BUILDING 4.0

5TH SEMESTER LPE-REPORT
Architectural Technology and Construction Management - VIA University College, Horsens

Research on the importance of steel
By Andreas Vuylsteke (341960) and supervised by Jan Uwe Wolff - Submitted 24/11/2023

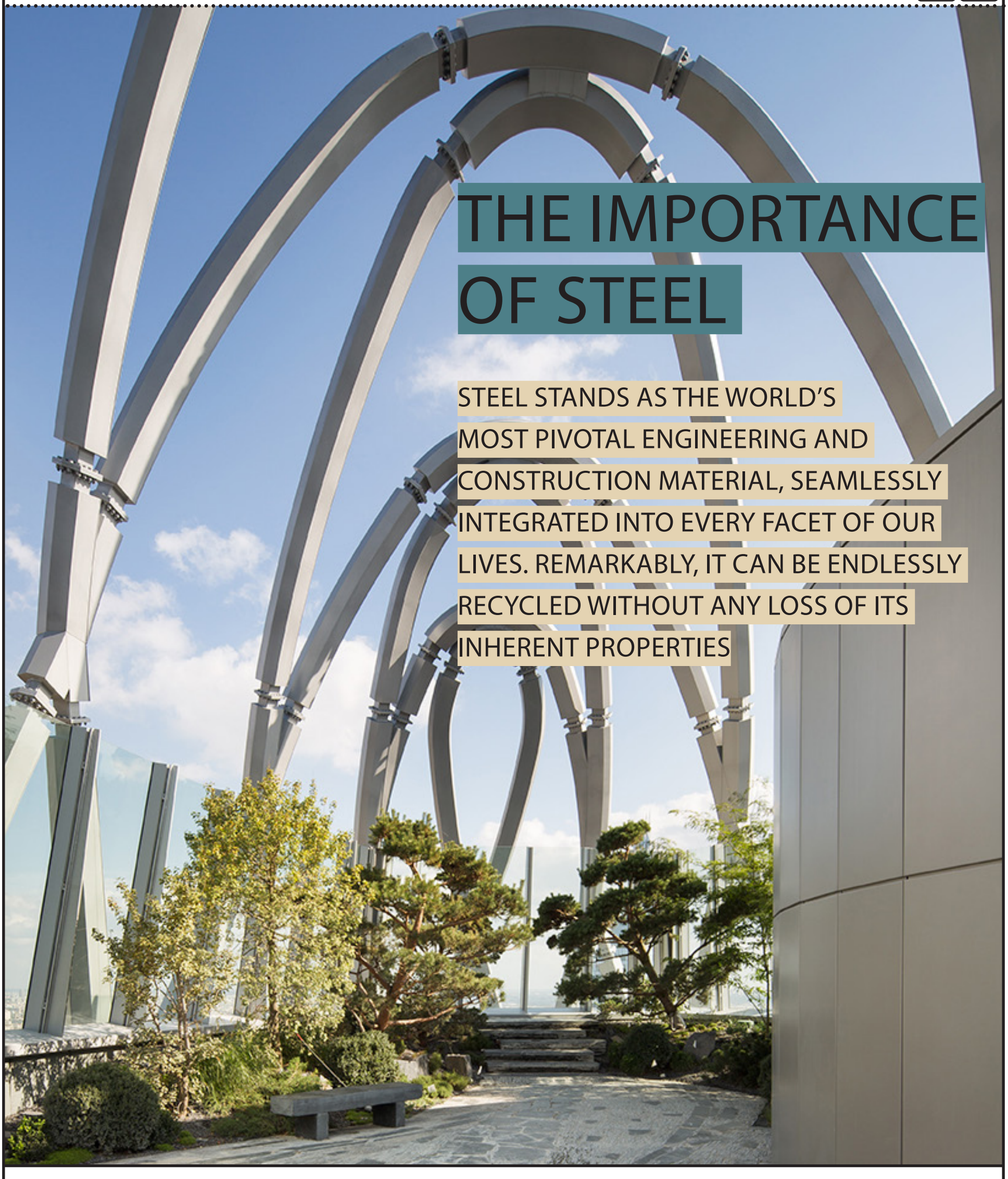
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24 NOVEMBER 2023

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THE IMPORTANCE OF STEEL

STEEL STANDS AS THE WORLD'S MOST PIVOTAL ENGINEERING AND CONSTRUCTION MATERIAL, SEAMLESSLY INTEGRATED INTO EVERY FACET OF OUR LIVES. REMARKABLY, IT CAN BE ENDLESSLY RECYCLED WITHOUT ANY LOSS OF ITS INHERENT PROPERTIES

LOCAL PROJECT ELEMENT ASSIGNMENT - RESEARCH CONVERTED INTO A MAGAZINE

TEXT SOURCES: ORTON, A. (1988). THE WAY WE BUILD NOW: FORM, SCALE AND TECHNIQUE (1ST ED.). PAGE 9-13. VAN NOSTRAND REINHOLD CO. LTD.
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WATTS, A. (2019). MODERN CONSTRUCTION HANDBOOK (4TH ED.). PAGE 20–22, 25. BIRKHÄUSER VERLAG.

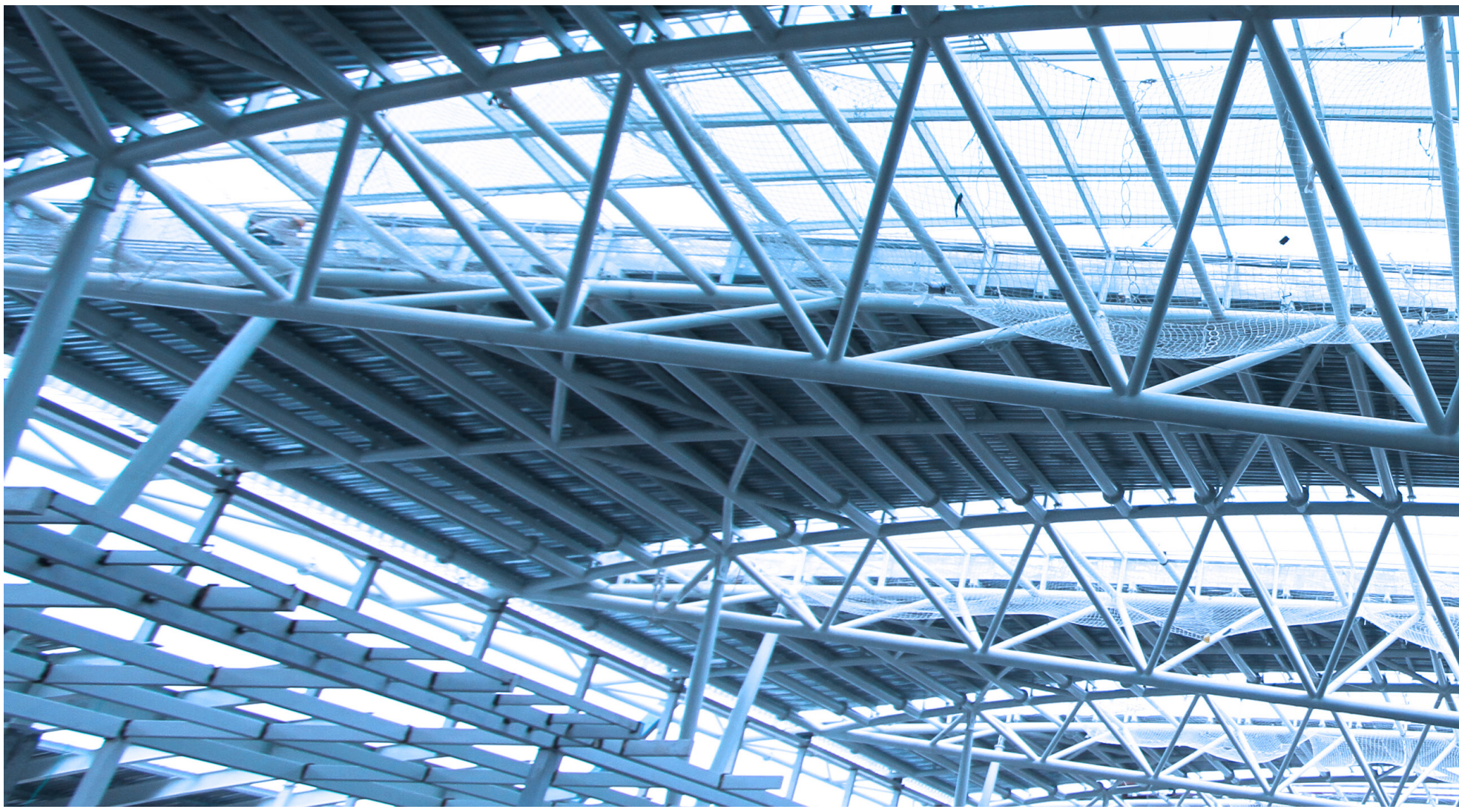


IMAGE: DA NANG INTERNATIONAL AIRPORT PROJECT, VIETNAM

Evolution, benefits and impact

Structural Carbon Steel is easily the most important class of steel for the construction industry, valued for its affordability and convenience. It boasts a high strength-to-weight ratio, coupled with a low cost-to-strenght ratio.

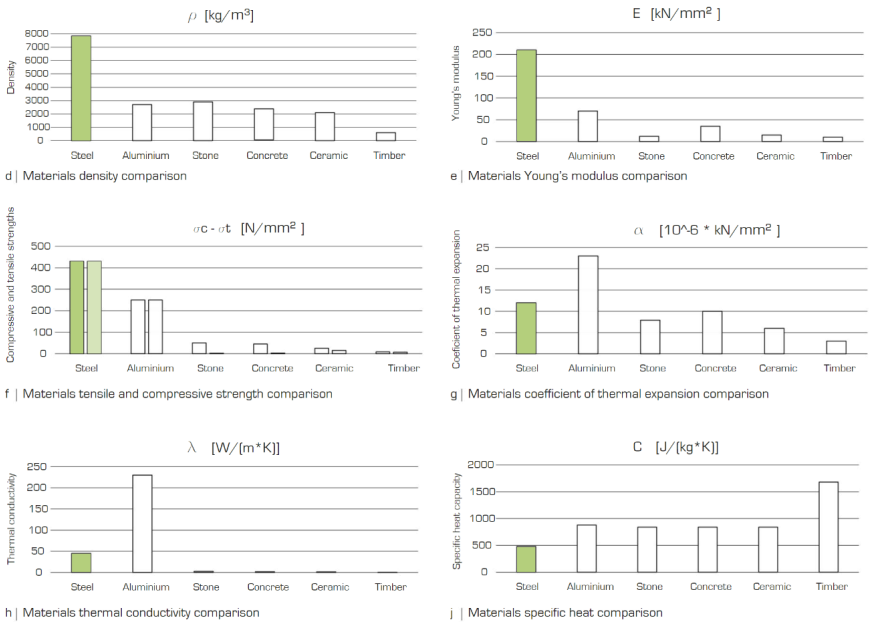
Construction materials are used in large quantities and it is therefore important that the materials used be cheap. Although bulk costs of metal are high compared to most other building materials, iron and steel, and aluminium to a much lesser extent, are still reasonably priced compared to other metals and have found wide application in building. Several thousand types of steel and aluminium alloys are produced for specific purposes. Of these only a small number are in general use in the construction industry. HISTORICAL USE AND EVOLUTION OF THE MATERIAL The basic materials for the manufacture of all types of iron and steel are iron ores, which are rocks containing iron in chemical combination with other materials. To free the iron from the ore, heat is required. The ferrous metals can be broadly divided into three groups: cast irons, wrought iron and steel. The manner in which iron was first extracted from its ores can not be known, because iron was used by prehistoric man. Probably the first from in which it was obtained was a type of wrought iron pulled from the primitive furnace as a pasty mass and afterwards hammered into shape. Cast iron was probably discovered when as a result of heating at a high temperature it was found that the metal became molten and could be cat into shapes made in sand. Although steel has been made for hundreds of years, until the latter half of the 19th century it was expensive and only produced in small quantities for swords and springs. PRODUCTION In modern methods of production, the first stage in the manufacture of any type of iron or steel is the heating of the ore in a blast furnace to produce pig iron. The pig iron, which runs from the furnace in a molten stream, is cast into moulds or taken direct to the steel furnace. Cast iron is produced by the remelting of pig iron, and according to the refining process and added ingredients, various types of cast iron can be obtained. Wrought iron also is made by refining pig iron, but the process is laborious and not so amenable to the use of mass-production processes as is steel. The temperature at which wrought iron is produced is not high enough to keep the metal molten, and the wrought iron is extracted from the furnace as white-hot spongy lumps which are hammered or rolled into plates, bars, etc. This has been used for many hundred of years for ornamental ironwork, as for example, gates and grilles, as well as for links of chains. To produce steel, pig iron, or pig iron together with steel scrap, is purified by heating in a furnace to drive off carbon, phosphorus, etc. To the liquid metal thus purified are added the exact amounts of the various ingredients (incl. carbon) necessary to give the steel the desired properties. The steel is tapped as a molten liquid into ingot moulds, the ingots are eventually reheated to make the metal soft, and rolled into plates, bars and other shapes. Alternatively, castings can be made by running steel into moulds of the required shape. Structural steel, as used for beams and columns in buildings and for bars in reinforced concrete, contains only a small amount of carbon (about 0.2%). It was not until 1878-1879 that Sidney Thomas and Percy Gilchrist introduced a method for eliminating phosphorus by lining furnaces with materials capable of combining with the unwanted material and removing it from the iron. BENEFITS General properties, are: High ductility, deforming long before they fail, lighter than an equivalent structural member in reinforced concrete, high stiffness. High rigidity in both tension and compression, high strength in both tension and compression, appearance is smooth in sheet form, rougher of texture in rolled sections and castings, even with paint applied, high impact resistance, thermal expansion approximately half that of aluminium, high thermal and electrical conductivity, susceptibility to continuous rusting (excluding weathering steels) and low fire resistance for specific heat.



Author: Andreas Vuylsteke (2002°)

Student Applied Architecture at Howest Bruges in Belgium, finishing bachelor degree next year. His great interest and personal experience with steel lead him to the research of this topic.

> Steel construction is the 'complete fulfilment of our dreams of beauty, power and joy' and the engineer is 'the true architect of modern age'.



d | Materials density comparison
e | Materials Young's modulus comparison
f | Materials tensile and compressive strength comparison
g | Materials coefficient of thermal expansion comparison
h | Materials thermal conductivity comparison
j | Materials specific heat comparison

IMAGE: A. ORTON - MODERN CONSTRUCTION HANDBOOK - STEEL PROPERTIES

IMPACT Iron started replacing the traditional materials and was used in mainstream building construction early on for two reasons - one visual, the other for safety reasons. In all the cases from 1770 to 1790, it was the slenderness of the columns that attracted most attention. The strength of iron meant the columns could be less than half the diameter of ones made from timber or stone. Altough iron columns soon became standard practice for supoorting the balconies of theatres to provide a less obstructed view of the stage, it was the second significant property of iron, being its incombutibility, that first led theatre designers to use it. So here in the last decade of the 18th century, we find cat-iron columns and beams being designed in a rational and scientific way to produce a minimum-weight structure. The remaining ingredients of the all metal frame buildings were primarily developed in Britain. The first roof truss built entirely of wrought iron to make a fireproof structure was in the late 1780s. Some 40 years later followed the development of the I-section beams and columns to further minimise the amount of iron. With only the load-bearing walls remaining, wind-bracing was introduced as merely a matter of developing what we nowadays call a cladding system. By 1860 all structural elements were replaced by iron. It was only until 1910 that Austrian publicist and architectural critic Joseph August Lux praised iron construction as the 'complete fulfilment of our dreams of beauty, power and joy', and hailed the engineer as the 'the true architect of the modern age'. Viollet-le-Duc and August Choisy follow him, Otto Wagner and Walter Gropius disapproved of iron. The first one to make a difference was Peter Behrens. Following 'constructive laws' solely could only lead to a 'pseudoaesthetic'. This is so because the system of laws for mechanical construction are the same as the 'system of laws for the organic process of creation, which nature reveals in all her work. Nature is not culture, however; thus, the exclusively human fulfilment of solely utilitarian and material intentions cannot create it'. Therefore, art can never be derived from technology alone, it cannot be achieved as the automatic result, as it were, of the intended use, the material, the tools, or the manufacturing procedure. In the work of art, Behrens saw rather – citing Alois Riegl – 'the result of a specific purpose-oriented Kunstwollen (…), which prevails in the struggle with intended use, raw material and technology'. It should be said that these three factors are awarded only the function of 'coefficients of friction withing the total product'. In the end, they only server; they are means in the 'fulfilment of psychic urges'. True architecture 'occurs not by chance, but through creation, according to the intensive and conscious will of the liberated human mind. It is the fulfilment of psychic goals, i.e. those that are translated into the mental realm.

TEXT SOURCE: WORLDSTEEL ASSOCIATION. (2023C, OCTOBER 2). CIRCULAR ECONOMY WORLDSTEEL.ORG. HTTPS://WORLDSTEEL.ORG/CIRCULAR-ECONOMY/
ORTON, A. (1988). THE WAY WE BUILD NOW: FORM, SCALE AND TECHNIQUE (1ST ED.). PAGE 9-13. VAN NOSTRAND REINHOLD CO. LTD.

How do the alternatives compare to it ?

When it comes to building materials, steel has long been one of the key players on the market. Renowned for its strenght, durability, and cost-effectiveness, steel is, however, highly rigid with limited flexibility. This makes it prone to denting or damage upon impact compared to wood or FRP.

Brick, stone and concrete are granular, brittle materials and therefore have little resistance to tension and shear but great resistance to compression. They are used for piers, walls and foundations when the loads induce only compressive stresses or, at the extreme, very small tensile stresses. Timber is strong in tension as well as in compression and is elastic, but its tensile, shear and compressive strengths are very much less than those of structural steel. The permissible stresses for all these materials are given in standard specifications and building by-laws, and are based on adequate factors of safety in relation to the stresses which would cause failure or yield.

Fibre-reinforced plastic (FRP) is an excellent material for use in construction, offering surprisingly innovative and durable solutions. When compared pound for pound, FRP is a stronger steel alternative, whilst being an extremely lightweight material. This means that FRP is easier to install in building applications, minimizing time and overall labor costs. FRP also works as a steel alternative as FRP has high tensile and compression strength. Steel is often lower in price initially than FRP, until installation costs are factored in, and the knowledge that over time steel requires maintenance, upkeep, and ultimately replacement; FRP is far more cost-effective in the long term. Using FRP structural shapes or building panels as a steel alternative offers significant structural advantages as they are easy to assemble, low in maintenance, and have a high aesthetic appeal.

Wood has been used in construction for thousands of years, being a steel alternative before steel was even widely used. Engineers have successfully harnessed this natural resource throughout history to build a range of structures. Both wood and FRP are beneficial as a steel alternative as they are not conductive. However, wood is rarely a viable steel alternative as it can warp or crack when subjected to higher temperatures, dryness, or excessive moisture. In applications such as waterparks or pools, FRP is much better as a steel alternative not only is it not affected by heat (up to 150 F, generally) or a broad range of chemicals, and it does not splinter or become harmful to users in normal use conditions. Wood also often requires dangerous chemicals to permeate or coat it so it becomes resistant to mildew, fungus, or rot. FRP is a safer, more viable steel alternative as it is not vulnerable to any of these things, even without any specific coating. Whilst wood is relatively strong, it cannot be used as a steel alternative in harsh environments such as structures adjacent to marine environments FRP outlasts both wood and steel in these areas, as it will not corrode, rust, splinter like wood, or be subject to insect infection. Initially, wood is a cheaper steel alternative than FRP, but this is only true at the point of purchase. When installation costs, maintenance, sealants, and wear and tear replacement are factored in, FRP is the most cost-effective solution.

> Welded structural steel supports are undoubtedly a strong and proven solution, but alternative options might suit your specific needs better.



IMAGE: BEJING NATIONAL STADIUM BY AI WEIWEI. BEJING, CHINA (2003).

NO CHALLENGE TOO GREAT FOR STEEL

Steel was not readily available in siginificant quantities until Henry Bessemer invented his converter in 1856. This device introduced a method for burning away impurities that helps extracting purer iron.

Cast iron and wrought iron were the forerunners of steel. Cast iron, a brittle material with high compressive strength, came into general use as a building material at the end of the 18th century, while wrought iron was developed some 50 years later. Wrought iron is a more ductile material and has greater tensile strength, making it less susceptible to shock damage. By the end of the 19th century, both materials had been superseded by steel. Steel was first produced around 1740, but was not available in large quantities until Bessemer invented his converter in 1856. This device introduced a method of blasting air into the furnace (hence 'blast furnace') to burn away the impurities that inhibited the extraction of a purer iron. By 1840, standard shapes in wrought iron, mainly rolled flat sections, tees and angles were available which could be fabricated intro structural components, which are then assembled by riveting them together.

Some shapes of steel section can be difficult to achieve with conventional processing methods. Specially fabricated steel components are made using advanced computational modelling and digital fabrication tools. A recent example of the application of this method is the structural frame of the Beijing National Stadium, designed by architects Herzog and de Meuron. A significant challenge, from the point of view of fabrication, was to use steel box sections for structural beams of varying cross-sectional shape, which also resulted in complex geometries at the junctions between the structural members. The outer faces of the steel box sections were maintained as always begin parallel to the base surface, which resulted in twisting box sections, made from flat steel plate which was curved to from each box sections. Consequently, all surfaces of those box sections remained developable, that is to say that they were mad from flat sheet. The individual faces of the box sections were curved to shape, then assembled and welded together to from complex structural sections that could not be made by conventional means.

WORLD'S LARGEST STEEL STRUCTURE

The National Stadium's main structure is an enormous saddle-shaped elliptic steel structure weighing 42,000t. The stadium extends 333m from north to south and 294m from east to west, with a height of 69.2m. The stadium design included demountable seats of 11,000. It consists of two independent structures, standing 50 feet apart: a red concrete seating bowl and the outer steel frame around it. The seperation of these elements makes The Bird's Nest resistant to a seismic level 8 event. To reduce the construction costs, the designers removed the top roof and enlarged the area of the roof opening, which reduced the total steel weight from 45,000 to 42,000 tons. The project budget began at $500M before it was drastically reduced to just under $300M. Beijing's stadium took five years of work, its construction site first opening on December 24, 2003. nitial preparations were put in place along with the pile foundations, which had to be dug 36 metres (121 feet) below the surface to support the weight of the building.

TEXT SOURCE: ARCELORMITTAL. (N.D.). INDUSTRIES – CONSTRUCTION – ARCELORMITTAL.COM. HTTPS://CORPORATE.ARCELORMITTAL.COM/INDUSTRIES/CONSTRUCTION/
BENEFITS – STELIGENCE® ARCELORMITTAL. (N.D.). HTTPS://STELIGENCE.ARCELORMITTAL.COM/BENEFITS
WORLDSTEEL ASSOCIATION. (2023C, OCTOBER 2). CIRCULAR ECONOMY - WORLDSTEEL.ORG. HTTPS://WORLDSTEEL.ORG/CIRCULAR-ECONOMY/

Modern-day use

Steel is omnipresent in the built environment, spanning from the deepest foundations and tunnels tot the talles buildings and iconic bridges. Its strength, versatility, and enduring durability make it an indispensable material for constructing the structures we rely on today and will continue to need tomorrow.

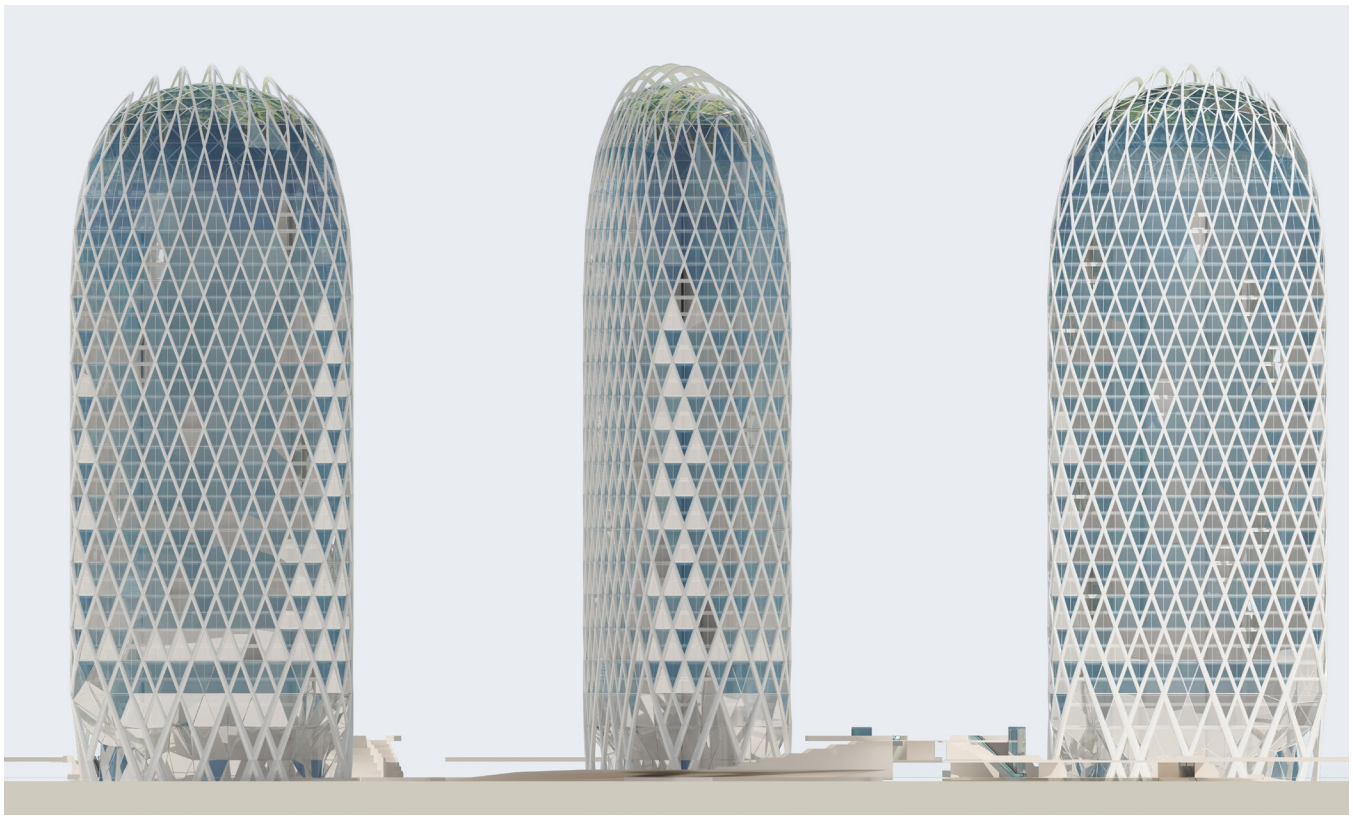


IMAGE: D2 TOWER BY ANTHONY BÉCHU AND TOM SHEEHAN. PARIS, FRANCE (2015).

TODAY, EVEN WITHOUT ACCOUNTING FOR THE WASTE CARBON EMITTED DURING THE MANUFACTURING OF BUILDING MATERIALS, THE BUILT ENVIRONMENT IS RESPONSIBLE FOR MORE THAN 40% OF GLOBAL CARBON EMISSIONS.

INNOVATION: BETTER BUILDING Compared with industries such as automotive and energy, construction has not seen fundamental change over the last 50 years. But today's technologies and challenges present the industry with exciting opportunities to transform through innovation. ArcelorMittal's industry-leading R&D function continuously develops new products for the industry. These include steels with special properties that enable them to 'self-heal' when protective coatings are breached; steel powders and wires developed for use as feedstocks for additive manufacturing (3D printing); and special grades of rebar developed for areas at greater risk of earthquakes. SUSTAINABILITY Steel has been central to human progress. And steel will continue to be inherently useful because it is strong, durable, flexible and reusable, and is the most easily recycled material - perfect for a circular economy. But it is essential that steel keeps evolving to become smarter and more sustainable. This means preparing for and responding to the most significant long-term environmental and social trends that are transforming the context in which is being operated. This means continuing to produce innovative steel products and solutions while maintaining operational standards that meet and exceed the expectations of customers and investors. The integration of sustainable development into the business is essential in ensuring steel is the material of choice in the transition toward a circular and low-carbon economy. STELIGENCE® The industry-leading, independently peer-reviewed Steligence® concept encourages the separate disciplines within architectural and engineering practices to collaborate and to see buildings as integrated, holistic, and almost 'living' entities. This philosophy, combined with the range of products within the portfolio, helps to make construction more cost-effective, sustainable and efficient. With the use of their beams and compact floors, a more optimal and flexible space and height can be achieved. Steel foundation solutions result in average 39% foundation cost savings and 13m spans can be erected up to twice as fast, saving 24% of the construction costs. Buildings using ArcelorMittal steel solutions attain higher levels of certification in building rating schemes than those built with traditional materials. It requires fewer site deliveries and thus has a reduced impact on the urban environment. CONSTRUCTALIA® The comprehensive database for architects and engineers, is the most complete construction industry information system on the market. Comprising thousands of cross-referenced product listings, technical specifications and illustrated case studies from around the world, it is acknowledged as an indispensable resource for the architectural and engineering communities. D2 TOWER At 171 metres tall and with 37 storeys, the 5,000 m² D2 Tower in Paris's La Défense business district is the French capital's first steel-framed tower and one of the first steel-framed skyscrapers in France. The tower's external 'diagrid' structure gives the building a faceted, diamond-like sparkle, with thousands of diamond-shaped windows reflecting the light during both night and day. The D2 Tower was designed by architect Anthony Béchu in collaboration with architect Tom Sheehan. During the study phase, steel quickly stood out as the material of choice, mainly due to the speed of construction it offers: "We pushed for a steel structure while most of the bidders offered a solution based on concrete as their main construction material", commented Anthony Béchu in an interview with property development company, Bouygues Immobilier. Using steel allowed the architects to use 30% less material compared to other structural solutions, a saving which has helped to improve the tower's environmental footprint. SELF-HEALING STEEL On a 15-hectare solar farm on industrial land owned by ArcelorMittal is a structure that supports the solar panels made from steel coated with ArcelorMittal's Magnelis® metallic coating product. Offering remarkable corrosion protection, especially needed on solar farms, which are typically exposed to extremes of temperature, moisture and salt, Magnelis® combines zinc with 3.5% aluminium and 3% magnesium. Its effect is that when the steel surface becomes exposed, for example on edges, welds, perforations or scratches, Magnelis® naturally forms a very dense, practically impenetrable zinc-based protective film over the exposed area. REBAR FOR BOLIVIA Located at an altitude of over 3,600m and built on the slopes of the canyon network eroded by the Choqueyapu river and its main tributaries, the city of La Paz, Bolivia, is the highest administrative capital in the world. Additionally, the city is located in a seismic 'subduction' zone with potential for earthquakes. ArcelorMittal Brazil became the first steel company to develop and supply the Bolivian market with a new earthquake-resistant product, not just for the capital but for the entire country and numerous different projects.

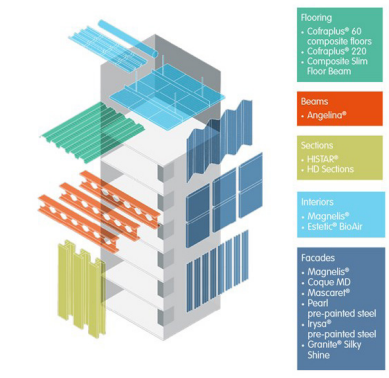


IMAGE: ARCELORMITTAL STELIGENCE®

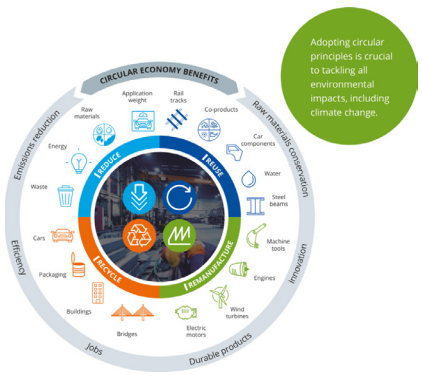


IMAGE: WORDSTEEL ASSOCIATION - CIRCULAR ECONOMY

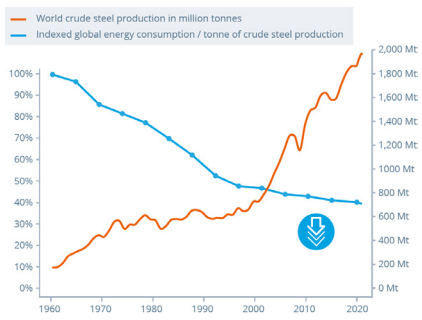


IMAGE: WORLDSTEEL ASSOCIATION - REDUCE IN MATERIAL

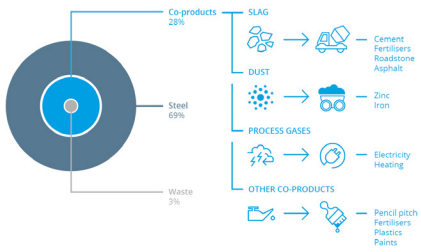


IMAGE: WORDSTEEL ASSOCIATION - MATERIAL EFFICIENCY