# Appendix: SMART projects conducted at VUB

### Seyedreza Kashef Tabrizian: "Researchers like to make technology complex, industry, however, likes it simple"

If soft robots want to enter mass market applications, their technology will need to be good, but researchers will also need to learn to speak to industry. In a secondment Seyedreza Kashef Tabrizian, a PhD candidate at the Vrije Universiteit Brussel (VUB) & imec, did exactly that. He learned how to convince industry to take a risk on self-healing robots.

Kashef Tabrizian's research tries to integrate soft robotics and self-healing materials. "Soft robots are, predictably, made out of soft materials", says the researcher. "These materials are resistant to, say, collisions, but don't withstand contact with sharp objects. That's why it's key to also make them self-healing."

The researcher is trying to create a system where possible damage in a soft robot can be easily localised, and healed. "The human body has a nervous system that can detect damage. Robots also need this ability. They need to sense damage, localise it and see how severe it is. They need to do damage detection, clean the puncture and then close the damage up. All of this, we should do autonomously, without the intervention of a human."

In his design, Kashef Tabrizian uses heat to heal the damage, with the heater integrated into the robot design. In this way the robot can autonomously heal itself, and doesn't necessarily need any human intervention when it's damaged.

"When you need external assistance it increases the cost", says Kashef Tabrizian. "You need to have people monitor and fix the robot. When the robot is self-sufficient it works better. Then there's also robots working in environments where there's limited human access. Take for example space exploration. If a robot is damaged on Mars, and cannot heal itself, that's a big problem."

#### Complexity

To develop these ideas Kashef Tabrizian did a secondment at the German robotics company Festo. There he discovered where his ideas ran into their limits. "In research we don't care as much about complexity", says Kashef Tabrizian. "We make our systems more complex, while industry likes to have things simple. There's a gap, and we need to bridge it."

The researcher is positive about the experience he had in the SMART project. "SMART was a good opportunity for me", says Kashef Tabrizian. "It allowed me to broaden my network, and do events in a lot of universities across Europe. Also, going to industry for three months was key for my ideas. It was great training on how to convince industry to do something with your technology. We tackled a lot of challenges, and convinced them to start taking risks."

In the process, he also learned lessons beyond what can be taught in academia. "Researchers need to be more realistic", says Kashef Tabrizian. "We sometimes

oversell our research. When you approach industry and do real field tests, we're forced to be honest with ourselves."

**Francesca Furia: Why it’s hard to 3D-print soft, self-healing materials: “we're linking the worlds of robotics and materials”**

Soft, self-healing materials are poised to change fields from robotics to recycling. They are also notoriously hard to 3D-print. Francesca Furia, a PhD student at the Vrije Universiteit Brussel (VUB), is trying to change that. For now, however, some hard research into soft materials remains.

Furia is trying to improve the properties of self-healing polymers. These polymers already exist, and they can under various circumstances repair themselves when they, for example, are punctured. They are, however, often hard to 3D-print. A conundrum Furia is trying to solve.

"Regular polymers crystallise very fast after they are 3D-printed", she says. "Self-healing polymers, however, solidify much slower, which makes it hard to print them."

Furia is looking at several avenues to combine the best of both worlds. She for example added fillers to the chemical matrices of polymers, which shows promising results. Together with another colleague, she also added dynamic bonds to improve print-ability.

**Different worlds**

When these new materials will be available, however, remains uncertain. "It's gonna be sooner than expected", she says. "But we still need to do quite some research. The main problem is that a lot of regulations need to be followed. Even if the material is ready, we need to go through this process."

In robotics, interest is high for 3D-printing soft, self-healing materials. "It could be used for human interaction", Furia says. "Today, robots made from hard materials like steel are quite dangerous for humans. But if we make them out of soft materials, the danger is lowered dramatically. Soft materials would also improve their performance. If a robot arm needs to pick up, say, a tomato, then you need soft tissue to do that. A steel robot will probably just squish the tomato."

Even beyond robotics, the potential of these new kinds of materials is great. "We could really reduce a lot of waste with self-healing materials", says Furia. "Right now a lot of synthetic soft materials are thrown away after they’re damaged. If they would heal themselves, that would reduce our waste pile significantly.”

During the SMART project Furia could cooperate with roboticists on these questions. "It forced everyone out of their comfort zones", she says. "It makes you understand how important communication is. We're linking the worlds of robotics and materials here. The first barrier to overcome is to show the other side what the possibilities, but also the limitations, of your field are. That's exactly what we did here."

**Aleix Costa Cornellà: How castor oil is making the unrecyclable recyclable**

Sustainability needs to be front and centre of science, not just an afterthought. That's what Aleix Costa Cornellà, a PhD student at the Vrije Universiteit Brussel (VUB), is trying to do in his research. His work on soft and self-healing materials might just help us recycle unrecyclable waste.

Costa Cornellà tries to make self-healing materials as sustainable as possible. "My lab in the past has already developed a first generation of self-healing materials", he says. "But this material has a lot of drawbacks."

Which is why they designed a second and third generation of the material. The first generation was a synthetic material. The second generation, however, was based on castor oil. This has a range of advantages. The oil is not toxic, but also not edible, which doesn't make its cultivation compete with food sources. Now they are designing the third generation. This material would still be self-healing, and have a sustainable source. But it has the added property that it can be turned into a liquid under certain conditions. This would solve a major recycling problem.

"A lot of materials today cannot be recycled", says Costa Cornellà. "Rubber tires are for example made out of a material that's impossible to recycle. There are of course processes to re-use them in some way, where recyclers grind them into fine particles. But that's not ideal. Often the tires are just burnt to at least recover some energy, which is very bad. If we would make tires from this new material, we could recycle them by exposing them to heat. Additionally, they could self-heal when they develop a puncture."

**Sustainable by design**

New materials are, according to Costa Cornellà, crucial in our transition to a more sustainable world. "We're destroying the planet", he says. "Materials that cannot be recycled need to be replaced by new materials. That's why this research is so important."

When these new materials will be ready for mass use is, however, still uncertain. "They are already used", says Costa Cornellà. "But that's mostly in niche markets. Hopefully we can reach mass markets in a short timeframe, in around five years."

For the young researcher, the SMART project offered a step forward."I learnt how to manage a long-term research project", says Costa Cornellà. "It meant that I learned new skills, and the experience took me out of my comfort zone."

For Costa Cornellà a mind-shift needs to happen in scientific research, one that places sustainability at the centre of technology. "Sometimes we first develop the technology and bring it to market, only then do we think about sustainability", he says. "In my opinion any technological advance needs to use sustainability as a main driver in its design process. It needs to be incorporated from the bottom. That's what my PhD is all about."

**Marwa ElDiwiny: Why bio-inspired robots might be the future: “in the beginning I doubted myself a lot”**

ElDiwiny’s research relies on inspiration from nature. "Mother nature has already figured out many of the problems we face in robotics", she says. "Take for example the issue of soft robotics. Most robots in factories are rigid, and not safe to interact with. If we want to introduce them into our homes and daily lives, they will need to be soft. But at the same time they will also need to be able to resist damage."

According to ElDiwiny, the solution to this problem might be in animals that combine soft and hard tissues, such as shellfish that carry a seashell for protection. She looks at the morphology of animals to inspire designs of robots.

But finding this ideal balance between hard and soft might also have applications beyond just robotics. "Another use-case is the design of insoles. We want their design to better support runners’ feet, but we also want them to serve for a long time", says ElDiwiny. "By combining hard and soft materials, we can do this." In the SMART project ElDiwiny also designed a sensor based on the structure of a spider web. This structure would make the sensor more resistant to damage.

**Fashion**

This kind of biologically inspired design has the potential to impact many fields according to ElDiwiny. One of those is clothing, where bio-inspired designs are already being used. "Nike and Adidas are investing in artificial muscles'', she says. "Clothes that are supporting athletes need to resist damage and be strong."

In academia, bio-inspired design, however, isn’t always accepted. "In the beginning there were a lot of doubts about this research", says ElDiwiny. "I doubted a lot whether this was a good idea. But just now several of my papers got published. The entire journey was very interesting for me."

ElDiwiny is confident now about the future of her research. "I'm obsessed with nature, and coming up with these new solutions. I'm happy I can take it forward."