Recent advancements on traditional and engineered materials for structural applications

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MATERIAL CHOICE CAN MAKE A DIFFERENCE

"Sustainable Construction" is a **living concept** and varies in different scenarios based on peoples' needs.

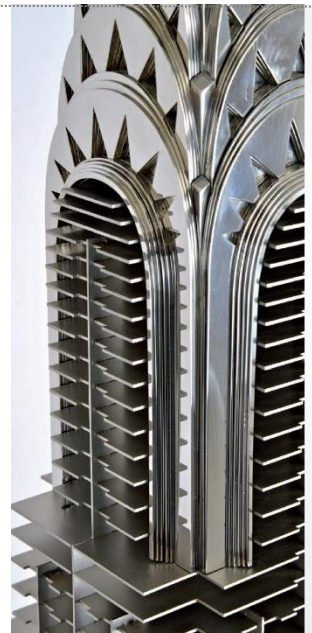
In the United States, the **Environmental Protection Agency** (EPA) defines sustainable construction as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction."

"a way of building which aims at reducing (negative) health and environmental impacts caused by the construction process or by buildings or by the built-up environment."

"structural systems in combination with material choice almost always comprise the largest source of embodied carbon in the building—up to 80%, depending on the building type"
Key concepts include the protection of the natural environment, choice of non-toxic materials, reduction and reuse of resources, waste minimization, and the use of life-cycle cost analysis

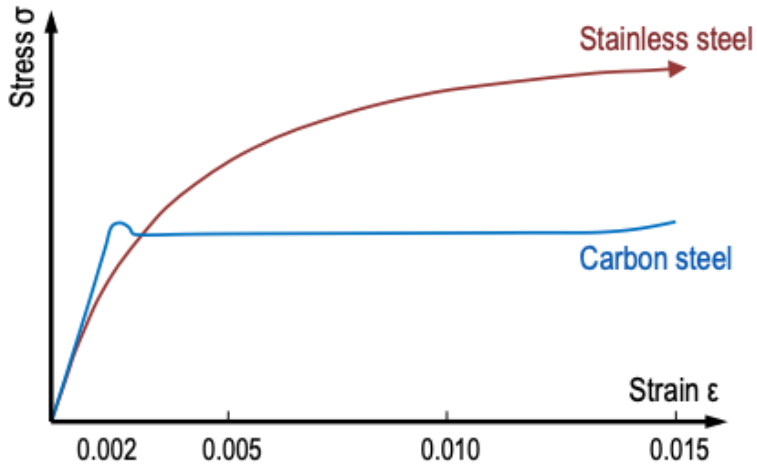
Metallic alloys in structural applications

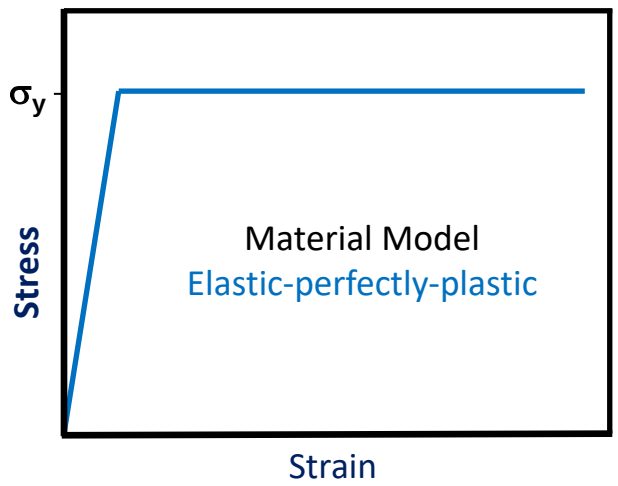
- High strength-to-weight ratio
- Recyclable/ Reusable to achieve circularity
- Stainless steel alloys could offer very high strength
- Corrosion resistance and durability are key elements to achieve sustainability



CHRYSLER BUILDING, USA

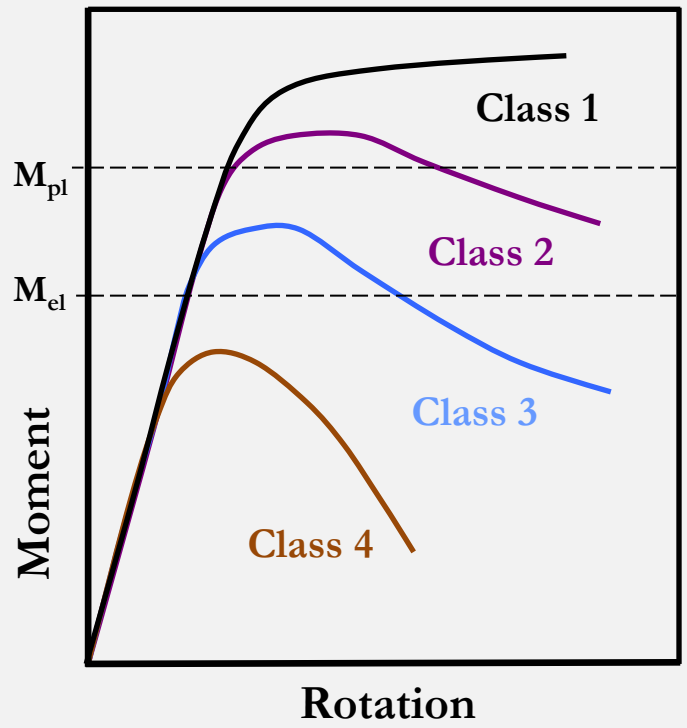
Ordinary carbon steel design





Elastic perfectly plastic material model

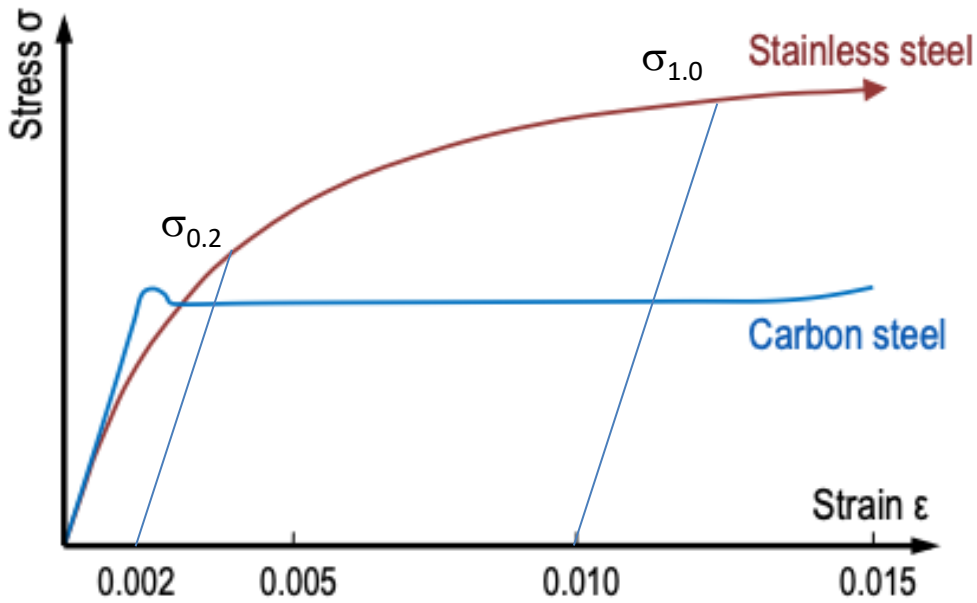
Cross-section classification approach is well suited



Cross-section Classification

Plastic, Compact,
Semi-compact & Slender

Material model for stainless steel alloys



- Use of virgin material properties produce conservative results for member resistance
- Corner regions are mostly affected by cold-working
- Material properties in the flat regions of roll-formed sections are significantly different from virgin material

Material nonlinearity

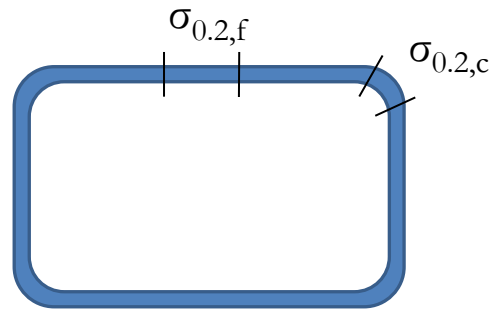
No sharply defined yield point

Pronounced strain hardening

Enhanced strength at corners

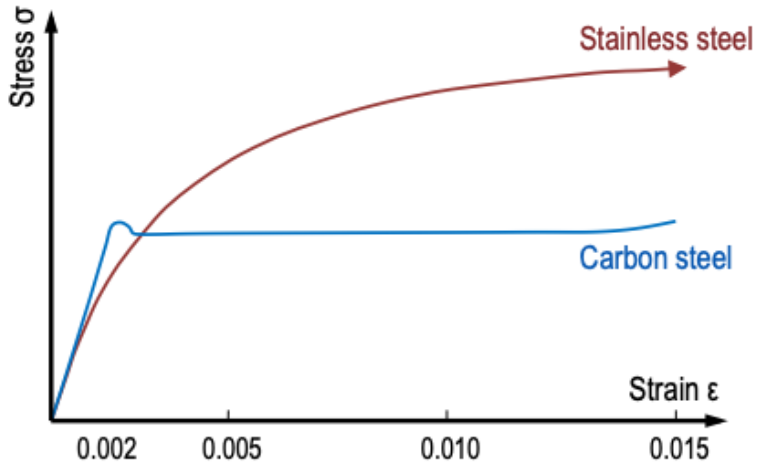
$$\varepsilon = \frac{\sigma}{E_0} + 0.002\left(\frac{\sigma}{\sigma_{0.2}}\right)^{n} \quad \text{for } \sigma \le \sigma_{0.2}$$

$$\varepsilon = \frac{(\sigma - \sigma_{0.2})}{E_{0.2}} + \left(\varepsilon_{t1.0} - \varepsilon_{t0.2} - \frac{\sigma_{1.0} - \sigma_{0.2}}{E_{0.2}}\right)\left(\frac{\sigma - \sigma_{0.2}}{\sigma_{1.0} - \sigma_{0.2}}\right)^{n'_{0.2,1.0}} + \varepsilon_{t0.2}$$



$$\sigma_{0.2,c} = \frac{1.881\sigma_{0.2,v}}{(r_i / t)^{0.194}}$$

Continuous Strength Method (CSM) for stainless steel alloys



$$\varepsilon = \frac{\sigma}{E_0} + 0.002\left(\frac{\sigma}{\sigma_{0.2}}\right)^{n} \quad \text{for } \sigma \le \sigma_{0.2}$$

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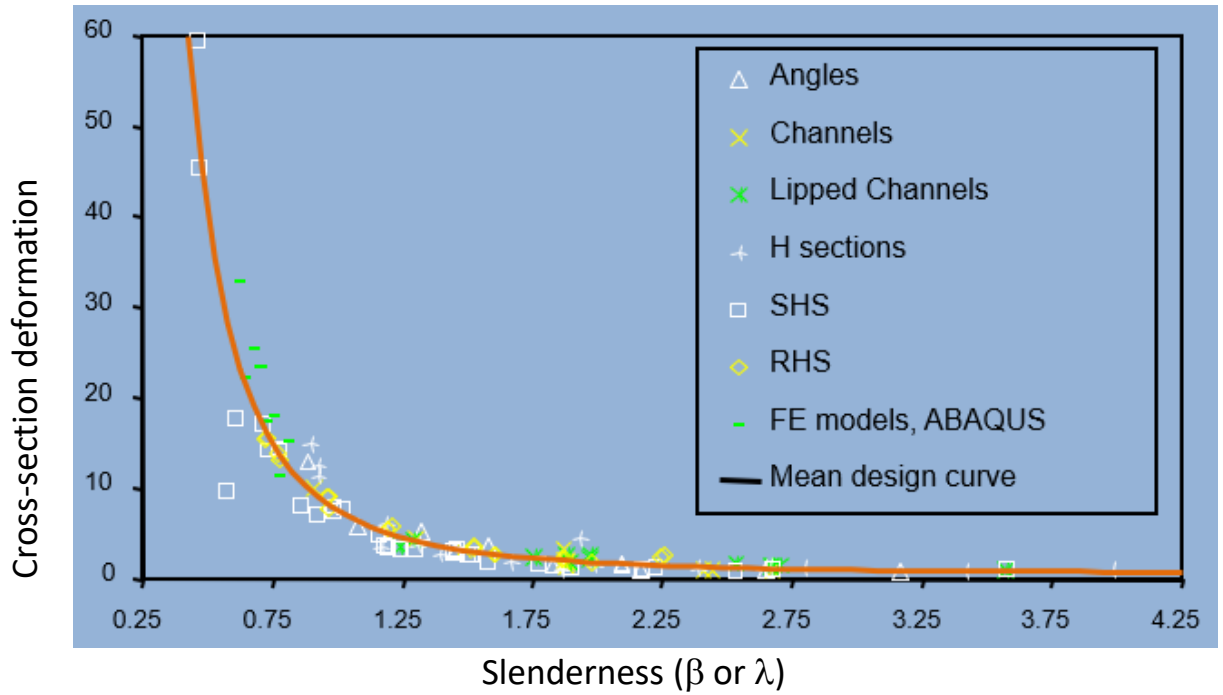
- Continuous relationship was observed between cross-section deformation capacity and cross-section slenderness
- Critical local buckling strain can be determined from this relationship
- Material model can be used to determined the corresponding stress
- No cross-section classification is required

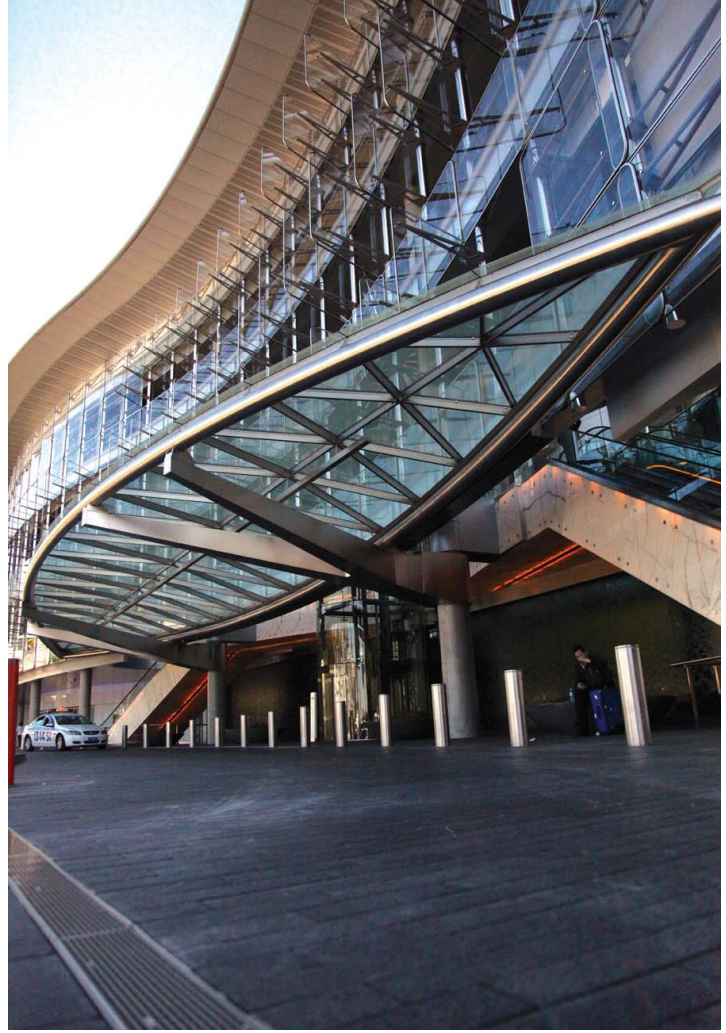


Stainless steel in structural applications

STAR CITY CASINO, SYDNEY

‘From a practical perspective, we chose stainless steel because it’s so close to the water and we needed something that was resilient.’

completed in 2011



The Helix Bridge at Singapore’s Marina Bay was inspired by the geometric arrangement of a DNA strand, resulting in a walkway that is enclosed by opposing double-helix structures of stainless steel.

COX Architecture | completed in 2010

Dublin Spire (*Spire of Light*) is a 120 m tall stainless steel structure.

Ian Ritchie & ARUP | Completed in 2003

Duplex and Lean duplex alloys

Very high strength ~800 MPa

Lean duplex has low nickel content and a stable price tag

A hydraulic pedestrian drawbridge using lightweight lean duplex stainless steel Outokumpu Forta LDX 2101 plate as the primary construction material

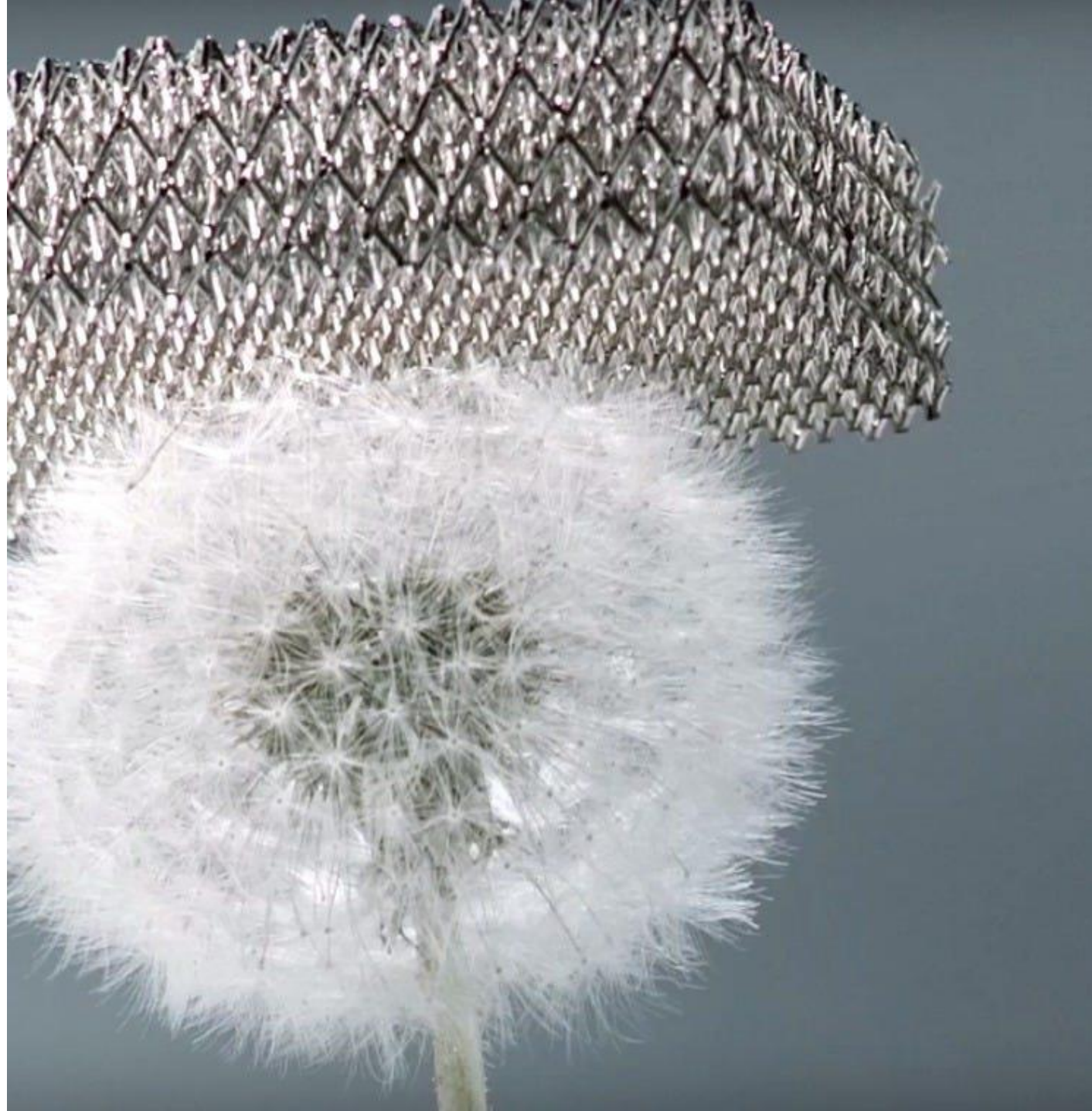
Lean duplex was chosen for high strength and for its high resistance to extreme Nordic climatic conditions

Completed in 2018

3D Printing in Engineering Applications

WORLD'S LIGHTEST MATERIAL, HRL LABORATORY 2011

The microlattice is a "3D open-cellular polymer structure" and is made up of interconnecting hollow tubes whose outer walls measure just one-1,000th the width of a human hair



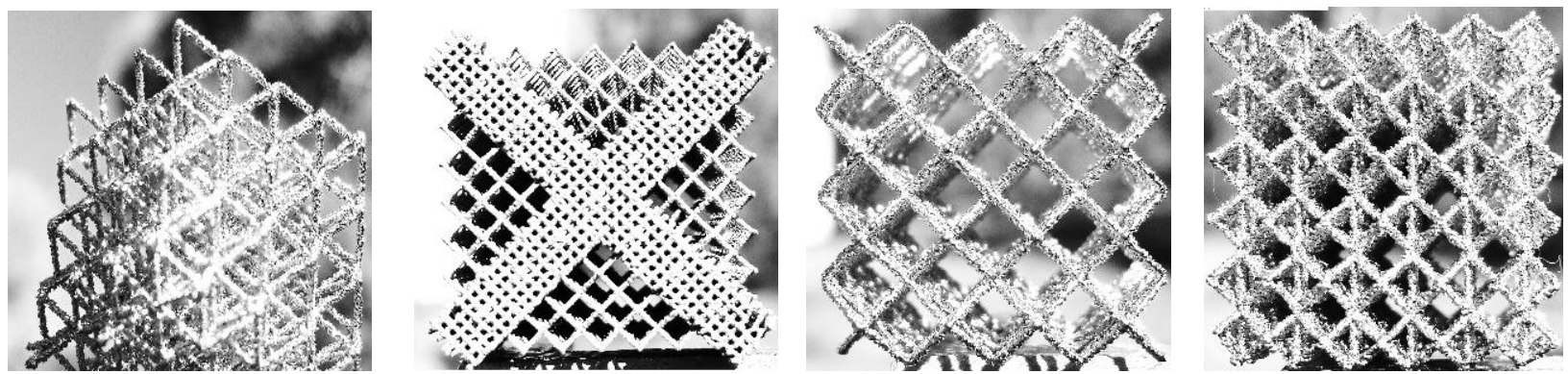
3D PRINTING

Three Dimensional (3D) printing is often seen as the popular name for Additive Manufacturing (AM), which is an advanced manufacturing process that can produce complex shape geometries automatically from a 3D computer-aided design model

Powder Bed Fusion (SLM/EBM)
Material deposition (FDM)
Binder Jetting
Direct Energy Deposition
Sheet Lamination
Metal Jetting
VAT Polymerisation

ASTM F42 – Additive Manufacturing

METALLIC MICROLATTICE MATERIALS



3D Printing

Endless possibilities!

Radiolaria Pavilion, Italy

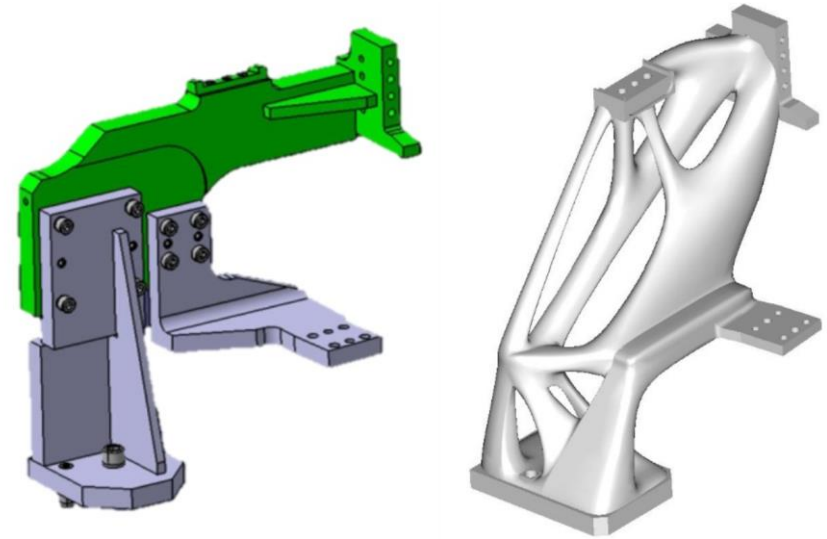
Proto House, UK

Sagrada Familia, Barcelona
Construction started in 1882

Unborn babies

Engineering examples

STAINLESS STEEL NODE, ARUP, 2014



METAL CLAMP AT FIAT

MX3D BRIDGE –
The Netherlands

3D printed stainless steel pedestrian bridge

Hejmans, MX3D's technology and Joris Laarman Lab are using a robotic arm to print the whole bridge gradually.

3D Printing in Construction

D SHAPE – 12 X 12 X 10

WINSUN (CHINA)

- Complex geometry
- Negligible (or no) waste
- Reduced environmental impact

Challenges in 3D printing

3D printing is NOT an alternative to traditional manufacturing
– at least for now!

Binding material

- PLA (Polylactic Acid) is the most commonly used plastic filament material that is used in 3D printing
- ABS (Acrylonitrile Butadiene Styrene) is also very common in 3D printing
- Metals are ‘relatively easy’ to print as they melt and then can be joined together to form a desired shape
- Concrete 3D printing uses cement but researcher are looking for alternatives. We still cannot print reinforced concrete.

“Biodegradable” printing

- Wood fibre (Cellulose + PLA) filament are often misunderstood as biodegradable
- FLAM (fungi-like adhesive material) was created from cellulose and chitin
- Starch based filaments are recently getting attention as an alternative to PLA

Once we find the desired material, we have to design a printer too!

RENEWABLE MATERAILS

Bamboo & Engineered bamboo

Bamboo is edible, well, most of them (some taste horrible!) The new shoots are harvested while they are still soft. They are often used in asian cuisine or stir frys!

A panda's diet is 99% made up of bamboo shoots, poles and leaves, around 12-38kg every day! The other 1% is made up of meat and other plants.

Clumping bamboo purifies the air up to 30% more effectively then any other plant! Your brain literally gets an oxygen high around it! This makes you happier & relieves tension & headaches!

There are over 1,500 species of bamboo in the world! Australia has around 400 and we specialise in the top 50 species that suit home gardens the best! (And pandas only eat 42 species out of 1,500!)

Bamboo is mostly drought tolerant and will survive lack of water, but if they are thirsty they will curl up their leaves! They do this to shy away from the heat and await rain or water. After a few days of being dry, they will drop some leaves to self mulch and reduce the amount of leaves needing hydration!

Bamboo poles are incredibly strong and sturdy (some are stronger then steel!) and are often used for construction and building throughout the world! Thin poles are good stakes in the garden or for weaving furniture. Larger poles are often used for scaffolding or building frames!

Bamboo is one of the best plants to use for soil stability and to prevent soil erosion. Perfect for protecting a riverbank, creek or dam walls, steep garden beds etc.

During earthquakes in Asian countries, people run into bamboo groves and forests as they are known as very safe places. This is due to their very safe and stable root structure but also their symbolism for luck and fortune!

Bamboo is naturally anti-bacterial and anti-fungal. Bamboo is used to produce clothing, linen, and bamboo charcoal. Bamboo charcoal absorbs, purifies & deodorises the surrounding atmosphere.

Bamboo leaves are made into a delicious tea! It tastes similar to green tea and is comparable with nutritional benefits.

Thomas Edison used a carbonized bamboo filament in his very FIRST successful lightbulb!

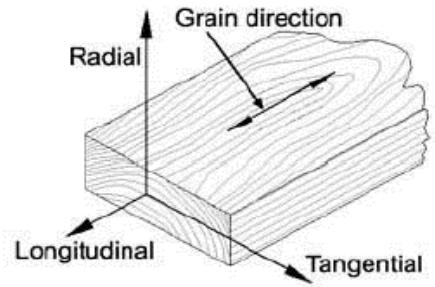
Bamboo is such a regenerative plant; with the natural leaf drop being so nutrient-dense that the soil 'absorbs' these nutrients as the mulch breaks down, feeding the bamboo & surrounding plants again! Bamboo mulch can also be used in compost bins and is an excellent weed barrier!

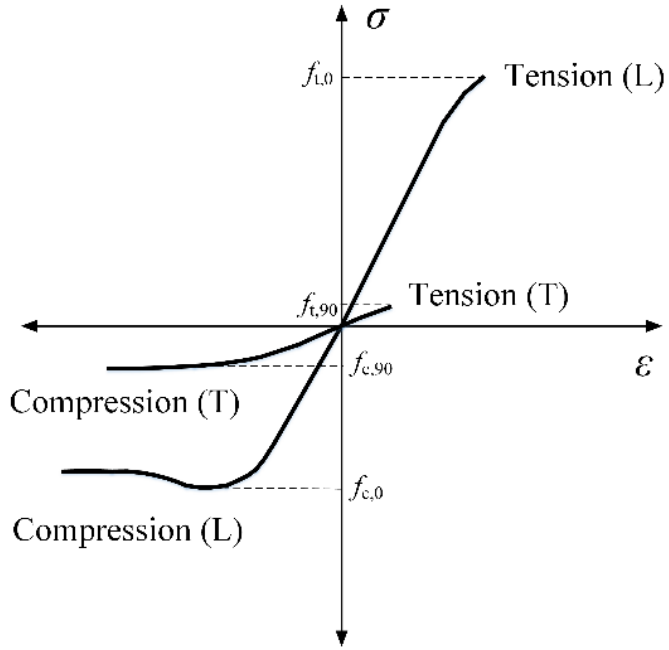
INBAR

International Bamboo and Rattan Organization

ENGINEERED TIMBER

Sawn Timber





Bamboo strips

- Natural fibre with random defects; material properties could vary significantly in raw bamboo/ timber
- Orthotropic – material property varies in all 3 directions. Strong in parallel to the grain direction.
- Behaves differently in tension and compression. Bamboo is stronger in tension but timber is strong in compression
- Deflection dominates most design cases.

ENGINEERED TIMBER & BAMBOO

Laminated Veneer Lumber (LVL)

Glued laminated timber (Glulam)

Cross laminated timber (CLT)

Bamboo scrimber/
Parallel bamboo strand lumber (PBSL)

Laminated Bamboo Lumber (LBL) &
Glubam

Bamboo strip thickness in glubam and LBL are between 5-8 and 20 – 25 mm respectively.

Timber research in Deakin

DEAKIN RESEARCH PARTNERSHIP WITH XLAM

GEELONG CIVIC PRECINCT

Mechanical characterisation of Australian heterogenous CLT – Xin Li

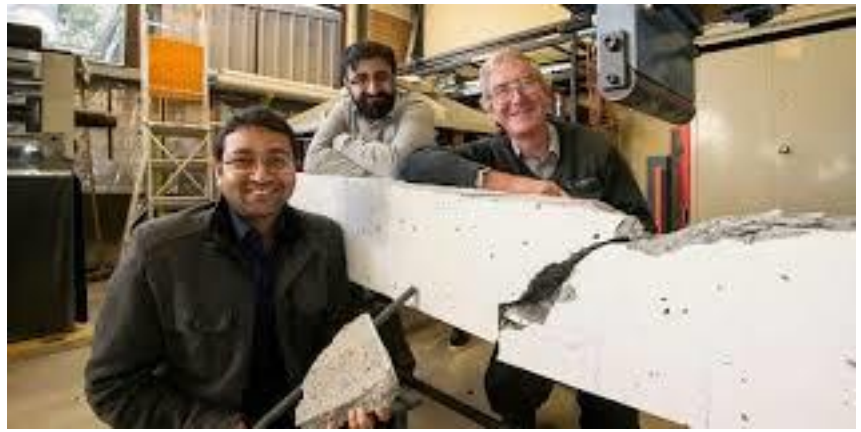
Fracture behaviour of timber and glued timber – Shaikh Atikur Rahman

Densification of timber – John Paul Cabral

A new approach to structural design of engineered bamboo – Janeshka Goonewardena

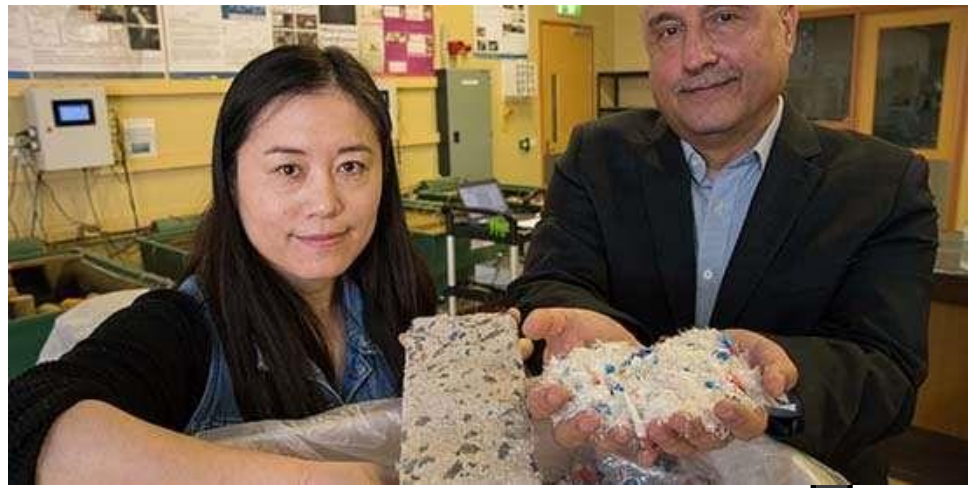
Innovative thin-walled timber-polymer composites for structural applications – Dr. Johannes Reiner and Dr. Mahbube Subhani

Concrete research



Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules.

BFRP REINFORCEMENT



CEMENT IS THE SOURCE OF ABOUT 8% OF THE WORLD'S CARBON DIOXIDE EMISSIONS.

Concrete's versatility, durability and economy have made it the world's most used construction material.

HYBRID STRUCTURES

'TREET' BUILDING, NORWAY

55 Southbank is a landmark project for CLT and Mass Timber construction. The project was originally planned as just a 6 storey vertical extension using conventional structural materials. In contrast, the use of CLT enabled the extension to be pushed to 10 storeys.

Treet or "The Tree" in Norway is an example of sustainable hybrid building. The building was constructed in modules. Each module complies with Passive House standards. Every fourth level is a “Power Story” covered by a load-bearing glulam framework. Concrete slabs were needed on two different levels in order to achieve stability limit states.

ADINA APARTMENT HOTEL, MELBOURNE

FUTURE OUTLOOK FOR BUILT-ENVIRONMENT

Climate change is REAL and WE ARE RESPONSIBLE FOR THIS!

Extending the lifespans of building materials through “circular construction”.

A building’s design can function not only as a blueprint for construction, its traditional use, but as a highly-accurate “bill of materials” and blueprint for deconstruction. Approaching buildings as “material banks,” temporary storehouses for materials that will later be used in numerous projects down the line.

Moving construction off-site for “prefabricated” and/or “modular” structures

In addition to keeping tolerances tight, assembling building sections in a factory or a similarly controlled environment eliminates construction waste, significantly reduces operational risk and the time it takes to complete a project is greatly reduced.

Making the most use of materials through “hybrid” design approach

Hybrid design concept is the future of construction. All available material and structural options must be considered to achieve the most “sustainable” design for a given project.