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CONCRETE: AN EPIC REDEMPTION STORY

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ABSTRACT

This paper examines the phenomena of concrete use as a civilization altering material and deduces its use in a sustainable future. Evidence suggests that concrete was found in both ancient Egypt and even earlier in ancient Turkey, 22000 years ago. It was the Romans who first capitalized the widespread use of concrete in 600 BC. Since the early 19th century, it has attained the universal status of industry wide dominion. The concrete story had many chapters of celebrations with brutalists and modernists making it a lifestyle. However, it also had unpopular eras where it was considered wasteful, ugly, expensive, poorly planned and simply bad for the environment. How is concrete placed today in the modern rhetoric of sustainability and concepts of resilient cities?
The material sciences are pushing the envelope with chemical as well mechanical properties, pushing concrete to be sustainable. Enhancing concrete properties has been a huge industry driver of invention. Contemporary trends using; bio-cements, cement composite from waste and fibre/nano-particle infused concrete are still not able to get a foothold considering the volume of concrete used today. Contemporary uses: smart concrete, self-healing concrete, transparent concrete, space concrete and deep-sea marine concrete. To make concrete redeemable as a sustainable, innovative structural material poised to make the future lighter, bigger and ever higher. Ecological ideas need to be incorporated in concrete, while its inherent properties can be a huge asset for creating resilient materials. This paper will focus on the dire need for an innovation driven environment focused, new products and invention in concrete. The stage is set for what the future holds for the renaissance of concrete.

KEYWORDS: Future-ready, concrete, innovation, sustainability, material science, smart concrete, innovation, mitigation, entry barriers, fabrications

1. ANCIENT BEGINNINGS

The search for sustainable building materials is a multi-approach process. Building materials not only provide strength, transfer load, and need to be durable. Authors, Jahren and Sui, investigate the complete history of the evolution of concrete. Concrete historically is intrinsically embedded with human civilization, notably they mention concrete mortar that was discovered in '**Nevali Core in Turkey 22,600 years ago**'. As a matter of fact, lime-glue was used even earlier in history simultaneously found throughout the world pointing to several cultures around the world contemporaneously innovating with the material. Dr. Sui states that fragments of '**Baihuimian**' mortar were instituted in the floors and walls of early human cavedwellings including the crypts used as early as in the Neolithic Yangshao period." [1]

"The land between the rivers Euphrates and Tigris, **Mesopotamia**, is not only the cradle of civilization, but also where the first concrete was made." [1] Still, it was the Romans who first capitalized the widespread use of concrete made up of volcanic ash, lime, and seawater in 600 BC.

They attribute the slow and long development process of concrete to it being initially used for religious purposes only with its manufacturing kept a secret. It's not surprising how widespread the innovation in concrete was around the world. Some notably changed human civilization permanently. Nabatea traders, or Bedouins, much ahaead of their times even created historical concrete structures using hydraulic lime that hardened underwaterin modern-day Syria and Jordan. While the Egyptians developed a technique to use in the Great Pyramid at Giza, which required 500,00 tons of mortar, that still stands today. On the other side of the world, China used a form of concrete created with sticky rice to build boats and other structures, including the Great Wall of China. The widespread use of concrete by the Greeks and the Romans coincided with their geographical domination of their dominion. A name synonymous with concrete production during this era of innovation is architect and engineer Vitruvius 25 B.C. He recognized the inherent characteristics of concrete that he later formulated into the idea that all buildings should have: firmitas, utilitas, and venustas ("strength", "utility", and "beauty"). [1]

1.1. CONCRETE LOST AND FOUND

After theRoman Empire disintegrated in 476 AD, the techniques for manufacturing the now favored historic '**pozzolan'** cement were lost in history until its re-discovery in 1414 its modus operandi treasured in archaic manuscripts working drawings and composition, processes and techniques. It was centuries before ta truly modernized form of concrete emerged. In 1973 British civil engineer, John Smeaton used limestone that contained clay and fired it to create a more robust concrete that he used to design dams, bridges, canals, harbors and lighthouses. Smeaton left behind a legacy of being the "father of civil engineering" much attributed to his work with concrete. In 1924, a bricklayer named Joseph Aspdin helped spur the use of cement and concrete in modern constructions by creating the Portland cement as we know it today. [2]

1.2. INDUSTRIAL DOMINANCE OF CONCRETE

Concrete gained popularity as a more efficient material. The industrial complex fueled by the imperialist and war efforts, and nation building rhetoric saw the enhancing of concrete with man-made processes. As technology advanced in the late 1800s, several nations around the world like Germany, France and the United States were concurrently developing reinforced steel concrete in a race to build bigger and higher and grander. Another innovation that escalated the trajectory of concrete was the development of ready-mix concrete in 1913, allowing for easy transportation of concrete and its widespread use. The 1930, launch of air-entrainment substances to concrete endowed the building material better ease to work with and made it superior in many ways including its use in extreme temperatures as it became less prone to freezing which afforded concrete the flexibility for the use of concrete in cold areas. Around the same time the lighter weight of thin-shell concrete structure shielded the large expansive spaces without the need of copious quantities of concrete that made olden concrete structure heavy and unsustainable.[2].

As the history of concrete also traces human history of values, we see alongside with innovation, builders and architects developed different styles. Concrete is seen as an aesthetic tool to record and transmute human history in thought and form. Brutalist, modern and other concrete structures include feats and artistic creations that hold testimony to the life and times but also to the aspirations and values of materiality through space and time. Concrete is ideal as a record keeper as it has truly withstood the test of time.

1.3 BRUTALISTS FROM MODERNISTS

Niebrzydowski notes that Le Corbusier made a shift from 'the machine aesthetic of modernism' finding functionalism too narrow and in the 1930's. He re-iterates that a building in addition to being functional must also generate human emotions." Moreover, author explores principles of showcasing the building structural elements and material properties, including all sorts of cladding properties and plaster finishes as "They preferred raw aesthetic and simple forms and emphasized ethical values of architecture, such as sincerity and truth." [3]. Primarily we witness a shift in human values as; the modernist architects, brilliantly centered, massive and monumental, concrete formal ideas for its tactile and tectonic patrimony with raw and natural surfaces while brutalists humanized small imperfections in the concrete construction process with; curing to strengthening processes, lifecycle changes celebrated in the authentic expression of individualized personality of concrete work created using human hands. The original concrete texture speaking its own story of creation, evolution and integration re-igniting concrete in various architecture times making it canon in various vernacular architectural innovations.

In all, the Brutalist architect's rejection of the modernist aesthetic of the machine led to an appreciation of the craft of concrete as a building material. Brutalist architecture of the 1950s is a post-war era response and made concrete more fashionable. In fact, the predominantly used material in brutalist architecture is concrete. This ideology termed **'*béton brut*'**, represents the imprint of the formwork in the concreting process as part of the design aesthetic as it adds value introspectively sharing the material properties of the formwork from which it was birthed from. This era of material exploration like never before led to the science of **'*chiaroscuro effects'*** : a three -dimensional, alternating concave and convex concrete texture expression created as a result of scaffolding and shuttering. Hence the entire construction process of creating concrete became the artistic elements for Le Corbusier concrete explorations in his **'*signes*'**. Famous brutalists experiments with concrete also included designing concrete surfaces with exposed aggregate and led to the development of many styles of architecture aesthetics including: brushing, sand-blasting or washing. Niebrzydowski proclaims that "according to the principles of New Brutalism, the meaning of the material lay in itself, but later, the material took on symbolic meaning and became a transcendent medium of ideological values." [3]

Niebrzydowski speaks about the loss of imagebility of concrete as a material overtime, he notes "The prevailing opinion is that concrete as a choice of material was intentionally ugly, unresponsive to the needs of users, and unfriendly." [4] However, as with many literary heroes, this unpopular era of brutalism started the **'heroes journey'** for concrete with innovation of concrete as a futuristic sustainable and desirable material again. Many architects saw it as the material that would usher in a new world, that would fulfil all the utopian dreams of social architecture, democracy, socialism with mass housing and urban renewal. Brutalist concrete was thus converted into a modern, efficient and cheap solution for mass public housing, in conjunction to the architects dream of; design as a tool for change, sustainability, equity, equality and a force for good ridding the society of evil. However, the **'heroes journey'** had many disappointments of this included: the regular maintenance over the life cycle of concrete buildings as concrete deteriorates, chemical changes as brown stains were a part of the leaking joints of the metal reinforcements in popular RCC structure. The rusting associated with buildings of this era, the overconsumption of natural resources and the excessing waste generated from concrete along with the lack of material responses and concessions to local climate or conditions of the context of the building gave concrete a bad reputation amongst the more conscientious architects, builders, engineers and the general public. It felt like concrete had reached an irredeemable place in the mass consciousness.

As with all heroes, however these times of disesteem allowed concrete technology to resurrect in the era of optimism and belief in the permanence of built artifacts. A ecologically responsive adaptive revival evoked both the Brutalism ideals along with concrete innovation that help soar concrete from its, humble beginnings to being maligned as the scourge of our cities and back to becoming the ultimate lifestyle and innovation concept. A revival and conservation of mid-century architecture has created an opportunity to reimagine the concrete buildings in a significantly more sustainable setting. New found appreciation of the economy and conservation of materials and honesty of these buildings has turned into a movement. The World Monuments Fund has placed many buildings on its monuments watch database.

The restoration and adaptive reuse of some of these concrete buildings is poised to become beacons of heritage and re-assertion of its relevance. Especially given the century long discourse about concrete's carbon footprint, the renewed interest in concrete us set to re-imagine landmark Brutalist design as a landmark in sustainability.

2. GLOBAL IMPACT OF CONCRETE

Keegan Ramsden points out that humans have covered approximately 1.18 million km² of the Earth with concrete, asphalt or other types of man-made surfaces – including cities. This is colossal as it is about 0.8% of the Earth's area. The subsequent CO2 emissions now emitted; is between 4-8% of total global CO2 emissions. This stupendous impact to the atmosphere, global warming and climate change that comes from the irresponsible and profit-driven use of concrete is seeing a decline in all sectors across the planet. Additionally concrete waste likely makes up as much as one-fourth of all landfill and industry and investors have all become more sensitive to pollution, and contamination and the human lives affected by unsustainable building practices. [5]

This makes it essential that we support innovation that ensures cement and hence concrete adapt to a clean future. Natural Resources Defense Council (NRDC) advocates that suitable concrete should: use less cement—reducing the over specification of cement in concrete mixes and encouraging the use of supplementary cementitious partially replace cement in concrete mixes, cement kilns more efficient so they require less fossil fuel; and transition to truly cleaner fuels—for example, electrification from renewable sources. [6]

2.1. MATERIAL SCIENCE INNOVATIONS

Material science can bolster modern concrete with pioneering products and additives to enhance both its plastic and hardening properties. Several supplementary cementitious materials (SCMs) such as fly ash, slag cement and silica fume are used to increase several chemical, mechanical and sustainable features not limited to strength, durability and workability while keeping the concrete more sustainable.

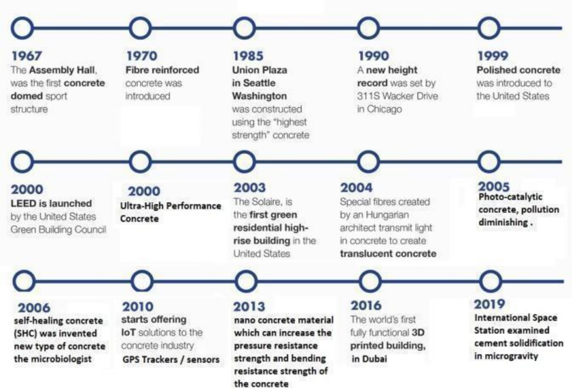
The global cement and concrete association (GCCA) address many of the sustainability concerns and proposes use of concrete to reduce carbon footprints by: introducing manufacturing efficiency and by promoting the permanent sequestering of CO2 in buildings. They advocate circularity as concrete can be 100% recyclable. Globally cement industry has reduced its carbon emissions to 19% in 2020 since 1990. GCCA also launched 'Climate Ambition' to be carbon neutral by 2050. [7]

Table 1. Properties of concrete for sustainability. [7]

Company name	**Environmental**	**Social**	**Economic**
Fire Resistance	Does not burn. Reduces both the waste and the noxious emissions.	Safe and secure cities.	Economic resilience due to safer investments
Durability	Concrete structures long lifecycle can build efficiently and have less impacts on the environment	Durability allows for longer usage, lower maintenance and minimum social disruption.	Maintenance costs are extremely low for concrete structures.
Acoustic Performance	Concrete has good acoustic performance not needing additional materials so less material used and less potential waste	Concrete's mass absorbs sound, ensuring quality of life, particularly in high density living.	Concrete walls and floors provide acoustic separation with minimal costs and maintenance.
Earthquake and Flood resilience	Concrete retains its structural integrity, resulting in minimal waste of materials following a disaster event.	Can resist water penetration, keeping inconvenience and disruption to the community to a minimum.	Downtime of businesses, homes and essential community services is minimized.
Thermal Mass	Concrete's thermal mass allows it to be used to reduce buildings' heating and cooling energy load, thus reducing operational carbon.	The thermal mass inherent in concrete provides a simple and effective means to reduce overheating for those who do not have air conditioning. Overheating is a growing health and wellbeing issue, particularly among the elderly.	Using the thermal mass of concrete will lower running costs of a building. It will also reduce the plant needed on site, leading to lower operating and maintenance costs.

These inherent properties are greatly exploited by scientists to work towards sustainability goals. A few of the more exciting proven transformations are captured in the figure below.

Fig 1: TIMELINE INNOVATION IN CONCRETE for Sustainability (summarized by author, various)



Recently researchers Kota Machida and Yuya Sakai developed a technology to convert food waste into "cement". This is the world's first process for making concrete completely from food waste. It is tested to be four-times stronger than ordinary concrete. [8]

2.2. PRECEDENT STUDY OF SCM

The foundational study for the competition project and the subsequent studio exercise is from a rice husk ash (RHA) study done by Safiuddin, West and Soudki. They studied some freshly mixed self-consolidating concrete (SCC) that incorporated the additive rice husk ash (RHA). By the substitution of 0–30% of cement by weight, they noticed several fundamental improvements as RHA also affected air entrainment and satisfactorily decreased the unit weight of concrete. They conclusively determined remarkable results, suggesting that 10–15% RHA can have extraordinary and impressive improvements to SCC. An astonishing improvement in performance iwith this optimum content of RHA can further obtained when SCC is used in concrete with a higher water/binder (W/B) ratio. [9]

2.3. PROJECT BASED STUDY OF CONCRETE

A submission for the 2020, Government of Telangana Urban Centre of Excellence (UCE) incorporated my own exploration of creating a sustainable concrete project. In a sprawling 45 acres campus on the outskirts of Hyderabad this project derived its material choices from its functions. The central building housed a kinetic building that exists as a machine. It houses within itself a double helix wind turbine that generates power. The fingers of the building progressively narrow towards the center creating a wind tunnel. [10]

Table 2. Summary(data from a*bove* study) [9]

Properties	W/B Ratio	RHA	Comment
filling ability	Low	High	decreased aggregate content
passing ability	Low	High	Increased paste volume
orimet and inverted slump cone flow and segregation resistance	Low	High	increased volume fraction and surface area of the binder
Unit weight of Concrete	Low	High	decreased with higher RHA content due to the lighter weight of RHA
design air contents	Low	High	target air content increased

The form merges with the double helix turbine flawlessly to create a composite building with a slowly moving/ churning top half. The double helical wind turbine of 45m height atop 45m high structure with skewed outer slabs at top level, needed multi-functional, cost-effective and sustainable solution.

Designed as 'Shell' this structure is a continuous curved surface. The thickness of the concrete is greatly reduced while its able to span several large scale spans. The structure is proposed to be of high performing concrete and the turbine atop is an independent structure of steel.

Over each wing, columns are placed at intervals near corridors and edges. Also, core walls are proposed in the mid portion to be raised till the level from where turbine is installed. Lateral loads especially wind load is of great concern because of building height and the location. The shell structure proposed, resist external forces mostly by the mechanism of 'Membrane action'. The design basis for this choice of material is because; shells have a structural display like membranes, but just in an inverted way. In membranes the efforts are almost exclusively of tension, when being inverted, or "turned upside down," these efforts become compression and concrete is the ideal material to resist them.

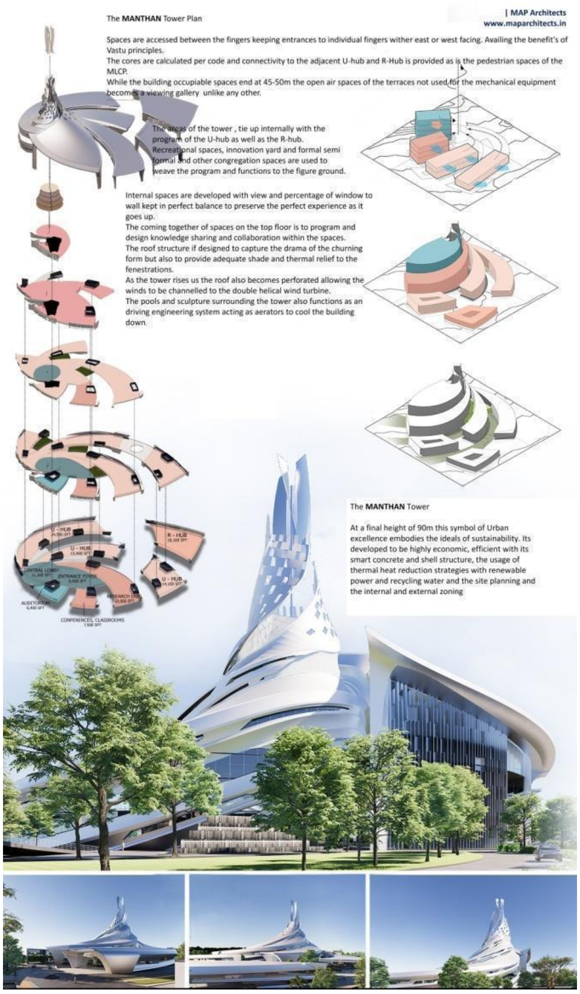


Fig 2: PROJECT MANTHAN (by author) [10]

A shell has pure membrane behavior provided certain boundary requirements, loading conditions, and shell geometrical configurations are satisfied. Unique features of shells are also reflected in their design as well as in their method of construction. The folded plates are individually modeled using the finite plate analysis.

Table 3. LOAD CALCULATIONS Project Manthan (by author) [10]

Load Components		**THICKNESS (mm)**	**UDL (kN/m^2)**
Main Centre of Excellence tower building	Dead Load	As per actuals	
	SDL	-	2.3
	Live Load	-	3.0
	Finishes	75	0.5 (services)

Fig. 3 DESIGN OF SLAB (by author) [10]

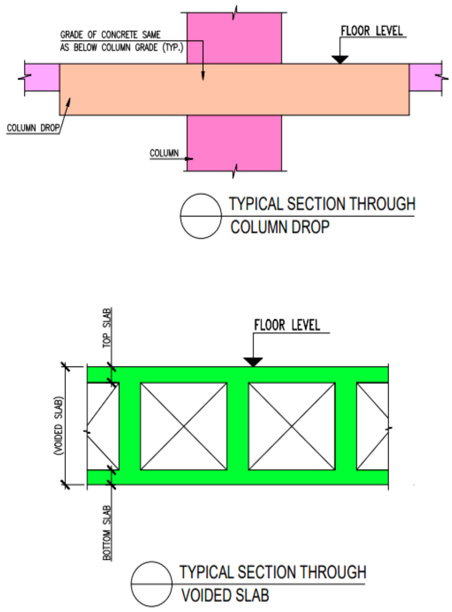
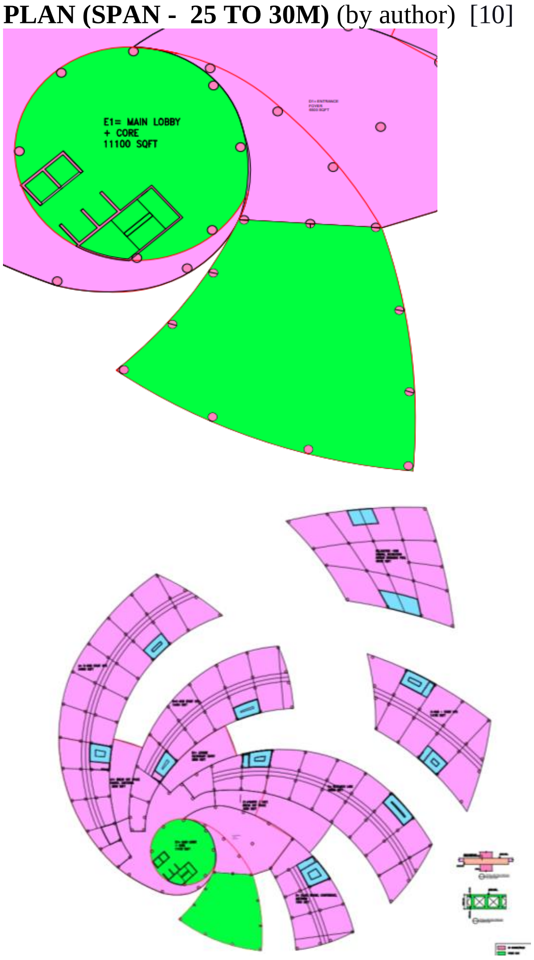


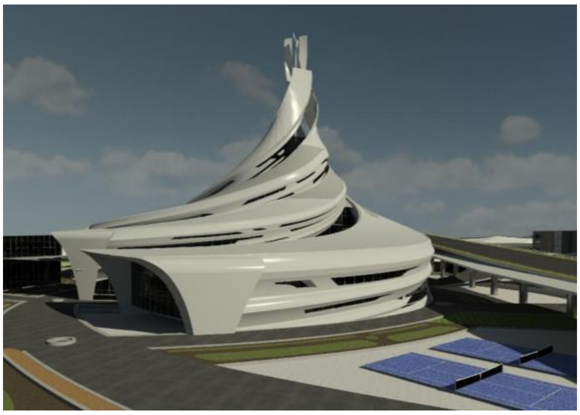
Fig.4 PLAN (SPAN - 25 TO 30M) (by author) [10]



Self-compacting concrete (SCC) is a special type of concrete which can be placed and consolidated under its own weight without any vibration effort due to its excellent deformability, and which at the same time is cohesive enough to be handled without segregation or bleeding. Smart dynamic concrete is proposed, a special invented concrete based on studies done with RHA. This new concrete is chosen as it is crucially higher on flow rate and has non-segregating properties to its spread into the place of formwork by using its own weight. Astonishingly, it can materially fill the shape of any three dimensional form work even in the presence of dense reinforcement.

Moreover the use of smooth formwork can reduce any additional finishes and can aid in the movement of the wind into the turbines.

Fig.5 CONCRETE FINISHES (by author) [10]



The manthan project done by author above was an attempt to explore new and innovative ways to use concrete in a sustainable fashion. Focused on both the style and aesthetic of design, the choice of material very well established the technological advance of shell structure, the material advantages of SCC especially the introduction of chitin and other additives freely and locally available and often considered waste. And finally the project effectively and dynamically establishes the ingenuity of an efficient, readily and universally available and considerably drab material like concrete in a new and ecologically adaptive, responsive and sustainable way.

3. METHODOLOGY FOR STUDIO PROJECT

Inspired by the manthan project above the author continued the exploration of concrete in an academic setting. In Aug 2022, the author led a third year studio which based its design exploration on responsive ecologies. Amongst its modules 'Sentient Matter' refers to the idea that matter embodies the capacity to perceive and respond to stimuli. The module on materiality in architecture focused on environmental considerations, aesthetic considerations and sustainable options. Application of the concrete material juxta-positioning the delicate balance of composition and material property enhancement, therefore represents a truly demanding task and requires knowledge and experience on the various mechanical, chemical, tectonic and taxidermic properties.

The author along with students of Sushant school of architecture India, conducted explorations of new concretes an SCC using the natural material chitin. The summary of this lab is compiled below.

3.1. CHITIN-CRETE: SM01 [11]

200BARCH015 | ISHA DUTIA
200BARCH028 | ARYAN AGARWAL

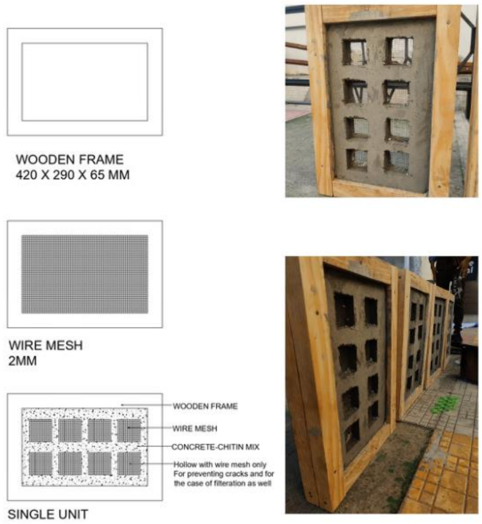
This team created a system that analyzes the materiality and structural elements of a new composition of concrete and then tests it. Chitin-based concrete was chosen possess a bactericidal effect. Its lack of toxicity to human and environment (air, water and soil) is a great opportunity for making concrete revolutionary, innovative and sustainable again. The start point of the experiment was the use of an organic matrix which is the cuticle of shells which is primarily chitin, protein an combining with inorganic traditional elements of concrete and testing its structural composition under a microscope. This experiment tested properties of self-compaction, drying curing time and more importantly adherence and subsequently strength and endurance.

Fig.6 PROTOTYPE 1.1~3 STUDY OF CHITIN STRENGTH Project work by Student: SM01 [11]

These models help understand the strength of the chitin fiber. Chitin chains assembled in one direction (1D) in a linear form. The subsequent arrangement was in the x-y plane, and could take any 2D form, in this case it took the form of a broken curve. The strength was comparatively more in case of this 2D form. In the final iteration, the units are in a 3-D cluster. It is found to be the steadiest during loading. This experiment hence demonstrates how the chitin fibers 3D structure enhances the strength of the concrete due to its intermolecular bonds and structure.

Final prototype study of chitin in concrete was the actual composition of the Chitin-crete. Using ratios of: chitin powder 5% by weight, Portland cement 5 kg, white cement 2kg, sand 15kg. This mixture was then poured into a mold made of wooden frame, wire mesh, hinges, nuts and screws.
Weight of one panel: 6kg

Fig.7 MATERIAL: CHITIN-CRETE [11]



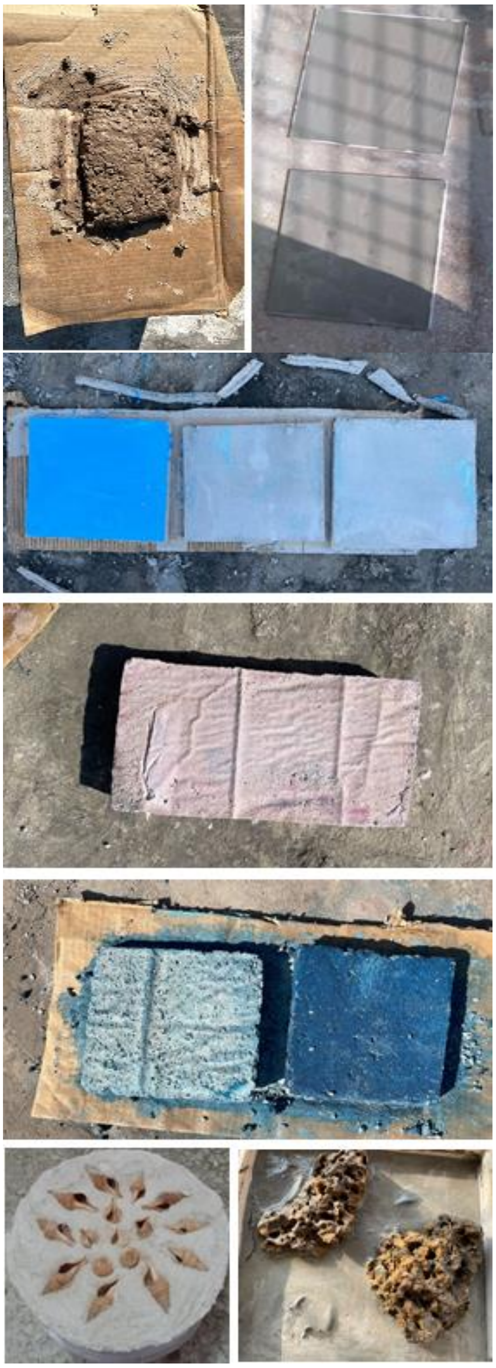
Project work by Student: SM01

3.2. CHITIN-CRETE: SM02 [11]

211BARCH001 | AYAAN MOBIN
200BARCH028 | NETHRA RAJ

This team built on the previous teams work and experimented with various additives and water/ binder ratios to check for changes in properties of the Chitin-crete. The ratio of water was more than that of chitin, for it to be able to form gel molecules within and be able to absorb the CO_2, hence the cracks this causes a temperature gradient between the surface and the core, if the differential in temperature is too large it causes thermal cracking.

Fig.8 PROTOTYPE 2.1~10 COMBINING CHITIN WITH CONCRETE IN DIFFERENT RATIOS Project work by Student: SM02 [11]



The process of layering of the chitin fiber and its chemical structure with various types of aggregates was studied for porosity and density. The experiment proved denser (or the less porous) the concrete the better its performance and the greater its durability in the long run. The density of concrete is increased by optimizing the dimensions and packing of the aggregate and reducing the water content.

4. RESULTS AND CONCLUSION

Chitin is the second most abundant biopolymer on the planet and is structurally similar to cellulose. The tiny fibers generate a hard outer shell or armor in organisms for protection. Chitin tends to trap heat and keep it cool so, when chitin mixed with concrete it can keep the interiors of the build structure cool. Chitin's concrete can also retain carbon dioxide and is an ideal sustainable green concrete option.

Inferences from the studio study

- The nanoparticle strength was maximum when in 3-D plane
- The closer and tightly pack the aggregate are, more steady is the material
- 40 % increase in bending strength 12 % improvement in compression strength

Observation:
Use of mesh in the structure, allows air to pass through and also creates a cavity, which helps in preventing cracks to occur.

This paper focuses on the dire need for an innovation driven environment, for new products and invention in concrete. The concrete studies conducted in both practice as well as academics hopes to set the the future holds for the renaissance of concrete.

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