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Engineering Between History and Future

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Engineering between History and Future

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Abstract

My students often ask me: “Tell me, prof, what is the use of history of civil engineering?”, revisiting the question that opens Marc Bloch's famous book "The Historian's Craft". For some time now, I have been responding to their provocation (I teach civil engineering history) by telling 3 short stories: the stories of three engineers who lived in the nineteenth century, in the twentieth century and in the first century of the new millennium.
The first is the story of Charles, born in 1810 in France and a graduate of the École Polytechnique. Charles tells in first person all the transformations he saw in the world of structural engineering in the nineteenth century: materials, construction techniques, and calculation theory developed so rapidly that we went form the 40-meter span cast-iron Coalbrookdale arch bridge to the 500-meter span Gerber truss Firth of Forth bridge.
The story of Giulio, born in 1900 in Rome and graduated in engineering, is similar. He tells us too of the many technical changes linked to reinforced concrete in Italy and around the world, embedded in the political and social history of the twentieth century. In particular, he tells how a great difficulty such as the fascist autarkic propaganda triggered the most interesting experiments of post-war Italy. In particular, he recalls how reinforced concrete, just born in the early 20th century, underwent two genetic mutations in few decades: thin vaults and prestressing, so useful during reconstruction after World War II.
Neo Jane, born in Botswana in 2000, tells the last story. She predicts the story of structures in the 21st century. In particular, how everything changed in her university years, after the covid-19 pandemic. And how new rare earths materials applied in bridges, new transportation paradigms, new theories have led to very fast transformations in structures.
The three fictional stories should serve to clarify to my students what is the point of studying and researching history in structural engineering.

Keywords: Teaching, Future, Design, History, Construction History, Engineering History

INTRODUCTION

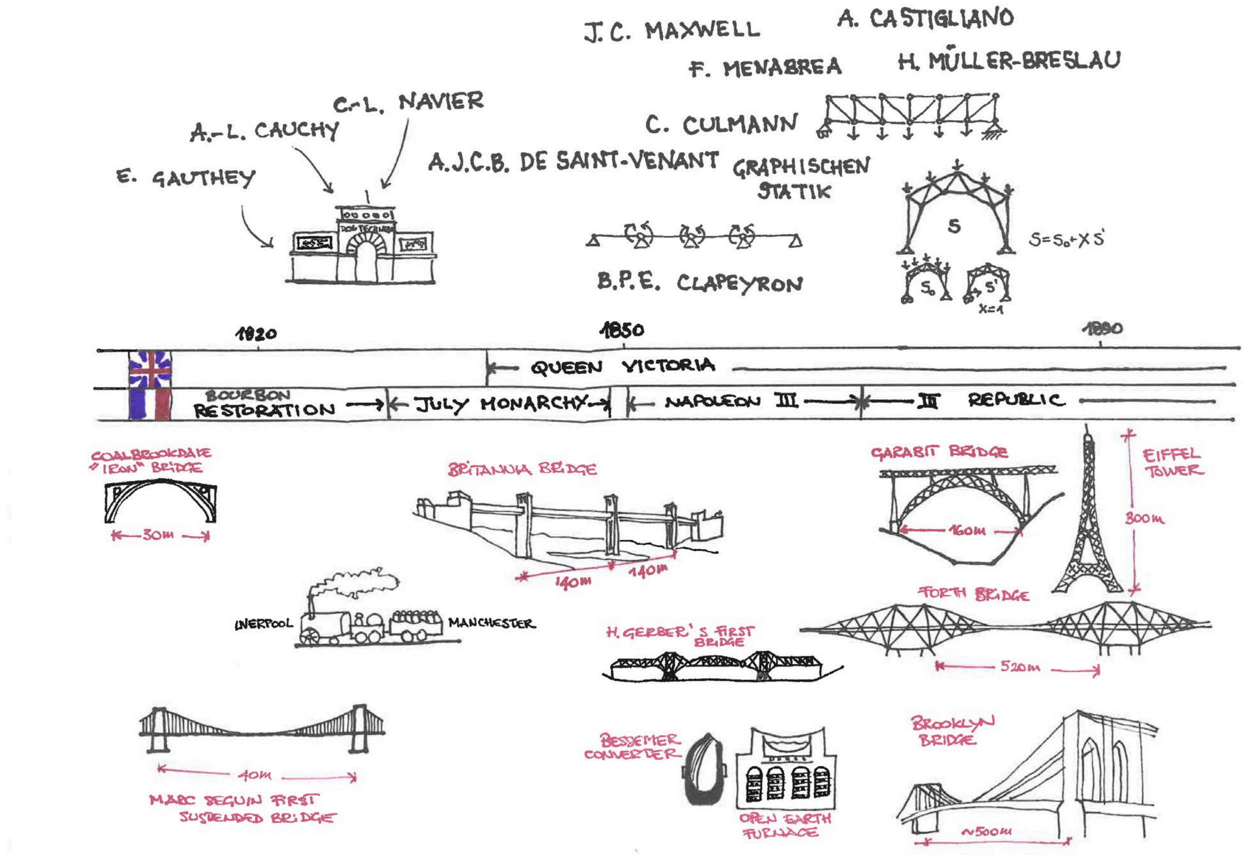
Predicting the future of technological development can only be conjecture: but change is certain and waiting for us.
Do we train students in change at the university? Generally, we explain what we know and train generically to solve problems (that's what engineers do: solve problems). However, we are aware that our students, in the future, will face other problems, different from those for which we offer them solutions. But we do not go into the classroom and say: we have no idea what you will be handling, and what you will really need to know. We have no idea of the material, the theory, the tools that you will be dealing with, but we are sure that they will be different from what we are explaining to you.
How can we be so sure that everything will change? Even without a crystal ball or specific courses in futurology: banally, it is history that predicts the future.
To demonstrate this, I offer three short stories, stories of engineers who did not really exist: they are

fictional but feasible stories; three fictional engineers who lived in the nineteenth century, in the twentieth century and in the first century of the new millennium. I accepted one of the most popular lines in futurology research, predictive history, with constant speed, no acceleration and no technological singularity.

Charles' Tale

The first story is about Charles.
According to his diary: "I was born in 1810, in France. My family was rich and in 1830 I attended the École Polytechnique, the best engineering school in the world at that time. My mathematical analysis professor was Augustin-Louis Cauchy and Claude-Louis Navier taught Mechanics. At that time, teaching bridge construction meant teaching masonry bridge construction. The textbook was decades old, full of Ancient Roman bridges examples. Around 1820, Marc Seguin invented wire suspension bridges. In 1826, Navier tried to build one suspended bridge over the Seine but he failed. What an embarrassment for the École!
I wasn't interested in suspended bridges – they seemed to me medieval, like drawbridges. Instead, I preferred to design bridges for railways, the new superfast way of connecting places. I admired George and Robert Stephenson, who completed the first railway between Liverpool and Manchester in 1830. As soon as I graduated, I moved to England to join my uncle. Stephenson hired me and I managed many construction sites. Then, in 1846, he involved me in the design team for the Britannia Bridge, a continuous wrought-iron beam 140 m span. What I had studied at the École was not enough. To understand the behaviour of the continuous beam, we tested a scale model, and it worked fine. Then, a few years after the inauguration, a classmate of mine, Benoît Clapeyron, demonstrated the "three moment theorem". After him came many scholars devoted to understanding statically indeterminate structures – the big calculation dilemma of that period – and they fixed it: they just added a condition – the minimum work – and everything was solved. The solution to the big question was in plain sight, but only Maxwell understood it in 1856! In the meantime, I decided to move back to France. For a few years, I designed compressed-air foundations for bridges, a new technique for bridge foundations in deep water. I designed the metal caissons, but I never went down into the caisson: the workers were sick after returning to the surface and many of them died. A few years later, a doctor figured out why workers were getting sick and how to prevent it – the compressed air technique spread throughout the world and completely transformed methods of building bridges. Then, I met Gustave Eiffel. He was 34 when he founded his company and he hired me: I had a lot of experience in construction and he needed someone older to manage his team. He hired young engineers from Switzerland. They studied with Carl Culmann in Zurich, at the best university in the world at that time. They calculated faster than us, using a new technique: graphical statics. I understood nothing about the theory behind it, but the application was easy. Our company was the only one in France using this new method of calculation: Eiffel won all the bids. I managed the construction site of the Maria Pia bridge in Porto (1877), a gigantic arch spanning 160 m. Meanwhile, new things were happening: in 1867 a German engineer, Heinrich Gerber, invented a new kind of beam bridge, the cantilever beam, named the Gerber beam in his honour. There was more to come: we started to use steel, the new material, produced with the Bessemer converter and the open-earth process. But Eiffel didn't trust steel: he said, "wrought iron was the perfect material for bridges". In 1883 I received a telegram from the United States (my first telegram, just invented!) from Emily Warren, the wife of Washington Roebling, who I met in France visiting a compressed air foundation site. She invited me to the inauguration of a suspension bridge spanning almost 500 m in New York, the Brooklyn bridge: the piers were neo-medieval, but it looked nothing like a drawbridge. I was wrong when I was young! When I retired, Gustave asked a last favour of me: to manage the construction site of a tower in Paris for the 1889 Expo: we changed the skyline of Paris! What a pity that the tower had to be demolished. The following year, we went to the inauguration of another stunning bridge: in

Edinburgh, on the Firth of Forth: 520 meters of span. A steel bridge: looking at the bridge, Eiffel realized that he had underestimated that powerful material. Heinrich Gerber was there too, with us: he couldn't believe his eyes. His simple invention transformed into such a huge bridge! Every now and then, I think of Navier's classes. Before his time, technological progress went very slowly. New things took decades, centuries to mature. Navier figured that the world would always go at the same speed. What an error! In our century, we knew of completely new, amazing materials, revolutionary ways of performing calculations, big, global new challenges like the railway. In the nineteenth century, the history of engineering changed completely". (Figure 1)

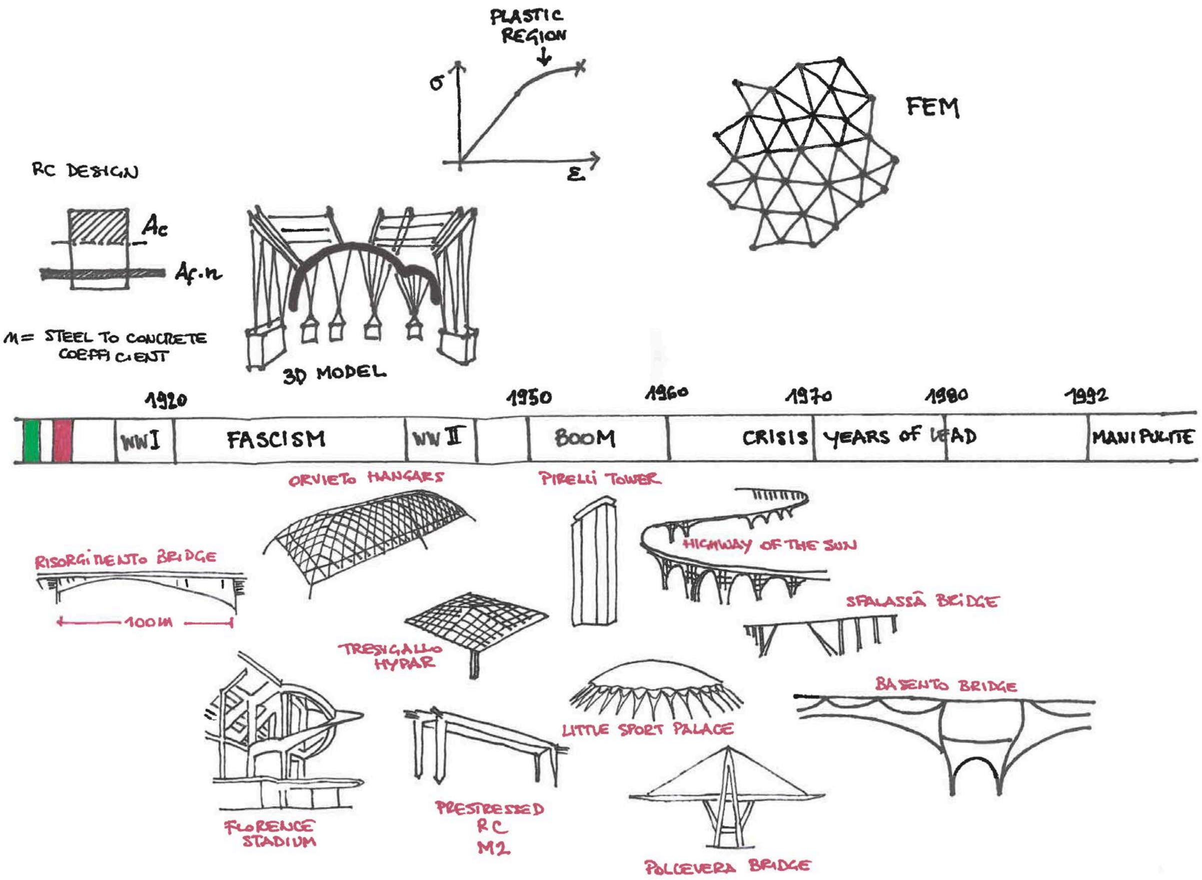


Giulio's Tale

The second story is about Giulio, an engineer of the 20th century. Again, according to his diary: "I was born in 1900 in Italy, in Rome. When I was 10 years old, my father took me to see the construction site of the Risorgimento Bridge, over the Tiber. The company used a new material: reinforced concrete. Every now and then, on the banks of the river, I would see a gentleman in a white raincoat, who spoke French: his name was François Hennebique. He decided to design the bridge, with its 100-meter span, without following the rules of his patent. Thanks to him and the revolutionary bridge in Rome, reinforced concrete became a free material: no more royalties! After the bridge was inaugurated, no one believed that it would remain standing. Hennebique calculated it, refusing to use elasticity theory. A German engineer checked the calculations of the bridge and demonstrated that the bridge should collapse. But the bridge did not collapse. I still walk on it each Sunday! I fell in love with that stubborn reinforced concrete: concrete and steel together, joined in a marriage. Each material takes the load it can bear best. It was so easy to think of this kind of mixed solution, but nobody did it before Monier and Hennebique. I graduated in engineering in Turin, in 1924. We studied mostly masonry and steel construction; reinforced concrete was given very little space in the books. But at my university the teacher was Camillo Guidi, a fan of reinforced concrete.

I was hired by Pier Luigi Nervi's construction company: he founded his first company when he was 30 years old. He asked me to supervise the construction of a stadium in Florence. It was a success! Nervi never smiled: there was nothing to smile about, in those years in Italy. Mussolini had taken power: dictatorship and fascism. Mussolini did not like reinforced concrete: he preferred the materials used by the ancient Romans, marble and bricks. In 1935, Mussolini invaded Ethiopia and the League of Nations imposed sanctions against Italy. Nobody sold us steel anymore. We could no longer find steel rebar on the market. In 1936, Mussolini said that to build with reinforced concrete was forbidden. The fascists said we had to build with stone and brick, as the Romans had always done. Fortunately, Nervi didn't listen to them. He obtained some work from the Air Force: hangars to protect aircraft. We could use reinforced concrete but we had to save steel. He invented a new way to build structures: he divided them into many pieces and our workers prepared them on the ground. Then they would put the pieces on a scaffold and connect the pieces with cast-in-place concrete: a jigsaw puzzle. Nervi got help from a professor at the Milan Polytechnic, Arturo Danusso, who made a scale model for him to understand the behaviour of the structure without mathematical calculation. Nervi also invented a new material, ferroconcrete, to build thin curved slabs. Then, in July, 1943 Fascism fell in Italy. In September, after the armistice, Rome was occupied by the Nazis. Nervi closed the Company for a year. He did not want to collaborate with the Nazis. He took the slabs home and spent time checking how they performed under the weather. After the war, putting the two inventions together, Nervi built his masterpieces: 100 m diameter domes using ferroconcrete and structural prefabrication. He became the most famous engineer in the world: the fascists forbidden him to use his favourite material and, without complaint, he invented a new successful way of building.
In the meantime, I escaped to Switzerland. I was Jewish and I couldn't stay in Italy. In Switzerland I met Gustavo Colonnetti, he was my professor at the Turin Polytechnic. He also had to escape, because he was an anti-fascist militant. In Vevey, he organized a university camp where young exiled people could study and I helped him. Colonnetti taught everyone a technique he learned in France: prestressed concrete. It seemed like an ingenious invention. Prestressing concrete with steel cables lends the concrete tensile strength. Again, it was so easy to think about this kind of coaction, but nobody could do it before Eugène Freyssinet. In the university camp, I met Silvano Zorzi. When the war ended, I went to work with him. We designed dozens of prestressed concrete bridges together. In the meantime, the private car became popular. Italy built hundreds of kilometres of highways. In 1964, when the Highway of the Sun was opened, Italian engineers were a benchmark for the world. They did everything with concrete: skyscrapers, dams, highways, domes, even cable-stayed bridges like the Morandi bridge in Genoa: no other material could compete in our country. So much for the fascists!
Later, things changed in Italy: the economic boom ended, workers began to strike, and students began to protest. When workers began to cost too much, Zorzi invented machines to build beautiful bridges using fewer workers: self-launching formworks, "little by little" automatic systems.
I retired when a visionary engineer, Sergio Musmeci, built a fantastic bridge in southern Italy, in Potenza, using a soap bubble as a model.
Musmeci tried to use finite elements methods (FEM), a method of calculation that four guys had invented in the United States in 1956, but he needed an automatic calculator. "Calculators will come soon" Musmeci said "and then everything will change. I can't wait!". He unluckily died young, and he didn't see the advent of computers. Every now and then, I thought about professors of my era: how much more of them I have seen! Everything changed in the 20th century: new materials, new ways of building, new calculation methods, and new social challenges. My teachers knew that everything would change: they had learned the lessons of the 19th century, but now the pace of change was much faster. The most important thing they taught me by their example is not to be afraid of crises. Crises are incredible opportunities for change, for growth. This is true on a personal level, too: after the persecutions, the war, and the exile, a second life began for me. Crises

propose new problems, and new problems need new solutions. (Figure 2)



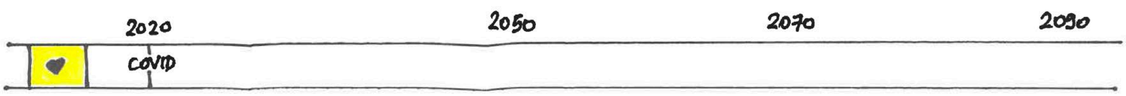
Neo Jane's Tale

We have walked the timeline of the nineteenth century; then that of the twentieth century; now it is the turn of the 21st century. This is the history of Neo Jane, a female engineer. According to her diary: "I was born in 2000, in Botswana. While I was attending university, the Covid-19 pandemic arrived. During the curfew, from my home, thanks to the internet, I could attend university courses all over the world: a big opportunity amid the tragedy. I took my PhD in Singapore. In the meantime, in the second half of the 20s, the world witnessed the birth of the United States of Africa. The peaceful revolution started from South Africa and from my rich Botswana. Africa did what the United States of America and Italy had done in the 19th century, and Europe in the 20th century (after a very bloody war). Africa was saturated with "rare earths", the lanthanide series of chemical elements, the new oil. Due to strong investments, Cape Town's university became the most important engineering university in the world. In its laboratories, a new construction material was invented: starting with a rare metal, dysprosium, number 66 in the periodic table, and reinforcing it with Thulium, another lanthanide with the atomic number 69. The combined material was stronger than steel and more beautiful than silver and titanium: thuliumed dysprosium, the material of the century.

After graduation, I was hired by a company investing in modern, high-speed transportation system across Africa: it was kind of a guided road. We would design the plan and then the robots would assemble it on their own: the beams were all the same, so the robots were never wrong. And above all, they didn't get hurt (zero accidents at work) and there were no strikes.

Then, with thuliumed dysprosium, we designed and built a bridge over the Strait of Gibraltar spanning 13 kilometres to connect Africa to Europe. (We did a little test before: the bridge over the Strait of Messina, in Italy, 3 kilometres span, a big dream for that backward country.)

Then, in the middle of the century, a new calculation theory for structures arrived: trying to understand the behaviour of rare-earths metal structures, scientists finally understood that elasticity does not exist, it is only an apparent effect of a more complex theory. Everything became much clearer, just as it did when Einstein explained that Newton's gravity force was only an apparent force due to curvature of space-time. The new theory was under everyone's eyes, but only Sharbat, an Afghan professor, understood it in 2056 (56, what a special year: in 1856 the Maxwell paper, in 1956 the FEM paper, and now the Sharbat paper). She was in exile, in Africa, after the return of the Taliban dictatorship to Afghanistan: she was expelled from the university, like the Jews during fascism. A second life began for her in Cape Town. And then….". (Figure 3)



Conclusions

What is the moral of my tales? Don't be afraid of innovations, new materials, new systems of calculations, new technologies, and new challenges. Even if you don't accept these turnarounds, they will still come. Don't be afraid of crises: crises are always an opportunity for innovation. Be an engineer of your time. Always look around you. And do it quickly, because everything is faster now.
Let's study history! To make new things, you have to know everything already happened in your world. History is a tool to imagine the future!
Learn the path that your predecessors took. Put yourself in their path and continue their journey. You are leading a very large group, standing behind you, watching you and supporting you: Navier, Stephenson, Eiffel, Hennebique, Nervi, Musmeci… and many other engineers are near you along the way and can help you, like Hugo Corres, a master of structures. Join him in the history of structural engineering!

Figure 1. Concept map of Structural engineering in the 19^{th} century
Figure 2. Concept map of Structural engineering in the 20^{th} century in Italy
Figure 3. Concept map of the possible history of structural engineering in the 21^{st} century