is far-reaching, across these ten contests. This makes Solar Decathlon India all-encompassing, setting it apart from any other capacity development programs for building professionals.

There is a transformation in the design process of the students, wherein sustainability, innovation, and market-readiness have become important considerations. Through a series of deliverable submissions, participants analysed the Energy Use Intensity (EUI) of their building, renewable energy potential on-site and established the target costs. Initially, they struggled to understand and establish the EUI targets as this was a fairly new concept. They showed a good understanding of estimating the renewable energy potential in their buildings, including solar, wind, and biomass. They provided their pre-design analysis, climate analysis, and simulations for energy and daylighting and defined appropriate strategies. Participants have also demonstrated a net-zero water approach in their designs.

In subsequent deliverables, they showed progress towards all 10 contests of the decathlon. They provided estimates of EUI and provided strategies to reduce it. Using simulations, where some teams also included Computational Fluid Dynamics, they estimated the number of hours in which their passive designs can perform without air-conditioning. They also calculated incremental costs and Return on Investment for their proposals.

There is a transformation not only in their work but also in the way they have incorporated sustainability practices in their lives. The understanding that for one unit of electricity consumed on-site, 4 units of energy are expended at the source, has resulted in a sense of responsibility among the participants towards the planet. They have developed an awareness of what they consume and the related implications. This will have a ripple effect and set the course for mainstreaming efficiency and resilience in all sectors in India. The participants are also getting a chance to sharpen their soft skills such as team management, report writing, and communication. These students will soon become sought-after professionals in the clean energy field.

The Design Challenge Finals 2021 revealed that leading real estate developers in India are keen on providing internship and job opportunities to the first year's participants of the competition.

Faculty mentors supporting the participants are amplifying the reach of the competition to more students. Many leading architecture and engineering schools have included Solar Decathlon India in their course curriculum. This is creating a change in the teaching pedagogy, as theoretical learning is supported by practical work. In a faculty conference hosted by Solar Decathlon India in 2020, faculty mentors discussed ways to integrate the competition into the curriculum as part of a Choice Based Credit System. They pointed out that Solar Decathlon India fulfils the need for industry tie-ups and exposure to real-life scenarios for the students. Through the competition, they plan to integrate energy performance, Heating Ventilation, and Air Conditioning (HVAC), software applications, measurements, and experimentations into the coursework. The gap between academia and the industry is slowly dissolving, as students, faculty, and the industry are collaborating towards a common goal. Furthermore, faculty mentors themselves are getting an opportunity to keep up with the industry and effectively guide their students based on the latest trends. They are taking up roles as agents of change in leading the students towards creating real-world impact. A knowledge pool on energy efficiency and sustainability is created as academicians from all over the country are part of the Solar Decathlon India network.

The collaborations between students and the industry are risk-free and benefit both stakeholders. Students are given a ground to test new technologies and learn from real-life scenarios. This in turn enables the industry to step out of their business-

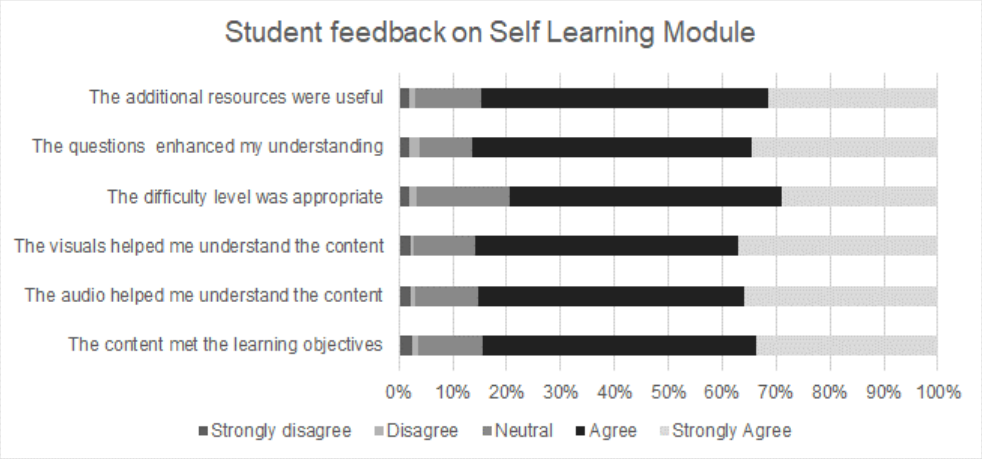

Figure 3. Solar Decathlon India 2020–21 participant's feedback on Self-Learning Modules.

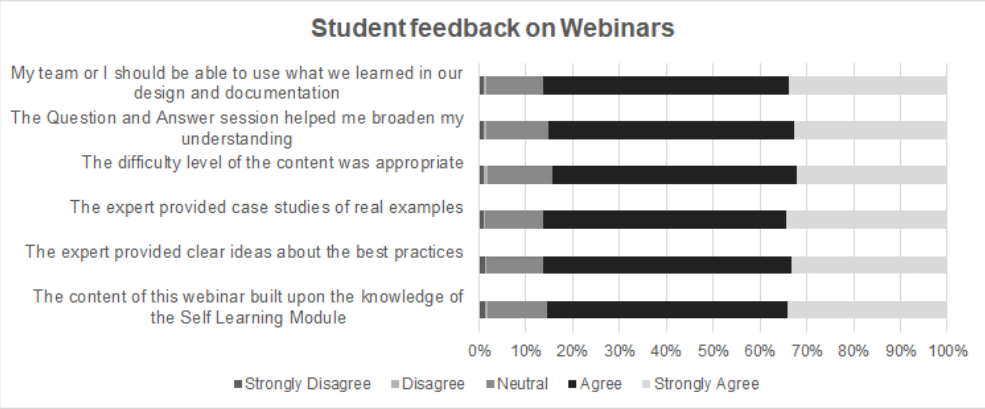

Figure 4. Solar Decathlon India 2020–21 participant's feedback on Technical Webinars.

as-usual and consider possibilities of implementing fresh ideas. Real estate developers who earlier thought only about the energy efficiency of their buildings, have now begun considering net-zero performance after their engagements with participants of Solar Decathlon India. Such collaboration will gradually shift the market towards greater acceptance of net-zero energy buildings. The students are already talking to their communities about the possibilities of net-zero energy buildings and the positive impacts on their health and well-being. With the success of their designs, developers could take them to their customer base. In this manner, industry experts are getting an entry into academia and become mentors for students. They feel a sense of fulfilment in contributing beyond their work in the industry and adding value to the lives of the students.

The building sector in India contributes to almost 30 % of greenhouse gas emissions, and net-zero energy buildings will address this problem. In the first year alone, students have collectively designed over 12 million ft^2 of net-zero energy-water buildings that are high performance and resilient. In the next 5 years, more than a billion square feet of real estate will be designed and implemented in real projects. There will be a steep increase in the number of net-zero energy buildings constructed in India by the year 2025. Students are being trained to implement national codes such as the Energy Conservation Building Code (ECBC) for commercial buildings and the Eco-Niwas Samhita for residential buildings, that prescribe standards for energy efficient technology and design. Currently, these codes are not stringent in India, but these future professionals can be facilitated to push for it, causing a trickle effect in the buildings sector. Furthermore, this will support India's emissions targets and achievement of the National Action Plan on Climate Change.

Support to national missions and policies

Solar Decathlon India supports six of the eight National Missions that were set up under India's National Action Plan on Climate Change as summarised in Table 3.

Solar Decathlon India as a building design competition will provide the much-needed innovation for affordable and energy-efficient construction under the Pradhan Mantri Awas Yojana, and pushing forward the goal of Affordable Thermal Comfort for All. Resilient building designs will demonstrate solutions for the State and National Disaster Management Authorities.

This competition will enable the Ministry of Environment, Forests, and Climate Change (MoEF&CC) to explore the pathways identified in the IPCC Report that are compatible with the 1.5 ºC rise in temperatures, as indicated in Table 4. The competition aims to develop market-ready solutions and test the dimensions of feasibility for accelerating the implementation of these pathways.

Working towards the 1.5 ºC limit of the Paris Agreement requires decarbonisation of the building sector. In India, the opportunity to do so is presented in the new floor space to be

Table 3. Mapping of India's national missions with Solar Decathlon India.

National Mission	Solar Decathlon India Support
National Solar Mission	Distributed solar generation in buildings
National Mission for Enhanced Energy Efficiency	Demand Side Management in buildings
National Mission on Sustainable Habitat	Implementing and strengthening the Energy Conservation Building Code
National Water Mission	Net-zero-water communities, greater than 25 % water efficiency, reduce water scarcity
National Mission for Sustaining the Himalayan Eco-system	NA
National Mission for a Green India	NA
National Mission for Sustainable Agriculture	Urban agriculture for Zero-Waste
National Mission on Strategic Knowledge for Climate Change	Knowledge network, and watch system for risk-minimized technologies, regional variation

Table 4. Solar Decathlon India's support to accelerate the 1.5 °C pathways.

1.5 ºC Pathway Characteristic	Solar Decathlon India Support
Rapid and profound near-term decarbonization of energy supply	Acceleration of distributed roof-top, onsite, on-campus renewables with grid interactivity
Greater mitigation efforts on the demand side	Super efficiency building envelope and appliance to reduce energy demand in all end-uses
Switching from fossil fuels to electricity in end-use sectors	E-mobility with grid-integration of net-zero energy buildings
Comprehensive emission reductions are implemented in the coming decade	Explore a net-zero energy building code new construction
Additional reductions, on top of reductions from both CO_2 and non-CO_2 required for 2 °C	Reduction in refrigerants due to 50 % less cooling demand and 33% reduction in installed cooling capacity
Considerable shifts in investment patterns	An affordable market-ready solution in partnership with real-estate investors
Options are available to align 1.5 °C pathways (focusing on lowering demand) with sustainable development	Aligned with 10 of the 17 SDGs
CDR at scale before mid-century	NA

constructed as the country develops and urbanizes. India is likely to move towards a Net Zero Energy (NZE) new construction policy similar to regulations in other countries around the world. This will require an NZE capable design-construction workforce that will grow at a rate of about 10 % per year. Solar Decathlon India provides a proven pathway to achieve this.

Next steps

Solar Decathlon India is a unique opportunity for students to learn, innovate, and become the stewards of their sustainable future. Solar decathlon India 2021–22 challenge will be launched in July 2021 with expected participation of 125 teams, with 1,200 students, and about 100 live real estate projects. As in the first year, colleges will be encouraged to include this in their coursework. Students will form multidisciplinary teams of 5–15 members and a faculty mentor. Participating students will be given access to high-quality education, expert mentorship, and professional-grade software resources. These participating teams will partner with real estate developers or clients and work on live, real projects. Teams will also be encouraged to engage with the industry as technology and knowledge partners. The key goal is to develop Net-zero-energy-water-waste building solutions, that are market-ready, affordable, and resilient to the effects of Climate Change.

Finalist teams from the 2021–2022 Challenge will be shortlisted for a 6-week incubation over the summer break where the teams present their innovative business ideas to an expert jury panel. During this period, the winning teams will revisit their work, fix gaps, and develop market-ready solutions to a level at par with the industry. At the end of the annual cycle, these teams will have had the education and first-hand experience to design zero-carbon climate-resilient buildings, and ready to hit the ground running when they enter the profession.

As a part of this umbrella, over 300 faculty members across India will also get trained on high-performance buildings. They will incorporate the competition approach into the college curriculum, resulting in even more students getting educated in this area. A Faculty Development Program will be held during the summer break which will enable the faculty to incorporate the challenge, related research work, innovation, and learning materials into their curriculum in a variety of pedagogical styles. This will enable the capacity building of faculty on the best approaches and technologies to make net-zero resilient, carbon-neutral buildings, including energy modelling using simulation software. The aim is to develop curriculum ideas and coursework aligned with India's National Education Policy 2020 specifically towards scientific temperament, creative imagination and multidisciplinary learning in engineering, architecture, and management streams. The overarching goal remains to help India lead with commitment and innovation in the 21st century to achieve the Sustainable Development Goals and to support India's National Action Plan on Climate Change.

Discussion

The Solar Decathlon India is a multi-year, long-term program to scale up capacity for net-zero, currently planned for five years until 2025. The stakeholder engagement plan for policy work has three phases:

Phase 1 (2020–2022): The focus in this phase is on initial implementation and improvement of the program, and demonstration of impact. Along with the execution of the program, this stage involves discussions and meetings with the primary stakeholders i.e., faculty and students from colleges, real estate, and the manufacturing industry. Interactions with faculty helps to understand the preparedness of students in combating climate change and how the college curriculum helps the students to get equipped with the right knowledge and experience. Participants from past Solar Decathlons are also invited to share their learnings and experiences with the students and faculty members. Through these discussions and surveys, feedback is gathered, the kinks in the program addressed, and the impact documented. Industry experts are brought in as Jury members and Advisors to help improve the program. An important aspect of the impact is to demonstrate a career pathway for the alumni in the clean energy sector. Another important aspect is to bridge the gap between academia and the industry. Civil society organisations and the industry come on board as project partners, industry partners, or affiliates of Solar Decathlon India. In the first year, we have collaborated with the Institute of Electrical and Electronics Engineers Standards Association (IEEE SA), the Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE), ClimateLaunchpad, and about 40 other organisations that offered internship opportunities to the participants. All primary and key stakeholders are invited to witness the solutions presented by the student teams and interact with them. The gamification aspect of the program creates awareness among consumers and enables a pathway for a net-zero built environment.

Phase 2 (2022–2024): The focus in this phase is to build trust with the central, state, and local government agencies, and other bilateral, multilateral agencies by leveraging participants' success stories, experiences, and learnings. The aim is to showcase the results from Phase 1 and start a dialogue with policymakers showing the effectiveness and robustness of the program. There will be an effort to compile strong case studies backed by demonstration projects where completed building prototypes will be monitored using various performance indicators. The team will also work with colleges and faculty members to conduct skilling and analytics surveys documenting the impact of Solar Decathlon India. The team will track the curriculum changes in colleges, courses offered, and job placements that result out of Solar Decathlon India. The program has already received support from the Department of Science and Technology (DST), and the Ministry of New and Renewable Energy (MNRE). Discussions have been initiated with the Council of Architecture (CoA) which is responsible for the architecture curriculum in the country. ISHRAE and IEEE SA, two large industry organisations are also outreach partners. Already, a few local government bodies have come on board as project partners. Discussions have been started with the United States Agency for International Development (USAID), Council of Scientific and Industrial Research – Central Building Research Institute (CSIR–CBRI), International Solar Alliance (ISA), and NITI Aayog to gain their support for the program. Solar Decathlon India could also be expanded to South Asia.

Phase 3 (2024–2025): Drawing from the learnings and experience of Phase 1 and 2, policy recommendations will be proposed to upscale the capacity building of net-zero-equipped

young professionals, to support net-zero codes/guidelines. These recommendations will be backed by data and analytical reports on the skilling and its impact on alumni careers and monitored data from prototype buildings. The target government agencies will be the AICTE and COA for curricula changes, Ministry of Skill Development and Entrepreneurship for career impacts, and the Ministries of Power, New and Renewable Energy, Environment Forest and Climate Change, Housing and Urban Affairs for codes and guidelines.

Conclusion

The paper makes a case for creative approaches to scaling up capacity building in ways that excite the students and faculty, while engaging with the industry and delivering market-ready solutions. The Solar Decathlon is an annual collegiate competition that challenges student teams to design resilient, super-efficient, zero-energy buildings powered by renewable energy. The competition aligns with 10 out of the 17 SDGs, the National Missions under India's National Action Plan on Climate Change, and the National Education Policy. So far, only about 100 students from India have participated in Solar Decathlons in the USA, Europe, and China. Solar Decathlon India envisages to enable larger participation and address the needs in the Indian context that will create a larger, and stronger real-world impact. The Solar Decathlon India, as a hands-on, practical, innovation-based academic activity, touches on multiple issues that are of concern to businesses, governments, and society in India, uniquely creating some sweet spots. In the first year of Solar Decathlon India, over 948 students from 103 institutions, 165 faculty mentors, 53 real estate partners, and 63 manufacturers have come together to drive a change in the way buildings are constructed in India. Within five years of the program, Solar Decathlon India intends to equip over 7,000 students (future professionals) who will be able to design net-zero, resilient, and resource-efficient buildings, and fully implement India's energy codes. They will have the know-how of performance, constructability, and affordability. They will catalyse large-scale change and influence India's future building stock. Over 700 faculty members across India will get trained on high-performance buildings. They will incorporate the competition approach in their curriculum, resulting in even more students getting educated in this area. Over 700 real building projects will have affordable design solutions or prototypes for climate change mitigation and adaptation, including net-zero-energy-water performance. These projects alone can result in 15 million tons of CO_2 reduction over the life of the buildings. Plus, there will be cascading effects from the students' learning, industry involvement, and policy implementation on a larger scale. There will be partnerships and industry collaboration in the design and construction of 300 Net-Zero-Energy-Water buildings. These will be related to efficient appliances, renewable energy systems, energy storage, smart meters, energy management, IoT, home automation, building materials, lighting, HVAC, etc. The gamification and media attention will build demand for high-performance buildings and low/zero-carbon-centric business models.

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