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Challenges and opportunities of utilizing design thinking in the industry 4.0 era: based on the case study of industry wastewater treatment system development project process

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Abstract
This paper reviews the research process conducted on developing a new system for industry wastewater treatment application to increase efficiency and sustainability by adopting industry 4.0 technology. The challenge of this project was to (a) utilize the design thinking methodology (human-centered design) entire process; (b) focus on heavy industry rather than the targeted user; and (c) adapt state of art technology. The objective was to revisit and invent new methods, such as metaphoric analysis, body thinking, and organization persona that would contribute to high-level innovative ideas: specifically, (a) the organization persona allowed to understand the dynamics of the complicated stakeholder structure; (b) the role of prototyping was mainly descriptive for communication; and (c) the case's idea generation was used to affect the entire process of the project as well as benchmarking other industries. This paper attempts to address whether it is possible to create a new methodology that would address innovative business opportunities in complicated and high-tech adapting industries.

Keywords: Industry 4.0 technology, Industry wastewater treatment (IWWT), Design thinking, Design-driven innovation, Business model generation

Introduction
Currently, we are entering the fourth industry or Industry 4.0 revolution era which is likely beyond our imagination and expectation compared to the industry 3.0 experience and tools. This project for Georg Fischer was to create ways of transforming the existing industry wastewater treatment system to an innovative one by utilizing industry 4.0 technology. The authors cannot say that this project is a typical model of transforming the industry by utilizing Industry 4.0 technology. However, this experience would be a good way of learning how design thinking methodology can be used in an industry 4.0 project.

Industry 4.0

"The scale, scope and complexity of how technological revolution influences our behavior and way of living will be unlike anything humankind has experienced." The fourth industrial revolution, a term coined by Klaus Schwab, founder and executive chairman of the World Economic Forum, describes a world where individuals move between digital domains and offline reality with the use of connected technology to enable and manage their lives. It is a fusion of technologies that blur the lines between physical, digital, and biological spheres (Schwab, 2015) (Table 1).

The Fourth Industrial Revolution was built on the Third, i.e., the digital revolution that has been occurring since the middle of the last century. There are three reasons why today's transformations represent not merely a prolongation of the Third Industrial Revolution but rather the arrival of a Fourth and distinct one: velocity, scope, and systems impact. The speed of current breakthroughs has no historical precedent. When compared with previous industrial revolutions, the Fourth is evolving at an exponential rather than a linear pace. Moreover, it is disrupting almost every industry in every country. And the breadth and depth of these changes herald the transformation of entire systems of production, management, and governance (Schwab, 2015).

Industry 4.0 cannot be defined well, but it includes the following: smart factories, cyber–physical systems (CPSs), Internet of Things (IoT), and services, self-organization, new systems for distribution and procurement, new systems for the development of products and services, adaptation to human needs, and corporate social responsibility (Jazdi, 2014; Lasi et al., 2014). Connecting people, objects and systems lead to the emergence of a dynamic, real-time optimized and self-organizing cross-company value network that can be optimized based on different criteria such as cost, availability, and resource consumption (Plattform Industrie 4.0—Fehler!, 2021).

Since the Fourth Industrial Revolution affects business models, it could reshape customer expectations, the quality of products and services, open and collaborative innovation, and the organizational forms to deliver values. Job specifications and professional competencies in various innovative business models should evolve through these developments.

While new technologies and platforms are increasingly enabling citizens to engage with governments, governments are facing pressure to adjust their systems of public engagement and policymaking. New technologies make the redistribution and decentralization of power possible. Technological developments also affect aspects of our

Table 1 Main characteristics of industrial revolutions (Prisecaru, 2016)

Period	Transition period	Energy resource a	Main technical achievement	Main developed industries	Transport means
I: 1760–1900	1860–1900	Coal	Steam engine	Textile, steel	Train
II: 1900–1960	1940–1960	Oil electricity	Internal combustion engine	Metallurgy, auto, machine building	Train, car
III: 1960–2000	1980–2000	Nuclear energy Natural gas	Computers, robots	Auto, chemistry	Car, plane
IV: 2000–	2000–2010	Green energies	Internet, 3D printer, genetic engineering	High Tech industries	Electric car, ultra-fast train

individual lives, such as our sense of privacy, consumption patterns, career developments, work and leisure time, social networks, and relationships. The impacts could be bounded by our imagination, while disruptive applications are possible (Lee et al., 2018).

Design thinking

Design Thinking is the latest successor in a long-ranging history of research and development on design methods. More than half a century ago, in the mid-1960s, a need for a structured design process arose due to the rising complexities of developing technologies (Beckman & Barry, 2007). Herbert Simon was the first to describe the design as a "way of thinking" (Simon, 2019). Design Thinking was grounded in the observation of how designers approach problems and how they develop new solutions (Cross, 1982).

According to David and Tom Kelley "Design Thinking is a way of finding human needs and creating new solutions using the tools and mindsets of design practitioners" (Kelley & Kelley, 2013). Design Thinkers combine empathy for the context of a problem, creativity in the generation of insights and solutions, and rationality in analyzing and fitting various solutions to the problem context.

Although many tried to define what Design Thinking is (Razzouk & Shute, 2012), there is still uncertainty whether to describe it as a methodology, a process or a mindset. The words design, designing, design process, design methodology was widely used to help create the best product with given, matching technology. We have been "designing" most of the products and services while the technology and the needs of the markets were matched, or at least being able to expect to a certain degree of imagination including form, material, shape, usability, etc. Because of that, most of the design theories and methodologies were developed based on this assumption.

Background

About Georg Fischer

The project was sponsored by Georg Fischer (GF), the global expert for the safe and reliable transportation of water, chemicals, and gas. GF was founded in 1802 by Johann Conrad Fischer in Switzerland. According to the official data in 2018 Georg Fischer has its own sales offices in 34 countries and 6852 employees worldwide. Benefiting from more than 60 years of experience in plastic systems and application knowledge, Georg Fischer Piping Systems provides its customers with maintenance-free, long-lived piping systems made of plastics and with support throughout all phases of their projects from planning to commissioning. In the trend of industry 4.0, Georg Fischer is looking for smart solutions for factories in the wastewater treatment industry. They always put customer needs first and keep innovating, hoping to bring the wastewater industry into a smarter, more automated future (Vision & Strategy—GF Piping Systems Ltd, 2015).

GF Piping System has been active in China since 1997 offering highly efficient water treatment solutions that can increase capacity by up to 50% even on the same footprint. Active in Asia since 1994, GF Piping Systems has grown from its regional headquarters in Singapore to a workforce of close to 600 employees in the Asia/Pacific region with additional 1400 employees in the Chinaust joint-venture in China. "Our solutions address ever-growing capacity needs and rising requirements for water quality and environmental protection", says Adrian Schwyzer, Global Market Segment Water Treatment at GF Piping Systems. "Anticipated stricter wastewater treatment regulations, requests for higher process automation, and process data monitoring and analysis are among the drivers for this initiative." (Making Water Treatment in China More Efficient and Sustainable with Design Thinking—GF Piping Systems Ltd, 2021)

Wastewater situation in China

Since 2016, China has become one of the world's largest countries in terms of wastewater treatment capacity (Zhongguo Yichengwei Quanshijie Wushui Chuli Nengli Zuidade Guojia Zhiyi [China Has Become One of the Countries with the Largest Wastewater Treatment Capacity in the World], 2016). According to the statistics, the annual treatment volume of industrial wastewater and domestic wastewater is up to 97.1 billion tons (Disan Fang Chuli Jiang Chengwei Wushui Chuli Hangye Xin Moshi [The Third Party Treatment Will Become the New Model of Wastewater Treatment Industry], 2019). Since 2015, China has issued policies to promote industry park wastewater treatment plants as the main body of industrial sewage treatment. According to the Action Plan for Water Pollution Prevention and Control issued by the State Council in April 2015, industry parks should build centralized wastewater treatment facilities by the end of 2017. The regulation has pushed more than 950 industrial clusters to build wastewater treatment facilities. The scale of wastewater treatment increased by 28.58 million tons/day (Shengtai Huanjingbu Tongbao Woguo Gongye Jujiqu Shuiwuran Fangzhi Gongzuo Jieduanxing Jinzhan [The Ministry of Ecology and Environment Has Announced the Progress of Water Pollution Prevention and Control in Industrial Areas in China], 2018). By the end of September 2018, 97 percent of wastewater treatment plants in 2,411 industrial clusters at the provincial level had been built. However, many incidents of water pollution have occurred in industrial parks, exposing the existing problems in the treatment process of industrial parks in China, such as inadequate policies and supervision. If the wastewater treatment plant in the park does not play its due role, it will seriously affect China's industrial wastewater problem. Due to new regulations, China was mandated to reduce environmental pollution, and factories and industrial parks are forced to comply with the new wastewater standards. Therefore, Georg Fischer aims at creating new solutions that support Chinese companies to adapt to the situation effectively.

Design procedures

Understanding wastewater treatment

To understand the wastewater treatment system and process, first, we need to elaborate on the water cycle and then look at the current processes in wastewater treatment by reading reports from environmental agencies, governmental standards, and industrial parks with pharmaceutical and chemical focus. Wastewater is a complex topic. To understand it in its context, we need to understand how it interacts with its environment. The term 'water cycle' refers to the movement of water from one sector to another and at the end, it comes back to the first sector. At large it is somehow all connected. Industrial wastewater is typically treated by a wastewater treatment plant until a permissible level is reached, and afterward, it is discharged into the environment. However, some of the industry-generated wastewater is directly

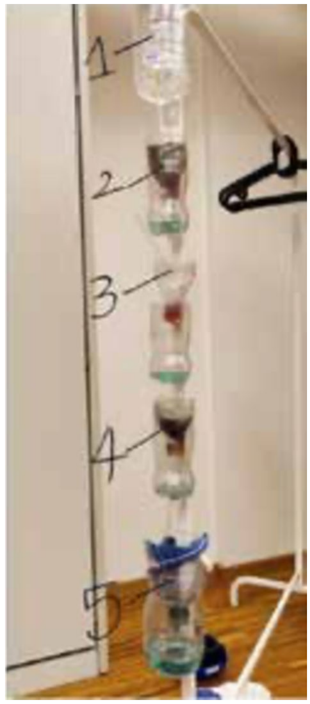

Fig. 1 To illustrate the wastewater treatment process created by using transparent plastic bottle

discharged into the environment illegally. The water consumed daily in household use for showers, drinking, and cooking has likely been wastewater and could have even been used for industrial production. Hence, it is essential to understand that it is necessary to treat industrial wastewater so that it is in the least toxic form when released into the environment because this water is reused for various other crucial purposes.

Industrial wastewater treatment (IWWT) describes the processes used for treating wastewater that is produced by industries as an undesirable by-product. In general, the industrial wastewater treatment process generally has four kinds: a physical method, a chemical method, a physical chemistry method, and a biological method. To understand the process, we constructed our wastewater treatment system. We built a wastewater system using transparent plastic bottles.

We began the process by stacking up the water bottles and numbering them based on different parts of the wastewater treatment process. We connected the bottles using straws. In the next step, we built various types of filters for the filtration and separation process. The second bottle was filled with sand and pebbles for separation. In the third bottle, a small handheld fan was inserted to create aeration action in emerging water from bottle 2. Bottle number 4 was filled with activated charcoal. We found out through a literature study that activated charcoal is an effective adsorbent because it is a highly porous material and provides a large surface area to which contaminants may adsorb. Bottle 4 performed the last step of filtration and disinfection, then the emerging water was collected in the last bottle, numbered 5 (Fig. 1).

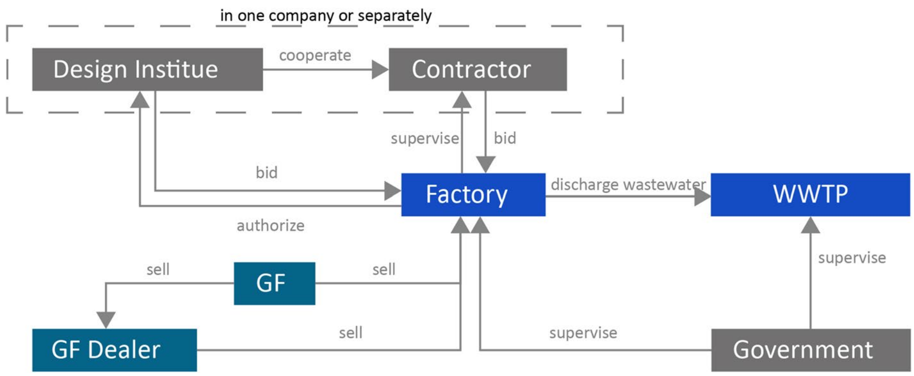

Fig. 2 Illustration of stakeholder map of wastewater treatment system around GF

Stakeholder research

To understand the ecosystem around the wastewater treatment-related organizations, we researched on the stakeholders to generate the stakeholder map. The stakeholder map is a business tool that allows one to see a visual representation of the company's various stakeholders (individual and groups), their level of interest in the company, and their importance to the company (What Is a Stakeholder Map?, 2015).

Figure 2 describes the relationship between major stakeholders in the industrial wastewater treatment ecosystem and the position of Georg Fischer. In this figure, the factory is the core of the wastewater treatment industry. The factory decides the purchase of wastewater treatment equipment. The factory chooses the design institute and the contractor to build wastewater treatment equipment through competitive bidding. In some cases, the design institute and the contractor can also be a more comprehensive environmental company that provides both design and construction. The construction material will be bought according to the required specification, i.e., it is not said that a certain product must be bought from a certain manufacturer, but that it must be able to withstand a certain pressure or temperature. Sometimes Georg Fischer sells products directly to factories, but most of the time, they sell products through their dealers.

The factories discharge their wastewater to the WWTP (Waste Water Plant). Some factories perform simple pre-treatment, for example, to remove grit. The government has a supervisory role over all the factories and the wastewater treatment plant. Most of the pain point lies in the interaction between factories, wastewater treatment plants, and the government. Thus, we added the wastewater treatment plant and the government into the stakeholder map to show a relationship between the supervisor and the supervised, which leads to the pain point and needs we defined in the next stage.

Empathize with in-depth interview

In-depth interviews are a means of engaging a user to gather information using either direct or indirect questioning techniques. Direct questioning techniques are focused on having the user speak about specific topics, while indirect questioning techniques are focused on getting the user to tell stories about various aspects of a topic. Both kinds of techniques are used together for a deep exploration of ideas so that the interviewer can develop insights about the user (Milena et al., 2008).

The interview is a step throughout our entire design process. We conducted our first interview with GF to find out the company's history and expertise. We interviewed the GF company's head of design innovation, for the requirements of the project and details. Then we interviewed the head of GF in China, to understand their industry status and enterprise culture in the Chinese market. Also, we talked with two GF engineers and product managers for information about their current technical ability and future research plan. At the same time, as the conference was held in a scientific research institute, we also interviewed some robot scientists we could contact to understand some cutting-edge technology.

In the second round of interviews, we conducted 27 formal interviews with employees in various organizations, including different wastewater treatment plants, a design institute, two semiconductor companies, two environmental companies, and more. In this process, we took advantage of these interviewees to understand their enterprise background, their work routine, pain points during work, new technology applied in their work. After each interview, we wrote down the most inspiring points, then we went through all the interview transcripts and had a reflective discussion.

Our hypothesis that was set before the interview was that the people around the wastewater treatment ecosystem have their emotional frustrations on a daily or weekly basis. We assumed that it happens between the people in the same organization. Our initial hypothesis was more focused on the issues which were being generated in the same organization. However, we realized that all the negative issues are associated with relationships, not between people, but between organizations, and between humans and machines.

Such an insight changed our focus in the follow-up interviews. Instead of interviewees' emotions, we tried to discuss with them the deepest interest relationship behind these relationships, as well as people's great awe for future technologies. Thus, in the third round of interview, we carefully screened our interview questions, we contacted our interviewees through some third-party companies and asked them to help us find experts in the industrial sewage industry. The third round of interviews was conducted at the same time as testing.

As a result of the in-depth interview, we found that the organization is the smallest unit to understand the industry's plight because almost all of the industry key issues are faced by the organization as a whole, not by individuals. And the existing industry has already got a mature and fixed operation mode, so the best way to picture the industry should be an integrated process map that includes essential industry stakeholders. To find stakeholders' intersection, we choose such a process as wastewater product and pretreated from the factories, transport in the pipeline, and discharge after treat by the wastewater treatment plant to construct the wastewater flow map. In this way, we can give a general picture of the system and show its various roles' working relationships. Here, we first draw the current wastewater flow map of the IWWT industry and then mark the stakeholders' behaviors at each point. From this map, we can construct the necessary status quo of the entire industry (Fig. 3).

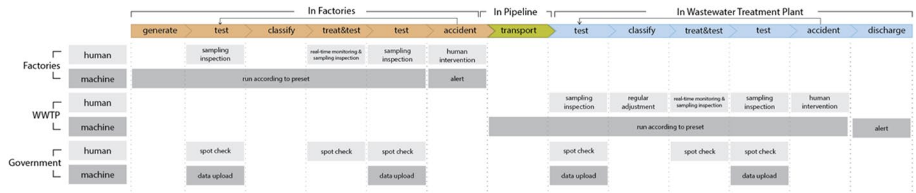

Fig. 3 Wastewater from generate to discharge

Organization persona

The definition of persona has been documented (What Are Personas?|Interaction Design Foundation (IxDF), 2015). Personas are a concept or descriptive model of a user, customer, or stakeholder that helps create empathy for different groups of potential users and inspire ideas. They are made based on observations, interviews, or focus groups. Focusing on specific archetypes or characteristics of a particular group of people differs from stereotypes or market segments. Usually, persona consists of someone's daily routine, profession, frustrations, and wishes. When creating new products or services or business models, personas help the design thinking team consider different personality aspects. Later in the design thinking process, appropriate development steps can be precisely based on a persona.

After interviewing 17 people, we identified as relevant in our stakeholder map, we gained essential insights to create our personas. As we have mentioned before, we chose to map persona on an organizational basis because our study focuses more on organization-to-organization interactions than on person-to-person exchanges within specific jobs. Also, we found out that the companies' employees share a similar view in terms of current operations and the attitude toward advanced technology. We named our persona "organization persona". We set performance indicators that mark the current decision preferences of each organization. We describe an organization's responsibility in the system, predicament and needs of each organization, then quote some words to express the external or internal attitude. Therefore, we can describe the characteristics and preferences of an organization and the environment in which they work.

We made four organization personas: small factory, big factory, short process plant, long process plant.

Small factory persona

The small factory's daily capability is ten tones of pre-treatment. They did not invest that much for the wastewater treatment-related equipment and no plan to improve it. They rely a lot on human skills (Fig. 4).

Big factory persona

The big factory's daily pre-treatment capacity is 1500 tons. They invested a lot of money to provide an excellent wastewater treatment process. They also have a plan to upgrade their equipment.

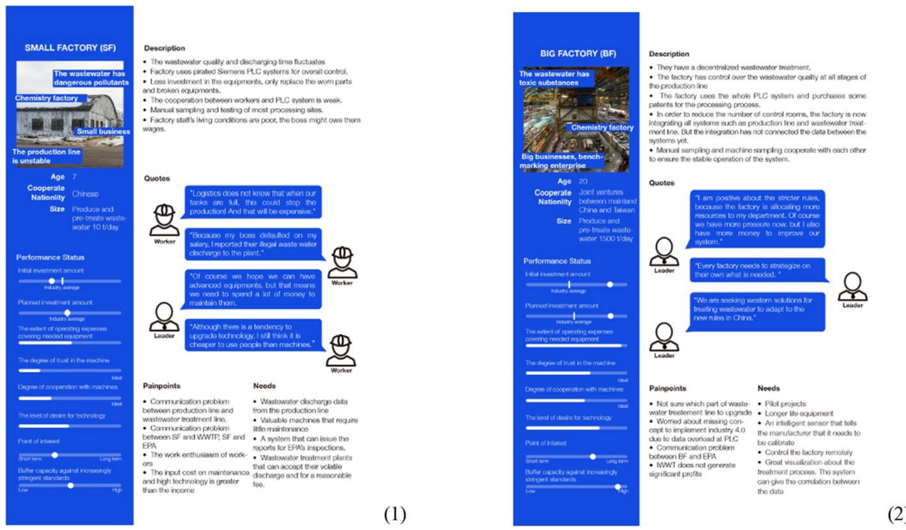

Fig. 4 Factory personas: (1) small factory persona and (2) big factory persona

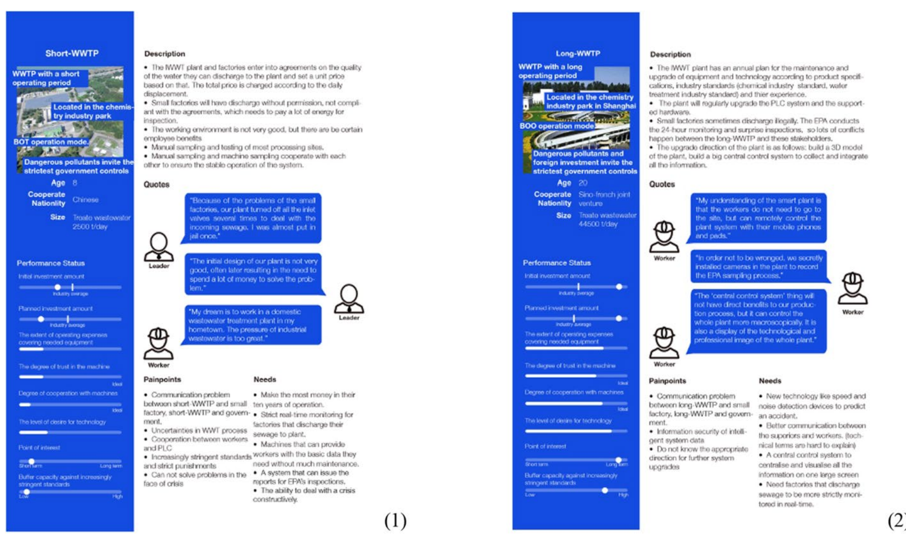

Fig. 5 WWTP personas: (1) short process WWTP and (2) long process WWTP persona

Short process operating WWTP persona The short process WWTP does not trust machines. It is hard for them to cooperate with machines. They never prepare for a crisis.

Long process operating WWTP persona The long process WWTP has a central control system that integrates all the data around. This plan is upgrading related equipment regularly (Fig. 5).

The pain points and the needs

To define problems to solve, we made a pain points map and a needs plan: using different depths of color, we represent the importance of each organization's issues. The darker the color, the more organizations face this dilemma.

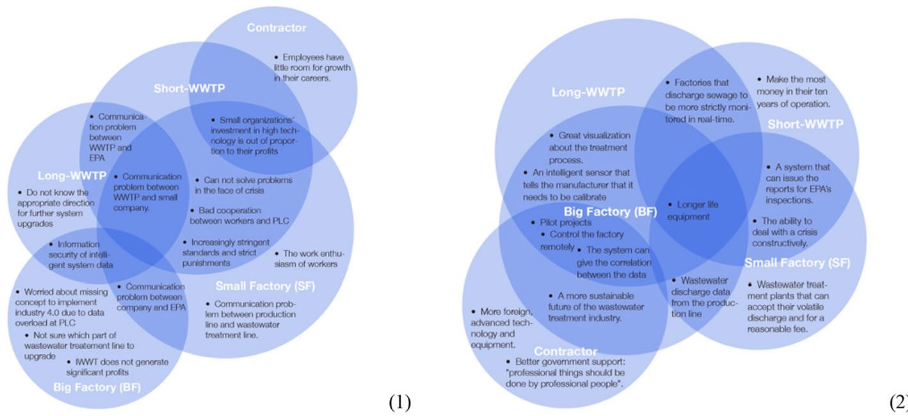

Fig. 6 (1) Pain points map and (2) needs map

Some of the findings are:

1. Factories need to predict the amount of wastewater coming from production.
2. They need a visualized data system that does not overload their programmable logic controller (PLC) and industrial digital computer adapted to control manufacturing processes that include all relevant information of the process and equipment maintenance.
3. Simultaneously, the factories fear security breaches and are reluctant to digitize and automate their systems due to cyberattacks' risk.
4. Furthermore, in China, the factories must balance automating the wastewater treatment process and not reducing the staff number or their work efforts.
5. A further relevant need in Germany and China is communication between the production department and the wastewater department. This need was found in pharmaceutical as well as in semiconductor companies. The wastewater department currently relies on its employees' experience and manual communication to determine how much wastewater will arrive at the plant and what the wastewater will contain. Manual labor increases workloads, and the production risks to be shut down (Fig. 6).

Ideation

In the ideation stage, we started with multiple rounds of brainstorming. In each round of brainstorming, we selected some promising ideas to continue developing. Secondly, we used "round-robin", a kind of relay cycle brainstorming, to organize a cocreate workshop with stakeholders. Brainstorming techniques indicate this method allowed participants to generate ideas and inspire others in some specific rules (Brainstorming techniques—8 Brainstorming Strategies for Teams, 2021). After that, we kept constantly ideating until the end of the prototype stage and the testing stage.

When starting to ideate, we considered both pain points and future trends that we learned from the benchmarking process. We also used futures wheel analysis (Glenn, 1972) to identify the potential consequences of trends and events. We paid attention to one of the future trends, in which the machine's role will be more decision-supporting.

Table 2 Ideas from brainstorming

No.	Ideas from brainstorming	Categorized ideas
1	Machine and people learn and adapt together	Human trust and happiness
2	Game in wastewater treatment	
3	Encouraging work report for workers	
4	Transparent pipes and valves	
5	Signal light for each machine in the IWWT system	Machines and human cooperation
6	Easy interaction with multi-devices	
7	IWWT factory of the future showroom	
8	Secure sampling sucker	
9	Wastewater hospital	Treatment process-related
10	Sentiment car	
11	Mother and son sampling	
12	IWWT kit	Solution for changing situation
13	Capsule medicine	
14	Real-time monitoring report from the machine	

At the same time, we assumed that people would work more remotely and issue commands remotely. The management would evolve to be more decentralized. Machines' role will move from replacing human power to replacing repetitive brainpower.

The first round of ideation

First, we used post-it notes to write down our insights from a series of desk research and interviews, including some problems, current situations, and industrial sewage treatment industry trends.

We then did a series of HMW (how might we) and brainstorming sessions using hot potato, a brainstorming method to let participants express ideas randomly and develop some exciting ideas, which is also mention in Brainstorming Techniques (Brainstorming Techniques—8 Brainstorming Strategies for Teams, 2021). Then we sorted, selected, and categorized them into 14 views in the end. And they can be classified into four categories: human trust and happiness, machines and human cooperation, treatment process-related, and solutions for changing the situation. We found an exciting thing from the first brainstorming outputs that the ideas vary from small improvements to new business models (Table 2).

Co-creation workshop

We went through all the ideas again and organized a co-creation workshop to develop further. We use 6 HMW (how might we) questions to come up with more ideas.

The co-creation workshop was conducted with many experts from the GF company. Most of them have a large amount of knowledge about this industry. So, the co-creation process was also a benchmarking process. Some ideas already existed with similar products, which give us a hint of feasibility. Some thoughts came to an end because experts thought they were too ideal. As we get to know more about the IWWT situation, our ideas became more practical and specific.

In the workshop, we invited four employees with different roles: a product manager, a technical service engineer, a sales manager and a sales engineer. Because of the diversity of the participants' positions and backgrounds, we could get views from different perspectives, fundamental to the workshop's co-creation.

We prepare the following 7 HMW questions for the co-creation process:

- How might we make human-machine collaboration more trustworthy and fun?
- How might we avoid testing sample confusion?
- How might we make the whole system have a more efficient information transmission/fault reporting mechanism?
- How might we avoid laying long pipes?
- How might we save time?
- How might we deal with the time-consuming and laborious maintenance of the factory?
- How might we deal with the wastewater in an industrial park centrally or in a decentralized way?

As a result of the co-creation, we got three valuable ideas:

First, "Equipment collaboration team", which means machines work with machines just like human work as a team. The equipment collaboration team will lead to more efficient information transmission and fault reporting mechanisms. Each piece of equipment can judge and report "colleagues"[1] problems according to its monitoring. The human can also join this team to make a decision together. The benefit is better communication between devices and decentralized decision-making.

Second, a real-time connection connects all single-point products in the factory through on-site master control and monitors them in real-time. When a problem occurs, the machine performs a remote troubleshooting call. If the problem is a technical one, the engineer could debug the equipment remotely and use various methods such as restarting to solve the on-site problem. The data are also uploaded in real-time to the database, used for a machine learning system.

The third, "Mobile wastewater treatment vehicle", is a skid-mounted processing device. This idea changes the traditional definition of industrial wastewater treatment plants. There will be no assembly lines inside the buildings. Instead, machinery and equipment will be moved to the road, and plants will be responsible for maintaining the "mobile wastewater treatment equipment".

After the co-creation workshop, we improved the ideas to move to the next step. The development direction was better interaction between humans and the machines, more systematic integration of the whole process, and organizing the wastewater in the industry park. As a result, we had three ideas to prototype.

Prototyping

Prototyping is a quick realization of physical and tangible models that are important to illustrate (interim) results and discover further potentials.

[1] Metaphoric meaning of other machine, equipment.

After we had some initial and promising ideas, we deepened them. In this process, we thought carefully about the following aspects. What problem does the idea solve? What are the points of opportunity that can make an existing idea more valuable? What is the difference between our concept and the current solution? Is the idea feasible? What technologies do ideas need? What are the strengths and weaknesses of the concept? In the vast stakeholder system, which stakeholders are the most influential?

To deepen our concepts from the co-creation workshop, we visualized our first vague and rough scheme. We built an industrial park with different roles by using small architectural models, lightweight clay. We also use notes and arrows to show the name of each item and their relationships. In the process of making these prototypes, we explored what stakeholders should be in the system. We made several scenarios within similar settings with different details. We also simulated the service flow in chronological order. In this way, we redefined the relationships between various stakeholders in this new scheme.

We used miniature houses and truck models to simulate the flexible flow of wastewater in the industrial park. We used the same proportion of pipes to experiment with how the different processes go back and forth and constrain each other. We used lightweight clay to reshape the sewage plant's internal wastewater flow process to explore the most appropriate way. These tangible objects helped us materialize abstract concepts to further think about more specific details of our ideas.

Idea 1: mobile wastewater treatment vehicle

No matter what type of factories and situation, the movable trucks can arrive and treat the wastewater. The vehicle(s) arrive at the factory to treat wastewater. After the treatment, it moves to the next factory as scheduled or returns to the vehicle depot. Factories can register services based on demand and duration of use, reducing purchasing equipment cost and management labor cost in wastewater treatment.

According to our research, sometimes some factories have problems with production lines, which leads to wastewater quality fluctuation. The factory's pre-treatment line might not be enough to treat such kind of wastewater. Currently, most of the factories prepare two sets of equipment and facility, one for use and the other for backup, in case some equipment breaks down suddenly. The square equipment causes a waste of space and equipment.

Some accidents in the production line cause some levels of wastewater to exceed the standard and could not be discharged or the water treatment equipment is broken. Some factories do not have enough labor and resources to cope with the tightening of environmental protection policies; small factories do not have enough wastewater treatment facilities. More and more factories are adopting flexible production, and the quality of produced wastewater is unstable.

Mobile wastewater treatment vehicle allows quick response to crisis, to reduce the opportunity cost to build the backup equipment and water treatment facilities. Also save space and human resources (Fig. 7).

Fig. 7 Mobile wastewater treatment vehicle

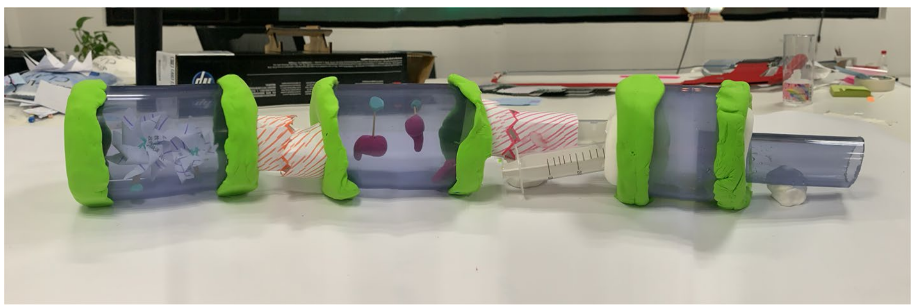

Fig. 8 Super pipe

Idea 2: super pipe

The function of water treatment is embedded in the pipe, which improves wastewater treatment efficiency and uses the time during which water flows in the pipeline. At the same time, we divide wastewater treatment into two types: "pre-mixing" and "process treatment". "Pre-mixing" can be carried out in pipelines. "Process treatment" is modularized and movable. Using sensor monitoring data, algorithms, and the Internet of Things technology to combine the required processing technology modules, each type of wastewater can have a customized treatment method.

The IoT technology opens up the possibility of decentralization, and this kind of decentralized system brings the opportunity to this flexible wastewater treatment. Currently, most of the factories prepare two sets of equipment, one for everyday use and the other for emergency backup. By installing modularized processing equipment like the super pipe, efficiency can increase to 70–80%.

Also, today's WWTP needs a large sedimentation tank to mix and settle the wastewater thoroughly. All the wastewater must flow through the same and fixed treatment line, although not all treatment steps are necessary. It is only a waste of time, space, and money (Fig. 8).

Idea 3: cloud computing platform

This idea is designed for industrial parks and treats wastewater with different water quality from other factories more efficiently and cost-effectively.

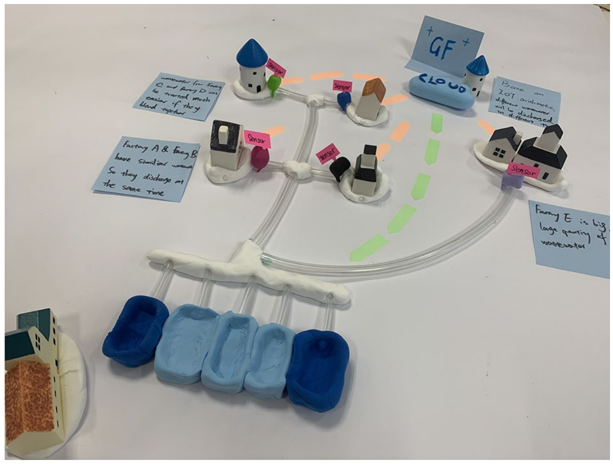

Fig. 9 Cloud computing platform

Fig. 10 Story telling animation

Sensors are embedded in the factory outlets. All the data from the sensors will be uploaded to the cloud computing platform. Data from different factories will be reviewed, communicated to generate daily wastewater plans. The collected data include pH value, COD, P, N, TDS, drainage volume, drainage time, and so on.

This platform integrates three crucial roles to improve and optimize the process: the plant operator, the laboratory technician, and the frontline worker. The plant operator's job is to control the wastewater treatment and ensure that everything is running according to the regulations. The laboratory technicians' job is to sample the wastewater from the factories' buffer tanks. He checks if the contamination of that wastewater is within the standards set by the agreement between the factory and the wastewater treatment plant. While the plant operator monitors the process at a high level, the frontline worker is in charge of checking and cleaning sensors, refilling additives, doing check-ups of the system, and fixing minor issues like blockages (Fig. 9).

Prototyping with storytelling animation

Understanding IWWT (Industrial Wastewater Treatment) business environment, IWWT (Industrial Wastewater Treatment) process, the whole system, stakeholders, and

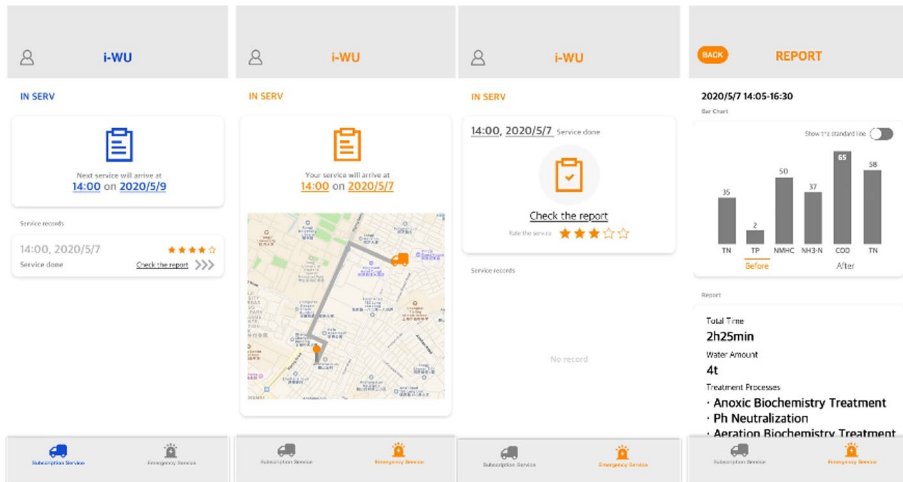

Fig. 11 Low-fidelity prototype for the mobile interface

its relationship is very complicated. Since the ideas presented with prototyping are process-based, we use the factory manager's perspective to tell a complete story to explain the context. We use animation to visualize and illustrate the new business concept. We also made the APP interface to show the process and details of the idea and simulate the specific situation (Figs. 10, 11).

Result

We invited two groups for the test: one group of potential users to get their feedback on usability and desirability and the other group of experts in the wastewater treatment industry. We interviewed the wastewater plant operators and engineers in industrial parks to get their opinion on the platform. We also tested with environmental company representatives, who are also active in China's wastewater treatment market. Moreover, we also spoke to renowned professors to get their technical expertise and expectations for the future wastewater treatment market.

We used the photos we took for our prototypes made with lightweight clay for the first round of testing. For online testing, we visualized our prototypes more clearly and made presentation slides to show our ideas. The slides included the pictures of all our three prototypes, their target users, pain point, current solution, key opportunities, the short description of the prototype, and their pros and cons, respectively. The three prototypes are a mobile wastewater treatment vehicle, super pipe factory, and cloud computing platform. We also used blueprints and system maps to illustrate the service design of some solutions.

The feedback is given from four aspects: advantages, disadvantages, things that can be improved, and other ideas. After the presentation and feedback, we asked the participants to talk about their opinion on the future of the wastewater treatment industry, which helps us understand the stakeholder's wishes and vision.

In the beginning, the mobile wastewater treatment solution seemed ideal and creative. The people from GF in China liked this idea the best. They thought that this would allow GF to develop a new business model. But some of the participants expressed

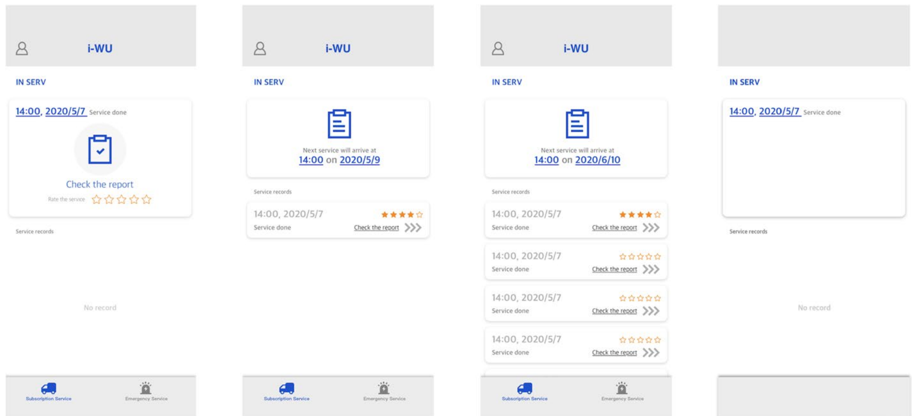

Fig. 12 Low-fidelity prototype of mobile wastewater treatment service flow

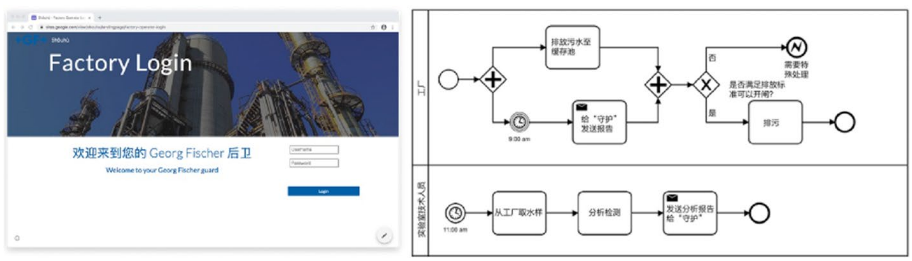

Fig. 13 Homepage of the online platform and the flowchart of cloud computing service

concerns about the feasibility of the solution. There were even more people concerned about the feasibility of the super pipe solution. However, we found that most participants stressed the communication between people and the information transmission between machines and organizations, which made us begin to rethink the value of our cloud-based platform solution. One of the wastewater treatment plant operators mentioned that how to communicate between various stakeholders in an industrial wastewater treatment plant is inefficient. Thus, improving communication via clouding platform would be a foundation to build any other implementation, including mobile wastewater treatment vehicle.

In the second round of testing, we focused on cloud platforms and mobile wastewater treatment vehicle solution with the service app.

For the mobile wastewater treatment vehicle solution, we provided two business models. The first one is that the service is provided directly by wastewater treatment plants by building a laboratory in the plant. In this case, the trucks are owned and operated by the plants. The other one is similar to Uber. Truck drivers can register on the platform and participate in the business as a third party. We illustrated the blueprints, system maps to explain the solution in detail. We presented the low-fidelity version of the mobile application to demonstrate the function and the flow of the service.

We showed them a rough prototype of our online platform for the cloud computing platform, making it easier to understand our work quickly. Besides, we used a flowchart and system map to explain the function (Figs. 12, 13).

In this stage, we reached more new testers to participate in the testing, contacted the people we interviewed earlier in the project and invited them to take the testing. We found that the previous interviewees know more about our project and are delighted to see our progress, giving many meaningful suggestions.

Similarly, the second round of testing participants expressed a positive attitude towards the cloud computing platform solution. One of the process engineers said that a cloud computing platform would be useful to see the data from different factories located at the industry park on one screen and easily compare them and identify which factories are performing pre-treatment and which are not. He thinks that he can quickly implement the required changes in treatment steps where necessary without wasting resources, and hence called the cloud computing platform a "scale-efficient".

In summary, we found that the users and experts confirmed that a cloud computing platform is implementable, and there is sound reasoning behind it. However, we are also aware that missing infrastructure and challenging relationships between park management and the factories can be an initial barrier. The test results also show that a cloud computing platform is right in line with current innovation trends in the wastewater sector, without having a direct competitor.

Discussion and conclusion

This article adopts a single explanatory case study method, taking the process of creating a new, innovative IWWT (Industrial Wastewater Treatment) system using industry 4.0 technology. We utilized the design thinking methodology in the process of researching and creating a new system. In this process, we found some interesting factors which are slightly different from the generic design thinking project:

Metaphoric analysis

As we conduct this research, the IWWT industry and the wastewater treatment process were initially not easy to understand. Throughout the process of benchmarking, we used metaphor methodology. In the book Metaphors We Live By, linguist George Lakoff and philosopher Mark Johnson said: "the essence of a metaphor is understanding and experiencing one kind of thing in terms of another." (Johnson, 1993).

While we were researching the wastewater treatment process, it reminds us of 'medicine for patient care.' Precision medicine is a medical model that proposes the customization of healthcare, with medical decisions, treatments, practices, or products being tailored to a subgroup of patients instead of a one-drug-fits-all model (Yau, 2019). In precision medicine, diagnostic testing is often employed for selecting appropriate and optimal therapies based on the context of a patient's genetic content or other molecular or cellular analysis (Lu et al., 2014). The current way the wastewater is treated looks like a one-drug-fits-all model. All the wastewater from the factories, regardless of the quality of the water sent to the wastewater plant tank to go through the preset process. Later on, this metaphor became a seed idea of the pre-treatment at the factory with a mobile treatment vehicle.

Body thinking

When Barbara McClintock[2] was researching the corn plants, she talked about developing a “feeling for the organism”. She got to know every one of her plants so intimately that she could truly identify with them when she studied their chromosomes. “When I was working with them, I wasn’t outside; I was down there. I was part of the system. I even was able to see the internal part of the chromosomes. It surprised me because I felt as if I were right down there, and these are my friends….” This type of emotional involvement played a critical role in pre-logical scientific thinking (Robert Root & Bernstein Michèle, 2013).

In the brainstorming process, we assumed the role of the wastewater that comes out of the different factories. Author A became and acted as clean water, author B became and acted as dirty water, and author C became and acted as severely dirty water. As we did role play, the author asked this question: “Do I want to travel to the plant tank with A or B? If I travel with A, I will make A dirty, which lead me to have a guilty feeling. If I travel with B, I would be more relaxed.”. Empathizing is related to body thinking. Many creative people “lose” themselves in the things they study, integrating “I” and “it”.

Descriptive prototype

There are low-fidelity prototypes and high-fidelity prototypes, depending on the details of the design. The prototypes’ role is to communicate, refine, and validate your ideas to make the right decisions with no manufacturing and implementation process errors.

We made many prototypes in the process of the experiment. Most of the prototypes that we made in the early stage were descriptive. We used clays and miniatures of the buildings, trucks, and posts to describe the relationship between the factories, industrial parks, and IWWT mobile vehicles. We made prototypes to tell the cloud platform, showing the flow of the data and the flow of the wastewater. We used 2D (data flow and description of the factories) and 3D (different size of the building miniature represent small and the big factories, plastic hoses represent the pipelines that connects from the factories to the wastewater treatment plant. Different color represents a different level (type) of the wastewater tank. The super pipe idea prototype also describes the concept of the super pipe rather than showing an exact function. Descriptive prototyping in the early stage of the process was beneficial to communicate with all the project stakeholders. It was helpful to understand context, flow, roles, process, especially for the project related to the complex system.

Organization persona

Personas are user models that are represented as specific, individual humans. They are not actual people but are synthesized directly from observations of real people. According to Cooper and Reinmann, activities, attitudes, aptitudes, motivations, and

[2] An American scientist and cytogeneticist who was awarded the 1983 Nobel Prize in Physiology or Medicine.

skills are the variables help uses to identify behavioral patterns to create a persona (Banerjee, 2004). However, the main users of our project were not specific, individuals humans but organizations. Age of organization, main activities, capacity, past and future investment on the subject, pain points are the variables that we used to describe organization personas. This area needs to be further developed to define it better.

Benchmarking and ideation has been done entire process

Due to the complexity of the wastewater industry and our effort to understand industry ecosystems, the stakeholders' structure was continuously put and continuously updated during the entire research process. The relationship between stakeholders in the industrial field becomes very complex due to government regulation and the interests of the whole industry ecosystem. This continuous update affects the process of research, design, prototype, and test. We came up with a new idea even during the prototype testing period. We learn something interesting from the industry expert we immediately designed and prototyped to accommodate the new concept. We think that this rarely happens during the consumer-based design process. Even if it happens, a new idea would be in the spectrum of expectation rather than completely out of the initial idea scope.

This paper was written after the project was completed. The authors decided to investigate the reasons that made this project so successful (according to the client). We have extracted some factors and methods in retrospect. If it was planned in advance, we could have compared two or multiple different tools to understand which one is more relevant for objectives, or perhaps we could investigate which tool would contribute to innovative ideas using state of the art technology.

One of the area that we would like to further examine is the organization persona. Most of the tools-methods that were used and mentioned in this paper, are already known. However, to the best of our knowledge, we could not find previous literature regarding organization persona. So, it appears to be an area to be further developed in the future projects.

Abbreviations

CPS	Cyber-physical system
GF	Georg Fischer
HMW	How might we
IoT	Internet of things
IWWT	Industrial wastewater treatment
PLC	Programmable logic controller
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

Wastewater properties

COD	Chemical oxygen demand
N	Nitrogen
P	Phosphorus
pH	Pondus Hydrogenii
TDS	Total dissolved solids

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Relevance to design practice

This paper would be applicable for design practitioners who are engaged in system design, the new business model in complicated technology-oriented environments and for the heavy tech companies who are facing the creation of innovative business models for next generation.

Author contributions

HL: project supervision, paper structure, participated in analysis process, ideation, selected the proposed concepts, wrote conclusions and discussions, and revised the manuscript. YL, XL, HZ: secondary research, primary research, analysis, ideation, design, prototyping, testing, iteration, communication and presentation, and wrote the majority of the manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests

The authors declare that they have no competing interests.

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