Prof. Thomas Bock

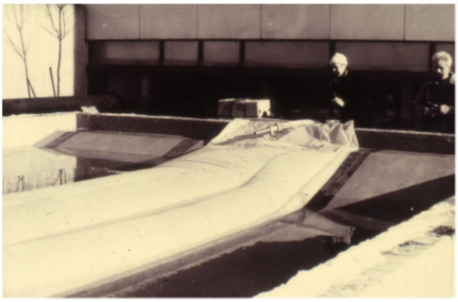
"Construction Robotics"

16 / 1 / 2019

My background

I got my first degree in University of Stuttgart, and then later I went onto Chicago. And later to Tokyo. I did some projects in France, Iran, and Germany and Spain.

Pic.1 was my studies in Stuttgart which was in the borderline between architecture and civil engineering because those days in Stuttgart, we had an interesting professor called Frei Otto. I designed a mobile canal dockage based on kinematic structures. So you could block the canal and then fix the canal just by pumping in water. And I came up with five chamber design based on the same method as Antoni Gaudi designed Sagrada Familia in Barcelona. So it was an inverse chain model, I had some kind of tension as springs, and I measured the force. And I simulated membrane strengths and the interior water pressure and the exterior air pressure or water pressure on this side of the canal.



Pic 1 mobile canal dockage

And later, I was involved in a professorship at the University of Catalonia, Politecnica de Catalunya in Barcelona for a position of professor who restored Sagrada Familia. So it was interesting again to see this old concept of Antoni Gaudi with the reverse chain model which was related also to this method by Professor Frei Otto.

And then, I did the first computer thesis at the University of Stuttgart. Those days, it was not common. I learned programming in Fortran. And I wrote a whole program so you could design the building on the screen and later print out the plans. Now you're laughing about it, but those days, it took quite long. Normally a diploma thesis takes about half year and it took me about one and a half years, but the professor liked it. It was a pioneering work, so he somehow hiding information to the exam commission that it only took officially six months. So it took actually one and a half years.

All interaction with the screen (Pic 2), you could design interior wall, exterior walls, structures, roof, floor, and so on. And then I made a parts listing which is also not so common in construction. I learned it from the manufacturing industry. I describe what kind of category this part is like interior wall, door, and I gave them a classification number, and I describe the quality, the quantity. And assembly criteria, how we can assemble it onsite, how you can cut it.

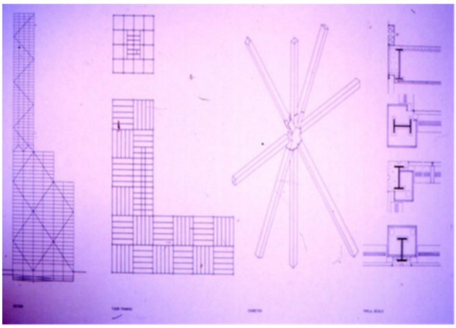
Pic 2 computer program to design buildings

Because those days I was researching in wasteless construction. We studied about a system developed by a British researcher called Walter Segal. This is very important maybe in the future since you have lots of waste. Actually constructing industry is producing most of the waste by volume and by quantity. Not by quality but by quantity. So there was the wasteless criteria means cutting criteria.

When the professor saw it, they somehow were very mad at me. They said, “This is not an architect thesis because you didn't draw the plans yourself. But my professor supported me, he went out to the other professors, and I think they had a very tough talk. Finally, I didn't fail, and I passed with the best grade. So anyhow, I thought I'm going to leave Stuttgart because I was so tired of this conservative school.

Then I got a scholarship for Chicago. I accepted because I wanted to study about the Sears Tower, now it's called Willis Tower. It was the tallest building in the world, mostly in 1981. And I studied under this professor who did the Sears Tower, and I chose the site near Chicago River to build multifunctional high-rise building. Those days, it was the first multiuse high-rise building in the downtown area. And I choose a difficult site, this kind of L shape. Normally as a developer you try to get a whole block because it's easier to design a high-rise. In the United States, you have to follow a building code and zoning ordinances. Actually, I studied the market in Chicago, what kind of sizes of apartments do they need and so on. And then, I got into the structure.

I happen to meet Buckminster Fuller once at a book store in Chicago, and I was not aware that it was the famous Buckminster Fuller and I talked with him. And he asked me what I'm doing, and I said, "I'm doing a full-time scholar, a student at IIT Chicago." And he said, "After I sign the books, I want to see your works." So he went with me to IIT, to the Crown Hall, and he'd seen my model. And first, I had a kind of copy of Hancock Tower with the cross braces. And he said, "No, that's not good. Just use one brace." And I build a model and calculated it. I showed it to Fazlur Khan. Actually they needed less steel consumption per square feet. This was the most efficient steel structure those days. If it would have been built the most efficient in the United States, and we also tested it in the computer at Skidmore Owings Merrill. Because Chicago is a windy city. They have no earthquake, but they have high strong winds. And here, it had a pretty low steel consumption. It would have been the most slender building those days because normally, efficient buildings have an aspect ratio of one to six, and we pushed it to one to nine, which is actually not so good for the structure of the system, but somehow because of this trick Buckminster Fuller told me, we had a kind of three-dimensional resistance system.



Pic3 high-rise building design in Chicago

Then, I built a model, but the problem was I didn't have much money and all the other American students, they had lots of money, and they built nice glass model. And I just cut cardboard, and I bought some kind of foil and mixed some ink and painted on it. And I got an award. I got even the best thesis award even though my model was just made of cardboard, and it made an exhibition about 150 years Chicago architecture.

Pic4 model in exhibition

Now I want to show projects. As a student, I bought some piece of land, didn't have to pay the money, and because the village was deserted, and I destroyed it. There was a fire, and then I rebuilt it on the weekends and the vacation times. And this was a quite good experience because if you have to do the hard labor yourself, you stop thinking about what you design and how you design next.

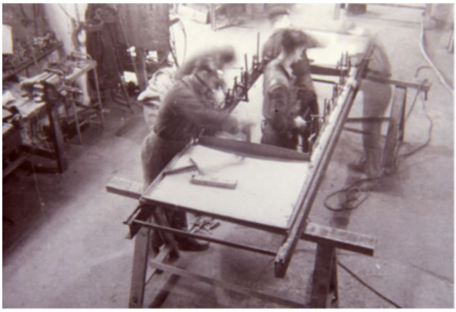
Pic5 rebuilding old house

Then later, I got into prefabrication because I thought just the manual labor of building these blocks and bricks, and conventional concrete, mixing on the side is too hard work. I injured myself a lot. So I worked for a company in Iran, just before the revolution. I did some kind of prefabrication factory. But then, the revolution started, and I had to run away.
Then later, I was interested in the works by Jean Prouve, and I got an opportunity to work for him, but he didn't have much money, so he let me sleep in his atelier in Paris. And his wife actually cooked for me. They treated me like I was their son. Anyhow, I did the reporting of Maison du Peuple which was a very revolutionary building. He designed it in the thirties, and he designed like a multifunctional community center. So there was a market, inside there was a movie theater with seating of 500 to 1,500 people. The roof could be pushed

away. I had to investigate quite a lot of time original pictures, negative films, how they make these parts.

Pic 6 Maison du Peuple (Jean Prouve)

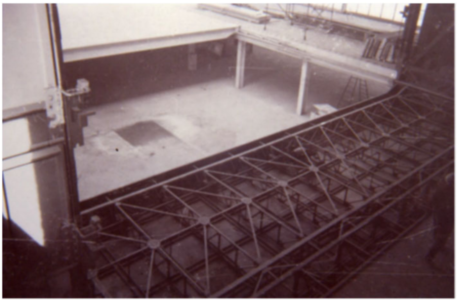
And he told me that he was friend of Citroën and in the 1920's, 30's, Citroën was maybe the most advanced car company in Europe, and they called Citroën the Henry Ford of Europe. So Prouve learned a lot from how Citroën built the cars. And Citroën built very lightweight cars and used the same steel sheet and by deformation, he got the resistance. And Jean Prouve used the same technology for the panels. So the panels are very lightweight steel. The factory in Nancy in the eastern part of France, in the suburb called Maxeville. And these are the original pictures of the factory (pic 7). Also, Prouve was the first person in Europe who started welding. Those days, people were still using bolts to make steel structures. Then, they used springs from mattresses to keep up this shape.



Pic 7 Prouve's factory

And he was an interesting guy. Even he was the boss of the company, but he didn't take more money than his workers. He was a little bit a communist person. So all his people I met who worked for him, they were somehow still very positive about him.

And then, the floor could move mechanically, and even the interior walls could move (Pic 8). So here, the floor, the beams moved, the interior walls moved. So you could have a theater of 500 to 1,500 people, or an open inside market space. And then the handrails slipped automatically so nobody falls down.



Pic 8 Maison du Peuple (inside)

Later, I built, as an architect, some houses. This was steep slope in the Black Forest in southern Germany. I used similar foundations, just a little retain wall because it’s very expensive to make retain walls on the steep hillside. And all this building was actually built in a week. I used standardized joints. So they knew each door has the same connections, and then they cut the parts. Here, you see all the standardized joints (pic 9).

Pic 9 standardized joints

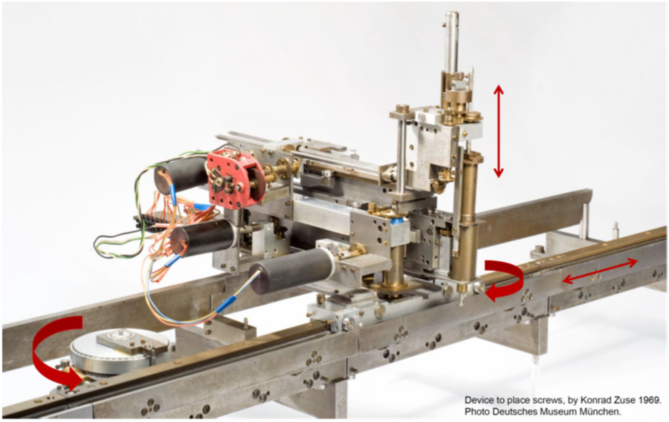
And also, the exterior walls were basically the same. So I got some discount because I told them, “Oh, it’s a repetitive job. You don’t have so much money”. And I thought about the installation. I, on purpose, shifted the secondary beams and the main beams for about 30 centimeters so I can enter from the center of an interior wall with water supply, hot water, cold water, waste water without having to drill a hole in the beam. So also you could later move interior walls if you want to and install them in different place.

And then, actually I wanted to be an astronaut, but NASA never answered my application. So at least I became a commercial pilot in Dallas. But then I found out this is not so interesting. It’s just a taxi driver only in three dimensions. And those days, found a Professor Larry Bell in the University of Houston. He took me in. I worked for him for one year. I designed a NASA tech house, which was the predecessor of the Biosphere 2. It produced its own energy, the solar photovoltaic panels, and recycled everything, the waste inside the house. But it just looked like a conventional American house where it had lots of technology. They tested the Biosphere 2 components also for the future space station. So it was about life support system for astronauts. I’m showing you this because later it relates to my research and also closed loop recycling of waste, energy harvesting foundation, space founding and so on. And then, while I was in Japan, I also worked in Shimizu for some space construction. A space hotel designed by Shimizu.

And then later, I did some further projects for the science museum in Munich. There was a German computer pioneer. His name was Zuse. In the late thirties, early forties, he built the first computer because he was too lazy to do the calculations as a structural engineer. So he developed a computer. I like those people who are lazy because they are innovative.

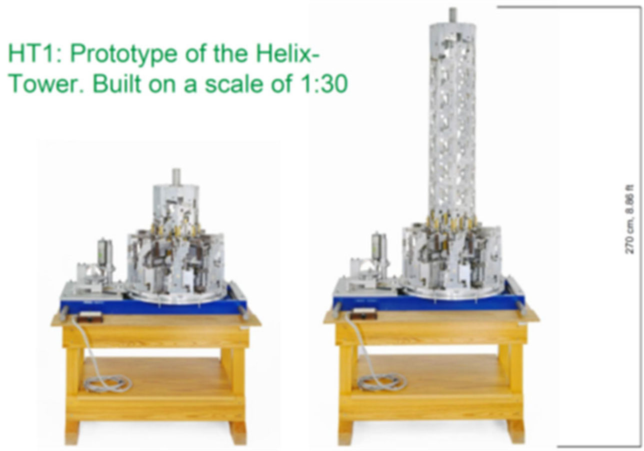
Suddenly I got a call from a German science museum, and they found some pieces from this famous computer pioneer, but they don't know what it means. And so I looked at it after a while, a couple of weeks, I found out he was into automated construction system, but I could only know it because before I had this experience in Japan about automated construction robots. And also, some self-replicating systems for space colonization. And also I could figure out these parts because I studied about the Toyota production system about machines and about space.

He was thinking about colonizing space and sending up some kind of machines that replicates itself in order to colonize space. This is the final machine that he thought he can send to space (pic 10). And now you can see at the science museum in Munich.



Pic 10 machine to send space

And then the helix tower, also they gave me little pieces. They were not connected. And then, we somehow figured out the mechanism and we built this. It was an automated construction system of a tower, and he wants to build windmills, actually. About one of the big towers 120 meters tall. Quite big. He is the computer pioneer, and this guy was a biologist, and he also advising Frei Otto because Frei Otto was into natural structures. This man, he was in Berlin as a professor, and he came to Frei Otto and showed him some kind of shell structures or weird biological, now you would call it bionics.

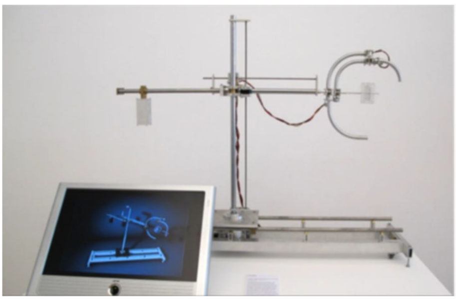


Pic 11 Helix tower

This is a typical analogy to the Amurad by Kajima in Japan. It builds anything on the ground. This (pic 12) is the reverse of the daruma-otoshi. So you cut the ground floor, you can recycle 96 percent of the buildings. And because if you do it like the Americans with implosion, everything you have to put in the waste. And if you do it like the Europeans do it with the wrecking ball, you create lots of dust. And in order to not have too much dust, they spray water. Do you know what happens to water and chips? You got a chemical reaction. Also, you cannot recycle any more. So this way is the best way. You can even extract rare metals from it.

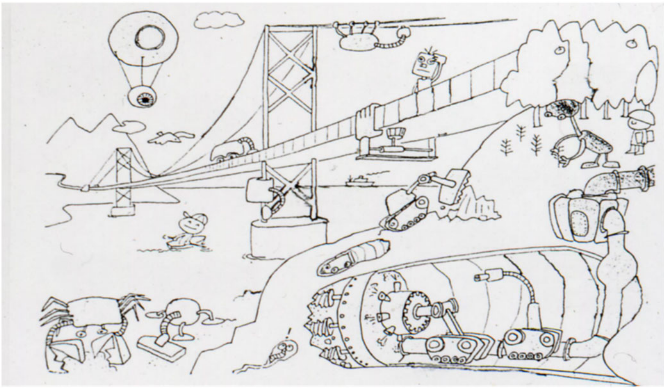
Pic 12 Daruma Otoshi by Kajima

Here's Zuse again, this was the location orientation manipulator. Again, we found the motion and we built this model in my institute in Munich. It was his last work before he died. Helix tower, also his last work before he died in the mid-90s. So when these genius people, before they died, they merged everything in their mind. He was thinking about automated production, robots, but he just didn't call it robots. He called it location orientation manipulator.



Pic 13 location orientation manipulator

And some of my things I did in Japan. Here was a very famous professor Uchida. He was, just before he retired, and he had very good connections to the whole industry. So he opened me many doors that I normally closed for foreigners. So I was also a member of the civil engineer society for robotic construction. And you know sometimes civil engineers don't like architects, but somebody respected me even though I was an architect because they liked my contribution, and they could see that I also had some civil engineering experience from Chicago. So I sketched a future civil engineering sites here (pic 14).



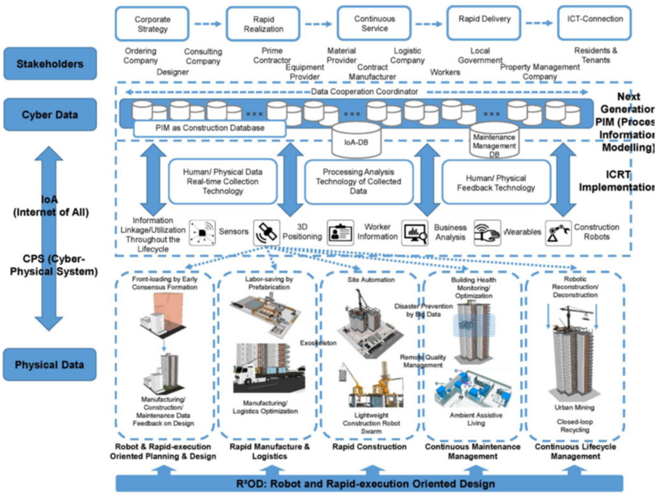
Pic 14 Kensetsu Manga (1984, Thomas Bock)

Because in the beginning I couldn't speak Japanese so well, so I just did my own manga. And then, I also did the same in some commission for the architect institute. The previous one was headed by Professor Kobayashi, and this one was headed by Professor Tomoda. And all people are retired now. It's funny you know because about 10 years later, this really happened. I did not know it when I sketched it. And then, I had some projects for the Japanese Science Society. Now, I'm not so good in sketching anymore.

Construction Robotics

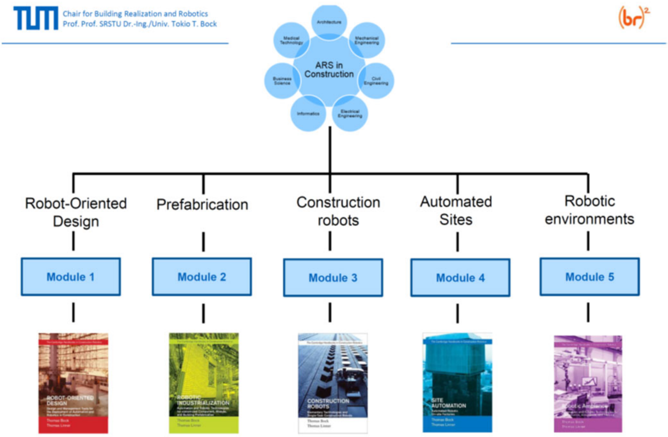
I'm going to show you a little bit about the constructor robotics and why we need it because of housing shortage and the high real estate prices. And even if the economy is not doing well, for example, now and some parts of China, but there will be still about 300 million people moving from the countryside to big cities. So we still need to build a lot and have to rebuild it. This is tendency of urbanization. At the same time, we don't have skilled workers available, and we have too many old constructor workers because young people don't want to work on the construction sites because the conditions are so difficult. So here, the robotic construction can help, but this needs a totally new approach. Actually, the university structure nowadays is not good because you are just being taught in one discipline like architecture or the others; just civil engineering or mechanical engineering or computer science or electrical engineering. But actually, you need all of those together. We need a new kind of university which has more transdisciplinary education and research because we can realize nowadays, the problems of the society are increasing, and one discipline cannot answer the question of the society. So we need a new type of professions and skills. What I combine at my laboratory in Munich is I have assistants from architecture, also recently from medical technology. I have people from business, computer scientists, electrical engineers, civil engineers, mechanical engineers. Even now, I also deployed a kind of physical therapists because we have to do lots of research also for elderly, which is also related to robotics. Of course, you need it in basic science like in chemistry or so on, and in physics. You need basic science, but on top of it, we have to go horizontally, cutting through all the disciplines like mixing like bioinformatics or biochemistry and so on. And that's my vision of the integrated models.

I'm not a fan of building information modeling even though everybody likes it. I think it's not very useful for building construction because it doesn't reflect the process. If you look in the Japanese or Chinese language, you'll find always ”do” or ”dao”, and this means the way how to do something. And the way how to do it is not represented in the product model. You need a process model, and this accessed already of the Toyota production system from the eighties. They had a good manufacturing process model, just-in-time delivery, and then you can have a success project whether it's construction or shipyards or airplanes.



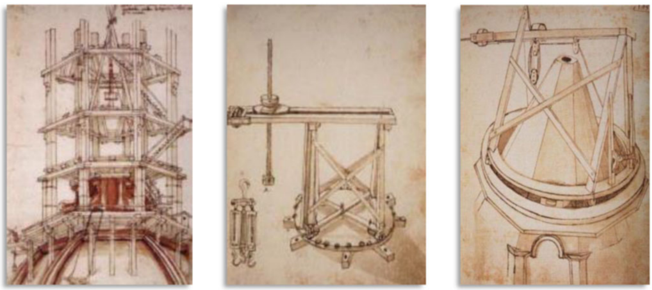
Pic 15 Process Information Modeling

Also, this is the structure of my research (Pic 16). First, robot-orient design. So we addressed the design so the robot can be easily applied. And second, you need more customized prefabrication and then single task robots, and the automated sites. And then in the end, you have some first robots build a building, and then buildings become the robot to service anybody or to service the elderly for independent life for example. They're also reflected in education like we have five modules with six European credits which means 30 credits, so you can cover one semester.



Pic 16 perspective of researches

And I study a lot about tools. You should go to the Takenaka Dougukan Museum. From the history of the last 10 thousand years. I like Brunelleschi because he also had an internship as a clockwork and a clockwork maker, and he designed also the machinery for Santa Marie del Fiore in Florence. He decided all the vertical lifting, and since he knew the clockwork mechanism, while they were turning the wheel to lift the stones upwards. They were bringing downwards. And they don't need to reverse because he knew how to shift the gears without reversing the course of the horses. And he also did the first horizontal tower frame in the world with wood.

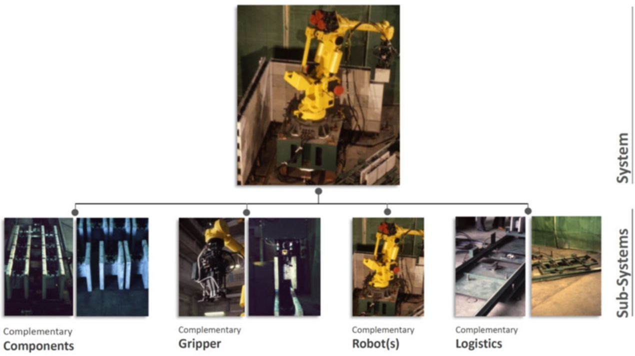


Pic 17 Brunelleschi sketches

Actually, you should be like a master builder. You should learn not only design of the product but the design of the process and the machinery just like the former master. The miyadaiku in Japan or the master builders in Europe, they make their own tools.

I happened to meet Mr. Engelberger at a conference. He talked to me after my presentation. He got so excited because he said he always thought a robot should be used more around industry. He did the first industrial robot in 1959 for General Motors. It was just pick-and place robot. And about the same time also, Konrad Wachsmann started this location orientation manipulator. But Konrad

Wachsmann didn't call it robot, he called it LOM, but he had seven degrees of freedom. So actually, Wachsmann, theoretically he was more advanced. And for me, it was then in 1984, I got into robotics. I produced this robot in the building research establishment in Tsukuba. I could assemble wall, I could design these blocks and the jointing system, and the end effector.



Pic 18 Solid Material Assembly System (SMAS)

Those days it was very difficult to program a robot. You had to program each point, and so it took quite long to program a robot, 35 years ago. And what happened is that the wall didn't become straight. So I was wondering why. So redesigned the blocks and the blocks are designed like a LEGO block, and then the jointing system because Professor Iguchi told me, in Japan all the walls have to be reinforced because of earthquakes which I did not know because I came from Germany. So I had to integrate the reinforcement, but I thought I don't integrate the whole reinforcement bars because it's too difficult. So split up the reinforcement horizontally and vertically for each block, and then I had to join it together.

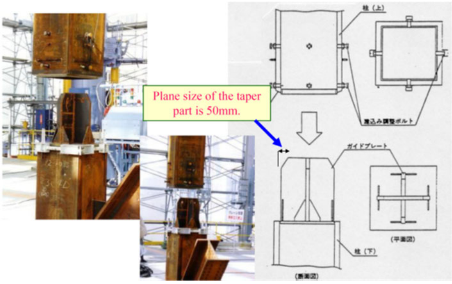
In the United States, I experienced mobile homes are very fast quickly installed onsite. You just bring it on there and you can only live in it. And the longest time for onsite is masonry because you have little pieces. So I thought the best would be if you combine both worlds. I want to have very fast production in the factory and very fast onsite production, so I thought I'll do a little block system, and I sampled very quickly this robot. You have to balance what you do onsite, what you do in the factory, and it's all decided by the design which is oriented towards the final assembly onsite.

And also, the flexibility of the design, of course as a mobile home, you can't change much anymore. And if you have masonry, you can do whatever you want to do, but it takes quite long to make it. So I thought if you have this kind of block, little blocks like bricks assembled thickly by robots. I have a high flexibility in design, and I can be very fast almost like a mobile home. And then, I structured the whole product and the process, what I'm doing onsite, what I'm doing in the factory. And I decided each component level. And then, I had two extremes. I had one which has a very high prefabrication ratio, and the other one had a very low prefabrication ratio, so you can shift in between. And then, I came up with this solution. And you see the kinematics and the joining system, and the reinforcement bar integrated into the wall.

But the problem was the robot could not move to the next position. I needed a little bit more time to solve the problem. If you check conventional construction sites, like in Germany it's kind of messy. Workers look around most of the time to search for some materials or tools.

The building blocks were in each position, very precise so the robot knows where to get it. Otherwise, if you do it in a messy way, the problem is lots of sensors could detect the material. And it happens sometimes. It's dusty, it's rainy on the construction site and the more sensors you have, and it's easier to fail.

And later, I was involved in this site from Shimizu, and I also designed the joints again between these columns. And here, you see the original drawings from Shimizu. How we adjusted all the joints, so they can be assembled by the robots.



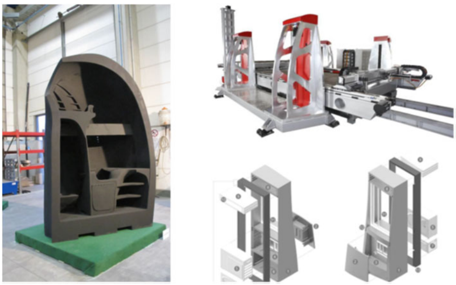
Pic 19 robot oriented design in Shimizu

And then also for Yuanda and they want to have very pavilion building for the expo in Shanghai in 2008. And then later they built several high-rises. And also, I was involved in the joints. So these buildings could be like a 10-story building in a week, 20 stories in 10 days, 30 stories in two weeks, and up to 60 stories in three weeks. So you can be very fast if you think about the final onsite activity already during the early design stages. I call it robot-oriented design.

Pic 20 57 story buildings in 19 days

And of course you can also apply to it for 3D printing. But for 3D printing, it still takes a long time, so I will only use 3D printing for small parts that each part is different. For example, this part is about two and half, almost three meters tall and 150 wide and one meter deep. It took about 120 hours. It's too long to produce. It's normally used for aircraft components (Pic 21 left).

And now, we do some robotic refurbishment of the exterior walls, and we have to attach high-precision exterior wall components to an old building which was built 50, 60 years ago. So the precision of the old structure is not high, so the joint has to compensate for the inaccuracy. So we just print out the joint which is the complied joint between the high precision exterior wall and the low precision structure (Pic 21 right).



Pic 21 concrete component 3 D printing

And I was involved in a project in Germany. Frank O Gerly, he made this kind of building, and I proposed to the German general contractor, we can do it with a robot. And they said, "No, we cannot do it." So we are betting. They say, "OK. We do three buildings and you can do one with your method." And so I got some software from CATIA, a French aircraft maker Dassault produced this system for aircraft manufacturing in the mid-90s. I could produce each precast concrete in a different shape because it's almost like an aircraft wing. The shapes are changing, and we were actually faster than the conventional way even for first time use.

Pic 22 Gerly building in Germany

Then, I show you some of the prefabrication I did. The problem is with little bricks, it takes quite long to assemble them. So the company asked me to produce a prefabrication order for brick walls, which is actually stupid because first you make a little brick and then you assemble it. But they already have invested in the brick making facility. First, I have to cut and sort different bricks as you need it in the wall because you have some openings for windows or doors and so on. And then, we assemble it.

Pic 23 robotic production system

And this second one, a different company, I choose a horizontal way just like you have this table here and a big metal table like 5 by 12-meter size almost like this room. And the robot places the bricks on this table. And this company was a little bit more flexible. They produced the brick according to my recommendation so the robot can grasp it easily and we can also place some reinforcement bars. We can place some water pipes, electrical wires, and so on. So the walls were already highly prefabricated. Some for the bathroom, windows, everything is already in there.

Pic 24 brickwork robot

And the same I did for concrete panel production. I developed a multifunctional, multipurpose production unit for concrete panels. So on one station, you could produce floor panels, wall panels and roof panels. And this robot was built in 1990, and it could already set all the formwork and place the reinforcement.

Pic 25 concrete component system

Some project we are planning now with Hong Kong and to make a high speed shuttering system. In fact, Hong Kong is one of the most expensive cities now. The living cost, real estate is more expensive than New York, so it's difficult for people to afford their own apartment. So we're trying this industrialization to bring down the cost of housing. Then, the robot places the reinforcement and then distributes the concrete.

I built the prototype at the University of Karlsruhe where I got my first professorship at the civil engineering department. I was the only architect, and they were shocked that I even built some robots. And I could exchange the end effectors, I changed the kinematic, and I could to all kinds of simulations in the laboratory. And later, became this kind of machine for production of concrete panels or brick walls or etc. And this is now one of the most advanced system. It's running in Britain near Nottingham. And now it became a commercial product and you see here how they placed the formwork, was this big robot.

Also, we did one of the fastest construction of housing in Germany. This was already about 25 years ago. And all these concrete panels were made by the same machine. So this whole building was assembled in eight hours and it only cost about 80 thousand euros, so it's affordable.

Pic 26 concrete panel houses

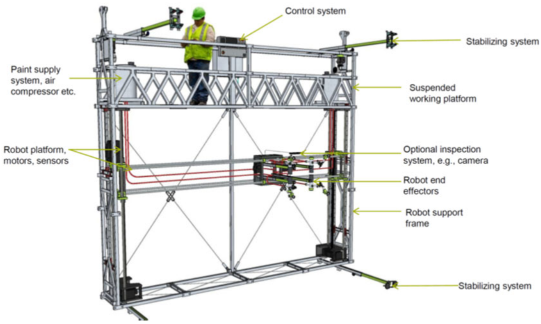
For onsite, there are now about 500 robots worldwide. During my PhD, I analyzed about 50 robots. The first 50 robots that have ever been built, and they're also not only recorded down, but also I went onsite, and I could see when they fail. So I could see the problem of diverse robots that had been used, and therefore I came up with this notion of free design and robot-oriented management to change the construction management, change the design, reengineering the whole process. Just imagine the first cars. They looked like horse carriages. Instead of the horse, you had to put a little combustion engine. And then, after the first car was a horse carriage, that's why it's called a car. "Car" comes from "horse carriage". And just imagine a horse carriage and how the car are nowadays. Now, we have affordable cars and mass-produced cars, but those days nobody could afford car. And the horses were faster than the cars. So you need to change the whole design of the horse carriage to become a real car. You need roads, you need fuel stations because they didn't exist before. But if you don't give up, then the chance is very high that the new technology will take over an existing one.

In construction, it will be more difficult because we have a very long product life cycle, so the products live longer than we live. So it's difficult to get some feedback. You die before you get the feedback whether the building was successful.

Even so you're an architect, I recommend you to also check civil engineering machines because the construction machinery in this sector is more advanced. I just came back from visiting an automated robotic excavator field in Kyushu. You know there happened some earthquakes three years ago in Kumamoto and a big landslide, and it's too dangerous for humans to go in there. So they go in this teleoperated robotic excavators.

Pic 27 teleoperated excavators

This one is a painting robot, first robot for Hong Kong now. They use this gondola to paint by hand. So I developed some attachment to this gondola, and then we can attach the robot there because the workers are used to the gondola in Hong Kong for social housing. Public housing is a little bit difficult because they have a peculiar design. So it's difficult to paint, so the robot needs to be very flexible to adjust to all the different shapes of the façade.



Pic28 painting robot for Hongkong

It's also a project for exterior walls. You have to think about the whole value chain, from design to prefabrication and to onsite and maintenance because then you can optimize the whole process. Here, we're going to place again energy efficient exterior walls and take off the existing old exterior wall because the problem in Europe is you have 98 percent of building stock. And this building stock is not energy efficient.

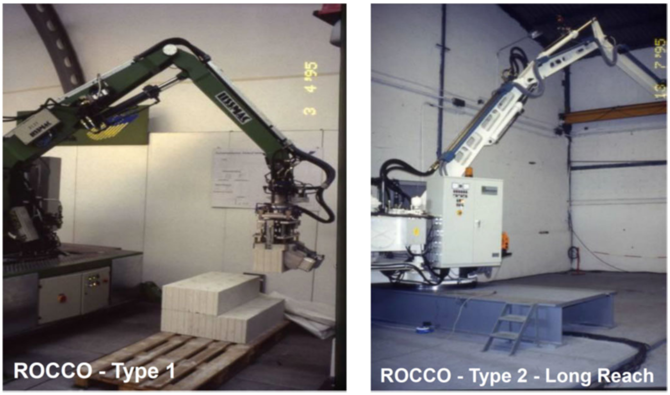
So it doesn't help if only the newly built houses or buildings become energy efficient. And I developed a kind of spider robot supported by eight cables.

Pic 29 eight cable robot

Conventional façade assembly is very difficult. They put it in from the crane hook. Sometimes if it's windy, this façade swings around, it hits and the glass breaks or it destroys the joint. And workers hurt themselves, so it's not an easy task. Therefore, we propose this kind of eight cleaver supported spider robot which is based on this robot that was developed for aircraft manufacturing. I've been to Toulouse, to the factory of Airbus, and I've seen this cable suspended robot. It was developed by the French Institute Laboratoire de robotique. And I told them, "OK. Let's take this robot and flip it around 90 degrees." The idea was good. We got the European funding because everybody said, "Wow." But after, I thought about it, “Shoot. I shouldn’t have proposed it because it’s really difficult.” Because if you flip it around 90 degrees, the center of gravity is off center, especially if it has to handle an exterior wall. So we have to develop a very special joint to adjust to this huge torsion due to off center of gravity. Just imagine you are hanging up to one-ton piece and it’s off-center and really is not straight anymore. So I decided in a two-step motion. First, we do the rough positioning, and we correct distortion. And then, we do the fine positioning and attach the façade.

Here, you see the first European onsite robot we did. Those days, it was in the mid-90s. There was not funding for robotics in construction, so I had to convince the European commission, and they told me, “Sorry, we have no budget. It doesn’t exist.” I said, “Look, it already exists over 10 years in Japan.” But they didn’t believe. So I had to get money from the mechanical manufacturing side, but they were not happy about that somebody from the construction industry tries to get money from manufacturing. But anyhow, we were successful. I teamed up with the professor from manufacturing. He was a famous professor in Spain. And he had a good political connections and I had the ideas, and then we got the money for the first European robot for onsite.

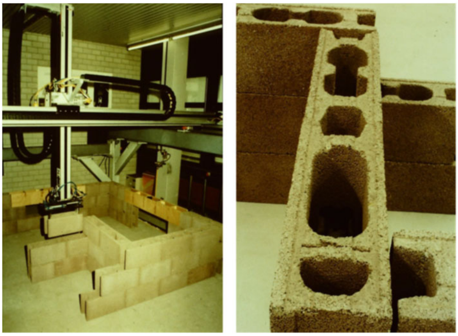
And then, we built two robots. One for housing construction, one for commercial building construction as a longer reach.



Pic 30 ROCCO (Robotic Computer Integrated Construction)

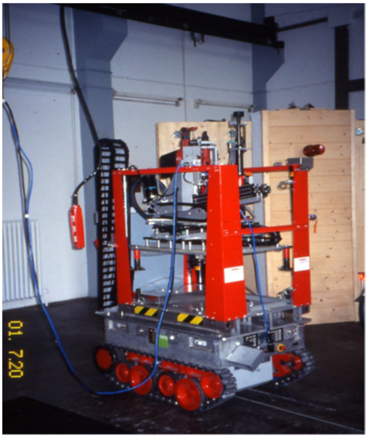
Those days, there was no high payload robot. The highest payload robot had 300-kilogram payload, but I wanted to have one ton, so we even had to develop our own manipulator, of course the own end effector which was a robot by itself, and the vehicle. So we did actually three robots. And I checked all the interface between the work piece and the work tool. This is something architects don't learn, but mechanical engineers learn it. They learn that the work piece and the work tool which is very important. Just think about Brunelleschi or master carpenters. They always think about both the tool and the product because if you don't think about the tool, you just think about the product.

And later also, with wooden blocks, when I moved to Bavaria now in Munich, the Bavarian state has a lot of forests, so they asked me, "Why don't you develop something we can use to sell our wood in the forest?" And I developed this kind of wooden building system which could be assembled by robots, for example, or do it yourself. Because if it's designed for the robot to be assembled, it's also good for somebody who has no experience. It can also be used for Do-It-Yourself.



Pic 30 robotic assembly of modular blocks

And this is the first interior robot in my laboratory in Munich. I designed a module system. I designed the locomotion unit and different work units for all kinds of interior task forces. Then, the ceiling assembly, interior walls, or logistics, or floor and roof tiling.



Pic 31 first German interior finishing robot

And, some exoskeleton, now some construction companies already use it. Also, in Hong Kong, the average age of the workers onsite was over 50 years, so some Hong Kong construction companies start using exoskeletons. I know one company which has 30 exoskeletons for their workers.

Pic 32 exoskeletons

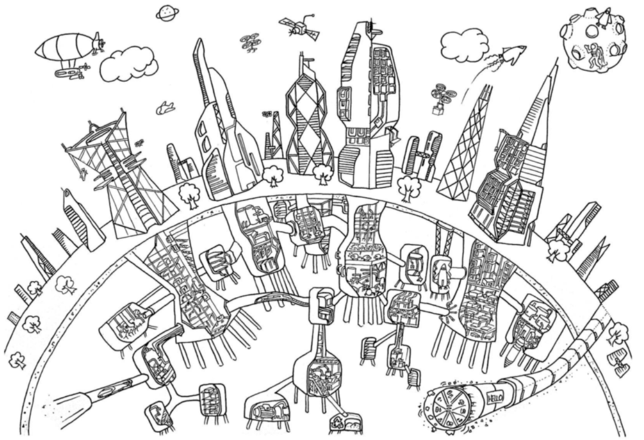
The next challenge is the humanoid construction robot. I just visited a construction site in Kyushu where they use a humanoid robot controlling an excavator. And this was a research project in Tsukuba at the National Institute of Advanced Industrial Science and Technology about 15 years ago (Pic 33 center). This is a humanoid robot developed by Kawada Sangyo and tested for cooperative work for interior wall assembly (Pic 33 left). It started out from a construction company of steel switches and then later, there was a construction slump, and they got into teleoperated helicopters for spraying fertilizers on rice fields, and then they developed this humanoid robot.

Pic 33 Humanoid construction robot

This is a German robot for tunneling construction, I was involved in. So here also, the work is very hard to do, so I tried to automate it, but the tunnel boring is some interesting tunnel boring machine, also fully automated for big tunnel sections. The segments of the tunnels have been prefabricated above ground and brought down with the lift, and then brought inside a tunnel to the final assembly place. And then, we have the robot assembling the tunnel segments. So there is no human involved anymore.

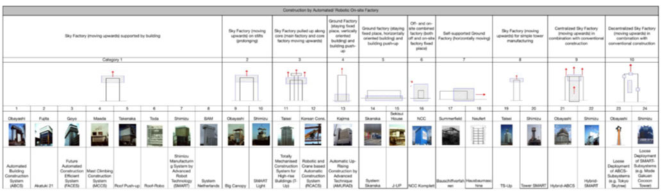
Pic 34 tunnel construction robot

Here’s the vision from my assistant (Pic 35). And the final one is the automated site. I think in the future, maybe megacities might use some kind of heavy payload drones. I don’t like little drones. They’re just toys. But if you would develop some kind of heavy payload drone that can carry several tons, then it could be really useful because just imagine the traffic in the cities. I’m very often here or in Osaka or in Hong Kong. And the traffic is awful. So if you have construction traffic, it’s even worse. So why not do the logistics by air, and then you could inspect bridges and roads, or you could even assemble buildings. So here, repair the roads, and you don’t need to stop the traffic. And this is one of the earlier editions we had for autonomous road construction. I think we can actually design very new type of machinery because we don’t need cabins or we could do something differently, and then the operator would sit here like an air traffic controller and control the whole site. So it becomes more like an air traffic controller in an airport.



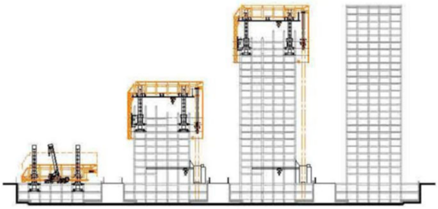
Pic 35 future infra

Now I want to show you for building construction, in the Cambridge books or before already, I categorized all the existing automated constructing sites to make a systematic production classification. So here you see the type, how the factory moves, and the logistics. Sometimes they have a two-way system. The core is built first, and the surrounding office spaces construction move follow. This is sometimes necessary when you have to build over some roads or you cannot block some train stations. You prefabricate the building and move it over.



Pic 36 classification of construction automation

This was the system I was involved in. This system pushes itself up in between the columns, and it has up to 20 trolley robots, so this system has most of the logistic robots that's been done here. So it's quite fast actually. And this was the first installation in 1992 in Nagoya. And then, it was going up until 1993 to build this bank building. And you see the construction site is very nice and clean. Here, the assembly of the floor panel. One of the 20 trolley robots. And they move over here, and this one cannot because now it's blocked, otherwise it will fall off. So it has to wait until the next rail appears, and then it can travel over.



Pic 37 SMART system

This is a Korean system (Pic 38) with the central core that was built independently, conventionally in a tower crane. The tower crane is the bottleneck. Because of the tower crane, the speed cannot be fast because you just have one logistic motion.

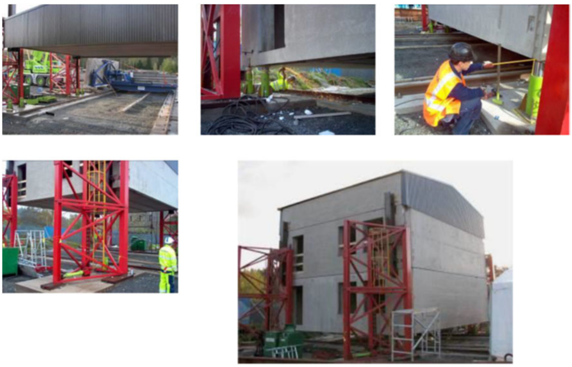
Pic 38CAS system

But the interesting thing here was the assembly of the beams they did. They developed a very sophisticated boating robot. You can see it here. It could boat these boat at the same. So this was kind of a nice device, but the rest was actually not so innovative. And here is the control unit for the boating robot.

And this system (Pic 39), first build the roof and then push it up. And if you look at these tracks here where the robot moves on the ground to build the building and then push the floor up, these tracks look similar like when you visit the tracks of the Airbus 380 factory in Toulouse because the 380 is such a huge airplane. It cannot move. When you go to Toulouse, you can see they use similar tracks on the ground because they have to move everything to the airplane, to the aircraft. And here, one of the huge hydraulic presses. They have power of up to 1,600 pounds.

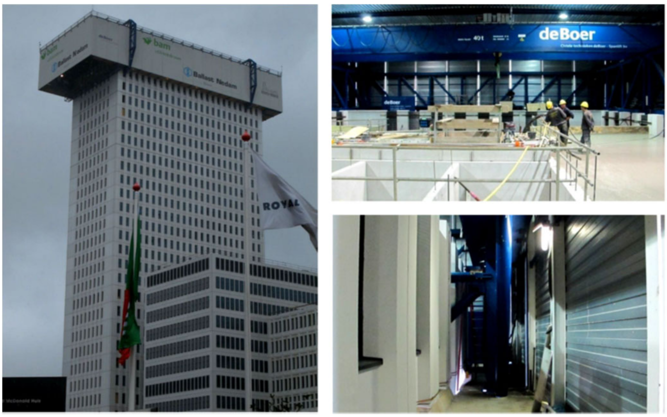
Pic 39 Amurad system

The Swedish copied a little bit this system, but they modified it because in Sweden, they don't build so tall buildings, just five floors. And they use large concrete panels like they use in Europe. It's about 12-meter lengths. But it's not an automated system. Everything is still operated. But why they do it? Because in Scandinavia, the winter is quite long. So they want to build all year around. And if they build first the roof, then they can do the rest under the roof protected by snowfall. So here is the typical Swedish building, five stories, six stories like here. And everything is onsite and teleoperated.



Pic 40 Swedish site automation

And this is also a very nice site in the Netherlands. It also was necessary to build in this way because in Netherlands, they have the law, if you install a tower crane, and you move over the next building, you have to consider a falling angle of seven degrees. This means the whole medical center has to stop operation which is not possible because one of the biggest medical centers in Netherlands. So I proposed to them to do it in this way. So here, we can do it everything in capsuled, so you don't need to sway over the next building. And this is also teleoperated. This was one of the nicest construction sites I've seen in Europe because it's very clean and precise. The whole tower is about 135 meters. It's due to the prefabrication of high-quality components and the onsite assembly.

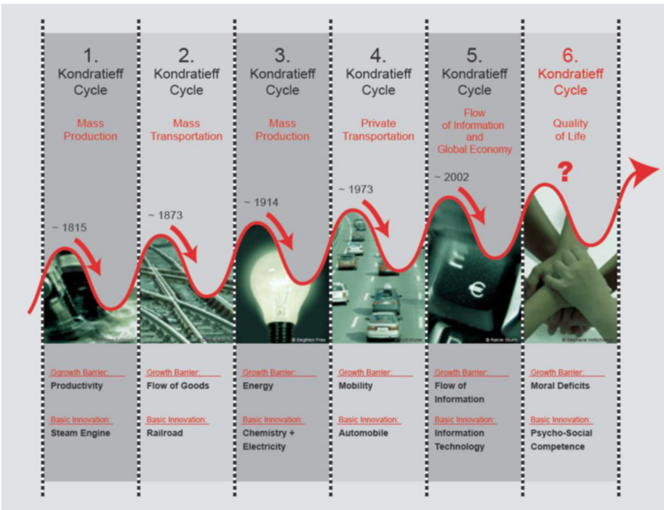


Pic 41 high-rise construction in Netherland

Here you see the next step, the deconstruction. So we cannot afford like I mentioned before to use implosion or wrecking ball, and then you have huge waste problem. So I think it's better in the future to think about the whole recycling, you can disassemble systematically, you can fix it again and upgrade the components. This is actually how our ancestors did it. When I built as a student, in a little village, I found very nice bricks, and I was wondering why. And then some farmer told me they're from some church when they divorced this kind of movement against the church in Europe. So they burned some churches, they disassembled them, and the farmers, they used the stones of the church building. Just recently, we just throw it away. Here is some disassembly site in Osaka by Takenaka, and from top down disassembly.

Pic 42 Hat Down Method (Takenaka)

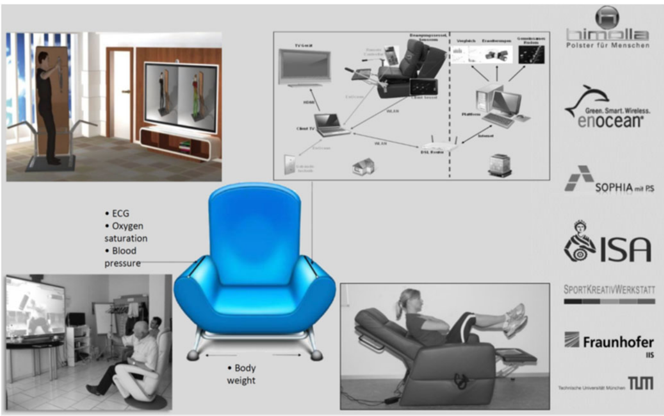
I think now, I'm also a member of the Russian Academy of Construction Science, so the Russians have some interesting researchers. Mr. Kondratieff put this notion of the social economic cycles. And he found out that when you have some new technology approaching, and you cannot deal with it, you start having societies that are having some problems whether it's civil unrest, unemployment. You could divide the relation between conflicts and wars and technological changes. So the social technical change and the trends are very important.



Pic 43 Kondratieff cycle

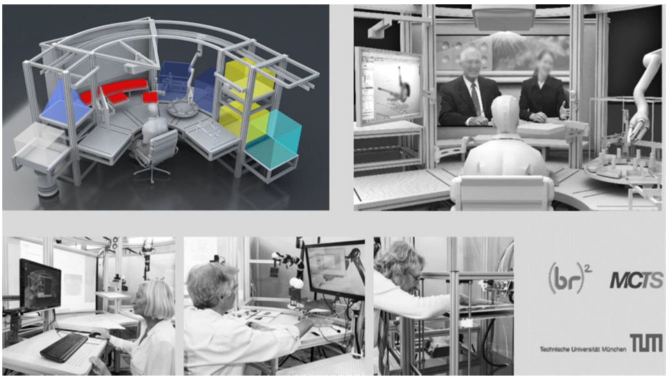
Now, it’s maybe about the aging society. So quality of life and health and this kind of thing, this could be a big challenge. And there’s already an indication that there might be bigger problem in the future. So if you cannot deal with it, then it might get worse. So, what I’m dealing also in research is first the robot builds the building, and the building becomes the robot, or the furniture becomes the robot. So the building can adjust to change in demands of the client.

We design a chair because old people like to sit in a chair and watch TV, so while they’re sitting in a chair, they check their health data even if they don’t wear any wearables like Fitbit. So they don’t become too lazy, the chair also an exercising machine.



Pic 44 GEWOS (Gesund Wohnen mit stil)

Or old people have good experience, but we don't ask them anymore. So I thought why not, some of the elderlies are confined to reach. I thought, let's design a cockpit work station like an aircraft cockpit because the panel sits on one place and can control the whole aircraft. You have a scanner here, you can work together with the robot, and you can print something. And everything is done in such a way that they can handle it without the need to program the robot because they control it in gestures. If they have some sort of skill, they can teach the robot actually. Maybe the robot can teach some inexperienced people. So here, they test with real elderly from the neighboring care home in Munich. It's about 500 meters away. We have a care home with 600 rooms and these old people, they really like to come to my laboratory and try out the new equipment.



Pic 45 Robot Assisted Working

Here, we developed the whole apartment. I call it terminals or mechatronic walls that have medical sensing, remote sensing, some robotic devices built in. And here, I'm standing in front of the bathroom mirror, and it's checking my fever. And here, I have again the sensor for the blood pressure and for the pulse rate and the arm rest.

Pic 46 LISA (Living Independently in Sudtiral Alto-Adige)

And, we developed some fall detection system. I had this idea of the fall detection while I was giving a talk, and later, I told my assistant, get this thing here. He disassembled it, and he found a little laser in there, and it only cost one to two euro. And we use it as a beam, and once the beam is cut, we know something is wrong. Of course, we have to look back side too because it could be wrong. But by reflection, we can tell it's a head, it's a bath towel, it's a human. And now, we use LED's. The laser was sticking out like two, three centimeters. It's very cheap. This one costed, for one bathroom, about 200 euro, the fall detection system. The existing system costs about 20 thousand euros but doesn't work in the bathroom because they use capacitors and they don't work in the humid space. And now with LED's, we are down to about 50 euros. But LED's are not so precise so we need many of them, but still we can tell it now whether it's a person that fell down, and we can send in a robot, or it can be contacted by some care person can stop by. Because it happens quite often in Germany that people fall in their apartment and nobody realizes. And we build our own sensors for contact less sensing of the health status ourselves. I employed some electrical engineers. And once we tested the components, we bring it to another care home. We already supplied two care homes in Italy. We developed for them and we installed it very fast. We shouldn't disturb the people in the care home too long. Normally, if you install something, if you put timing for a bathroom in Germany, if they fix it and remodel both bathroom, it takes about a week. This is awful. Old people would never accept it. They cannot use the toilet for one week. And so we do in such a way that we can do it in 30 minutes. It's like a plug and play system and everything is modular. You can configure any layout you need. And then also we test how they can deal with the system and they use the NASA task load level, what the NASA developed for astronauts. I asked some Italian designer from Milano, an industrial designer, a product designer to design this furniture because it has to look good or people wouldn't want to have ugly looking furniture. This can incline and it can help them getting out from the bed. This can lift up their legs, it can lift up the body, it can help you with putting on and taking off your shoes and so on, but you don't see it. It looks good. The Italian designer got actually an award for this too.

Pic 47 LISA designed by Italian designer

This is my laboratory in Munich. If you're in Europe, you can visit me, and we have constantly foreign researcher students here. Here is like the cockpit like workstation. Here is the apartment which is built like a theater so we can change everything in three dimensions.

Pic 48 laboratory in Munich