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THERMO-SMART: smart thermostat for smart cities

Executive summary

Unlike private houses - where the idea of the thermostat is efficiently applied - environments or buildings open to the public do not provide specific solutions for comfort management in accordance with users' needs. In many cases, the indoor comfort parameters are not appropriately controlled thus generating discrepancies between the needs of the users and the actions taken to meet them. In addition, this also leads to excessive energy consumptions that could be avoided through a specific optimization. Homify project has the aim to provide feasible solutions for the control and monitoring of the comfort level in the academic environment, a public space where the problem of indoor comfort is particularly important.

This is done through the creation of correlations of subjective and objective data, related respectively to the personal comfort sensation of the users and to the physical parameters of the environment. Subjective data are gathered from the users through a dedicated interface, while objective data are collected from an electronic board equipped with temperature, humidity, light, carbon dioxide and particulate sensors. Through the application of data analysis techniques performed in a Cloud server on the obtained data, the Homify concept provides customized control of the actuators of the HVAC system, specific suggestions to the users and complete reports to the management personnel. To verify the feasibility of this project, two prototypes were installed in Politecnico di Milano.

In this way, the Homify project provides not only the opportunity to control the objective parameters of an indoor environment to optimize the average global comfort of the users, but supplies also an efficient solution for the management of public spaces and for the reduction of the energetic consumption.

Key Words

Thermostat, comfort, public buildings, feedback, smart management

Figure 1. Homify Team in Loano (March 2019)

Figure 2. Homify main advantages.

Project description written by the Principal Academic Tutor

With the increasing interest in smart spaces and infrastructures, modern homes and private environments more in general are being equipped with autonomous systems that enhance residents' comfort and liveability. In particular, infrastructures able to govern and control specific comfort parameters and power consumption are fundamental for this purpose. These systems are designed to improve comfort while minimizing the energy consumed for heating and cooling. On the other hand, there are not similar solutions for public buildings where typically control systems tend not to be tailored to the needs and comfort perception of people using shared spaces. This can become a problem for people that tend to spend a lot of their time in public spaces, such as offices or universities, while it is not actually an issue in places where they spend short time periods. There is then a growing need to realize smart infrastructures on a city level preserving comfort conditions for users, while controlling costs for changing indoor parameters. In particular, university presents a great problem in terms of indoor comfort. This led the Homify team to design such a complex system in an academic environment: from sensors to actuators, from user interface to data analysis. The team developed a prototype employing off the shelf sensors, so as to reduce initial costs. The chosen sensors are: temperature, humidity, light, carbon dioxide and particulate. In order to address all the different users, the team chose a very simple method: asking them directly specific information to estimate their comfort level. Specifically, the system can test the whole comfort level of indoor space through a short questionnaire submitted to the users. Therefore, a suitable user interface is designed: a mobile app that interacts with the users. It is simple and intuitive to use and it allows users to monitor all the relevant parameters, to receive customized suggestions, to understand the energy-saving profile proposed by the system and to react appropriately. Moreover, the objective data coming from the selected sensors are used in combination with the subjective comfort evaluations to control the buildings actuators and to implement complex decision-making algorithms, in order to optimize the global comfort of the users. The data collected and elaborated are also at the basis of a web app that allows the system owner to optimize the management, control and maintenance of the building rooms, through fault detection, predictive maintenance and continuous improvement. As proof of concept, the Homify team developed a first application of this system in the university environment. In the Emilio Gatti conference room in Politecnico di Milano, a simple prototype, embedding temperature, humidity, light, CO2 and particulate sensor, was installed. In parallel with the gathering of sensors measures, users' comfort evaluation were collected through simple questionnaires accessible from QR codes that can be found on stickers applied on each desk inside the room. These data were analyzed obtaining correlations between the sensors themselves, in order to optimize device costs, and between subjective and objective results, that are those used to generate control signals for actuators and personal suggestions.

Team description by skill

Riccardo Baccetti
He deepened the issue of the practical applicability of the project concept into real public spaces dealing with feasibility and cost optimization. He coordinated the group work leading to a successful cooperation.

Luisa Cavallaro
She contributed to the definition of the project solution leading the analysis of the users' requirements. Luisa also developed the app interfaces and took care of the graphic design aspect.

Andrea Comino
He deepened the data science aspect of the project addressing preliminary data analysis and machine learning techniques. Moreover, he studied the possible optimization of the prototype.

Simone Dartizio
He worked at the creation of the control system and actuators model, helping also in the prototype building. He studied further evolutions of the project in the smart city context.

Francesca Madonini
She coordinated the building of the prototype dealing with the choice of sensors, the welding of cable connections and installation issues. She also followed its practical implementation.

Tommaso Alessandro Negretti
He studied the subjective comfort evaluation creating an effective tool to collect them. Moreover, he organized the implementation of the prototype at Politecnico di Milano.

Dejan Pejovski
He focused on the definition of the state-of-the-art allowing the team to develop an innovative own concept solution. Dejan also followed the analysis of needs and requirements and helped in building and installing the prototype.

Goal

The increasing number of smart technologies implemented in modern buildings generates numerous problems in their connection and management. This new trend is a consequence of the complexity of our contemporary societies, where conflicting needs and constraints of various natures require unconventional solutions.

As a main project goal stands creating a concept of a smart thermostat which is primarily aimed at optimizing the comfort level of the people present in the specific indoor environment, i.e., the users. To identify the actual situation of the user's well-being, which is defined by the temperature, humidity, air quality and lighting of the space occupied, two major information are necessary: what are the present values of all these parameters and how they are actually perceived by the users. Therefore, creating a model and a prototype of a sensor unit able to collect data on indoor parameters (temperature, humidity, CO_2, noise, lighting) is essential. By leveraging the existing user technologies (for example, the social media) personal comfort level sensation should be estimated. To do so, innovative ways of interaction with the existing widespread technologies are required in obtaining information about the users in a non-invasive way. The integration of data from various types and sources should enable mapping of the physical buildings, modelling of the heating and cooling systems, control of the energy consumption and improving personal comfort. All of the above is to be scaled on a smart city level.

Understanding the problem

A smart programmable thermostat can communicate with the Inter-/Intranet via a wired/wireless network [1]. Commercially available devices can exchange and store data and they can integrate with the existing Heating, Ventilation and Air Conditioning systems. Some of their most common features are: presetting desired temperature schedule, activation based on motion and voice detection, geolocation, energy-saving reports, etc. [2], [3]. These devices, although quite expensive, perform well in individual households. When it comes to public spaces, occupied by large number of people with various comfort preferences and numerous system operating conditions, such as universities, hospitals, offices, etc., a complete, all-inclusive solution does not exist. Issues such as accessibility, user interface choice, identification of "globally shared" comfort level are open for discussion. Network security and authorization are concerned as well, since no standards for this particular technology exist [4]. Installing such smart devices in public buildings with hundreds of rooms is a costly investment, especially if it comes as part of a renovation plan. The solution for all the above-listed problems makes sense only if it can interact with the users: obtaining subjective information which would be used to define control system outputs and giving feedback to the user in terms of suggestions and notifications.

Figure 3. The first prototype of the thermostat installed in Emilio Gatti Conference room.

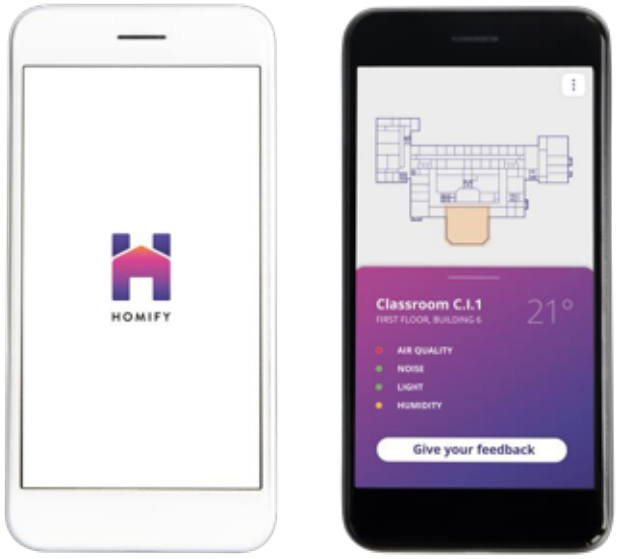

Figure 4. Homepage of Homify mobile app.

Exploring the opportunities

Each of the questionable aspects when a smart thermostat is to be implemented in a public environment can be solved in several ways. Collecting data about personal comfort is possible through filling in a short questionnaire which opens after scanning a QR code or which comes as part of a mobile application. Another option for user's interface is placing a touch screen at the entrance of each room, so that people are allowed to give their feedback. Instead of buying expensive thermostats, it is recommended to build a unit with embedded sensor which can measure all the relevant parameters and send the data wirelessly to a storage memory. Estimating the number of people present in a room can be done by implementing a presence sensor, or by asking the people in the questionnaire to report the number of occupants. Once the data are gathered and processed, some actions need to be taken in order to improve the user's well-being. A completely automated control can be implemented, or semi-automated in collaboration with the users, who can open/close the windows, turn off/on the lights, etc. Having a detailed picture of the situation in all the available rooms in the building in advance is for sure very useful for the person in order to help him choose the most suitable environment.

Generating a solution

Homify is a complex system able to take into account users' feedback in order to adjust their comfort level inside the building monitored. It concerns all the aspects related to personal comfort sensation, such as temperature, air quality, lighting and noise, in creating a complete well-being of the occupants.

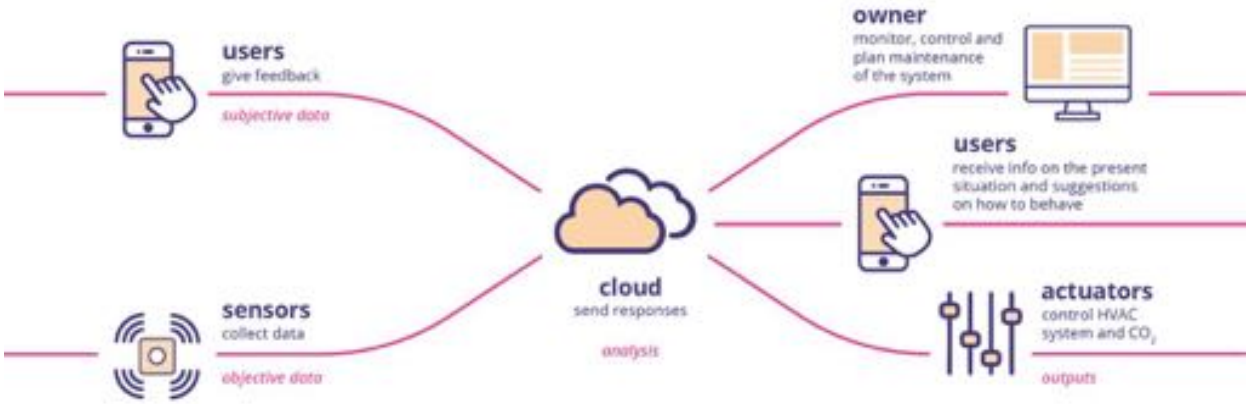

Figure 5. Homify's system concept.

The basic operation principle of the entire Homify solution relies on the collection of two data sets: objective and subjective. The former one is created by smart sensors integrated on a single unit placed inside the environment under observation, including air temperature, relative humidity, CO_2 concentration and light intensity sensors. The latter data series is generated by the users: each person present in the room fills in a simple questionnaire via a mobile application, answering questions related to his own sensation about the same parameters. All the data collected are sent and stored on the Cloud, where their processing occurs through a series of statistical analyses. The final processing aim is identifying corrective measures to be undertaken on the control systems to improve general personal comfort. Homify provides outputs to three different clusters of receivers:

- Technical systems and equipment;
- End-users (room's occupants);
- Maintenance and cleaning personnel.

All the equipment connected to the control unit receives signals sent to their actuators aimed at adjusting the indoor comfort. Most of these control signals are applied to the HVAC system for thermal conditioning and the Air Handling Unit. Stand-by function is available as well.

Homify prepares a set of information to be displayed on the smartphone on each end-user. With the dedicated mobile application, building's occupants have on disposal information about the present conditions of the environment. This solution generates suggestions to the users related to their personalized comfort, which are obtained through a comparison between user's answers on the questionnaire and the global comfort level. Extra information is given through real-time noise and occupancy level maps, lessons schedule, etc.

Malfunctioning signalization and average room occupancy are sent to a web application to improve maintenance and room cleaning strategies. Energy saving reports are generated on certain time intervals.

Homify is capable of improving user's comfort, reducing energy consumption and upgrading the concept of ordinary maintenance. The main concept value lies in its real-time analysis and response, based on data collected from various sources and direct interaction with the users. Homify can be installed in semi-private and public environments which proves the solution's scalability.

Main bibliographic references

[1] V. FABI, G. SPIGLIATINI, P. CORGNATI, "*Insights on Smart Home Concept and Occupant's Interaction with Building Controls*", Energy Procedia 111 from 8th International Conference on Sustainability in Energy and Buildings, SEB-16, Turin, Italy, 759-769, 2016;

[2] J. ANDREWS, ET. ALL., "*Nest Labs, Principles of Marketing*", Spring 2015;

[3] *Ecobee 3 User Guide*, 2014;

[4] D. MINOLI, K. SOHRABY, B. OCCHIOGROSSO, "*IoT Considerations, Requirements, and Architectures for Smart Buildings – Energy Optimization and Next Generation Building Management Systems*", IEEE Internet of Things Journal, Vol. 4, Iss. 1, 1-16, 2016;

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ZEGODI

Executive summary

The ZEGODI project involved the analysis of the goods display sector: these are marketing tools that you can find in stores and that help to highlight promotion. The main issue is that environmental and economic impact of goods displays is strongly underestimated both by companies and stores. Thus, P&G, our industrial partner in the project, asked us to quantify the problem and find a systemic solution that could improve the sector.

We first started by estimating the amount of displays produced both by P&G and overall in Italy. After various interviews we estimated a total of 17.5 million displays per year in Italy.

The next step was to understand the environmental impact of displays as of now: in order to do so we made a Life-Cycle Assessment, a tool that calculates all the pollutants created in a product life-cycle. We discovered that currently most displays are made of recyclable materials, but they are not recycled by stores due to long disassembly times: displays are designed to impress the customer more than to be easily handled. Correct recycling would bring their national environmental impact from 13 to 5 million kg of CO2.

We then proceeded with our solution. First, we improved the highest selling P&G display in order to make its disassembly easier: we removed redundant plastic rivets and replaced them with cardboard joints, cutting both disassembly times and economic costs (with up to 200.000€ of savings yearly). Then, we designed a checklist in which display producers can test their displays performance. The checklist controls both environmental impact and features that can reduce handling disadvantages for store clerks. The aim is for big companies like P&G to only adopt displays that have high performance scores.

Finally, we tested our solution with a theoretical pilot with Coop, investigating the effects of our solution on their stores: if adopted by all display producers, time savings and better recycling would result in 590.000€ of yearly savings.

Key Words

#GoodsDisplay #Recycling #P&G #NEDprotocol #AltaScuolaPolitecnica #LifeCycleAssessment #GrandeDistribuzioneOrganizzata

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P&G

NEVER ENDING DISPLAY

A change is coming...

want to be part of it?

Website link

Project description written by the Principal Academic Tutor

Much has been said about the need for societies to reduce resource consumption. Recent estimates of human appropriation of the net primary productivity of nature range from 20% to 34%; there is continued extraction of virgin minerals and ores due to linear material use patterns; moreover, energy inputs are predominantly supplied by non-renewable fossil resources. Increasing resource consumption has brought with it the global rise of a middle class; however, this has also led to an increasing waste generation. These events have continued in lockstep with economic growth since the dawn of the industrial age. One such challenge is the conservation of natural resources, defined as the minimization of consumption of renewable or non-renewable resources. Resource conservation may be achieved through waste prevention, waste reuse or recovery. The main phases of the projects were as follow:

- State of the art analysis regarding the current sales model and processes for goods displays;

- Interactions with multiple counterparts representing the 'end to end', such as:

  • the packing material suppliers for the displays;

  • the different Procter & Gamble (P&G) key resources (Sales Department, Customization Operation team);

  • the Customers;

  • the 3rd Party Logistic for the Integrated Ecological solutions.

- Development of a Life Cycle Assessment (LCA) in order to identify the potential environmental benefits;

- Creation of a tool to assess the 'sustainability' level of goods displays;

- Assessment of project feasibility through the development of a theoretical pilot;

- Design a solution (technical and process solution) with multiple decision makers;

- Development of a marketing campaign to promote the proposed solution.

Therefore, the main results of the project were:

- the definition of a circular supply-chain for the goods-displays and the process to assess its sustainability;

- the identification of a suitable goods display structure.

Team description by skill

Due to the complexity of the project, the skills we applied were various. Indeed, in order to satisfy all the stakeholders, it has been necessary to merge Product Design with Environment Evaluation and Management skills. The first ones have been used to find the optimal display, the second one to assess the impact of our protocol on the environment and the last one to build a business case and prove the feasibility.

Goal

The Point of Purchase sector is not strategically important for all the actors of its value chain: consumer goods Companies, displays' manufacturers, retailers and recyclers. For this reason, the first moral goal that we decided to accomplish is to shed a light upon this topic showing the economic and environmental impact that a careful attention on POP Display can lead.

The project has to accomplish several goals that cover all the matters regarding displays. These goals are:

- Identification of the parameters that determine the sustainability of a goods display, based on the EU and Italian current regulations;
- Definition of a solution in terms of product design and/or process which could satisfy the needs of the stakeholders described above;
- Evaluation of the identified solutions in terms of environmental and marketing impact.

Due to the complexity of these objectives, the project has been organized in several milestones that all together result in the project scope:

1. Market Size Estimate: calculation of the total number of displays circulating in Italy per year;
2. Estimate the Environmental Impact through a LCA by comparing a bad waste management with a virtuous one;
3. Create a software that evaluates the display compliance to our green strategy;
4. Create a POP Display compliant with our strategy and a set of use specification easily replicable by all value chain actors.
5. Test the effectiveness of solution performing a business case in store;
6. Finalize the project by creating a marketing campaign that promotes the benefits for all the stakeholders.

Understanding the problem

The Fast Moving Consumer Goods (FMCG) companies face one of their greatest battles within stores. The Point-of-sale goods displays are a powerful marketing tool to stand out from the crowd. Therefore, they need to be replaced every two weeks approximately. This is in contrast with the increasing concern regarding resources constraints and soil contamination. In fact, most of the temporary displays at the end of their lives are thrown away in the generic bin, without separating the different materials to allow recycling. This activity should be performed by the store operators, who usually skip this operation blaming the difficulty of disassembly. On the other hand, the goods displays producers have no incentive to reduce the complexity of their products and need to fulfill the marketing requests in terms of attractiveness and appealing to the customers.

The environmental regulation is becoming stricter and stricter, although no specific law exists for the goods-displays production and disposal so far. However, the gap is expected to be filled in the near future. Moreover, countries typically buying wastes from European countries, i.e. China and India, are reducing the level of impurity accepted in the recycled material. As a result, the quality of the waste should be as pure as possible, leading to the need for a more effective recycling system.

The actors of the goods-displays supply chain should be prepared to these types of disruption in the market.

The sector of POS displays is usually not seen as strategic by the goods producers and the GDO. As a matter of fact, there is no comprehensive case study on this topic in the literature in Italy.

The Zegodi project made for the first time an estimation of the problem. The study obtained a number equal to 17 million for the number of temporary goods displays produced per year in Italy.

Exploring the opportunities

Due to the lack of a standard process end to end and big room for improvement, the team explored several opportunities to find the best solution suitable for this business and environmental case.

First, we faced the choice between reuse and recycle. On one hand, reuse would have had higher impact allowing a reduction from 5 to 3 million kg of CO2, compared to recycling, but on the other, the setbacks were many: limited material choice, reduced appeal and attractiveness.

In this context, different stakeholders and departments had very divergent points of view and demands. On one side the need of addressing the problem, reducing CO2 emissions and wastes leading to better results both economically and environmentally speaking. On the other side, in many cases goods displays are still perceived only as marketing tools and their production is totally design oriented.

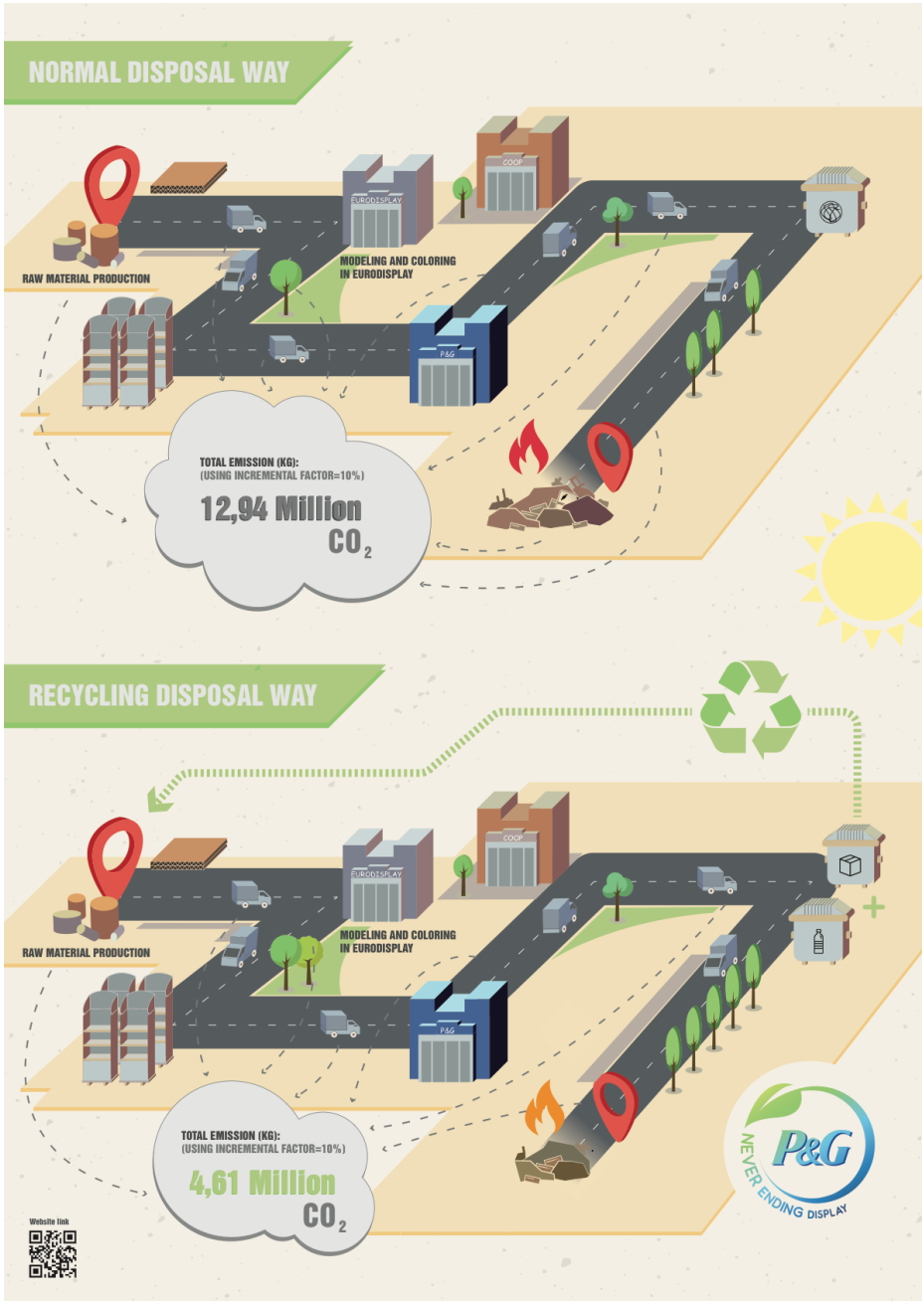
Therefore, even if at the beginning we wanted to focus on the radical solution of reuse, we decided to start step by step, bringing added value with a recycle oriented solution.

In the end, we agreed, under advice of our tutors, that this was the right direction for our project; today's society is not ready yet for such a strong change of paradigm and a big improvement can be already achieved with the usage of certain solutions.

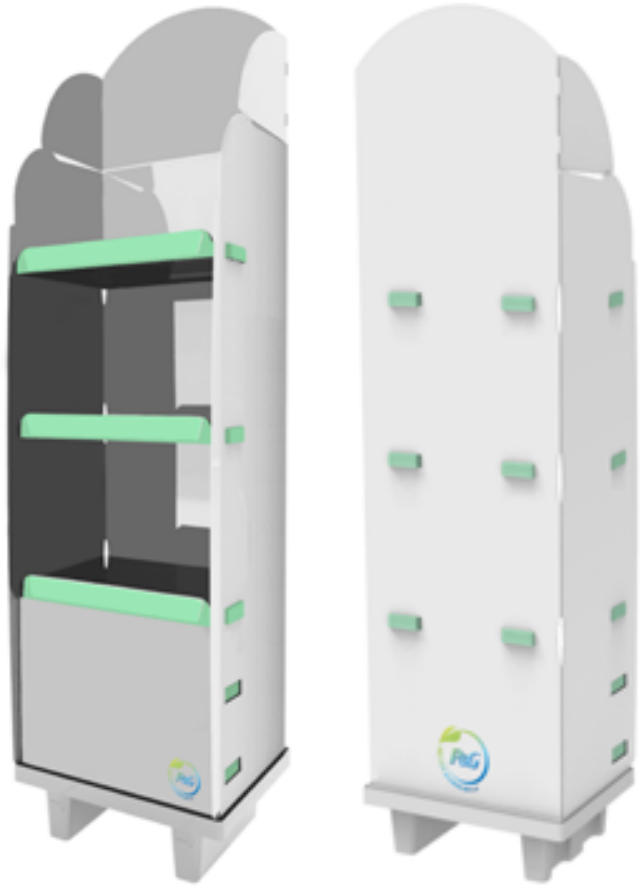
Generating a solution

The first big achievement is that, like never before, the issue has been addressed and quantified. Indeed, the team made an estimation of 17 million of temporary goods displays produced per year just in the Italian market (6,470,000 km travelled by car, or 12,940,000 usages of the dishwasher).Therefore, it can be easily understood that the amount is massive and that the problem needs to be managed quickly and wisely.

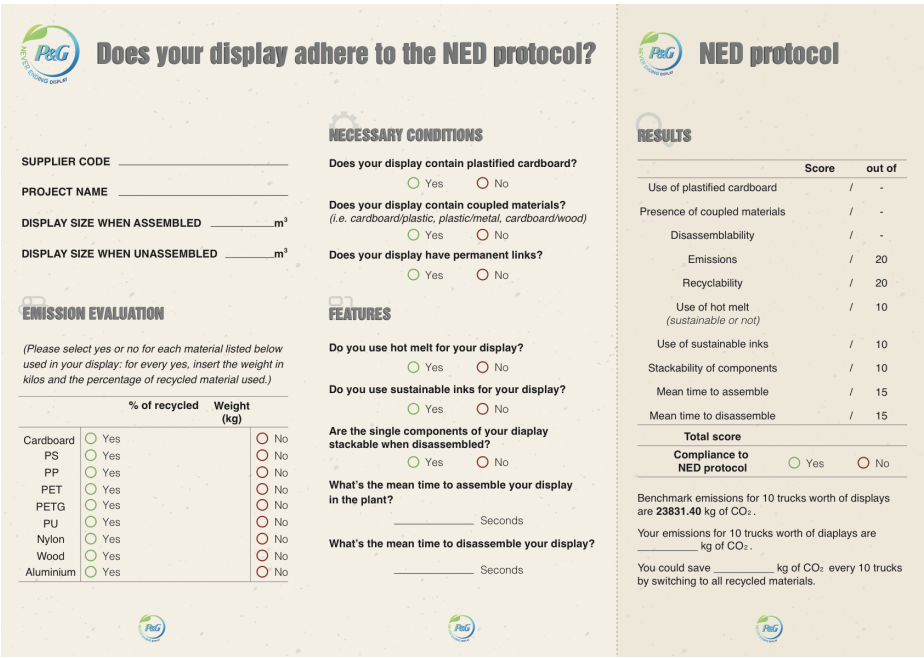
For the first time in literature, the impact of the goods displays supply chain has been estimated in CO2 equivalent, thanks to the usage of Life Cycle Assessment. By the examination of different situations and case studies, we found out that the majority of goods displays used in our country are built with recyclable materials, but that in the end they are not recycled because of long time of disassemble and wrong habits. Thanks to the LCA tool, it was estimated that, if all the displays were recycled, their impact would decrease from 13 to 5 million kg of CO2 produced.



Furthermore, a product-based solution was developed to simplify goods display already used in P&G' disassembly. Indeed, the junctions which connect the footer to the body of the display, were replaced by a system similar to pizza cardboard holes. In this way, both the BOM of the display and the required time for disassemble are reduced, promoting displays recycle and leading up to 200.000€ of savings yearly.



Moreover, the team designed a checklist to be used in order to define if a display can be considered sustainable or not. The criteria used have been elaborated together with our external partners, Eurodisplay and BozSei. The outcome allowed the company to assess all the displays in order to promote only the compliant ones to the NED protocol (developed by Eurodisplay with the aim of setting a standard in POP displays' recyclability).



Does your display adhere to the NED protocol?

SUPPLIER CODE _____

PROJECT NAME _____

DISPLAY SIZE WHEN ASSEMBLED _____ m^3

DISPLAY SIZE WHEN UNASSEMBLED _____ m^3

EMISSION EVALUATION

(Please select yes or no for each material listed below used in your display: for every yes, insert the weight in kilos and the percentage of recycled material used.)

		% of recycled	Weight (kg)	
Cardboard	○ Yes			○ No
PS	○ Yes			○ No
PP	○ Yes			○ No
PET	○ Yes			○ No
PETG	○ Yes			○ No
PU	○ Yes			○ No
Nylon	○ Yes			○ No
Wood	○ Yes			○ No
Aluminium	○ Yes			○ No

NECESSARY CONDITIONS

Does your display contain plastified cardboard?
○ Yes ○ No

Does your display contain coupled materials?
(i.e. cardboard/plastic, plastic/metal, cardboard/wood)
○ Yes ○ No

Does your display have permanent links?
○ Yes ○ No

FEATURES

Do you use hot melt for your display?
○ Yes ○ No

Do you use sustainable inks for your display?
○ Yes ○ No

Are the single components of your diaplay stackable when disassembled?
○ Yes ○ No

What's the mean time to assemble your display in the plant?
_____ Seconds

What's the mean time to disassemble your display?
_____ Seconds

NED protocol

RESULTS

	Score	out of
Use of plastified cardboard	/	-
Presence of coupled materials	/	-
Disassemblability	/	-
Emissions	/	20
Recyclability	/	20
Use of hot melt *(sustainable or not)*	/	10
Use of sustainable inks	/	10
Stackability of components	/	10
Mean time to assemble	/	15
Mean time to disassemble	/	15
Total score		
Compliance to NED protocol	○ Yes	○ No

Benchmark emissions for 10 trucks worth of displays are **23831.40** kg of CO_2.

Your emissions for 10 trucks worth of diaplays are _____ kg of CO_2.

You could save _____ kg of CO_2 every 10 trucks by switching to all recycled materials.

In the end, the combination of our solutions and ideas can certainly make the difference in this field and, to prove that, the team developed a theoretical pilot with COOP Alleanza 3.0. The results show that, if the NED protocol would have been applied to all the displays of this retailer, it could have saved 590.000€ yearly, plus advantages in terms of social and environmental awareness and corporate responsibility.

Main bibliographic references

Gazzetta ufficiale (2004). Direttiva 2004/12/CE del Parlamento Europeo e del consiglio dell'11 febbraio 2004. *EUR-Lex.* Retrieved on: https://eur-lex.europa.eu/resource.html?uri=cellar:f8128bcf-ee21-4b9c-b506-e0eaf56868e6.0008.02/DOC_1&format=PDF

Bosetti e Gatti (2006). Decreto legislativo 3 aprile 2006. *Bosetti e Gatti website.* Retrieved on: http://www.bosettiegatti.eu/info/norme/statali/2006_0152.htm.

European Commission (2018). Plastic waste: a European strategy to protect the plane, defend our citizens and empower our industries. *European Commission website.* http://europa.eu/rapid/press-release_IP-18-5_en.htm

Angelico and Pujari (2010). Mainstreaming green product innovation: why and how companies integrate environmental sustainability. *Journal of Business Ethics.* Retrieved on: https://www.jamk.fi/globalassets/koulutus--education/liiketalouden-ala/yamk_yrittajyyden-ja-liiketoimintaosaamisen-koulutusohjelma-yamk/mainstreaming-green-product-innovation_dangelico-and-pujari---2010.pdf

McKinsey & Co (2008). How companies think about climate change: a McKinsey global survey. *The McKinsey Quarterly February 2008.* Retrieved on: https://www.sallan.org/pdf-docs/clch08.pdf

Nielsen (2018). Global consumers seek companies that care about environmental issues. *Nielses.com.* Retrieved on: https://www.nielsen.com/eu/en/insights/article/2018/global-consumers-seek-companies-that-care-about-environmental-issues/

Eurodisplay (2019). Who is Eurodisplay. *Eurodisplay website.* Retrieved on: http://eurodisplay.it/it/chi-siamo.aspx

P&G (2019). Our functions. *P&G website.* Retrieved on: https://www.pg.com/vn/careers/our_functions/marketing.shtml

Newell, G. (n.a.). The New Marketing Trend Driving P&G Marketing and Unilever Marketing. *602Communications.* Retrieved on: http://602communications.com/the-new-marketing-trend-driving-pg-marketing-and-unilever-marketing/

Smithson, N. (2018). Procter & Gamble's Organizational Structure for Managing Products. *Panmore Institute Website.* Retrieved on: http://panmore.com/procter-gamble-organizational-structure-managing-products

P&G (2019). I nostri punti di forza. *P&G website.* Retrieved on: https://www.pg.com/it_IT/azienda/visione-e-strategia.shtml

Treccani (2012). Dizionario - Lessico del XXI Secolo. *Treccani website.* Retrieved on: http://www.treccani.it/enciclopedia/gdo_%28Lessico-del-XXI-Secolo%29/

La Repubblica (2018). Supermercati, crescono le vendite ma decrescono i margini. Economia e Finanza, *La Repubblica.* Retrieved on: https://www.repubblica.it/economia/rapporti/osserva-italia/mercati/2018/12/19/news/supermercati_crescono_le_vendite_ma_scendono_i_margini_il_mercato_verso_la_saturazione-214611537/?refresh_ce

Il Sole 24 Ore (2018). La Cina blocca l'import di rifiuti, caos riciclo in Europa. *Il Sole 24 Ore.* Retrieved on: https://www.ilsole24ore.com/art/la-cina-blocca-l-import-rifiuti-caos-riciclo-europa-AELQpUhD

Comieco (2019). Our Activity. *Comieco website.* Retrieved on: http://www.comieco.org/la-nostra-attivita/osservatorio-prezzi/Default.aspx?anni=2019&mesi=6

P&G (2019). Purpose, value and principles. *P&G website.* Retrieved on: https://en-ae.pg.com/policies-and-practices/purpose-values-and-principles/

Boutilier (2011). A stakeholder approach to issues management (Strategic Management Collection). *Business Expert Press.*

Matamalas and Ramos (2009). Marketing strategy of the supermarkets.

Kerfoot (2003). Visual merchandising and the creation of discernible retail brands. *International Journal of Retail and Distribution Management.*

Conai (2016). Futuro comune: Innovazione, bellezza, sostenibilità. *Conai website.* Retrieved on: http://www.conai.org/wp-content/uploads/2014/09/CONAI_Futuro_Comune_def.pdf

P&G (2018). P&G Announces New Environmental Sustainability Goals Focused on Enabling and Inspiring Positive Impact in the World. *P&G Website.* Retrieved on: https://news.pg.com/press-release/pg-announces-new-environmental-sustainability-goals-focused-enabling-and-inspiring-pos.

Proteus Smart Display (2019). About Proteus. *Proteus website.* Retrieved on: https://proteussmartdisplay.com/about-us/

Display Magazine (2019). Never Ending Display: l'espositore riciclabile lungo tutta la filiera. *Display Magazine.* Retrieved on: https://www.displaymagazine.eu/never-ending-display-lespositore-riciclabile-lungo-tutta-la-filiera/

EC - JRC (2010). ILCD Handbook: General guide for Life Cycle Assessment - Detailed Guidance. *EC - JRC website.* Retrieved on: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf

Grosso, M. and Rigamonti, L. (n.a.), Life-Cycle Assessment (LCA): General characteristics and application to waste management. *Politecnico di Milano.*

Rigamonti, L. (n.a.) LCA: introduction. *Politecnico di Milano.*

Muralikrishna, I. and Manickam, V. (2017), Environmental Management. *Elsevier Inc.* Retrieved on: https://www.sciencedirect.com/book/9780128119891/environmental-management

Grosso, M. and Rigamonti, L. (n.a.), LIFE CYCLE ASSESSMENT (LCA):

General characteristics and application to waste management. *Politecnico di Milano.*

Rigamonti, L. and Grosso, M. (2009), Riciclo dei rifiuti. *Dario Flaccovio Editore.*

Rigamonti, L. and Grosso, M. (2009), Riciclo dei rifiuti. *Dario Flaccovio Editore.*

Rigamonti, L. and Grosso, M. (2009), Riciclo dei rifiuti. *Dario Flaccovio Editore.*

K.Xue. (2013). Analysis on the Structural Performance of Traditional Chinese Furniture and Design Improvement of Mortise and Tenon Joint. Retrieved on: http://kreader.cnki.net/Kreader/CatalogViewPage.aspx?dbCode=cdmd&filename=1013045817.nh&tablename=CDFD1214&compose=&first=1&uid=

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iMAT:
Digitalizing, democratising and empowering materials development via Artificial Intelligence

Executive summary

The development of new materials has been identified by the European Material Modelling Council (EMMC) [1] as one of the main innovation drivers for the European industry. This concerns also a focus on sustainability of energy storage solutions, where the usage of optimised materials can bring important results. However, decision making in R&D departments regarding material discovery requires considerable investments in terms of time and money. Material Modelling has been used to screen materials and focus the company's efforts, but the required skills are usually not available. The figure of Translator has therefore been identified by the EMMC to bridge academic and industrial world but, due to the broad knowledge required for this purpose, the Translator cannot be an expert on each field therefore an aid is needed in the form of easily accessible information [2]. Due to the scarcity and incompleteness of existing databases, we decided to exploit the enormous amount of scientific literature as source of data to provide insights. These, information is however unstructured and need to be extracted and transformed in structured data such as databases and graphs. This process needs to be almost fully automatic and for this purpose Natural Language Processing (NPL) techniques can be applied. NPL is a branch of Artificial Intelligence used to process and analyse human language data. Its application to scientific literature is however challenging due to several limiting factors such as scientific language and data format. Even if some studies have been performed in the field, no fully comprehensive process pipeline from data recollection to extracted data structuring is available on the market. We decided to develop this pipeline on a real case study, the usage of zeolites in thermal storage, but constructing it in a way not to require any in-depth programming expertise, also to assure the adaptability of the process to different case studies. To do so we exploited also the collaboration with IBM Research [3], including several their tools. Our model is now able to autonomously recognise useful data in zeolites literature. We can then interrogate these data to have highlights about their distribution over relevant axis and emerging trends. Facing a new research topic, it is now possible to adapt this process and screen the existing literature to have important insights on how to better address efforts and resources. The pivotal difference and main value in our process is that it adopts and applies a set of simple and easily available tools, requiring no hard skills, and it leads the user throughout the whole process. It becomes then an important asset for future researches as the starting point for the construction of a new model, based on different topics and literature, which can be applied by users who are not familiar with Artificial Intelligence and NPL techniques.

Key Words

MATERIALS
RESEARCH
MACHINE LEARNING
TRANSLATOR

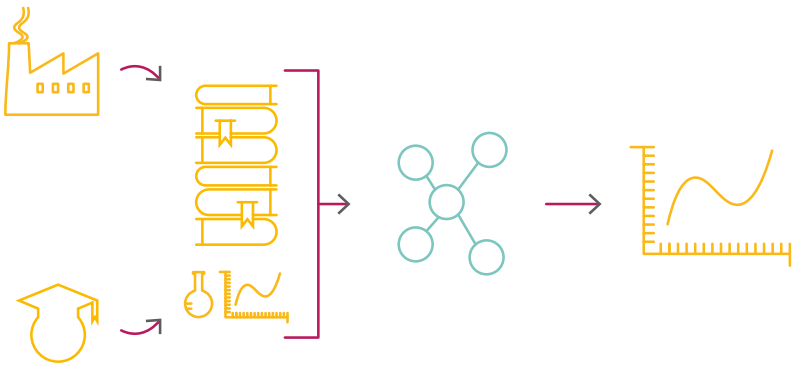

Fig. 1 - Concept of the process


in which these are already labelled by humans, able to


input output
Specific surface area
Pore diameter
Pore volume
Cell volume
Framework Density (FD)
Chemical composition
Isosteric heat
Adsorption isotherms
Temperature of charge
Max water uptake
Storage density
Thermal conductivity
H2O affinity
Mechanical strength
Mass diffusivity (water)
Henry constant
Energy barrier to diffusion
As this topic isn't deeply explored yet, data resulted scarce and heterogeneous.


Moreover, in the documents themselves synonyms were used to refer to the same concept.

Project description written by the Principal Academic Tutor

The rapid evolution of contemporary technologies requires continuous development of novel and/or improved materials. In this context, materials modelling techniques and numerical simulations can serve as powerful means to accelerate industrial innovation, alleviating time consumption and costs of tailored experimental procedures. Thanks to the always increasing computational power available, simulations for material screening have the possibility to become everyday more intensive - see e.g. high-throughput simulations. Notwithstanding, these techniques require proper modelling expertise, proper infrastructure and a considerable commitment. Apart from the modelling and simulation part, the generated (big) data outcome must then be properly interpreted and treated, to extract the most relevant information (mining) for the purpose. This is one of the reasons why, at least in the context of materials modelling - yet not only - development of proper data analysis and mining tools are assuming every day more and more importance, both in academia and industrial sector. These tools are more and more often landing towards the emerging field of artificial intelligence, term which now encompasses quite a large number of techniques and applications – e.g. machine learning. Apart from pure (simulation) data mining, these techniques have recently been applied to screen (i.e. mine) the information available in scientific literature in the form of text, using Natural Language Processing (NLP) techniques combined with machine learning. This approach represents an alternative approach to the generation and mining of big data from high-throughput numerical simulations and aims to take advantage of the huge amount of information which is already available in scientific papers.

This project focuses on materials analysis in the abovementioned context about efficient data handling and its continuously growing importance for industrial innovation (e.g. industrial digitalization). This attitude perfectly fits the role of the Translators, which have been recently defined by the European Materials Modelling Council (EMMC, https://emmc.info) as professional profiles able to bridge industrial needs and state-of-the-art academic research to drive industrial innovation. The project has been finally shaped to focus on the application of state-of-the-art artificial intelligence (IBM Watson) for automatic literature screening and materials data extraction via NLP/ML to speed up properties' assessment. The application case has been chosen to focus on the properties of materials for thermo-chemical heat storage (e.g. water adsorption on different zeolites), which is an active field of research due to its relevance to many industrial sectors, such as e.g. automotive and civil. The project consists of four main types of activities: (1) LEARN the basic technical concepts required to work in the context of data (NLP/ML in this case) for materials screening; (2) DEVELOP a proper machinery to implement the idea; (3) ANALYZE the outcome and assess the perspective impact; (4) CONVINCE the audience that the idea is valuable using proper communication channels. This project has benefited of the cooperation of the European Materials Modelling Council and of different academic and industrial partners to provide support and feedback on specific tasks.

Team description by skill

As Alta Scuola Politecnica is a program specifically designed to foster a multidisciplinary collaboration, our skillset was very various and required a precise organization.
The main competences present in our group were related on one hand to Chemistry and Material Science (Material Modelling sub-team) and on the other hand to computer science and digital innovation (AI and Machine Learning sub-team). This formal division was meant to explore the interactions between the two main topics of the project: Artificial Intelligence and Material Modelling. The former group was assigned with the task of framing the research context within the structure required to handle it with a machine learning logic. The latter one was required to explore the existing programming tools which would be pertinent in building the actual model and develop new solutions. The distinction was, however, blurry since the cooperation of all members was required for several tasks. For instance, a precise knowledge of the chemical properties of materials is required to build and train a supervised machine learning model.
The Communication Coordinator, thanks to her competencies in design and communication, covered the outreach and communication strategies, gathering and organising the outcomes from the rest of the group. The Team Controller was pivotal in keeping a connection within the different subunits of the team and sticking to the project schedule.

Goal

The main goal of the iMat project is to explore the possibilities of application to exploit emerging Artificial Intelligence algorithms to speed up research in the field of Material Modelling. Indeed, the EMMC also identifies the development of new materials as one of the main innovation drivers for the European industry, also from the point of view of sustainability. Therefore, great attention has been directed towards the screening of existing and hypothetical materials to have anticipating insights about the most promising directions and focus a company's energies on a few attempts. In this context, the professional figure of the Translator has been identified with the aim of supporting and bridging between academic research and business necessities. However, in many cases Translators may not have a complete knowledge of the problem they are working on. An AI tool able to read and understand a large amount of scientific articles would be crucial to strengthen the role of the translator. Indeed, such an algorithm would speed up bibliographic research and allow to summarise a large amount of unstructured information into a simple structured database. Therefore,, at the beginning of this project we wanted to build a completely-automatized tool for the text-mining of quantitative information from scientific articles.

Understanding the problem

Materials have marked the evolution of mankind since prehistoric times, naming the ages based on the dominant materials. Despite the fact that everything around us is made of materials, for almost the entire course of human history, the discovery of new materials was pursued as a sort of mystic art. Up to less a century ago this process involved a tremendous amount of trial-and-error and expensive testing. The traditional material discovery process is a tortuous path consisting of several steps. Generally, the time required from the formulation of the idea of a new material to its deployment is remarkably long: first of all, it requires skilled technicians to perform long and expensive experiments, that are necessary to get meaningful data. Secondly, the tests are carried out mainly with the aim of incrementally improving existing chemistries and already-well-established materials rather than with the idea of investigating completely new materials to assess their potential. However, modern advances in the understanding of the intrinsic physics provide a comprehensive framework to supervise the materials discovery process, laying the foundations of a new discipline called computational materials science. Materials modelling allows to optimize the scheduling of experimental activities, hence limiting expensive trial-and-error procedures. However, it requires highly specialized professional figures and high-performance-computing facilities. Hence, money and time consuming hard work is usually necessary to foster the research for innovative materials and this is an important limiting factor, especially for Small Medium Enterprises (SMEs) [4]. A completely different approach envisages the employment of Artificial Intelligence (AI) techniques to sift through the already huge amount of scientific articles and reports, assuming that the dataset under analysis embeds the intrinsic physics. Hence, the data-driven approach could gather relevant insights and propose innovative molecular structures to be further investigated. However, the major part of useful data appears in the scientific literature in an unstructured form and a well-established methodology to arrange them in a database for data-mining purposes still does not exist. EMMC has identified the professional figure of the Translator to push materials innovation. Since the Translator does not have a specific knowledge on each case study he has to face, it is necessary for him to easily gather the various pieces of information found in the scientific literature. Therefore, the development of a procedure to extract and organize data is of pivotal importance. A specific case study that is particularly relevant in the field of materials modeling has been investigated during this project. To reach a low-carbon emission system, energy production from renewable sources is strongly promoted nowadays, but their intermittent nature threatens to limit their applicability. To tackle this issue, the development of an efficient Thermal Energy Storage System (TESS) is of fundamental importance[5]. In particular, the use of zeolites in sorption-based TESS represents an important current research topic. Hence, chemical and energy industrial realities could be strongly interested in a process that would allow them to screen the state-of-the-art knowledge and that would manifest the best route to be followed for material innovation.

Exploring the opportunities

The present work opens a wide range of opportunities to be exploited. For instance it allows to offer external institutions a tool based on Natural Language Processing to extract numerical data from scientific literature. Furthermore, regarding the EMMC objective to bridge research and industry, it corroborates the role of the Translator by complementing his work with a tool that can foster materials modelling. In addition the support and the supervision of IBM guarantees to explore the potentialities of IBM Watson tools [6] and to gain precious insights on cutting edge Artificial Intelligence tools. Moreover, the case study of Thermal Energy Storage allows to tackle one of the most promising challenge that the present world has to tackle: renewable energy. Finally the innovative process that is developed can be formalized in the publication of a scientific paper.

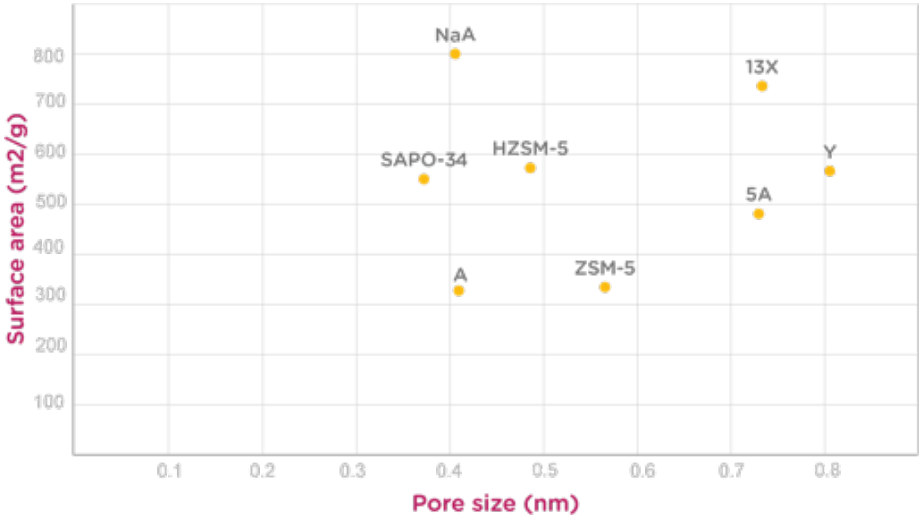

Fig. 2 - Extrapolated Ashby map comparing different zeolites over two relevant properties in TESS

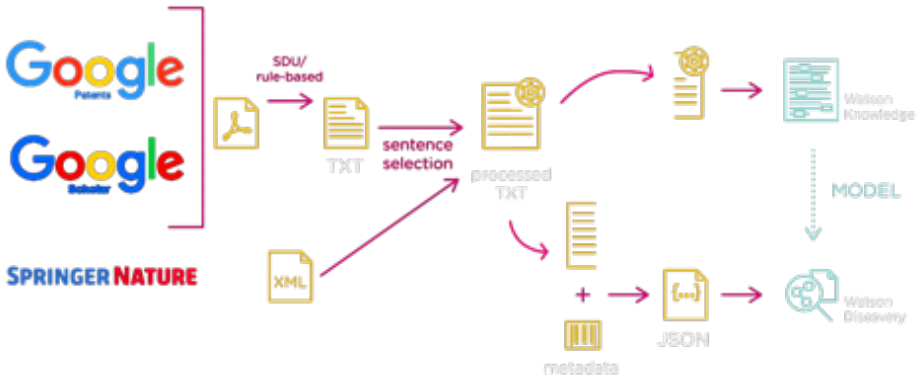

Fig. 3 - Preprocessing steps and model construction

Generating a solution

Our solution consists of a multistep process that exploits Artificial Intelligence and Natural Language processing to extrapolate structured data from unstructured information contained in scientific literature. Every year, around 2.5 millions of scientific articles are published and the development of an efficient automatic procedure of information extraction would make a major breakthrough in research, enhancing the connection between industry and academia.

Our results demonstrate that text-mining methods based on machine learning can be exploited to translate a verbal unsystematic input into a well-organised quantitative output that can be easily visualised. We applied AI tools provided by IBM Watson to convert scientific papers from PDF format to plain text and to implement a model that analyses them sentence-by-sentence. Our model categorises words according to their meaning and identifies relevant relations between them. In this way, we were able to automatically recognise patterns in the text and extract quantitative information related to our case study: zeolitic materials. We concentrated on a list of zeolites and properties of interest and we collected the corresponding numerical values. The data were eventually used to create Ashby maps, an efficient visualisation technique that can support decision-making.

Main bibliographic references

[1] Council, E.M.M.:TheEMMCRoadMap2018forMaterialsModellingandInformatics, 2018
[2] Council, E.M.M.:EMMCTranslatorsGuide.https://emmc.info/wp-content/uploads/2017/12/TranslatorsGuide.pdf,2017.
[3] IBM research.http://www.research.ibm.com/.
[4] Commission, E.:SMEPerformanceReview.https://ec.europa.eu/growth/smes/business-friendly-environment/performance-review_en,2018.
[5] Dincer I.,R.A.: Thermal Energy Storage: Systems and Applications. Wiley,2011.
[6] IBM Watson.https://www.ibm.com/watson/.

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Innovate Africa

Executive summary

"Innovate *Africa*" is a project with the objective to boost the Next Production Revolution (NPR) in *Africa*, while keeping a focus on the peculiar features of each country.

The weak infrastructural tissue and the Climate Change threat pose a serious challenge for the future socio-economic development of the Continent, which needs to leverage on its strengths (e.g. possibility to exploit renewable energies) to foster the NPR development.

To this end, a flexible and modular technological kit impacting directly on Water, Energy and Food (in line with Nexus framework) has been designed. Following a logic of optimization of resources, the project promotes a flexible approach in which actors (inhabitants of rural villages) can be an active part of the process (creating the kit they need to take advantage of it) and the final solutions would be extremely adapted to the context (therefore, untransferable and unique).

Indeed, in the frame of the project, the kit has been customized to the specific needs and peculiarities of three sub-Saharan Africa countries, deemed to be the most promising Countries for NPR development: Ethiopia, Kenya and Congo. Therefore, the final output is the configuration of the kit and the consequent final layout for 3 case study villages of 50 people each in the three analyzed Countries.

Conventional and high-tech technologies with a direct impact on Water, Energy and Food (WEF) have been combined, aiming at improving agricultural productivity of rural villages. In particular, the kit will enable water purification, green energy production and precision farming, enhancing village inhabitants living standards.

In conclusion, the kit is a structured but adaptive technology pack, with the main objective to support The Italian Agency for Development and Cooperation and Politecnico di Milano and Politecnico di Torino to find a sustainable pathway that can lead *Africa* out of poverty through innovation and the implementation of NPR.

Key Words

Africa, Innovation, Next Production Revolution, Flexibility, Context.


NCO
NDIAL

Project description written by the Principal Academic Tutor

The *Innovate Africa* project has the aim to understand how the Next Production Revolution (NPR) can be a leverage to socio-economic development in Sub-Saharan Africa through an investigation of some sustainable innovations tailored to the local context, including rural population.

The adopted approach to NPR wishes to focus on the development of solutions about the two clusters of technologies more suitable for the local context: digital and green technologies. Therefore, the confluence of integrated solutions that enable Energy, Mobility and Digitalization are deepened in order to induce substantial improvements and affect both technological and socio-economic development.

The project has a common bond within the collaboration of the ASP students with a group of the African Innovation Leaders (AILs) to enable, all along the project, the exchange of information and experience between Italian and African realities throughout the whole definition of the work.

The AILs belong to the first group of African professionals selected within the project supported by Italy during the Presidency of the G7 in 2017 and funded one year later by the Italian Agency of Cooperation and Development. The project is jointly managed by Politecnico di Milano and Politecnico di Torino[1].

More in details the project was developed by following a step-by-step structure, resumed as follows:

1- Contextualization and Country studies: during this phase, the current state of the art for the national innovation systems has been analyzed, after selecting the Sub-Saharan countries: Ethiopia, Kenya and Congo. These countries and their innovation ecosystem would represent the field of application of the solutions.
2- Main issues identification: in the context of the whole Sub-Saharan Africa, the major problems and themes of investigation have been identified and selected. They are mostly related to access to resources and common goods, like food and water security as well as the threat to ecosystem services posed by climate change and therefore the urgency of proper mitigation policies.
3- Technological exploration: after understanding the key aspects to be faced, a set of both conventional and high-tech technologies has been identified and solutions have been formulated. A development kit represents the technology sharing instruments to be provided to rural areas in order to start enabling and facilitating the seeds of the needed NPR in those areas.
4- Application of the solutions: the proposed modular kit has been differently assembled for a standardized village in the three countries in order to fulfill local needs, according to the specific political and economic constraints that characterize each country. Solutions are selected based on their suitability in the local areas and their costs.

At the end of the project work, part of the team was involved in a mission in Mozambique aimed at interacting with local authorities and experts in the field, trying to understand the opportunities for practical implementations of the project and further extend the usability of the development kit. Within this mission, which was of high relevance for the team's understanding of local boundary conditions, a visit to a rural village was organized to share the "development kit" and receive a feedback by the inhabitants of rural areas as perspective beneficiaries of the tool.

[1] Please visit the page http://community.africainlead.net/

Team description by skill

The *Innovate Africa* team is made of six students: Iacopo, Cristina, Luca, Marta, Giacomo and Olivia. Each member of the team possessed individual skills and shared with the other teammates his or her specific knowledge.

The fields of expertise of the team varied from Architecture to Management Engineering; thus encouraging a holistic approach when addressing the issues revolving around the project. The team was efficiently organized, allowing each team member to develop his or her abilities. The team, infact, decided to elect a team leader, **Giacomo Ferrari**, but to maintain a non hierarchical structure in order to favor a more creative and dynamic environment. Giacomo Ferrari is a Management Engineer from Politecnico di Milano and with **Luca Marzorati**, coming from the same Magistrale programme, helped coordinating and organizing the team tasks. Their role was essential in the creation of the project structure and during the interactions with the stakeholders and with the African Innovation Leaders who were crucial during the idea generation phase.

In this phase, the role of the three architects in the team was also of major importance. **Marta Riccò**, **Cristina Mordeglia** and **Olivia Boccardi** were fundamental during the brainstorming stage thanks to their ability to identify the main problems of the current reality and propose unconventional and innovative solutions. The three architects thanks to their skills were also in charge of project communication.

Finally, **Iacopo Ciuchi**, with his background in Energy and Nuclear Engineering, was the main reference for all of the more technical aspects of the project. His role was fundamental since the project's main topic is Energy. Furthermore, Iacopo was very helpful in the interaction with architects, collaborating with them he contributed to the creation of an otherwise less realistic and feasible project.

Goal

The main goal of the project is to identify a solution able to trigger the Next Production Revolution in sub-Saharan Africa.

Considering the needs and the constraints posed by the different stakeholders - i.e. the Italian Agency for Development and Cooperation (AICS), Politecnico di Milano and Politecnico di Torino, African Innovation Leaders (AILs) and ENI - a series of other goals emerged. In particular, the proposed solution has to have a direct impact on Water, Energy and Food, fitting the WEF framework and being feasible from a technical and an economic viewpoint. Moreover, agriculture has been recognized as the most promising area of intervention and specifically agricultural productivity improvement of rural sub-Saharan villages has been chosen as the main goal.

However, the Continent shows a high level of diversity in terms of natural resources, infrastructural tissue, people habits, et cetera. For this reason, the proposed solution has to be suitable for different contexts (represented in the project frame by three rural villages in Ethiopia, Kenya and Congo) and consequently flexibility, modularity and adaptability result to be core characteristics.

Therefore, the final goal of the project emerged to be the design and configuration of a flexible and WEF-Nexus-compliant solution aimed at improving the agricultural productivity of rural sub-Saharan *Africa* villages and villages inhabitants standards of living. Combining traditional and high-tech technologies, the proposed solution should become the trigger of a leap-frogging process to boost the Next Production Revolution in sub-Saharan *Africa*

Understanding the problem

NPR requires the support of both hard (e.g. water and electricity supply) and soft (e.g. governance mechanisms) infrastructures to be boosted and an analysis of them is the starting point of the work. With a twofold objective (i.e. understand the state-of-the-art and identify the main potentialities) the overview of African infrastructures is grouped in three macro-areas: Digitalization, Decarbonization and Mobility. Among all, Decarbonisation and, thus, the reliance on more sustainable energies, is of fundamental importance in a Continent where population and economy are increasing, continuously requiring larger amounts of resources.
Mobility and Digitalisation reveal to be crucial as well: if the first is a prerequisite for the growth and innovation of a Country, the second can increase the possibility to access to basic services requested by the society, while fostering the productivity in different sectors. This is particularly true for agriculture, the most impacted segment in "Innovate Africa" project.

The second step of the work is the identification of the most promising Countries for NPR development in sub-Saharan Africa (Kenya, Ethiopia and Congo) and an in-depth study of their peculiarities. Kenya is a worldwide case study for its exploitation of M-Pesa, the mobile application for money transfer largely adopted in the country, which, thanks to digitalization, represents a model of leapfrogging for other nations. Ethiopia and Congo are a fertile ground for the study of possible innovations in agriculture: the first is still heavily reliant on the primary sector, while the second is embracing a Governmental diversification strategy that should decrease the dependence on the industrial segment, allowing improvements in agriculture and in its productivity.

Then, the problem is considered from a broader viewpoint and environmental safeguard is set as a priority. For this reason, the agricultural studies are considered in relation with the global issue of Climate Change and respecting the paradigm of Water-Energy-Food (WEF) Nexus, which is an enabler for the creation of synergies between the three clusters, that can be considered as pillars for agriculture improvement. The key to keep together the WEF with a climate change mitigation vision is then identified in the use of renewable energy to fulfil agricultural and water issues and demand. The extensive presence of hydro, solar and wind resources should represent a breakthrough in understanding which technological, economic and political strategies need to be involved in order to fully exploit their potential. In particular, technological solutions involving renewables are perfectly suitable to African reality, where around 60% of the people live in decentralized areas, far from the cities: the most representative example is constituted by PV panels, whose small capacity and modularity are the fundamentals for a diffusion of a technology in those parts of the world where electrification is very low or, even worse, absent.

To sum up, a series of initial analyses are carried out to frame the problem and the surrounding context. In particular, the state-of-the-art and the potentialities of the infrastructural tissue of Africa are analysed in depth. Then, the analysis moves to the identification and the study of the most promising sub-Saharan Africa Countries for NPR development. Finally, the Climate Change threat is taken into consideration and the WEF Nexus framework is presented.

Africa Innovation Kit

Exploring the opportunities

After understanding the current problematic situation of sub-saharan Africa, the major issues to be considered has been recognized into:

1- Rural development;
2- Clean water supply;
3- Food security;
4- Renewable energy supply;
5- Information spread;
6- Climate change mitigation.

In order to include and take into account every factor, a set of existing technologies has been selected and collected in a Developement Kit to be provided to rural areas, trying to improve their inhabitants lifestyle in a sustainable manner. The chosen technologies are:

- Solar assisted pumps, whose aim is to exploit more the local resource of groundwater and surface water to irrigate agricultural fields with an almost completely sustainable energy supply: PV panels. They have clearly a different design if they are used to pump groundwater or surface one.
- Solar water disinfection (SODIS), that consists in a 25 liters Polyethylene tube surrounded by a solar parabolic concentrator, that aims at focusing solar irradiation on the tube in order to kill patogens. Moreover, water needs to be pretreated from turbidity. Consequently, two alternative solutions are proposed, namely the use of natural flocculants extracted by specific seeds or roughing filtration systems.
- PV driven Reverse Osmosis filtration (PV-RO), a more effective alternative to SODIS in providing potable water. It can be used also for water dissalation, being able to remove even very small ions dissolved in it.

- Anaerobic Digester, used for biogas production from agricultural waste. It promotes the idea of a closed system that could reuse the waste to produce a fuel that has an energy value and can be used for cooking purposes.
- Fertilizers and Urea Deep Placement (FDP and UDP), that are an alternative to traditional surface broadcasting of fertilizers across fields, consisting in fertilizer briquettes, placed at different depths below soil surface, that gradually release nitrogen according to different cultivation requirements.
- Aeroponic system, that, thanks to the fact that plant roots are suspended and directly sprayed by nutrient solutions without the use of soil, makes possible to recover disadvantaged cultivation areas, offering an alternative to overcome the difficulties linked to the fertility of land.
- Aerial agriculture and Variable Rate application Technology (VRT), that are used, respectively, to monitor the characteristics of the fields and to acquire data from sensors for the automation of inputs rate for site specific applications in a "smart agriculture" view.
- Solar Wi-Fi, needed in order to enable the previous smart agriculture systems. Following the idea of renewable systems, a solar powered network of kiosks is provided to convert energy from the sun into internet connection.

Generating a solution

Once identified all the technologies that can compose the kit, the project group has identified the potentiality of its application in three different 50 people standardized villages, respectively located in Kenya, Ethiopia and Congo. As a matter of fact, the kit is not unique and does not necessarily comprehend all of the technologies mentioned before, but can be assembled according to the specific needs of the single village, taking into account geomorphological, economic and political features.

Therefore, the final outputs are the choice of the three different configurations of the kit for the three case study villages and the visual representations of their assembling, highlighting how the technologies can be spatially disposed in the rural environment.

Finally, the different versions demonstrate the versatility of the system and are directly comparable in terms of investment costs for the different components (which depend on the resources and the limits of the country) and feasibility.

Final configuration of a rural village in Kenya

Final configuration of a rural village in Ethiopia

Final configuration of a rural village in Congo

Main bibliographic refereaces

[1] P. Leone, M. Taisch, F. Chell M. Pinzone, S. Arrigoni, C.F. Chiasserini, P. Boccardo, E. Colombo, «Toward Smart and Integrated Infrastructure for Africa: an Agenda for digitalisation, decarbonisation and mobility,» Infrastructure Consortium for Africa, 2017.

[2] World Economic Forum, "The Africa Competitiveness Report 2017.", Geneva, 2017.

[3] Deloitte, "Industry 4.0 - Is Africa ready for digital transformation?.", 2016.

[4] Organization for Economic Cooperation and Development, " The Next Production Revolution- Implications for Government and Business.", Paris, 2007.

[5] African Development Bank, «African Economic Outlook,» 2018.

[6] P. Garrone, F. Lamperti, «Country Study- Overview of the National Innovation Systems: Ethiopia.».

[7] B. Mrkajic, «Overview of the National Innovation Systems for the Emerging African Innovation Leaders, G7 Exchange and Empowerment Program – Kenya,» 2018.

[8] S. Tavneet, J. Williams, «The economics of M-Pesa,» 2010.

[9] A. Calzadilla, T. Zhu, K. Rehdanz, R.S.J. Tol, «Economy wide impacts of climate change on agriculture in Sub-Saharan Africa,» Ecological Economics, 2013.

[10] H.T. Aboelnga, M. Khalifa, I. McNamara L. Ribbe, J. Sycz, *The Water-Energy-Food Security Nexus: A review of Nexus literature and ongoing Nexus initiatives for policymakers*, Nexus Regional Dialogue Programme, Bonn 2018, pp. 20-26.

[11] IRENA, *Africa Power Sector: Planning and Prospects for Renewable Energy* (2015)

[12] FAO, "Climate-Smart Agriculture", www.fao.org.

[13] P. Pavelic, M. Giordano, B. Keraita, V. Ramesh and T. Rao, Groundwater Availability and Use in Sub-Saharian Africa: A review of 15 Countries, International Water Management Institute, Colombo, 2012.

[14] P. Ferna and E. Ares-Maza, Evaluation of the Solar Water Disinfection Process (SODIS) Against Cryptosporidium parvum Using a 25-L Static Solar Reactor Fitted with a Compound Parabolic Collector (CPC), 86:2, 223–228, 2012.

[15] M. W. Mbiyu, Use of aeroponics technique for potato (Solanum tuberosum) minitubers production in Kenya, Journal of Horticulture and Forestry 11:4, 172-177, 2012.

[16] African Union and The New Partnership for Africa's Development (NEPAD), Drones on the horizon – Transforming Africa's Agriculture, High Level APET Report, 2018.

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Data Analytics for Household Energy Consumption

DAHEC

Executive summary

The changing scenario in the residential energy market requires the energetic players of today to adopt innovative approaches for business to be still part of the competition tomorrow. Novel market opportunities need to be tested and the on-field validation can be prohibitive due to cost, time constraints and complexity of pilot projects.

DAHEC (Data Analytics for Household Energy Consumption) project aims to analyse and validate novel market opportunities through virtual pilot projects fed with synthetic but realistic disaggregated consumption data, overcoming the obstacles of real pilot projects. The synthetic data are outputs of a simulator of households' energy consumption, ad-hoc implemented during the project. The innovative path developed by DAHEC team makes the assessment of market opportunities feasible. Thanks to virtual pilot projects, Smart Bills for White Certificates as well as price-based and incentive-based Demand Response are evaluated to estimate stakeholders' benefits.

Key Words Energy market, Smart Bills, Demand Response, Simulator, Data analytics.

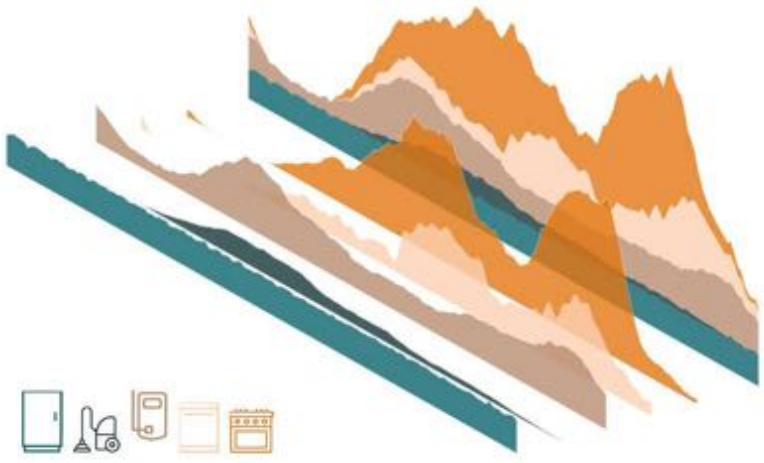

Figure 1: Disaggregated energy consumption data

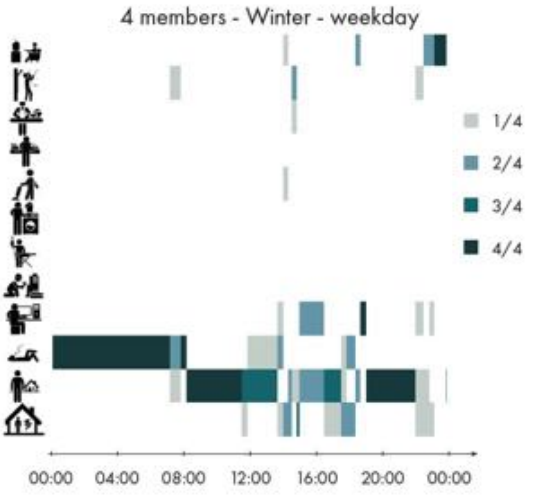

Figure 2: Example of behavioural simulation.
Daily behaviour of a 4-member family.

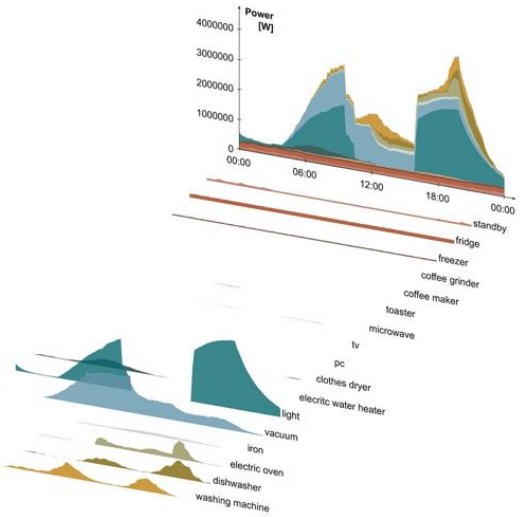

Figure 3: Disaggregated consumption profile.
Simulation of consumption profiles of 10 thousands families.

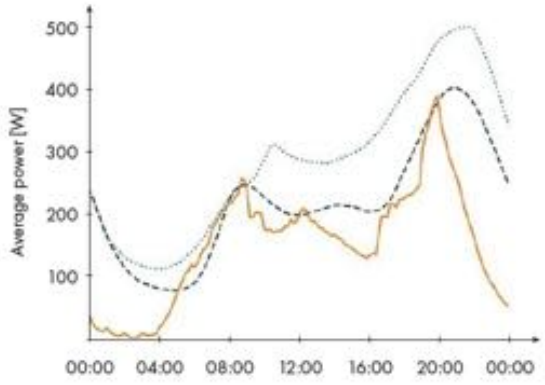

Figure 4: System validation.
DAHEC average power profile (orange) is compared with other studies about real households' energy consumption (blue).

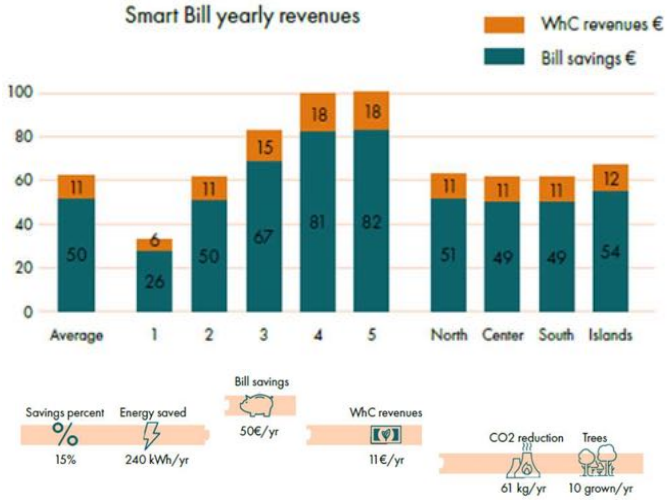

Figure 5: Output of Smart Bills virtual pilot project.
Final customers' savings and benefits for an average family.

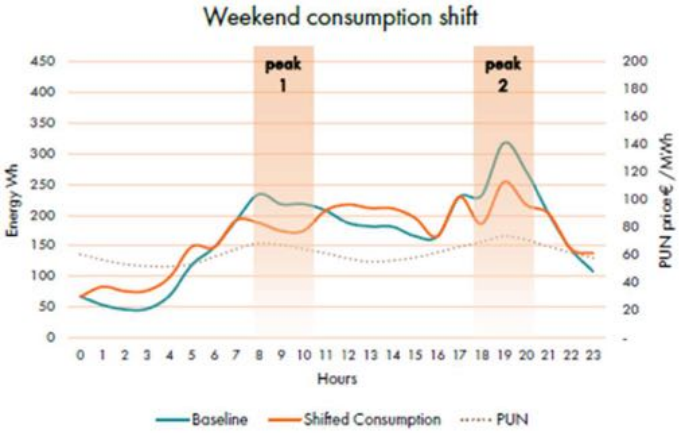

Figure 6: Design of price-based Demand Response virtual pilot project.

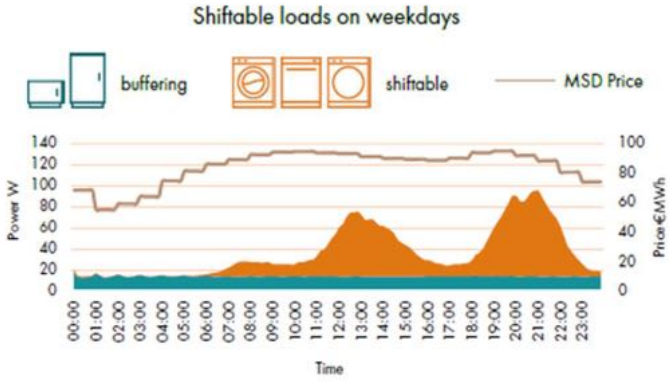

Figure 7: Preliminary step of incentive-based Demand Response virtual pilot project.
Selection of the shiftable load for the average simulated family.

Project description written by the Principal Academic Tutor

DAHEC project aims at designing a feasible and ready to use solution to evaluate market opportunities in the energy sector. In this context, it aims at developing a software tool for Big Data analytics based on energy load profiles.

The project starts from a market analysis that aims at identifying new data-driven business opportunities by exploiting fine-grained information about the appliances' energy consumption. From such analysis a set of stakeholders' requirements arises, which underlines the necessity of the design and development of a simulator of residential energy consumption to evaluate the impact of market opportunities previously identified.

The final outputs of the project are:

1. A set of requirements coming from an in-depth market analysis aiming at profiling the end-users based on their household energy consumption patterns.
2. A novel system architecture for Big Data Analytics to simulate end-users energy consumption profiles.
3. New market opportunities to foster new services in the electrical marketplace to be tested and validated in a virtual environment by exploiting the end-users energy consumption profiles.

Different stakeholders can take advantages of the results of this project:

- Energy companies can benefit from the output of the project to support their decision making, as a tool to evaluate new market opportunities, optimize planning activities of smart grid or support operational management. In addition, Energy utilities could profile consumers and offer personalized pricing policies.
- Researchers can take advantage of these results for different research activities (e.g. compensate lack of consumption profile data and perform behavioural and energy studies of the population).
- Policy makers can test novel services and control strategies for smart grid management and load balancing.

Team description by skill

DAHEC team is composed of two subgroups: the first one focused on the market analysis, the second one worked on the implementation of a households' energy consumption simulator.

Milica Vojinovic ad Marco Teodori were in charge of the market analysis. Milica Vojinovic applied her knowledge in Management Engineering to the analysis of the market context and validation of the opportunities. Marco Teodori provided meaningful insights with his background as an Energy Engineer and supported the identification of viable market opportunities.

Nicola Barletta, Ilaria Botticelli and Luca Colomba exploited their Computer Engineering and Data Science skills in the design and development of the software components required by the project. Alessandro Barilli and Celeste Principi, as Mathematical Engineers, provided fundamental support with their competencies in statistics and data modelling. Celeste Principi, as team leader, also supervised the coordination of the subgroups to achieve a cohesive result and cared of deadlines and deliveries.

Goal

Energy market in the residential sector is evolving due to new European regulations and a stronger awareness towards sustainability. Novel market opportunities to address these issues have been investigated and energy players are considering some new business models. DAHEC project focuses on the residential energy sector, exploiting disaggregated consumption data, in order to identify innovative yet feasible market opportunities to tackle the change.

The feasibility and profitability of market opportunities need to be assessed through pilot projects on a large scale. Actually, implementing pilot projects is not trivial: they require costly investment, they need to follow strict regulations

and people's involvement implies privacy issues. Moreover, they can take time to be performed and in such a dynamic market, time cannot be wasted.

In this context, DAHEC (Data Analytics for Household Energy Consumption) project aims to overcome the implementation impasse through virtual pilot projects fed with disaggregated consumption data. These data are generated by a simulator implemented ad hoc during the project to recreate a huge virtual population that resembles Italian families and to describe the energy consumption at device usage level during a potentially unlimited time span.

Understanding the problem

The energy market in the residential sector has been changing in the last few years and it is expected to undergo a stronger change in the next future. The well-known higher penetration of renewable energies is challenging the energy producers and the electrical grid itself will require a disruptive innovation. At the same time, the market regulation is promoting the final part of the liberalization process: in Italy the market is expected to become totally free in 2020, ending the Service of Greater Protection.

In order to keep its competitiveness, a player in the energetic market will be required to deeply change its approach and business. Novel market opportunities have been investigated and some business models are already "on the table" of energy players.

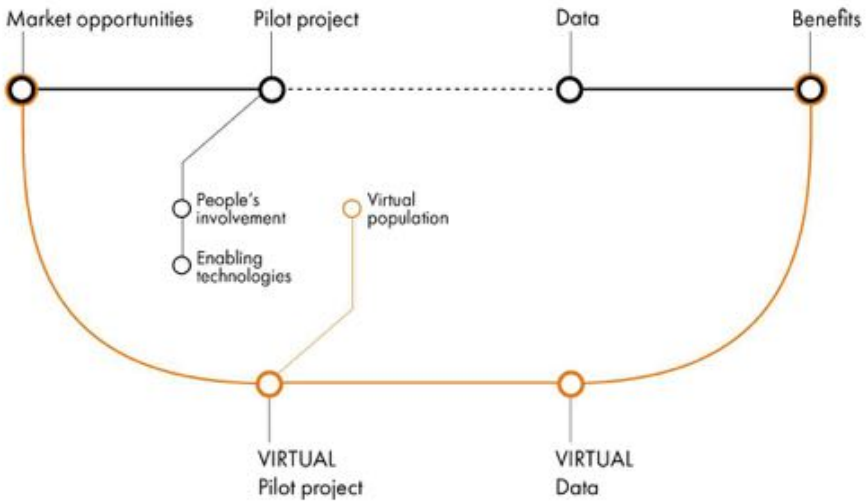

Figure 8: DAHEC path, from the canonical validation journey to an innovative simulative approach

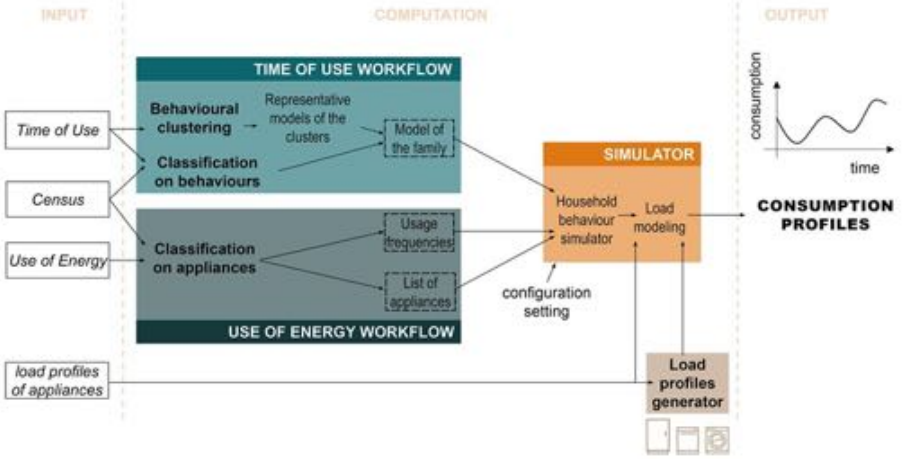

Figure 9: System architecture of the simulator

Exploring the opportunities

Implementing new strategies in the energy market has its barriers: the biggest one is that new market opportunities must be tested through pilot projects involving lots of households. The technologies to collect disaggregated households' consumption data are mature but still at their early stage of diffusion, so the very large scale required to have a substantial output from the pilot projects can be difficult to obtain because they require costly investment and involve privacy issues.

Generating a solution

DAHEC project aims to analyse and validate novel market opportunities through virtual pilot projects, overcoming the already mentioned obstacles of real ones (see Figure 8: DAHEC path). Virtual pilot projects are fed with disaggregated consumption data generated by DAHEC simulator, which is implemented to recreate a huge virtual population and to describe its energetic consumption at device usage level by modelling heterogeneous families' behaviours, ownership and usage of each type of appliance.

Assuming the availability of the disaggregated household consumption data, DAHEC project identifies several market opportunities and evaluates them based on the market analysis and direct contacts with companies from the energy sector. The identified market opportunities are: Demand Response, Smart Bills for White Certificates, energy saving virtual assistant, Energy Service Companies (ESCos) for energy efficiency, Feedback on appliance performance, Property monitoring based on appliance usage and Data trading with third parties. The selection process is performed based on insights obtained during the Utility day, the most important event about Italian energy industry and its output is the selection of two business opportunities that are mutually compatible: Smart Bills for White Certificates and Demand Response. The Smart Bill opportunity foresees that the electricity retailers provide a detailed bill, enhanced by the appliances consumption, which results in energy savings with twofold benefits: lower bill for customers and revenues from Energy Efficiency Certificates (White Certificates) for energy utilities [1]. Demand Response opportunity consists of price-based and incentive-based programs that motivate customers to shift a share of their consumption from the peak demand hours to off-peak periods, for which they receive financial benefits [2].

The selected market opportunities need to be tested for effectiveness through pilot projects. As already mentioned, DAHEC opts for designing virtual pilot projects fed virtual disaggregated consumption data that give details of consumption at device level. Taking inspiration from previous works [3], DAHEC simulator is an unlimited source of disaggregated consumption load curves with a degree of complexity and diversity comparable to that guaranteed by a large-scale pilot project. It considers four datasets as inputs. Three of them are ISTAT datasets: Time of Use (TOU) with data about families' members and their daily diary of activities; Use of Energy (UOE) containing data about electrical appliances; Census, that provides a general overview of the Italian population with information concerning both the household and its members. The fourth input is a collection of load curves of real appliances. The system architecture is composed of three macro-modules (see Figure 9: System architecture of the simulator). The first one, called Time of Use workflow, is focused on modelling families' behaviours. It splits families recorded in TOU in more than a hundred clusters with similar behaviours and it estimates one behavioural model for each of the clusters. Then, given a family of Census dataset, TOU-workflow assigns it to the cluster containing the families that show the most similar features, so that it results to be represented by the model of that cluster. The second macro-module, called Use of Energy workflow, is aimed at predicting appliances' ownership and weekly usage. In this block, classifiers of the presence of appliances in the households and predictors of their usage frequencies are trained over UOE dataset. Then, given a household of Census dataset, it can be characterized by the list of appliances it owns and their weekly usage. The core macro-module of the system is the simulator itself. Given a family of Census dataset, the simulator takes as input the model of family (output of TOU-workflow), the information about presence and usage of appliances (output of UOE-workflow), and load

profiles of appliances. Then, it follows a step-by-step approach: every 10-minutes it simulates the behaviour of the family (see Figure 2: Example of behavioural simulation) and it translates it in terms of appliances usage (e.g. TV is working) or activation (e.g. begin of a washing machine cycle). Finally, appliances usage and activation are turned into consumption profiles exploiting their load profiles, eventually pre-processed by a load profile generator that enriches them with metadata about type of cycle and energy class label.

The simulator is used to feed virtual pilot projects to evaluate the two most promising identified business models: Smart Bill and Demand Response. The pilot projects involve the simulation of disaggregated load curves of a sample of 10000 Italian families to get the overall energy consumption (see Figure 3: Disaggregated consumption profile). An analysis of member-based and geographically based consumption is allowed by simulating a sample of 10000 families with 1, 2, 3, 4 and 5 members and distributed in North, Centre, South and Islands respectively. The resulting load curves are reliable in terms of shape and placement of peaks, since they shows consistency with the previously available studies [4, 5] on real consumption (see Figure 4: System validation). From the pilot projects, the Smart Bill shows convenience for target segment of families with 3 and more members regardless of the geographic distribution starting from 67€ of electricity bill savings for customers and 15€ worth of White Certificates for the service provider (see Figure 5: Output of Smart Bills virtual pilot project). The economic benefits of Demand Response are not convenient within the current market context. The price-based DR (see Figure 6: Design of price-based DR virtual pilot project) creates up to 2% savings on the energy component of the electricity bill, and the incentive-based program (see Figure 7: Preliminary step of incentive-based DR virtual pilot project) brings 9€/year for the average household. The benefits will increase with the higher diffusion of shiftable loads (e.g. heat pumps, electric vehicles and smart appliances) and with the improved split of the overall system efficiency gains.

To the best of our knowledge, DAHEC is the first successful method for testing new market opportunities that can be adopted by energy market actors even before having the totality of data about the evolution of the market.

Main bibliographic references

[1] K. Ehrhardt-Martinez, K. Donnelly, and J. Laitner, Advanced metering initiatives and residential feedback programs: a meta-review for household electricity-saving opportunities. *American Council for energy-efficient economy*, 2010.

[2] European Commission. Impact Assessment Study On Downstream Flexibility, Price Flexibility, Demand Response Smart Metering, 2016.

[3] L. Bottaccioli, S. D. Cataldo, A. Acquaviva, and E. Patti, Realistic Multi-Scale Modelling of Household Electricity Behaviours, *IEEE Access*, 2018.

[4] S. Maggiore, Analisi di impatto dell'introduzione della tariffa bioraria obbligatoria, *Rapporto Ricerca di Sistema*, 2012.

[5] A. D. Almeida, Residential monitoring to decrease energy use and carbon emissions in Europe, *Intelligent Energy Europe*, vol. 3030, p. 290, 2008.

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SPACE ARCHITECTURE FOR EXTRAPLANETARY EXPLORATION

Executive summary

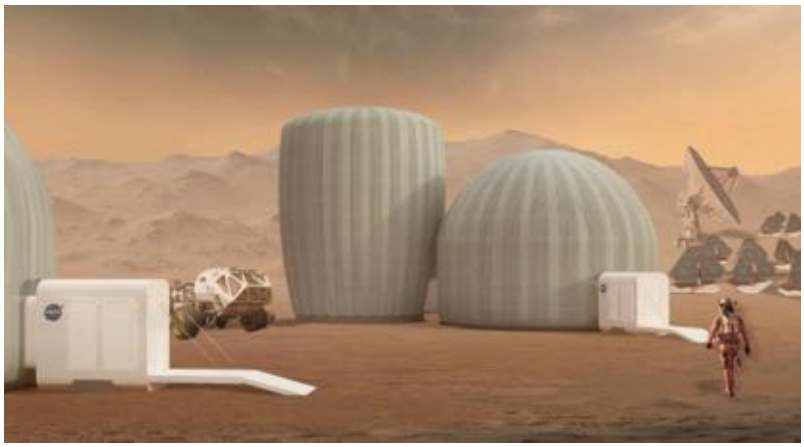
In an era of renewed interest in deep space exploration, the Space Architecture for Extraplanetary Exploration (SAEXE) project set the objective to provide an innovative yet feasible solution to allow manned exploration of Mars in the next years. The project addressed the design of a greenhouse for on-site food production on Mars, conceived to grant self-sufficiency to human-tended space missions, through the implementation of an optimized spiral design of the crops cultivation system. Moreover, the internal space of the module exploits innovative, human-oriented solutions to enhance mental and physical well-being of the crewmembers.

The project is the result of a joint research and design effort between our group of Alta Scuola Politecnica (ASP) and a team of students from the Massachusetts Institute of Technology (MIT). The collaboration of the two teams led to a project awarded second place at 2019 NASA BIG Idea Challenge, to the peer reviewed conference paper "Mars Garden: an Engineered Greenhouse for a Sustainable Residence on Mars" [1], included in the proceedings of the 2019 AIAA Propulsion and Energy forum, and to a poster awarded among the top 5 best works at the 2019 International Conference on Environmental Systems (ICES).

The proposed space habitat concept complements and integrates the Ice Home residential module designed by NASA [2], with an original greenhouse module creating a near closed-loop ecosystem. The proposed greenhouse combines three key elements: a hydroponic system for the cultivation of eight archetypes of plants; an internal helical layout that optimizes the usage of space; the exploitation of the same technological solutions chosen and adopted by NASA for the Mars Ice Home program, in order to guarantee full compatibility and efficient coupling with the existing module. The greenhouse is equipped with two spiral elements: an inner track for crops cultivation and an outer pathway for circulation and running. A functional and ergonomic workspace is located below the spiral at the bottom floor, while a relaxation space is arranged on top level.

Key Words

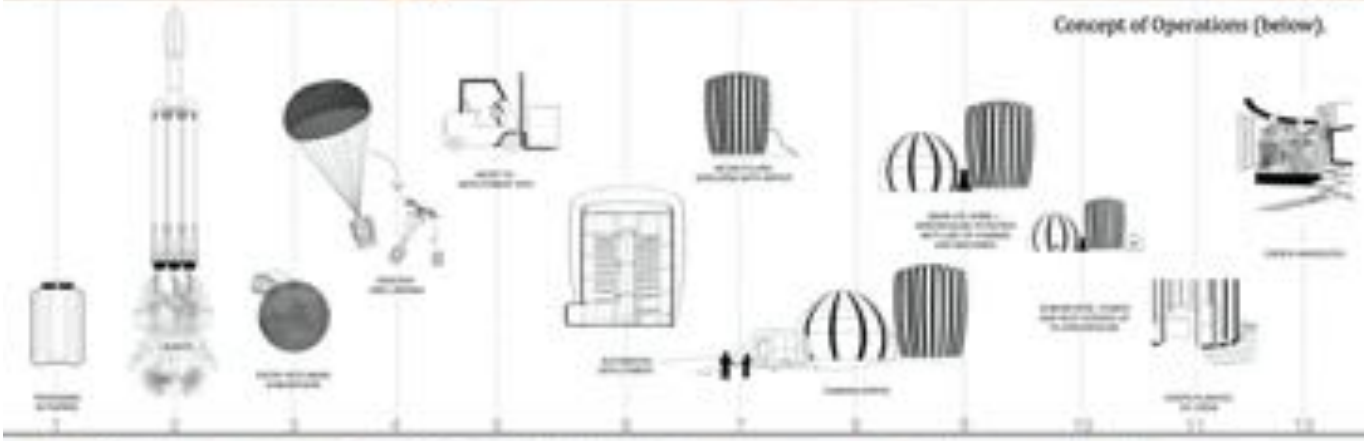
Space architecture; Mars; Hydroponic; Greenhouse; Self-sustainability.

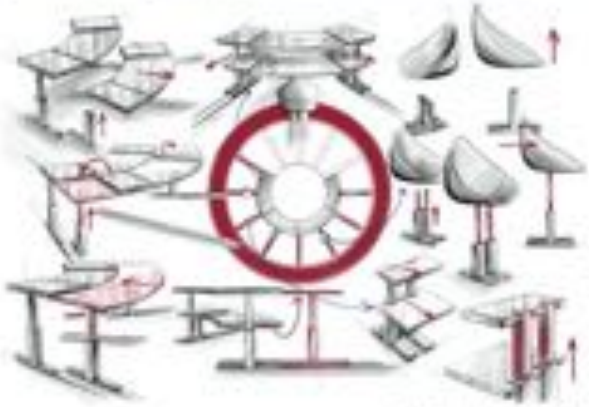


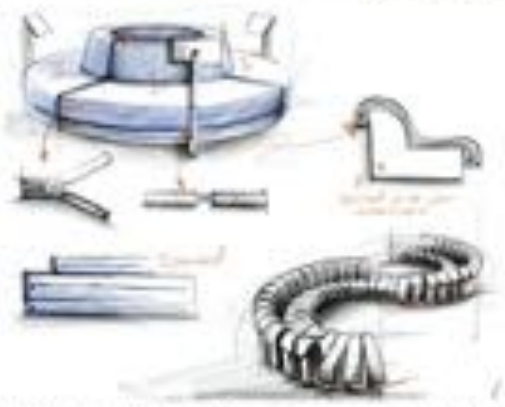
Rendered view of the proposed greenhouse module integrated with the NASA Ice Home.

Render of the colony on Mars, the basic image is courtesy of the motion picture ©The Martian.

Concept of Operations (below).







Rendered views of bottom floor (top left) and top floor (top right), furniture study drawings (bottom).

Project description written by the Principal Academic Tutor

Several decades after the first space age, there is renewed interest in space exploration and specifically in future human habitation far beyond the Earth's surface. NASA recently received funding with an ambitious target: to send a manned mission to Mars by the 2030s and allow for future human habitats and even cities. This challenging, multi-disciplinary problem requires expertise from a wide variety of fields including aerospace engineering, environmental engineering, social science, nuclear engineering, urban planning, design, architecture – and especially structural engineering. Unlike structural engineering for the built environment on Earth, there are virtually zero rules of thumb or design precedents to draw on for construction on Mars or the Moon. Project objectives include: (1) In Situ Resources Utilization for assessment and exploitation of construction materials and water; (2) energy sources and consumption: assessment of technologies; (3) system architecture and computational design methods for optimized architectural solutions; (4) construction autonomy of structures for unmanned missions that will survey current sites and start construction before human arrival; (5) integrated design solutions to solve psychological impact.

When considering a permanent settlement on another planets, one of the crucial aspects involves the evaluation of the total life cycle of the structure. That is, taking a system from conception through retirement and disposition or the recycling of the system and its components. Many factors affecting system life cannot be predicted due to the nature of the Lunar/Martian environment and inability to realistically assess the system before it is built and utilized. Therefore, even if the challenges in space exploration are very peculiar, the colonization of satellites and planets could teach us to be wiser in our consumption of natural resources, pushing us to pursue efficiency and sustainability here on Earth.

Team description by skill

The team then joined a group of students from the Massachusetts Institute of Technology (MIT) for the 2019 NASA BIG Idea Challenge. The project was developed by a strict collaboration: the SAEXE team mostly handled the architectural design and the layout of the greenhouse module, while the MIT students focused on the systems engineering and ecology.

Aldo Moccia | As the team controller, Aldo supervised the collaboration with the MIT and handled the development and the presentation of the technical paper. He also exploited his architectural expertise in the design of the deployment and the structure of the module.

Jana Lukic | As interior designer, Jana focused on the design of the tailored flexible furniture for the workplace and the relaxation area of the greenhouse. She also managed the visualization of the project with renders and videos.

Fabio Maffia | Fabio supported the managing activity of Aldo through a careful work breakdown analysis, while handling the design of the general layout of the module and the deployment system. He also supported Jana with the visualization of the project.

Samuele Sciarretta | As an architect, Samuele managed the complex detailing of the spiral hydroponic system, also providing a crisp visualization of the deployment phases and the technical drawings of the greenhouse. He also handled the advanced research phase and the project budget.

Goal

The module is conceived to grant a higher level of self-sufficiency to human missions to Mars through on-site food production, to increase mission feasibility and safety, as well as to safeguard the psychological and physical well-being of the astronauts during a long-term stay in space. Structures and systems are designed to survive each phase of deep space travel, from launch to landing and deployment, while also providing maximum functionality for mission operations. Mass, loads, energy and resources consumption are minimized to reduce reliance from Earth and fully support a long-term mission. The design is developed through the application of principles of Ecology, Architecture and Systems Engineering.

Ecology

Sustaining human life on Mars means providing reliable and complete nutrition to the crew of astronauts. Therefore, the plants to be harvested in the greenhouse must fulfil nutritional requirements, provide steady yield rates, and stay healthy. The crops must provide a balanced diet with an average of 2,700 calories per person per day [3]. Plant health is also of vital importance and, while it cannot be guaranteed, must be maximized with respect to both Mars micro-gravity [4,5] and the spread of disease. Moreover, the growing system itself needs to assure crops grow efficiently and reliably and must be space efficient, in order to maximize productivity and minimize material delivery from Earth. Finally, a balance between human labour and automation to complete tasks must be sought; a more automated system reduces the labour requirements of the astronauts but increases system complexity.

Architecture

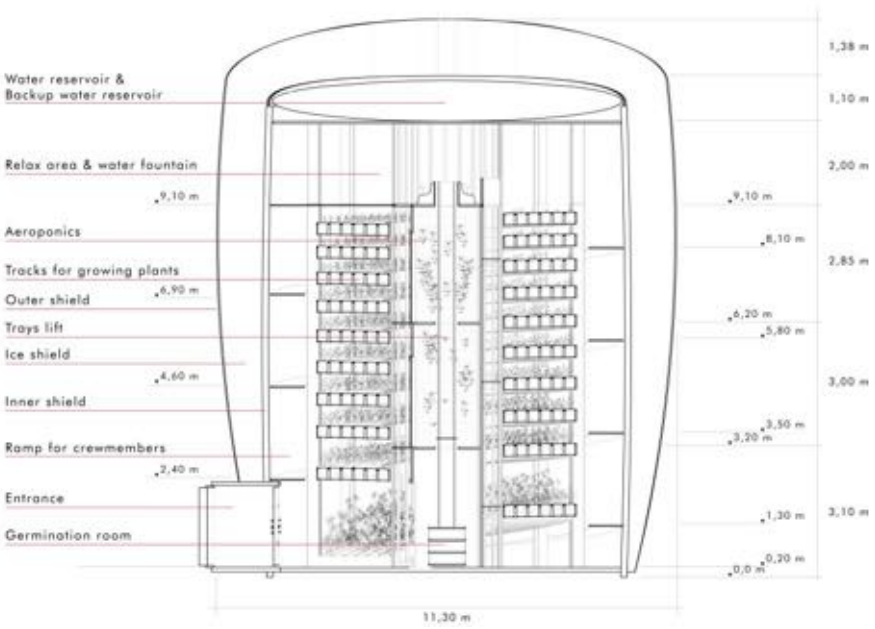
The key drivers of the design of space architecture are structural needs, functional needs and human needs. In a low-pressure environment, vertical loads become minor constraints compared to internal pressure loads, especially when an inflatable structure is used. Therefore, the shape of space modules needs to be optimized to best carry perpendicular loads. Additionally, the internal layout of the greenhouse must be arranged to host as many crops as possible, while also allowing room for a recreational area to provide mental health benefits for the crew. The entire structure must also be designed for compression and expansion in order to match a limited rocket fairing space. Finally, the selection of materials for the interior must consider each material's versatility, durability, strength to weight ratio, cost, and precedent in space use.

Systems Engineering

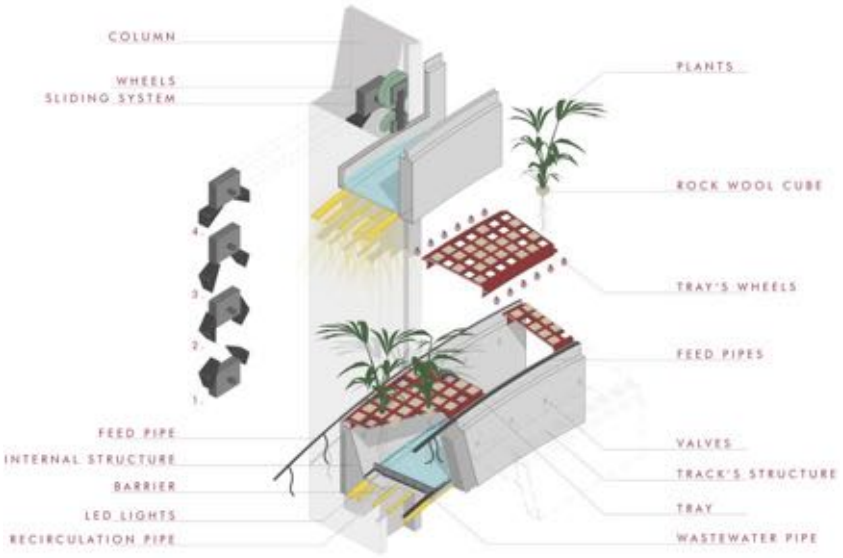
Three primary drivers lead the proposed design of systems: environmental control system, efficient resource utilization and risk mitigation. The environmental control and life support system, the tailored and original architecture designed for human well-being, and the adoption of automation technologies to enhance cultivation productivity make the greenhouse a physical and psychological healthy environment, realize a functional and ergonomic workplace, ease the intervention of the crewmembers, and foster human-machine integration. Sizing, supply, power demand, recycling and multipurpose systems are optimized to ensure an efficient use of the available resources. To mitigate the risk associated with malfunctioning and disruption, systems are designed to be multi-functional and integrated to achieve redundancy for all the critical functions.

Understanding the problem

In recent years, a renewed interest in Mars colonization, channelled into a variety of programs developed and supported by worldwide private and public space agencies, is boosting the effort for the exploration of the Red Planet through both unmanned and manned missions [6]. NASA's Mars Exploration program and Journey to Mars vision [7], ESA's Aurora program [8], the Starship / Superheavy System by SpaceX [9] stand out as the largest and most ambitious of ongoing plans, including and forecasting multiple steps of technological and scientific development. The lack of sustainability in proposed extra-planetary dwellings is one of the key aspects preventing the feasibility of space exploration: reliance on Earth supply for sustenance and maintenance needs implies too high risks and too low sustainability for the purpose of deep space exploration missions. When focusing on the human exploration of Mars, In Situ Resource Utilization (ISRU) can grant the needed self-sustainability and self-sufficiency of a mission system, with astronauts relying on the use of local resources such as water, air, nutrients and light as the basis for on-site energy and food production. The colonization of Mars opens up a broad spectrum of opportunities for the development of novel technological solutions to support human life in unconventional environments: solutions that might also be adopted for a more sustainable and safe life on Earth.



Cross section of the greenhouse module.



Axonometric detail of the hydroponic system and the trays.

Exploring the opportunities

The key criteria that drove the choice among different design alternatives relate to the overall module efficiency and the crew well-being. At the matter of fact, these objectives translate into design search directions towards higher crop productivity to guarantee food supply to the crew, lower ratios of occupied space over available volumes to allow for a better comfort of the crew, and system redundancy to guarantee a reliable implementation of all the critical functions. In response to Ecology driven requirements, the hydroponic technology is identified as the most appropriate among the alternatives because it is a well-established and reliable technology used on Earth.

In response to the architecture-related requirements, our design permits to optimize surfaces and volume distribution in the deployed configuration, while minimizing the weight and the space occupied in the packed configuration. In response to the requirements related to the functioning and integration of systems and equipment, energy production, supply and distribution constitute a critical aspect. For our greenhouse concept, nuclear power is preferred over solar power for its better performance in guaranteeing production continuity,

independently on day-night cycles and external environmental conditions; in addition, nuclear discourses require less maintenance interventions.

Generating a solution

The greenhouse is designed to integrate the NASA Ice Home prototype with a complementary food production module. The habitat implements a novel closed-loop hydroponic system to provide food support for a long-term extraplanetary mission. Its architecture is centred around an elegant and purposeful spiral. The harvesting process starts at the bottom floor of the module, where plants are seeded and germinate. Seedlings are then lifted to the top floor of the module through an elevator, they are transplanted into trays and placed on a helical track, that spirals back to the bottom floor. During their life-cycle, crops slowly slide down the spiral, reaching the ground floor of the module once they reach their maturity. At this stage they are ready to be harvested. The heights between levels of the spiral increase as one moves down from top to bottom, in order to match the growth of plants and thus maximize vertical space.

The greenhouse is stowable in a standard rocket fairing and can autonomously deploy to a larger configuration able to produce enough food to meet 100% of the astronauts' nutritional needs. The module is designed to minimize the risks of structural and energetic failure, as well as plants disease spreading with redundant systems and simplicity. The greenhouse is also conceived to minimize labour and maximize production.

Main bibliographic references

[1] S. Babakhanova, S. Baber, F. B. Zazzera, E. Hinterman, J. Hoffman, J. Kusters, G. Lordos, J. Lukic, F. Maffia, P. Maggiore, L. Mainini, A. Moccia, H. Nowak, T. Schneiderman, S. Sciarretta, S. Seager, S. Seaman, T. Smith, N. Stamler, V. Sumini, Z. Zhan, "Mars Garden: An Engineered Greenhouse for a Sustainable Residence on Mars", AIAA 2019-4059, August 2019.
https://arc.aiaa.org/doi/abs/10.2514/6.2019-4059

[2] NASA, "Ice Home Concept of Operations", *Ice HomeMars Habitat*, MIH.ConOps.001, 2017.
http://bigidea.nianet.org/wp-content/uploads/2018/07/IceDome-ConOps-2017-12-21vreduced.pdf

[3] NASA, "Space Flight Human-System Standard", NASA-STD-3001, Volume 2, Revision A, 2015.

[4] Maggia, F. and Pallud, C., "Martian base agriculture: The effect of low gravity on water flow, nutrient cycles, and microbial biomass dynamics", *Advances in Space Research*, Vol. 46, No. 10, 2010, pp. 1257-1265.
https://doi.org/10.1016/j.asr.2010.07.012

[5] Manzano, A., et al., "Novel, Moon and Mars, partial gravity simulation paradigms and their effects on the balance between cell growth and cell proliferation during early plant development", *Npj Microgravity*, Vol. 44, No. 9, 2018.
https://doi.org/10.1038/s41526-018-0041-4

[6] The Planetary Society, "Missions to Mars", n.d. Accessed January 28, 2019.
http://www.planetary.org/explore/space-topics/space-missions/missions-to-mars.html#grunt

[7] NASA Science, "Mars Exploration Program", n.d. Accessed January 28, 2019.
https://mars.nasa.gov/#mars_exploration_program/0

[8] ESA, "The European space exploration programme Aurora", n.d. Accessed January 28, 2019.
http://www.esa.int/Our_Activities/Human_and_Robotic_Exploration/Exploration/The_European_Space_Exploration_Programme_Aurora

[9] Space X, "Making life multiplanetary", n.d. Accessed January 28, 2019.
https://www.spacex.com/mars

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Let'Set

Executive summary

The tourism industry is undergoing a deep transformation due to new and different activities that people are willing to perform. This trend is called *experiential tourism*, since travellers are increasingly organizing their holidays looking for an occasion to try and discover something new, rather than a full week relax. Nevertheless, relax is not completely excluded and it can be turned into a new experience. Any entrepreneur or company interested in investing in hospitality service must be aware of this tendency; as a matter of fact, experiences should be perceived also inside the accommodation and several studies (*Booking, ISTAT, Osservatorio del Turismo*) have demonstrated how traditional hotel are no longer so much in demand.

Well-aware of the current change, the project has been focused on developing a *service* aimed at answering to these needs, called *Let'Set*, in collaboration with *LAM Ambiente*, an Italian company producing wooden accommodations. The service aims at providing the businessman with an experiential structure. The development of the service has been articulated in two levels:

- The first focused on the methodological process through which the client is addressed and the dwellings are designed;
- The second was about the technological design of the module.

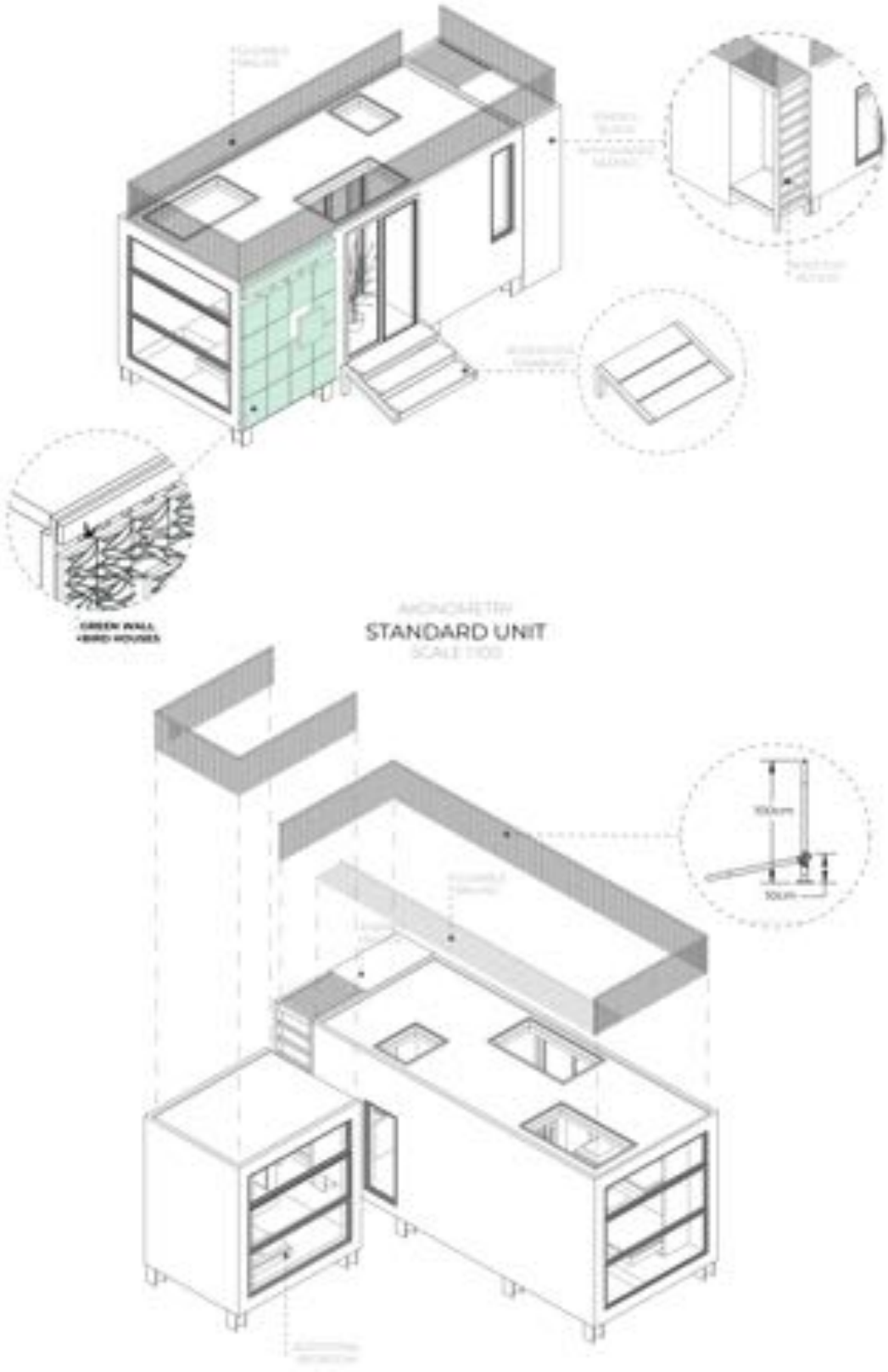
The cutting-edge methodology thought to manage the whole building process is the *core* of *Let'Set*, since it represents the innovative proposal which permits to stand out among various competitors. The owner requirements are collected by means of an online questionnaire, the *flow-chart*, by which he describes the basic information, such as the number of hosts or the location. These are the input data for the *matrix*, a decision-making tool containing all the possible solutions for each part of the module, selectable by simply clicking on the corresponding icon: the project is so designed *piece-by-piece*. Such a systematic management leads to provide the client with high-quality solutions in a short period of time.

The units, in line with the value proposition of LAM Ambiente, have to respect the key word of sustainability, generating an environmental impact as low as possible. This has been possible by using nearly fully recyclable materials to ensure high energy performance, together with the use of Renewable Energy Sources (RES) to satisfy the energy needs of the unit.

Moreover, the team developed the minimalistic idea in its accommodation: every unit has been designed to collect the higher number of experiences in the minimum space, since them must be moved, avoiding the use of special transport to reduce the cost, already prefabricated from LAM Ambiente headquarter to the building site. Finally, all the accommodation have been designed to ensure the accessibility also to disabled people, making *Let'Set* a promoter of social inclusion.

Key Words:

"Experience", "Building fast", "Service", "Sustainability"



Drawings of the dwelling designed for the city environment, as an example of the final layout. Experiences and possible modifications selectable by the client are shown.

Project description written by the Principal Academic Tutor

The De SEED Italy project for the Alta Scuola Politecnica was born from the selection of the group SEED Italy (Sustainable & Efficient Energy Design) as a competitor in the international challenge, for universities, on solar architecture, called Solar Decathlon Europe 2019, which was held nearby Budapest last July. The SDE19 competition is about the design and construction of a small residential solar-powered tiny house, that has to compete against 15 other houses, from all over Europe and beyond, through 10 contests (Architecture, Market Potential, Engineering Communications, Innovation, Water, Health & Comfort, Appliances, Home Life, Energy).

The team with the academic and the external tutors in LAM Ambiente headquarter.

The ASP team's students were supposed to support the SEED Italy team in the competition, exploring the design aspects of the solar energy module related to water: production and consumption but, above all, possible recycling in a strong sustainability logic. Unfortunately, due to organizational problems with the host country and economic issues related to the cost of participation, in February 2019, after almost a year of work, the SEED Italy team had to withdraw from the competition. Although the ASP team of students was already working on the aforementioned aspects, in the absence of a really built module their project would not have met the ASP program's concrete and validity requirements for the productive world.

Thanks to the resourcefulness of the ASP students, the support of external tutors and LAM Ambiente company, involved since the initial project's phases, a new topic was identified that could recover part of the work previously produced for the international competition but which at the same time, it could constitute an interesting development from the point of view of the implementation of the LAM business plan. The new project revolves around two key moments, two intensive workshops that saw the involvement of different stakeholders. The first at La Bella Vite in Carpeneto, where the external tutor Paolo Scoglio had already designed and built small modules for experiential tourism in the vineyard , and where the students of the ASP team, in addition to experiencing first-hand, were able to measure the modules and analyse them from the point of view of the energy consumption and their thermo-hygrometric performances, forming a cognitive framework of the critical aspects and possibilities, useful for the design of the original modules. The second workshop was organized at the LAM Ambiente company (AR), allowing the team to deal with the concrete problems that real production entails. Here is how the "De SEED Italy for Let 'Set" was born, starting from the idea of the small residential module, with low environmental impact, however declined for a particular tourist function, that is the experiential tourism in heterogeneous environmental contexts (city, seaside and mountain).

Team description by skill

The *Let'Set* team was originally formed by eight students, but subsequently reduced to the following seven members:

Anna Brazzini: With her architectural skills she contributed to design the accommodation for the seaside environment, as well as to cluster possible users and to study the structure of the unit.

Federica Caruso: With her expertise on web design and client relationship, she worked on designing the website interface to address the entrepreneur, helping in the development of the flow-chart, studying all his interactions with the company.

Aleksandra Cheremuchina [Team leader]: With her architectural skills she contributed to design the accommodation for the city environment and to transcript all the projects in BIM language for the Configurator platform.

Elia Lupo: With his expertise on stratigraphy and sustainable materials he developed and verified the unit envelope for each environment and the connection between two modules, designing also the mountain accommodation.

Ilaria Martarelli: With her architectural-constructive ability she contributed to design the accommodation for the seaside environment, as well as to analyse the connection between modules and the transportation constraints.

Francesca Meineri: With her architectural expertise she contributed to design the accommodation for the city environment and she led the development and the design of the decision-making matrix on which the Configurator is based.

Stefano Viti [Team Controller]: With his energy engineering skills he contributed to the climate classification of the three environments and to design the equipment and services to satisfy the dwelling energy needs, as well as their integration.

Goal

The *Let'Set* project aims at drawing the next frontier of experiential tourism, a brand-new concept that emphasizes the emotions and the discoveries of a journey. Since the experience of the tourist must begin with a suitable accomodation, consistent with his needs, *Let'Set* is a completely new approach in this field both for travellers and businessmen:

1. The latter can start or improve his activity by simply setting the features of the site and of the desired experience:
2. The tourist will find the perfect solution in terms of experiential accommodation: the tiny units are full of every needed comfort implemented by a basic experience and a deep contact with nature.

In this design framework, accessibility to disabled people has been always a must, also to overcome social barriers.

The team while prototyping its solutions in LAM Ambiente manufacturing department.

Understanding the problem

For a long time, tourism has been conceived as a standard product for masses, since holiday was seen only has an opportunity to take a break from the daily routine. Nowadays, people needs are undergoing a drastic change and this old concept is disappearing, giving way to a new trend denotated by richness in experience and interaction with tradition. Holidays are so understood an occasion of enrichment and tourists want to come back home with the memory of a journey that has left a mark inside them. One of the occasion to enjoy such experiences is surely when staying inside the chosen accommodations.

Therefore, firms designing them must know these new needs and propose suitable solution.

As the engagement of LAM Ambiente in the field of tourism is recent, they are not currently proposing solution to answer to the growing phenomenon of experiential travels. Thus, the team has been required to design suitable hospitality services to improve the catalogue of LAM Ambiente. Among the most challenging requests, that of space surely stands out: modules have to be completely prefabricated within the manufacturing department and be transported directly on the building site without the use of exceptional transport, as other companies currently do. In addition, every module must ensure the accessibility to disabled people, requiring so more space, and logically be comfortable for hosts. Satisfying together all these needs has been for sure the hardest challenge of the project.

Furthermore, LAM Ambiente is a milestone in the wooden structure sector and it has made sustainability one of its strength. Accommodations must embody this value, having low energy request and being made of nearly fully recyclable materials.

Masterplan of a possible hospitality service offered by *Let'Set* – City environment.

Exploring the opportunities

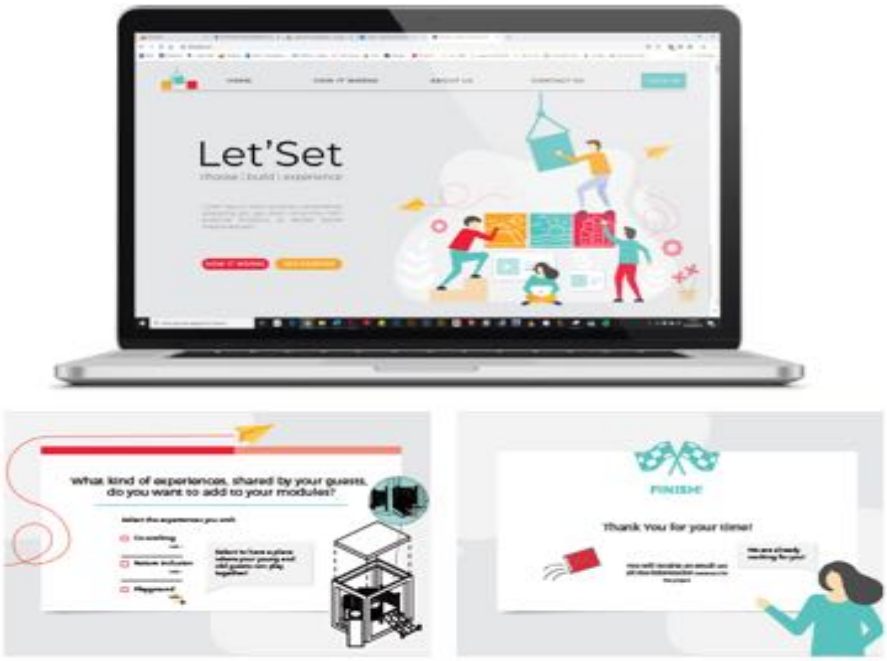
In the recent years, several examples of tiny experiential houses, even if not necessarily designed for tourism, are becoming increasingly spread throughout the world. Moreover, pertinent tourism analyses have demonstrated that in Italy the sector develops around three main environments: mountain, seaside and city. In these locations, dwellings able to ensure a deep contact with nature, provided with beautiful glass façade for breath-taking views, are the new target of architects. Also where nature lacks by definition, such as in cities and urban areas, minimalistic units can be found, especially on existing rooftops, as representative of the new architectural trend called parasitism. In this framework, the team had the opportunity to get physically in touch with experiential hospitality services designed by the architect Paolo Scoglio, an expert in this field, performing a workshop inside one of his projects.

Considering these examples as the state of the art of experiential tourism, the team has been required to design similar structures, for each one of the three environments. Nevertheless, limiting the project to the design of tiny, eco-sustainable and prefabricated dwellings would have been too reductive. Therefore, since "*building fast*" has always been a must, the team developed a way to lead this concept to the extreme, trying to give to its final solution something more with respect to other competitors already active in the market.

After all, the idea of *Let'Set* was born: the team decided to plan, alongside with the dwellings, a new way to address the entrepreneur and to fast design the accommodations. The service is thus based on an online platform able to collect the owner's requirements, communicate them quickly to the architects and drive the latter in the project. On the other hand, several technological solutions have been explored to satisfy all the requests: different possibilities for the wall structure (X-Lam, Platform, Hybrid wood/steel), several ways to connect two modules (Dovetal joint, Hooks and screws) and various plants to ensure the internal comfort. The final solution has been always established by doing the best trade-off between performances and techno-economic feasibility.

Generating a solution

Having in mind all these needs and requirements, the team developed the *Let'Set* service by rooting it on an online Configurator, to offer a direct and effective communication between the client and the designers and a complete control over the process. This online interface is composed by two parts: the *flow chart* (front-of-house) for the entrepreneur and the *matrix* (back-of-house) for the architects.



Website layout where the flow chart starts (top) with a possible question (bottom).

The first is a schematic questionnaire to collect the necessary information aimed at classifying the owner desires. Answering to some specific questions, the client who wants his experiential accommodations provides the architects with his needs and possibilities. He has to specify where he owns the location, if he has already an activity, the experience he wants to include and the number of hosts. The flow chart output will be a draft project of the required hospitality service, sent to the client by e-mail.

The second step of the Configurator is the matrix, seen only by the designers. This decision-making tool helps to visualize all the technical elements of the dwelling, guiding the architect in the project. For each row (i.e. the three environments) and each column (i.e. the elements), every box of the matrix contains the possible solutions among which the designers have to choose the one that best meets the requirements. Therefore, when an element has been clicked, the BIM model of the dwelling starts to take shape, being it so built systematically step-by-step; the possibility to avoiding the drawings of each elements, as if even the design itself were already prefabricated, dramatically increases the speed of the process.

On the other hand, the second level of *Let'Set* has been focused on developing some solutions to be inserted in the matrix database, especially those regarding the envelope, the connection and the energy plants, keeping in mind that the maximum external dimensions of each module to avoid special transport are 3.25x2.50x3.25 meters. Defining a correct technology used to link two modules has been a challenge, since nodes tend to be thermal bridges. They are provided with hooks to facilitate the first attachment, so that after the touching frames are joint with screws.

Matrix interface: choosing the best solution for each element (sides of the screen), the project is drawn in the center.

Sustainability is translated into practice with high energy performances and Zero Energy Building (ZEB). The envelope chosen according to the climate constraints of each environment is always able to guarantee low heating and cooling demand; stratigraphies are made of a platform OSB system containing two cork insulation layers, where the climate is particularly harsh, or coupled with a thermo-reflective cavity to manage the radiation in hot climates. Finally, RES based plants were adopted when it came to design the energy system: all the needs are satisfied by an electrically driven heat pump fed by photvoltaic panels coupled with storage batteries; these devices have been inserted all in a small cupboard easily integrated outside the house, following again the minimalistic idea. The total independency of the module from fossil fuels brings to several tons of CO_2 saved every year, like ZEBs do.

Main bibliographic references

Ching, F.D.K., 1980. *Building construction illustrated (2nd edition)*. Wiley.

Giordano, R. et al., 2016. The integrated design of building services by an equipped and eco-efficient module (MOTE2). In: *Vitruvio, International Journal of architecture Technology and Sustainability*, Vol. I, Issue 2.

Osterwalder, A. and Pigneur, Y., 2010. *Business model generation: a handbook for visionaries, game changers*. John Wiley & Sons.

Thullner, K, 2010. *Low energy building in Europe: Standards, criteria and consequences.* Lunds Universitet.

Lemon, K.N. and Verhoef, P.C., 2016. Understanding customer experience throughout the customer journey. In: *Journal of marketing*, Vol. 80, Issue 6, pp. 69-96.

Moreschi, C., 2017. *Experiential tourism: what it is and what is for*.

Richardson, P., 2011, *Nano House: Innovations for small dwellings*. Thames & Hudson.

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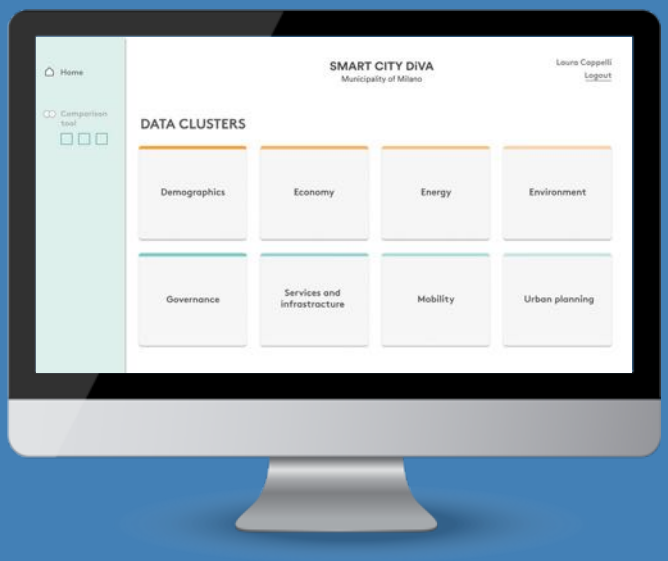
Executive summary

Smart City DiVA is the project that led to the design and implementation of a dashboard for the city of Milan. City dashboards are among the digital tools that try to handle the complexity of smart cities, by displaying indicators about the urban performance and aiding people that are accountable for it, namely the Municipality and its cooperators, making the most profitable choices for the city's wellbeing. In order to answer to the needs of our target (made by decision-makers and citizens) we developed two different platforms cooperating together: the first one is the actual dashboard that, together with visualizing the datasets, could also set up a forecast based on the available data, in order to provide support both for short term and long term decisions. The second platform is a mobile app, designed specially for citizens, that makes them create their "personal" dashboard, setting which kind of real time updates they want to receive about Milan's transportations, services, events and so forth.

Key Words

dashboard, prediction, visualization, e-government, communication



Smart City DiVA website allowing decision makers to monitor meaningful indi- cators and visual models describing the city perfor- mance, in order to act accordingly.

Smart City DiVA app allowing citizens to receive useful information about the city in real time, and get updates about the topics they care more about.

Project description written by the Principal Academic Tutor

The development of user interfaces in form of dashboards is becoming an emerging topic all around the world with the spreading of Smar City initiatives that promote pervasive data collection activities but did not show, yet, to be able to contribute to structured decision making processes, either top-down or bottom-up.The design of dashboards is a complex task due the cross-sectional skills required and to the heterogeneity of data sources. Competencies in data analytics, data visualization and communication, and web user interface design need to be integrated and applied for specific objectives including energy, environment, economics, transportation, buildings, etc. Smart City DiVA tried to face this contemporary and interesting challenge, developing a prototype of dashboard/platform built around the characteristics and the needs of Milano, one of the European cities at the forefront of the smart city initiatives. Data availability, privacy, quality and management issues have been encountered and overcome, as well as communication obstacle with public authorities and citizens about topics that are crucial for the city management but that imply many issues. The project required a high level of multi- and interdisciplinarity and forced the team members to continuously challenge themselves to interpret, understand, and propose innovative solutions for a nascent field of investigation and development.

Team description by skills

The team was made up by:
-Tommaso Bianchi (Computer Science Engineering)
-Laura Cappelli (Digital & Interaction Design)
-Paolo Colusso (Mathematical Engineering)
-Andrea Guzzetti (Architecture Built Environment Interiors)
-Valerio Volpe (Mathematical Engineering)

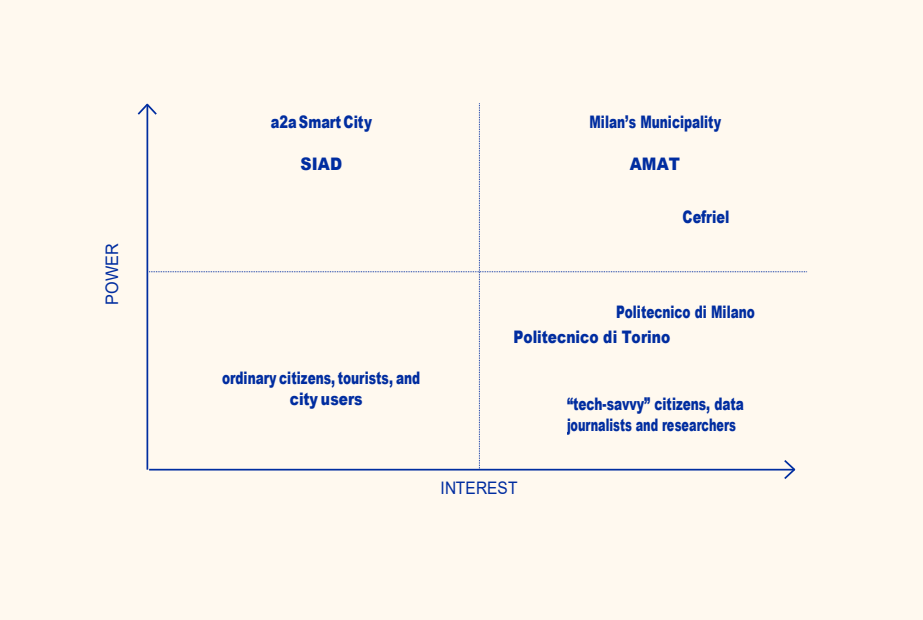
On the basis of the critical review and of the background of the people involved in the project, the team was organized in distinct groups in order to examine in depth the topic and to find innovative and better ways to deal with data analytics methodologies, API process and reuse, user interface design, KPIs definition, etc. Basically, two groups were created one for the data analytics part and one for the data visualization and user interface design part.

Goal

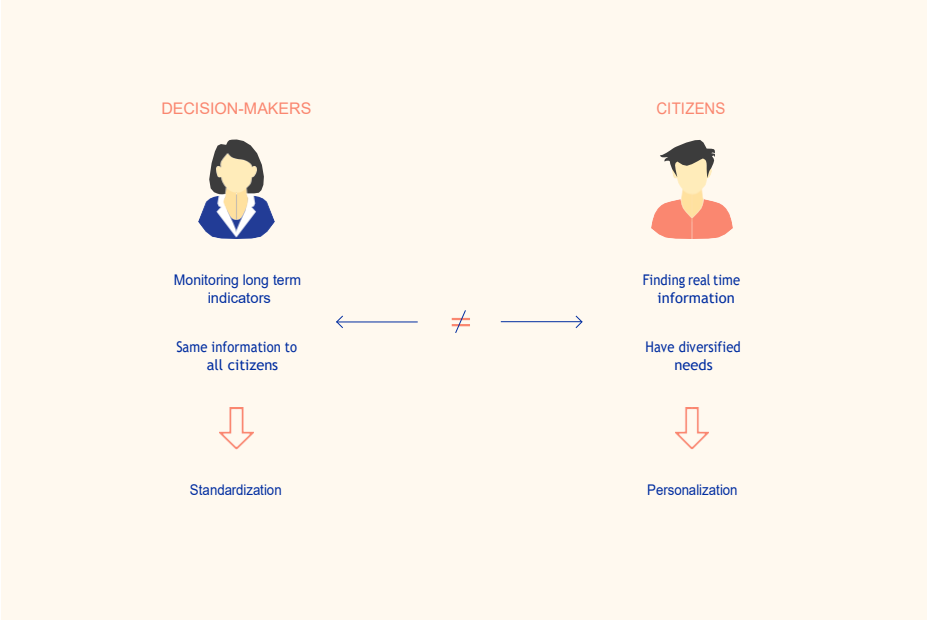
The ultimate purpouse of the project is providing Milan with a city dashboard, a platform aiding data visualization and analysis to monitor the city's current situation, analyse its past performance, and predict what could be the possible consequences of the Municipality's actions. Moreover, this tool could become an effective channel bridging the gap between the Municipality and citizens that, given the changes the city is undergoing, must be kept informed and always questioned about their needs.

Understanding the problem

The first step we took was trying to understand how other cities approached a dashboard design process. We started by analysing other dashboards, both from Italian and foreign cities, in order to map which categories of information they displayed in the first place. We then compared these clusters of information with the current categories displayed on Open Data Milano, the main dataset source we had at hand. From this comparison, we built the first draft of the website structure, dividing the information in eight categories (Demographics, Economy, Energy, Environment, Governance, Services and Infrastructure, Mobility, and Urban planning). Afterwards, we carried out a usability analysis of three examples (Amsterdam, Florence, and Dublin). We focussed on these three dashboards because many of their characteristics are reflected in the majority of the other examples. That's why we go as far as to say that most of the dashboards we saw have usability issues of some sort: they basically focus on technical efficiency, and on including as much data sources as possible, without verifying the actual usefulness of such information. Moreover, the dashboards we analysed were developed by teams with a single set of skills (computer scientists, geographers, architects...) and, given the complexity of such a platform, a multidisciplinary approach, like the one proposed by ASP, could be more effective. Therefore we agreed upon opposing the top-down approach proposed by other dashboards and embrace a bottom-up approach, with greater attention to users' needs, the only force that must shape the dashboard.



The project's stakeholders map



A summary of the users' needs

Exploring Opportunities

Before going any further into the project development, we really needed to have a clear idea about the target's needs. The user analysis was possibly the most insightful phase of the whole process, since nothing compares to the confrontation with users when in need of ideas and inputs. We carried out interviews with the decision-makers while we involved citizens through interviews and an online survey.
In this way, we understood that the decision-makers' needs were far removed from the citizens': the Municipality needs to look at performance indicators, based on a long-time perspective, and that's what they want to communicate to citizens, in order to show the improvements they worked on. On the other hand, citizens are more drawn towards real time information, that they look for in order to live the city in the current moment.

Generating a solution

At this point, we started shaping the solution based on the users' needs: we gradually understood that one platform was not enough to answer to all the requirements we set up to respect. We opted for an integrated solution made by two platforms (a web app and a mobile app) working together and connecting the two ends of the target, decision-makers and citizens.-The web platform is mainly targeted at decision-makers, that here can visualize the datasets they dispose of and use them to support decision making;-On the other hand, the app will provide citizens with real time information, displayed on a customized dashboard based on E015APIs.

Main bibliographic references

Few, S. (2013). *Information dashboard design: Displaying data for at-a-glance monitoring*. *Burlingame*, CA: Analytics Press.

Kirk, A. (2016). *Data visualisation: A handbook for data driven design*. Los Angeles: Sage Publications.

Brokaw, L. (2016, May 25). *Six Lessons From Amsterdam's Smart City Initiative*. Retrieved October 07, 2018, from https://sloanreview.mit.edu/article/six-lessons-from-amsterdams-smart-city-initiative/

Capozzoli, A., Piscitelli, M. S., Brandi, S., Grassi, D., & Chicco, G. (2018). *Automated load pattern learning and anomaly detection for en-hancing energy management in smart buildings*. Energy, 157, 336-352. doi:10.1016/j.energy.2018.05.127

Cocchia, A. (2014). *Smart and Digital City: A Systematic Literature Review*. Smart City Progress in IS, 13-43. doi:10.1007/978-3-319-06160-3_2

Polese V. (2018). *Smart City, Smart Land*, Switch City, ZeL edizioni

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SPACE BUSINESS 4.0

Executive summary

Space Business 4.0 stems from the efforts made by the European Union for fostering innovation in the Space Sector. It is a technology-push project whose goal is to generate and validate a business model for a new startup operating in the Space Economy, leveraging the huge amount of satellite data produced in the Space sector. While in the past satellites were used almost exclusively for governmental applications, nowadays business customers represent the main revenue stream for most satellite-data-based companies. Available satellite images have variable spatial, spectral and temporal resolution. Therefore, they can be utilized for a wide spectrum of solutions, depending on the required precision level. In Phase 1 of the project three industries (Civil Engineering, Urban Management, Agriculture) were identified as the most promising ones. A business model was generated for each selected industry, starting from the most evident customer pains for each sector and then tackling these issues through the analysis of satellite data. The first business idea is a decision support system for smart cities based on Earth Observation (EO) data. The second is a web-based platform for optimizing market research in bidding processes for construction projects. The third is a multi-sided platform for the agricultural sector, removing information asymmetries along the agri-food supply chain. Subsequently, the concept selection phase had the goal to identify the most promising business model among the three generated, in order to proceed with its validation. In Phase 2 of the project the team focused on developing and validating the selected business model. Wapi is a multi-sided platform inspired by successful digital companies such as Facebook. Farmers receive free-of-charge technological consultancy based on the analysis of satellite images of their fields. They can have insights about irrigation, fertilization, pests and diseases, together with meteorological data and digital farm management tools. The choice of a free-of-charge business model allows to overcome economic barriers to adoption. The goal is to reach a critical mass of users and activate indirect network effects, attracting businesses interested in reliable and specific data about the agricultural sector. Thanks to a gamified and community-based user experience a prizing system encourages farmers to integrate this information with data about treatments, soil analyses and past performances. Farmers benefit from Wapi's community as they can signal early symptoms of crop diseases (e.g. blight) to neighbors, thus favoring prevention. An active user base permits to produce more data for businesses on the other sides of the platform, but also to increase the quantity of data given in input to Wapi's machine learning algorithms, with positive effects on the accuracy of the underlying mathematical and agronomic models. The business model has been validated by surveying 135 Italian farmers and by interviewing professionals from relevant customer groups. In the future, Wapi's priority needs to be the construction of a solid network of farmers: only once there is a sufficiently wide and active community of users, profit-side customers (food-processing firms, insurances, etc.) will be willing to pay for our data. To achieve this goal, it is required to potentiate the team by adding ICT and agronomic competences. Initial investments can be covered with founders' funds. However, to scale up quickly and gain large market shares it will be necessary to look for other forms of entrepreneurial finance such as Business Angels (the most likely), Equity Crowdfunding or Venture Capital.

Key Words: "Space", "Agriculture", "Satellite", "Data"

Project description written by the Principal Academic Tutor

In the recent past, Europe has invested in the creation of satellite networks providing high-quality data for Earth Observation and navigation, through the Copernicus and Galileo programs. Furthermore, the presence of a growing number of players in the sector increases the availability of satellite data. However, these data are not yet exploited in their full capacity.

Space Business 4.0 (SB4) stems from these baselines. SB4 has the goal to generate innovative business models based on satellite data. The team has been required to analyze the space ecosystem, highlight enabling and limiting factors for the creation of satellite-based business models, generate several innovative downstream applications, select the most promising, develop and validate it by interviewing prospective adopters.

SB4 has been supported by leading external partners and stakeholders operating in the space sector. These are the Italian Space Agency (ASI), the Italian satellite system company D-Orbit and Maxq, a firm supporting the growth of startups and SMEs in the space sector.

ASI and D-Orbit contributed to the project by outlining opportunities and limitations to the use of satellite data in downstream applications. Maxq actively supported the team in the development of the selected business models.

The project generated three research papers, presented in the XXV International Congress of the Italian Association of Aeronautics and Astronautics:

- "Analysis of Innovations in Earth Observation data exploitation" analyzes the evolution of EO-based startups, focusing on sectors of application and targeted customers.
- "Developing and monitoring smart cities: the potential of Earth Observation data" provides policymakers with an overview on how satellite data can revolutionize the management of modern cities.
- "Potential benefits of satellite data in precision agriculture: a comparative and empirical analysis of satellite-driven, IoT-driven and airborne-driven data-based precision agriculture startups" analyzes the ecosystem of data-based service providers for agriculture, identifying critical success factors for business models exploiting satellite data in the primary sector.

Part of the team at the International Congress of the Italian Association of Aeronautics and Astronautics (AIDAA) in Rome. From left to right: Luigi Mazzer, Lorenzo Piovani, Marijana Zora Kuzmanovic and prof. Franco Bernelli Zazzera.

Space Business 4.0's main outcome is Wapi, a multi-sided platform democratizing access to technological tools for farmers. Wapi represents an innovative proposal for reducing inefficiencies along the agri-food supply chain, eliminating information asymmetries and increasing productivity. Wapi's business model has been validated by directly interviewing prospective users. With the feedback of potential adopters, a mock-up illustrating the functioning of the application has been realized.

Team description

The team consisted of seven members. Lorenzo Piovani was appointed as team leader. The rest of the team was divided into two sub-groups, Management and Technical team. Jelena, Zora and Luigi were members of the Management Team. They oversaw market research, business model design, development and validation. The Technical Team was composed by Gianluca, Marco and Giuliano. They studied the data available from satellites, analyzed the key roles in the space supply chain and were in charge of the technical feasibility analysis of the business models.

Part of the team attending International Astronautical Congress in Bremen, Germany. From left to right: Jelena Petrovic, Lorenzo Piovani, M. Zora Kuzmanovic and Luigi Mazzer

Project goals

Due to the technology-push nature of the project, the project development was divided into two phases, with different goals.

In phase 1, the team explored the opportunities created by the availability of satellite data, with the following milestones:

1. Performing a state-of-the-art analysis of available satellite technologies (types of data, structure of the value chain, institutional actors involved)
2. Analyzing the global ecosystem of satellite-based startups (sectors of application, type of business model, relevant customer categories)

This preliminary analysis was the starting point for the generation of three innovative business models based on Earth Observation satellite data.

The goal of the second phase was to select, develop and validate the most promising among the proposed concepts.

Understanding the problem

Space Economy is expected to grow up to $1 trillion by 2040. High-resolution satellite images (in particular multispectral and SAR images) are becoming increasingly accessible for a wide set of users. Practical applications of such data have demonstrated that satellites can deliver tangible benefits in several domains. Space is a privileged observation point to monitor what happens on our planet, therefore remotely-sensed data constitute a valuable support for decision makers. In recent years, institutional actors, such as ESA, NASA and other governmental agencies have developed numerous initiatives to foster innovation in this direction (e.g. Copernicus Programme). Furthermore, private actors (e.g. Planet, ICEYE, DigitalGlobe) have entered the Earth Observation domain, contributing to the growth of the industry in terms of spatial/temporal/spectral resolution and data accessibility. Nevertheless, the diffusion of EO-based business models is still concentrated on traditional sectors (e.g. emergency management, environmental preservation). Governmental agencies remain a major customer segments for most providers of satellite images. Even if B2B business models are acquiring increasing importance, their clients are almost exclusively large multinational enterprises. Business models targeting small businesses and end users have achieved low diffusion so far.

Exploring the opportunities

We analyzed several sectors and their current challenges, to understand how satellite data could help solving such issues. We focused our attention on agriculture, civil engineering, mining, urban management, animal breeding, emergency management, advertising, logistics, naval transportation. Three promising industries (civil engineering, urban management, agriculture) were identified and three business models were generated:

- *Space City*, a decision support system for smart cities based on Earth Observation data
- *WorldCon*, a platform for market research optimization addressing construction companies bidding for projects in foreign markets
- *Wapi*, a multi-sided platform reducing information asymmetries along the agri-food supply chain.

Hence, we proceeded with the concept selection phase. First, selection criteria (economic, technological, organizational, social) were defined. Then, relevance weights were assigned to each dimension. Finally, after evaluating each alternative, the alternative with the highest total score – Wapi – was chosen.

Selection Criteria		Weights	Space City	**Wapi**	WorldCon
ECONOMIC	Market potential	0.35	1	**1**	0
	Business Model profitability	0.25	0	**2**	1
TECHNOLOGICAL	Technological feasibility	0.15	-1	**0**	1
ORGANIZATIONAL	Compatibility with team skills	0.05	-2	**-1**	1
	Stakeholders management simplicity	0.10	-2	**-1**	0
SOCIAL	Alignment with SDGs	0.10	2	**1**	-2
Total Score		1.00	0.10	**0.8**	0.25

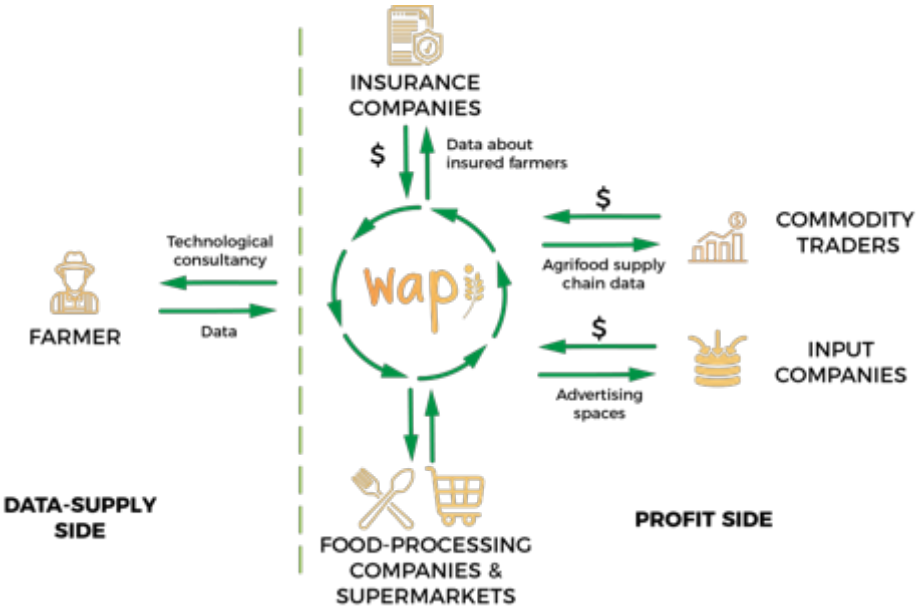
Concept selection: weighted decision matrix.
Legend: -2 (very low performances), -1 (low), 0 (medium), 1 (high), 2 (very high)

Generating a solution

Through the analysis of satellite images, farmers can receive procedural recommendations for treatments such as irrigation, fertilization and pest detection. It is also possible to forecast not only timing, but also yield and quality of the crop. Operationally, satellite images are translated into indicators such as NDWI, Nitrogen indices and Phosphorus indices, respectively describing the conditions of a field in terms of hydric, nitrogen and phosphorus requirements. Then, the calculated index is compared to a desirable value, i.e. the optimal value of the indicator given the context in which the crop grows (e.g. climate, soil, variety of product…), estimated experimentally. Finally, deviations from the optimal value are translated into operational recommendations for the farmer's daily activities. These methodologies have been developed since the early-1990s. Today, academicians unanimously agree on the economic and environmental benefits of satellite-driven precision agriculture. Nevertheless, the use of satellite images in agriculture remains limited to niche high-value-added applications and to large plantations in agriculturally advanced countries such as USA and Australia. The percentage of Italian fields cultivated with precision agriculture techniques amounts to less than 2%.

The first step for generating a solution was to study the reasons for this scarce diffusion. The team carried out on-site interviews to farmers and distributed an online survey about the diffusion of technology in agriculture. Both the interviews and the survey confirmed academic findings on the topic: the scarce diffusion of technological tools for diagnostics in agriculture is largely due to economic barriers.

Inspired by mainstream digital companies such as Instagram and Facebook, we decided to reverse the classical paradigm of precision agriculture services offered with SaaS business models. Therefore, we ideated Wapi. Wapi subsidizes farmers by providing free-of-charge precision agriculture services in exchange for data about their treatments. Thanks to these data, actors of the agri-food supply chain (generally, large established corporations with higher financial capabilities compared to farmers) can reduce information asymmetries that limit their profitability. In other words, Wapi solves productivity-related problems in agriculture by transferring the duty to pay from farmers to higher-budget actors of the industry.



Wapi: schematic representation of the platform's functioning

A second requirement that emerged from interactions with prospective adopters is the need for simplicity and user-friendliness. Existing solutions are technologically complex and create low engagement. This highlighted the

necessity for new, gamified solutions fostering frequent users-app interactions and encouraging collaboration among farmers (e.g. pest alarms).

Based on these requirements and thanks to the collaboration of experienced farmers (Società Agricola Stringa, Voghera (PV) and Società Agricola Dossena, Pieve Fissiraga (LO)), a mock-up was developed.

To validate the business model, we needed to collect feedback from prospective customers, from both sides of the platform. First, the mock-up was tested with farmers. This phase was particularly useful as potential users proposed corrections to the original version of the mock-up according to their direct needs. Second, the business model was validated with prospective data purchasers by studying inefficiencies in the agri-food supply chains from the point of view of both food-processing companies (e.g. Mutti Spa, Vini Alois) and insurance firms (Assicurazioni Generali Spa). The validation phase verified the assumptions of the business model.

Main bibliographic references

Piovani, L. et al., "Analysis of Innovations in Earth Observation data exploitation", 2019.

Mazzer, L. et al., "Developing and monitoring smart cities: the potential of Earth Observation data", 2019.

Piovani, L. et al., "Potential benefits of satellite data in precision agriculture: a comparative and empirical analysis of satellite-driven, IoT-driven and airborne-driven data-based precision agriculture startups", 2019

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NYMPHAEA (FM SEI)

Executive summary

Clean water scarcity is one of the main issues of our world, and it is listed among the UN SDG to be reached by 2030. It is particularly severe in Sub-Saharan Africa, the only region in the Earth in which the number of people without safely managed drinking water is increasing, especially in rural and isolated areas.

Several technical solutions that want to bring water in isolated villages have been proposed, but they often missed two crucial requirements: they rely on specialized first-world technologies or supplies of chemicals/filters, which are hard to maintain, repair and resupply in such a context; they are not integrated and accepted in the community in which they are put.

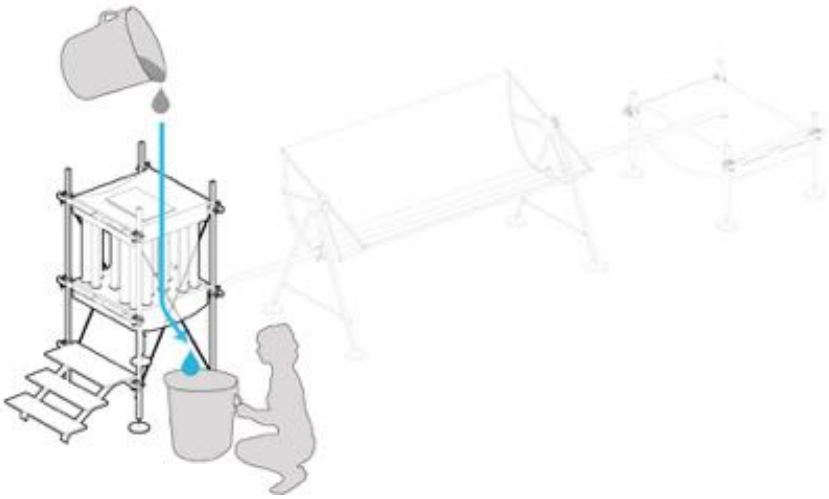
Nymphaea aims to address this problem using a cheap, low-tech solution, with the combination of a sand filter, to remove debris and heavy metals, and a parabolic solar concentrator, to heat up the water and purify it from microbiological contamination. This design requires no electric energy, no chemicals and no supplies for maintenance. The device has been mathematically modelled and a small prototype has been built, demonstrating the technical feasibility of the concept.

Nymphaea is a community-level product, designed to produce 300 l/d of clean water. Its objective is also to be easily introduced and adopted by the end users, the inhabitants of the villages. Creating a network of local entrepreneurs that sell the drinking water at a fair price in their communities, Nymphaea becomes a source of income and local development.

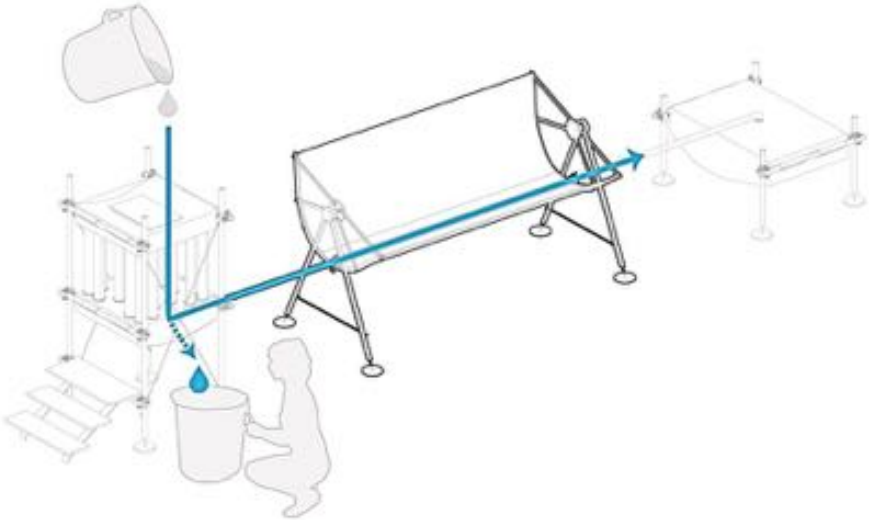
Key Words

water; local development; Africa; sustainability; social innovation

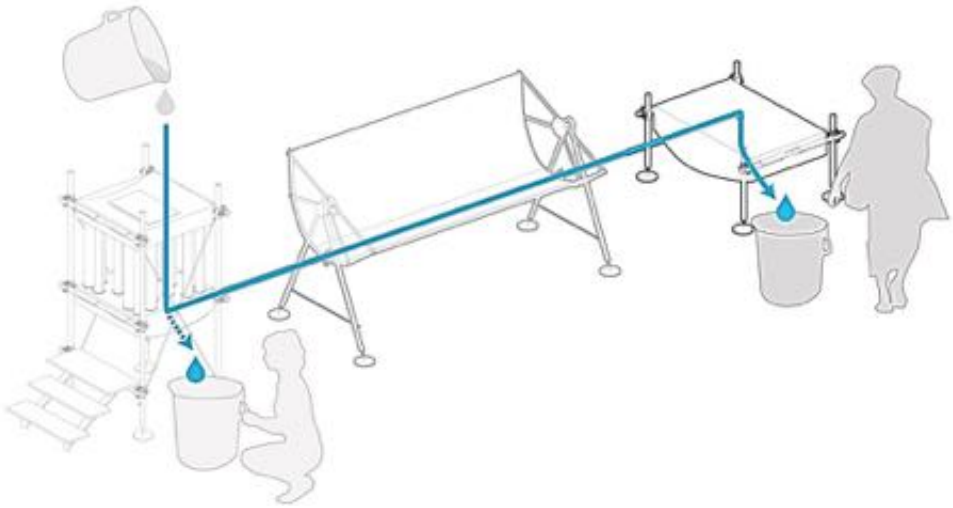
nymphaea



1ST PHASE: FILTRATION



2ND PHASE: SOLAR HEATING



3RD PHASE: STORAGE AND COLLECTION

Project description written by the Principal Academic Tutor

The lack of safely managed drinking water is a problem that still today affects about a third of world population. "Clean Water and Sanitation" is the 6th UN Sustainable Development Goal, and in fact in almost all world's continents the number of people affected by this situation is steadily decreasing. Only in Sub-Saharan Africa the trend is reversed, due to the lack of proper solutions and the rising population. The problem is particularly harsh in the rural areas, where electricity is a scarce resource, the logistics is extremely complicated and hence the use of common first-world products or infrastructures is not effective at all. The people living in this context are estimated to be 200 million.

The ASP Nymphaea (FM SEI) project has addressed this complicated topic by proposing a novel combination of two simple technologies and a new business approach, efficiently combining all the different academic backgrounds of the team members (Energy, Aeronautical, Industrial Production and Transport Engineering, and Architecture). Before doing this, they deeply analysed the environment of Sub-Saharan Africa, of its isolated, rural communities, and of the existing solutions to the problem of drinking water, also directly talking with many different stakeholders and actors with a direct experience in the field.

A solution like the one proposed by Nymphaea can create a new last mile logistics paradigm for water supply in this scenario. As it is happening with renewable energy generation, it is possible to imagine infrastructures built at a very local level whose aim is to purify water, with water storage tanks that connect a plurality of these devices and deliver clean water where is needed.

Team description by skill

Silvia Cosentino: Engineering for Industrial Production @ Politecnico di Torino. Silvia mainly worked on the business model of our project and she was responsible for the communication with the stakeholders.

Francesco Cuzzocrea: Civil Engineering with specialization in Transport Infrastructure @ Politecnico di Milano. Francesco was the Team Controller, and he took in charge the definition of the timeline of the project. He designed and made the project videos and website.

Luca Galli: Building Architecture @ Politecnico di Milano. Luca had a major role in the prototyping phase and on the concept design of our project. He delivered the final pitch in the June 2019 Demo Day.

Alessandro Innocenti: Energy Engineering @ Politecnico di Milano. Alessandro mainly studied the technical feasibility of Nymphaea, and he modelized the water production system to verify its consistency. He contributed to the prototyping phase.

Lucia Miglietta: Architecture for Sustainable Design @ Politecnico di Torino. Lucia investigated the problem of drinking water in the world, and she focused on the relations between the project's stakeholders. She was responsible for the visual communication of the project.

Fabio Giovanni Parisi: Aeronautical Engineering @ Politecnico di Milano. Fabio reviewed the state of the art, comparing the various technologies. He carried out the market and competitor analysis.

Goal

The project started in June 2018, in collaboration with the School of Entrepreneurship & Innovation (SEI). Indeed, Pioneer is one of the main modules of the school that is dedicated to high tech and innovation. It is a 12-month experience which accompanied the team along a complete path of innovative product development: visioning, ideation, user validation, business feasibility, prototyping, presentation to an audience of investors, companies, entrepreneurs and partners. The aim of the program was to launch a startup idea, working with an entrepreneurial approach. The innovation theme pre-established in the program was the one of last mile logistics, which at the end was interpreted by our team as last mile water supply in developing countries and going towards a social innovation solution. The name of Nymphaea was chosen, inspired by the natural water purification properties of water lilies.

Understanding the problem

As reported by the United Nations, 3 out of 10 people in the world lack access to safely managed drinking water services. Besides the appalling consequences of this phenomenon in terms of diseases and deaths, the issue of sanitized water seriously impacts on the growth of developing countries. The hidden costs of polluted water are huge: thus, investing in water sanitation could produce a great economic return in these areas. For this reason, the United Nations have dedicated the sixth objective of the Sustainable Development Goals to the achievement of clean water and sanitation for all citizens of the world.

While in most regions the number of people that lack access to improved water services has been decreasing in the last three decades, this figure has been rising in Sub-Saharan Africa. Most of the population in this region lives in rural areas, where water infrastructure is highly fragmented and inadequate, and electricity is not widely available. The issue of polluted water underlies the persistency of poverty in Sub-Saharan Africa and addressing the problem is the first step in kick-starting the socio-economic development of this region.

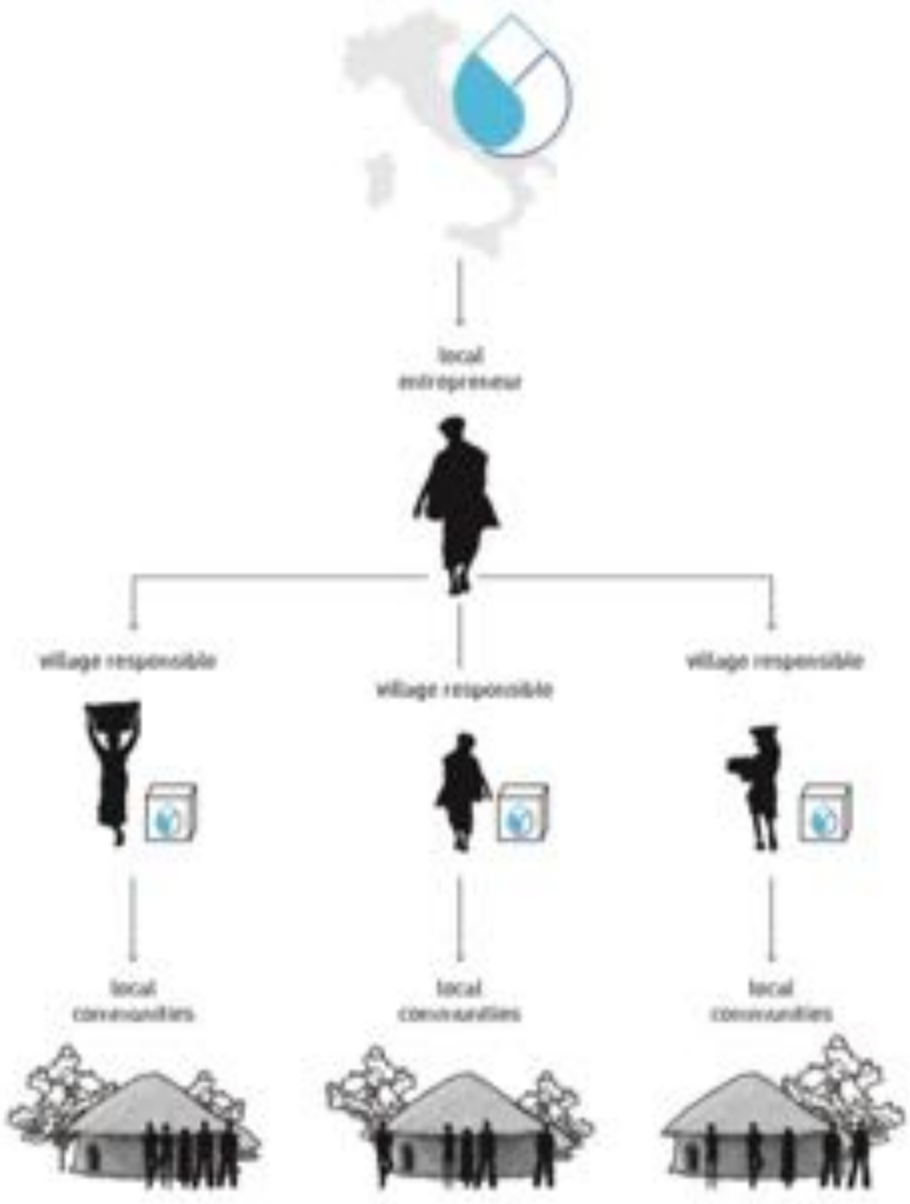
Understanding the complicated stakeholders' network related to this problem has been fundamental. The formulation of the needs and the requirements of these actors helped us in selecting the most suitable solutions for the technology, the design and the business model of Nymphaea.

Exploring the opportunities

Our idea is that development in Sub-Saharan countries must come from the empowerment of local communities. People should not just be passive users of the water sanitation device but should actively capture value from it. The business model of a startup that commercializes a device for cleaning water should be built on a strong ecosystem of customers and stakeholders deeply rooted in the territory. In our proposal, the relationship between the startup and local entrepreneurs of the Sub-Saharan region plays a crucial role.

They rent one or more water sanitation devices at the price of a monthly subscription, that includes training and support from the startup team. Once learnt the basics to run and make the most of the product, the local entrepreneur leans on a village responsible for the operational management of the devices. The village responsibles are in charge of operating the devices within a rural community and selling the clean water produced to the inhabitants of the village. Due to the cost-effectiveness of Nymphaea, it is possible to sell water at a highly competitive price compared to other sellers in the region.

The first beneficiaries are the people from rural areas, who do not only save money, but also time: instead of walking long distances to find a clean water source, it is possible for them to dedicate themselves to other valuables activities. On the other hand, village responsibles reap the benefits of water sales, by retaining a percentage on those. Finally, local entrepreneurs earn a profit on the sales performed by the village responsibles. Thus, Nymphaea will trigger a virtuous circle, by promoting health and generating wealth in local communities.



Generating a solution

All these remarks have been the main drivers for the development of Nymphaea solution, a water sanitation device that has been designed to be implemented in remote regions of the world and to be run at a community level. Although other products have been developed with the same purpose and the same target, Nymphaea presents some features that considerably differentiate it from its competitors. First of all, the product does not need any electricity to work and is only powered by solar radiation. Moreover, it is built with low-tech and low-cost materials that do not require continuous maintenance, that do not require supplies and that guarantee the sustainability of the device throughout its life cycle.

Nymphaea is able to remove debris and heavy metals from polluted water thanks to a sand filter. On top of this, the concentration of sunlight with a parabolic concentrator allow heating the water up to 75-80°C, and subsequently ensures the removal of microbiological contaminants from polluted water. The device is expected to produce on average about 300 l/day of drinkable water, therefore being suitable for serving the needs of a small rural community.

The current configuration of the product, which presents compact dimensions and affordable costs, has been proved to reach the target production of clean water thanks to a feasibility study supported by mathematical models. Nevertheless, Nymphaea needs to be tested on field, not only from the technical point of view but also for what concerns the ecosystem of people that should be involved in the project. The validation of the product and business model should be achieved with a first pilot project.

The pilot is scheduled in 2020 and will target Kenya, which is deemed to offer a favourable environment for the first implementation of the devices. Indeed, it is one of the developing countries with the highest spending power and most stable political situation. The field trial will last about one year and will allow to concretely assess the performance of the product and suggest ideas for further improvements.

Main bibliographic references

Baher L. (2014). *This bizarre structure could provide drinking water even in a desert*. Business Insider. Retrieved from https://www.businessinsider.com/warkawater-clean-drinking-water-2014-4

Cascini, G., Fantoni, G., Montagna, F. (2013). *Situating Needs and Requirements in the FBS framework*, Design Studies, 34, 636-662

Connor, R., Uhlenbrook, S., Koncagül, E. (2019). *The United Nations world water development report 2019: leaving no one behind, executive summary*, Perugia: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000367303

Ericson, A., Müller, P., Larsson T., Stark R., (2009) *Product-Service Systems – From Customer Needs to Requirements in Early Development Phases*, Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference, Cranfield, UK.

Duffle, J. A. and Beckman, W. A. (2006). *Solar Engineering of Thermal Processes*. John Wiley & Sons, Inc., Hoboken, New Jersey

Food and Agriculture Organization of the United Nations (n.d.). *WATER and PEOPLE: whose right is it?* http://www.fao.org/3/y4555e/y4555e00.htm

Islam, T., Huda, N., Abdullah, A. B., Saidur, R. (2018*). A comprehensive review of state-of-the-art concentrating solar power (CSP) technologies: current status and research trends*. Renewable and Sustainable Energy Reviews, 91, 987-1018.

Jibu Kenya (2018). *Jibu Kenya Water Services*. https://jibuco.com/ke/

Link to Good Living (2016). *The true cost of poor sanitation*. Retrieved from https://www.lixil.com/en/sustainability/pdf/the_true_cost_of_poor_sanitation_e.pdf

Muhammad, Nur (1998). *Removal of heavy metals by slow sand filtration*, Doctoral Thesis, Loughborough University

Ritchie, H., Roser, M., (n.d.) *Water Use and Sanitation*. Retrieved from https://ourworldindata.org/water-use-sanitation#

Saleem, M., Burdett, T., Heaslip V. (2019). *Health and social impacts of open defecation on women: a systematic review*, BMC Public Health, 19:158

Santos-González, I., Sandoval-Reyes, M., García-Valladares, O., Ortega, N., Gómez., V.H. (2014*). Design and Evaluation of a Compound Parabolic Concentrator for Heat Generation of Thermal Processes*. Energy Procedia, 57, 2956-2965.

UNICEF and World Health Organization (2015), *Progress on Sanitation and Drinking Water (2015 Update and MDG assessment),* USA: WHO Press

United Nations (n.d.) Goal 6: *Ensure access to water and sanitation for all*. https://www.un.org/sustainabledevelopment/water-and-sanitation/

United Nations Educational, Scientific and Cultural Organization (2009). 3rd *United Nations World Water Development Report: Water in a Changing World. Facts and Figures*.

United Nations Educational, Scientific and Cultural Organization (2019), *Leaving no one behind (The United Nations World Water Development Report 2019),* Paris: UNESCO

United Nations General Assembly (1987), *Our Common Future (Report of the World Commission on Environment and Development).* Retrieved from https://www.are.admin.ch/are/en/home/sustainable-development/international-cooperation/2030agenda/un--milestones-in-sustainable-development/1987--brundtland-report.html

United States Department of State - Bureau of Democracy, Human Rights and Labor (2015), *Kenya Report on Human Rights Practices for 2015*

United States Environmental Protection Agency (2016). *Types of drinking water contaminants*. Retrieved from https://www.epa.gov/ccl/types-drinking-water-contaminants

World Bank Group (2017). *Senegal – Solar Radiation Measurement Data*. Retrieved from https://energydata.info/dataset/senegal-solar-radiation-measurement-data

World Bank Group (n.d.). *Access to electricity*. Retrieved from https://data.worldbank.org /indicator/eg.elc.accs.zs

World Health Organization (2004). *Disinfectants and disinfectant by-products*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/42274/WHO_EHC_216.pdf

World Health Organization (2017). *Guidelines for drinking-water quality: fourth edition incorporating the first addendum*. Retrieved from https://apps.who.int/iris/bitstream/handle/ 10665/254637/9789241549950-eng.pdf

World Health Organization (2016). *Key facts from JMP 2015 report*. Retrieved from https://www.who.int/water_sanitation_health/monitoring/jmp-2015-key-facts/en/

World Health Organization (2019). *Sanitation - Key Fact.* Retrieved from https://www.who.int/en/news-room/fact-sheets/detail/sanitation

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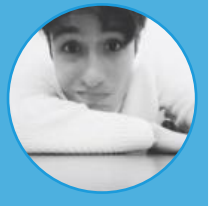

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THERALIGHT

Lightwave Technologies for Theranostic of Tumors

Executive summary

Thermal Ablation (TA) is a class of interventional techniques that deploy electromagnetic energy sources to treat malignant diseases by inducing thermal damage and, eventually, coagulation necrosis in tissues. Among similar techniques, laser thermal ablation (LTA) stands out as particularly promising due to a number of factors:

- it can be used in combination with many different imaging systems (such as ultrasounds, computerized tomography and magnetic resonance);
- the optic fibers can be designed to fit the double function of energy delivery and temperature sensing;
- the probe it uses in order to reach the area to be ablated has a small diameter, that allows for its use also in tissues at high risk of damage;
- it is economically convenient with respect to similar technologies.

The main limitations of LTA, however, are the restricted dimensions of the area ablated with a single fiber and the technical complexity of manually inserting the probe.

Theralight project aims at identifying a novel concept capable of overcoming the current LTA limitations.

The solution entails the following aspects:

- redesign of the probe handling system, to support surgeons during the insertion procedure to reach the tumor mass with the utmost accuracy;
- research of alternative biocompatible materials for the probe, to further reduce the cost of the instrumentation and, consequently, facilitate its adoption in clinical practice. Due to its flexibility, transparency, and resistance, polycarbonate was selected as the most suitable material for the probe, while polypropylene well performs the functions associated to the handling;
- introduction of alternative and sophisticated temperature monitoring techniques that could provide a more accurate feedback, in real time, on the outcome of the procedure. The fluorescence sensing and mapping system is demonstrated as a promising approach to the temperature monitoring in real time during LTA procedures;
- design of Virtual Reality training systems for encouraging surgeons to adopt LTA (which is currently not as used as it should be).

The ensemble of these solutions can breed a new generation of LTA tools that could become an important alternative to traditional surgical resection.

Key Words

"Laser Thermal Ablation", "Tumor Theranostic", "Temperature Monitoring", "Biocompatible Materials", "Probe Design"

Project description written by the Principal Academic Tutor

LTA is a powerful minimally-invasive treatment with high potential, but so far with limited clinical use for its novelty and the lack of tools for patient-specific treatment.

With the aim of providing a contribution to help overcoming current limitations, THERALIGHT will analyze novel strategies for laser-based theranostric of cancer by combining patient-specific beam delivery solutions and advanced monitoring techniques. Following the design of an innovative LA system, lab tests with phantoms and ex-vivo trials will allow the team to validate the proposed solutions and to drive the possible workflow re-design. Then, the most promising solution will have the possibility to be tested in a practical environment to assess its impact in practical cases of tumor ablation.

In more detail, the project will consist of five phases, with three of them partially overlapped:

- Review of the state-of-the-art (All – M1-M3): analysis of the literature and of other ongoing research projects (e.g., European funded projects) to become familiar with laser ablation procedures.
- Identification of requirements (Sub-team A – M4-M10): interaction with possible end-users (mainly surgeons) to identify the needs and to carry out preliminary assessments of the relevance (and acceptance) of the innovative aspects; definition of the regulatory framework for the medical device developed by the team.
- Development of new prototypes (Sub-team B – M4-M10): study of the applicators that embed two different functions: laser light delivery and process outcome measurement (mainly through the evaluation of the temperature field during the LA procedure). Different light emission patterns and laser wavelengths will be investigated with the goal of adapting the shape and size of the treatment affected region to the tumor lesion. The measured temperature values will be processed and used to represent and visualize in real time the evolution of the ablation volume, with the aim to provide the clinician with a visual feedback of the LA outcome. The possible development of magnetic-resonance (MR) compliant needles to allow the percutaneous insertion of the applicators under MR procedures will be considered as well.
- Preliminary lab tests (All – M7-M10): metrological assessment of the sensors, preliminary tests in tissue-mimicking phantoms, and validation of the platform for the real-time visualization of measured temperature values.
- Final assessments (All – M11-M15): final ex-vivo and in-vivo trials to validate the devices and the workflow in simulated clinical scenario, data analysis, demonstration to end-users and survey to evaluate the usability of the tool, preparation of conclusive reports.

Team description by skill

Chiara Bregoli: her Biomedical Engineering expertise with a specialization in biomechanics she contributed with her skills in biomechanics and biomaterials analysis at the design of the LTA instrumentation, focusing both on device's structure and suitable materials research.

Federica Buccino: with her Biomedical Engineering expertise with a specialization in biomechanics she contributed with her skills in biomechanics and biomaterials selection at the design of the instrumentation, both as morphology and as materials composition.

Chiara Coletti: with her Biomedical Engineering expertise with a specialization in electronic technologies she contributed with her skills in signal and image processing and radiation physics at the research for temperature monitoring techniques, sensing and controlling principles and imaging.

Chiara Di Vece: with her Biomedical Engineering expertise with a specialization in electronic technologies she contributed with her skills in signal and image processing, sensors and computer-aided surgery at the research for temperature monitoring techniques, sensing and controlling principles and virtual reality developments.

Davide Manzionna: with his Management Engineering expertise he contributed with his skills in product industrialization at the research for the product value and positioning inside its reference market, as well as the practical economic feasibility of the proposed solutions.

Elena Hilary Rondoni: with her Biomedical Engineering expertise with a specialization in electronic technologies she contributed with her skills in biotechnology, radiation physics and medical imaging at the research for temperature monitoring techniques, sensing and controlling principles and imaging.

Antonio Sindoni: thanks to his Mechanical Engineering expertise, he contributed with his skills in Designing for Additive Manufacturing and 3D printing optimization at studying new solutions for the main tools regarding LTA, realizing also the 3D functional prototypes of two different probes.

Luca Viale: with his Mechanical Engineering expertise he contributed with his skills in design and automation at the design of the instrumentation, both as morphology and materials composition.

Goal

THERALIGHT project aims at identifying a novel design concept capable of overcoming the current limitations in LTA and, as a result, promote its use for the minimally invasive treatment of lesions from solid tumors.

The design of a theranostic tool, able to perform laser ablation of soft tissue with real-time process outcome monitoring capabilities, needs to be carried out following two parallel, but communicating, research lines, from the early state-of-the-art study until the latest developments. As already seen in the team composition, the objective of this project must be pursued both in the field of electronic with the research for temperature monitoring techniques, sensing and controlling principles, and in the biomechanic one with the study of the design of the instrumentation, in terms of morphology and materials composition.

The importance of these results is not limited to the external institutions involved in the project – actually, they can be considered more "support institutions" than stakeholders – but they could give benefits to the entire society if a reduction of the mortality rate of very aggressive tumors (an example for all, pancreatic cancer) can be successfully achieved. Moreover, the developed procedure could even have a stronger impact as it could be extended to other fields of medicine, such as in the ablation of obstructed blood vessels, brain lesions, etc.

Understanding the problem

"Those diseases which iron cannot cure, fire cures".

Hyppocrates' quote introduces the paradigma behind thermal ablation (TA) techniques.

It refers to the destruction of tissue by extreme hyperthermia. The TA techniques have been introduced as alternatives to classic surgical resection only in the second half of 1900 and are still being developed. The working principle of this technology is to deploy electromagnetic energy sources, such as radiofrequencies, microwave or laser to induce thermal damage and, eventually, coagulation necrosis in tissues and treat malignant diseases.

The key feature of TA is that it turns out to be a less invasive solution with respect to traditional surgery; in addition, sometimes, this is the only way to proceed when a traditional approach is not feasible to cure certain tumors. Indeed, TA can be performed using an open, laparoscopic, or endoscopic approach. Operation lasts about 10-30 minutes and, even if it is different from a classical surgical operation, anesthesia is generally used. For most cell types, necrosis occurs at temperatures below -40 °C or in excess of 60 °C.

Laser Thermal ablation (LTA), in particular, has the peculiarity of being MRI-compatible, allowing also for temperature mapping, since energy is conveyed through optic fibers; it is economically convenient with respect to the other TA technologies and the small diameter of the probe allows for its use also in tissues at higher risk of damage. Furthermore, the fiber used to deliver the treating light can also be used to collect information on the temperature and, thus, combine therapeutic and diagnostic functionalities, unlike any other thermal ablation technology. The main limitation of LTA, however, are the restricted dimensions of the ablated area with a single fiber, due to the high absorption of light by body tissues, and the technical complexity in the manual insertion of the probe. These factors require the adoption of several strategies to facilitate the interventional procedure and increase energy penetration.

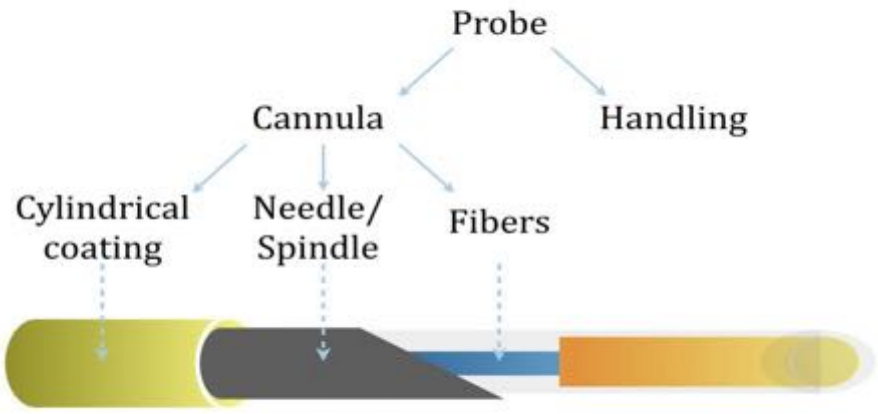
Considering the strengths and weaknesses of LTA, the final goal is to make this treatment possible and affordable for a larger amount of people. In this project, in particular, the first phase has been dedicated to the analysis of the state-of-the-art in order to prepare a significative questionnaire to be given to the surgeons. The comprehension of the answers and the analysis of different suggestions, led to the second phase, more focused on the concept of the new device. The 3D prototype derives both from the surgeons' observation and Theralight team's researches and studies. This third phase is completed by the feasibility analysis which includes the research of the sensors and the materials and the analysis of different competitive techniques in order to make the proposal cutting-edge on the market.

Exploring the opportunities

As mentioned before, starting from the researches related to the laser interaction with different human tissues, the need for water injection and mechanical guidance during the treatment to better control the process, we tried to understand in details the structural composition of the whole real systems with needles and probes as leading sub-systems, as shown in the figure below.

Subsequently, the surveys given to the surgeons helped us to solve the main issues related to current laser ablation devices, to explore the foremost needs of the stakeholders and to translate them into specific requirements. The surveys aimed at collecting as much data as possible from previous experiences of surgeons, who have already performed interventions with laser ablation systems, in order to

identify strengths and possible improvements to make this technique even more efficient and advanced. The opinions of the majority of the physicians focuses on the minimally invasiveness of the considered technique, on the reduction of the post-operative complications and of the convalescence period, on the higher tolerability, also in high-risk patients, and on the reduced dimensions of the probe (2,5 mm in diameter). However, what is perceived as a limiting factor for the diffusion of LTA practice, is basically the adoption of LTA by the hosting structure and the novelty of the technique, that implies the necessity to introduce more specific - and expensive - training for LTA.



Representation of the structural composition of the whole system. The needle and the probe are considered as leading sub-systems.

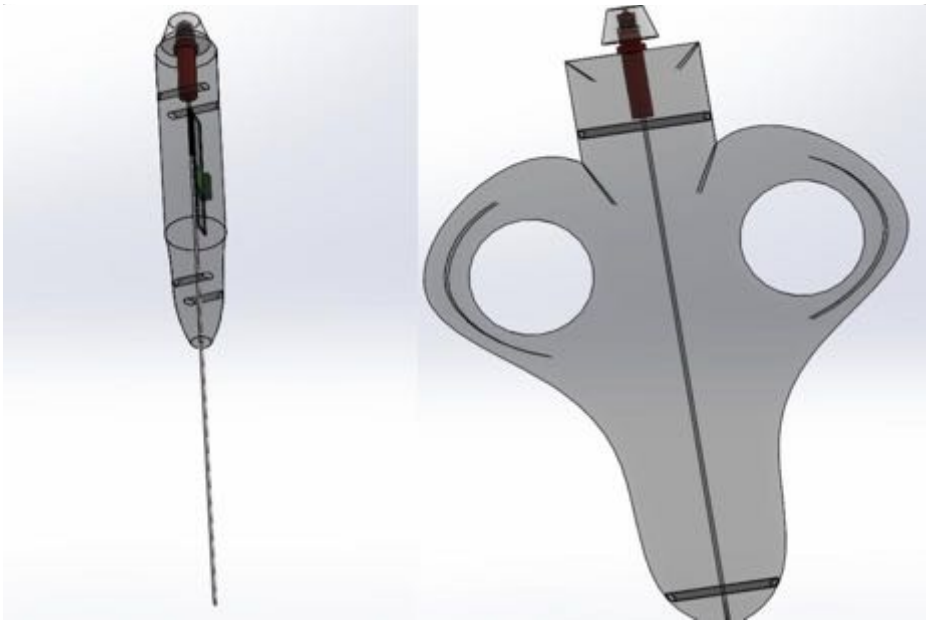
According to the interviewed physicians, one aspect that turned out is the necessity for a LTA probe improvement: the reliability of the measurements and the completeness in monitoring temperature parameters seem to be the most urgent features to be revised. The necessity to perform a control on the distribution of the temperatures in the periphery of the ablation zone, in order to avoid damages on the contiguous vital structures, has been highlighted by most of the surgeons. Another relevant improvement should be performed in the reduction of probe fragility. For these reasons, a re-design of the LTA tool was performed.

The selected price (economical requirements) for the whole LTA instrumentation should range from 500 to 1000 €: this is one of the key parameters that must be considered in the implementation of an improved device since the commercialized ones are considered too expensive.

Generating a solution

Some issues and concerns have arisen from the study of surgeons' opinions and LTA system components. The objective of this work is to tackle them, mainly from two different perspectives. The first one regards the research done in terms of best materials to be used for probe fabrication. They must respond to precise requirements dictated by mechanical properties that the device should present. Moreover, a new design for the handling portion of the probe itself is proposed. The second one focuses on the necessity of finding evermore precise implementations for the monitoring system. In particular, a novel solution, that uses fluorescence is proposed. According to the devices already available and the suggestions expressed by the interviewed surgeons, a transparent, quite flexible and resistant polymeric material may be the right choice for the probe. It is

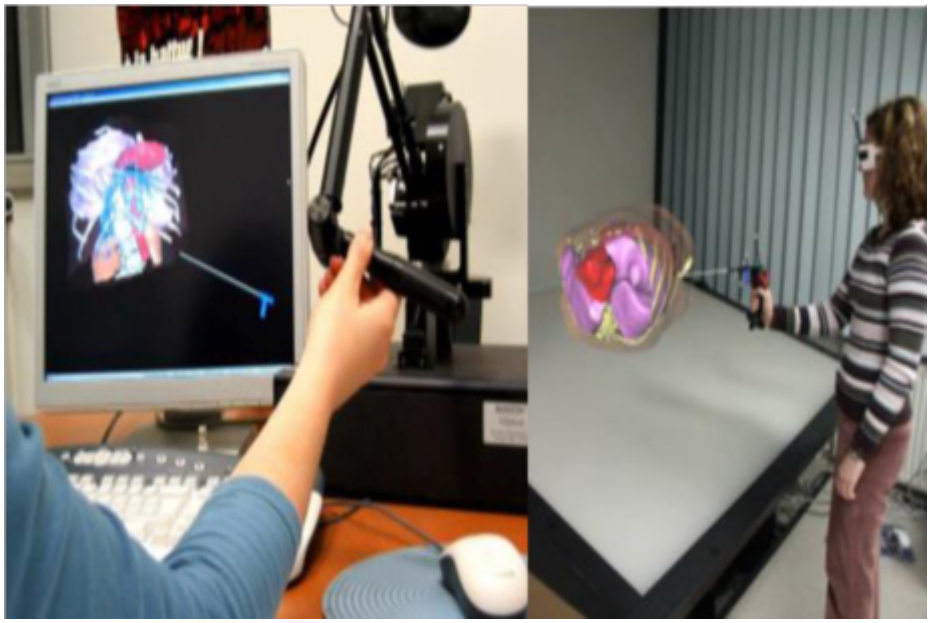
possible to state that polycarbonate could be a good material for this purpose. For the same reasons, polypropylene with a possibility of an anti-slip silicone covering was chosen for the handling, in order to increase the manageability and to avoid uncomfortable surfaces. Moreover, regarding the handling, it turned out from the survey that many surgeons have complained about the absence of ergonomic features. This is the reason why the Theralight team have tried to generate a prototype through 3D printing able to give some useful indications. The type of prototype, shown in the figure below, is a conceptual one, i.e., only aimed at verifying the idea. Giving a brief description, the first is thinner with a tubular structure. On the other hand, the second allows surgeon to firmly keep the device inserting fingers in the two holes. The tubular handling could also be provided with a system able to customize and change the length of the fibers in order to fit perfectly the purpose for which it is using.



Conceptual prototype of the handling portion of the probe generated through 3D printing. The first one on the left is thinner and presents a tabular structure, whereas the one on the right allows the surgeon to keep more firmly the device since he or she is able to insert the fingers in the holes.

Regarding the sensors monitoring study, instead, the fluorescence sensing for laser ablation monitoring has proven to be a promising technique, even though it is at its primordial stages and it is still limited to experimental studies. Its main limitations are the background noise, caused by the tissues autofluorescence, and the photobleaching process, in which the emission is reduced due to chemical degradation of the fluorophores. For what concerns the noise, possible alternatives have been studied, such as the exploitation of the Förster resonance energy transfer mechanism to absorb the background emission, hence used as an excitation source. To deal with photobleaching, ratiometric measurements may be a possible solution.

In conclusion, since LTA is not commonly carried out yet, also because the success of the intervention strongly depends on the skill level of the operator, it was suggested that virtual and augmented reality simulators could represent the key to progress, allowing trainees to be able to cope better and with less stress with the intraoperative situations of real life. These tools could be used to train the next generation of surgeons specialized in TA.



Examples of simulators that could be effective in order to train the next generation of surgeons specialized in TA. Virtual reality in particular could be useful for the development of surgical simulators in order to train and improve the acquisition of the necessary psychomotor skills.

Main bibliographic references

C. M. Pacella, G. Bizzarri, G. Francica, A. Bianchini, S. De Nuntis, S. Pacella, A. Crescenzi, S. Taccogna, G. Forlini, Z. Rossi, et al., *Percutaneous laser ablation in the treatment of hepatocellular carcinoma with small tumors: Analysis of factors affecting the achievement of tumor necrosis*, Journal of vascular and interventional radiology, vol. 16, no. 11, pp. 1447–1457, 2005.

S. N. Goldberg, G. S. Gazelle, and P. R. Mueller, *Thermal ablation therapy for focal malignancy: A unified approach to underlying principles, techniques, and diagnostic imaging guidance*, American Journal of Roentgenology, vol. 174, no. 2, pp. 323–331, 2000.

D. J. Webb, M. Hathaway, D. A. Jackson, S. Jones, L. Zhang, and I. Bennion, *First in-vivo trials of a fiber bragg grating based temperature profiling system*, Journal of biomedical optics, vol. 5, no. 1, pp. 45–51, 2000.

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Knowai

Executive summary

The need of saving and sharing knowledge is a hot topic from the start of mankind and internet has represented a breakthrough for its spread and relevance. It started as a simple tool to enable people to save and share information they considered valuable and now it is common to search online for retrieving information about any topic of interest. The need to save information in a structured and easily accessible way is present in any human context, from the personal environment (e.g. find a recipe) to the industrial context. Nowadays companies are still facing some issues in managing knowledge.

The Knowai project was born from the cooperation of Alta Scuola Politecnica (ASP) with School of Entrepreneurship and Innovation (SEI): the purpose of the experience is the creation of a deep tech startup. After an initial period made of interviews, analysis and research, the team has decided to develop a system for **industrial knowledge management**.

The main goal of Knowai project was to develop an innovative solution based on the use of Artificial Intelligence techniques that deals with the complex but challenging problems of knowledge digitalization and management in the industrial context. For this purpose, the developed MVP is configured as a hybrid solution between a Chatbot and a Knowledge Management System (KMS) and it has been realized for an application in assistance processes.

Key Words

Knowledge Management, Customers' Assistance Process, Natural Language Processing (NLP).

Knowai

Figure 1: Graphic representation of the working principles of the solution developed by the Knowai team.
The software aims to facilitate the identification and resolution of problems between the selling company and the customer company using the knowledge extracted from the past communication flows.
Two software interfaces are shown here: the tab used by the expert (left) for having a conversation with the operator that reported the symptom and the tab used by the operator himself (right) for answering to the questions.
The added value of the Knowai system is given by the fact that knowledge displayed in the interfaces is extracted from previous exchanges of information.

Project description written by the Principal Academic Tutor

Artificial Intelligence (AI) history started more than 50 years ago, but it has shown to the world its real capabilities only in last two decades.
New applications are growing in any conceivable field and products based on image recognition or recommender systems have now reached several markets. Despite the fast diffusion of AI, there are still some sectors where few real solution are present, and one of this is the industrial knowledge management. Industry 4.0 revolution led all businesses to the production of tons of data regarding their processes but for the moment companies are focusing more in data collection rather than in data exploration. The latest AI developments enabled new tools that can disrupt the way we manage data and the kind of data we can manage. Natural Language Processing (NLP) progresses indeed open unexpected opportunity for processing "human generated data", like documents and conversations, offering the chance to capture meaning behind words and so increase the possibility of comprehension.

Knowai team worked to find a touching point between opportunities given by the usage of new technologies and market needs. Focusing on industrial processes, they analysed the way in which companies are attempting to manage their knowledge, trying to identify hidden criticalities. According to the results collected during the research phase, they attempted to develop a solution for the management of knowledge in the assistance process, which seemed to be the suitable entry point for approaching the issue. After a first phase focused on the product definition, the team faced the implementation challenge, developing a working Minimum Viable Product (MVP) and testing it in a real case scenario. Together with first technical results, the team managed also a product validation phase, aimed at understanding whether the developed solution could reach the market fit. This whole work helped them to identify which are the challenges hidden behind the development of a real deep tech product based on AI.

Team description by skill

The team is composed by seven engineering students, coming from the Politecnico di Milano (PoliMI) and Politecnico di Torino (PoliTO):

Federico Betti, Computer Science and Engineering, *PoliMI*, Techno-economic Assessment, Application Development, Machine Learning Engineer.

Marco Centurioni, Automation and Control Engineering, *PoliMI*, Strategy, Business Analysis, Business Model Development, Project Management.

Alessio Colucci, Electronic Engineering, *PoliTO*, Application Development, Backend Development, Software Deployment.

Domenico Ruben Pangallo, Biomedical Engineering, Team Controller, *PoliTO*, Economic Assessment, Competitor and Stakeholder Analysis, Market Analysis.

Nicola Pivaro, Automation and Control Engineering, *PoliMI*, Strategy, Business Analysis, Business Model Development, Project Management.

Alessandro Rosiello, Space Engineering, *PoliMI*, Competitor and Stakeholder Analysis, Market Analysis.

Ivan Vrsajkov, Computer Science and Engineering, *PoliMI*, Application Development, Frontend Development (User Interface).

Goal (Main Issues, Proposed Solution, Advantages)

The objective of Knowai project was to develop an innovative solution based on the use of AI techniques that deals with the problem of knowledge digitalization and management in the industrial context.

The result of the market analysis and the study of the solutions actually present have been compared with the needs and requirements of companies (especially Italian SMEs). What emerged is the technological incapacity of the current solutions (KMSs, Chatbots, Ticketing software) to fully guarantee some fundamental features requested by the employees and consequently by the companies themselves. In particular, the industrial technical assistance appears to be one of the most mature application context for the introduction of tools for the management and sharing of knowledge. Therefore, Knowai team has decided to develop a technological solution designed specifically to manage this process.

The aim of the product is to provide a platform that customers can use as a messaging service from which to extract information, save knowledge in a Knowledge Base (KB) and make everything available later on. In this regard, it is therefore configured as a hybrid solution between a chatbot and a KMS applied in the field of technical assistance and is characterized by the adoption of modern techniques of NLP and AI for saving hidden knowledge in a semi-structured information flow. In particular, the Knowai system aims to read, learn and broaden the knowledge base processing past communication flows (i.e. assistance requests). In this way, the trained KB can be used to provide advices to the expert who delivers assistance on the procedure for identifying and resolving the problem encountered by the operator of the customer company.

Figure 2: Knowai Team path from the launching of the Pioneer Programme

Understanding the problem

The subject of knowledge management has always been a topic of interest, since good efficiency of any process is strongly dependent on the saving, sorting and accessing of useful information. For example, the last few years saw the birth of the concept of Industry 4.0. According to its basic principles, the future development of companies will depend mainly on the collection, management and analysis of data. Data are substantially numeric information, whose collection and processing generate well-known economic advantages. It is interesting to note that the data themselves are not profitable: value comes when people are able to take more aware actions in the light of the carried out analyses. The economic driver is not data, but rather knowledge that derives from it: successful companies are knowledge-driven and not simply data-driven. The last ten years opened a new historical period in which the theme of knowledge management has reached a new hype thanks to the great amount of

data that has been saved and thanks to the new technologies that have been developed. In the following points, an analysis about elements involved in the rise of need and interest for knowledge management is shown.

The last 40 years of history have been mainly characterized by two factors for what concern industrial development: *technology growth inside companies* and *Increment of technology growth rate*.
The first factor is related to the need of keeping competitive advantages which forced companies to study and develop new solutions, especially for what concern technical tools. One of the direct consequences of the tech growth is the increase of knowledge that companies have to manage to produce their specific products or services. It is evident that one of the needs is knowledge accessibility. This kind of issue is becoming more and more relevant in several industrial situations where the amount of knowledge involved in the processes is increasing month after month.
The second factor is related to the fact that technology growth rate is increasing year after year: on the one side this brings direct advantages enabling new opportunities, but on the other side this peculiar transformation is showing to the world new scenarios where technology growth is so fast that people are struggling to keep pace. One of the most significant examples of this transformation is related to the automation processes.

Exploring the opportunities

After acquiring a complete vision of the problem of knowledge management, both from the technical and the business sides, the team started exploring different possible solutions: the first ideas that came out were related to state-of-the-art, like chatbots, digital manuals, ticketing systems and knowledge management systems. However, each of these current solutions is extremely focused only on a certain aspect.

Chatbots are very good for interaction when the involved knowledge is limited, like in the case of a customer service application.
Regarding digital manuals, instead, they are very useful because there is a lot of knowledge inside, but most of it is unstructured in terms of problem-solution occurrence, while being structured in terms of content. Consequently, it is very difficult to use in real life scenarios when a new problem shows up, requiring a different solution.
Ticketing systems are widely used for support since they provide an easy way to categorize interactions: however, they do not extract knowledge from them, so they partially solve the problem of knowledge management.
Finally, knowledge management systems (KMSs) are the most useful in managing knowledge, but their problem is they are not feasible for interaction with customers, thus knowledge has to be entered manually by experts. This process hinders the creation of a vast knowledge database, actually slowing down the whole process of knowledge management. An example in this direction is given by Maana, which aims to build a KMS and is currently gaining traction, thanks also to its being backed by powerhouses (e.g. Microsoft) that provide integration with their own management framework. Nonetheless it is still lacking the interaction with the customers.

These are the different solutions which are currently used as state-of-the-art, but Knowai wants to put them all together to create a single system which is easily accessible but stores an enormous quantitative of structured knowledge,

obtained directly from the interactions between customers and operators, and enriched through other available data such as the one from sensors.

Generating a solution

As previously stated, the Knowai team decided to focus on the field of technical customer assistance. The information exchange between the operator, who is reporting an issue, and the expert, who is trying to find the root cause of it and fix it, contains unstructured knowledge that constitutes the expert's know-how. Therefore, the proposed solution is a product that is able to extract unstructured and hidden knowledge from a semi-structured information flow and utilize it in future uses.

The conversation between the operator and the expert can be modelled as a process that begins with the **symptom** reported by the operator and continues with a sequence of **questions and answers** between the two subjects. In particular, the symptom is the way the problem is being manifested to the operator. The questions are then asked by the expert. The point of the conversation is to identify the actual problem and suggest a way to fix it.

The main features of the product are the recommendation of the best suited questions and the prediction of the most likely problem based on the conversation up to that point. The algorithm tries to find the best possible sequence according to the probabilities assigned on the basis of previously encountered conversations, which represents the **knowledge** the product has collected so far.

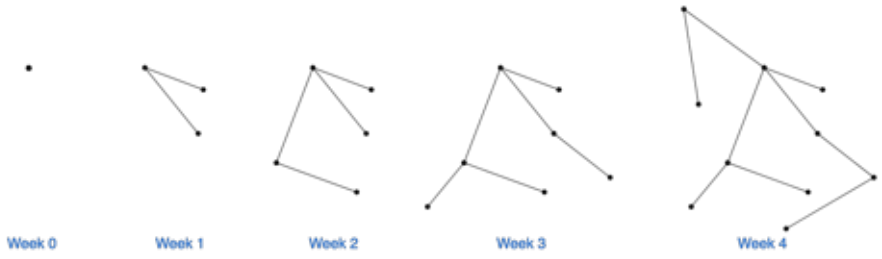

Figure 3: Growing of the Knowledge Base (KB) with the usage of the system.

However, there are far too many possible questions an expert could ask the operator: the knowledge gathered can be too broad. This is why the symptom analysis by using NLP techniques is done in the beginning, to find the best entry point in the knowledge that will most likely lead to a correct prediction. Throughout the whole process, the experts can provide feedback to questions and state the correct outcome at the end of the process. This will be used by the product to learn and make better predictions in the future.
The system as a whole is deployed on a server in order to be able to collect the knowledge in one single centralized database. In this way, knowledge can be shared among all experts of the same company. The users of the proposed solution access it through client applications that interact with the server.

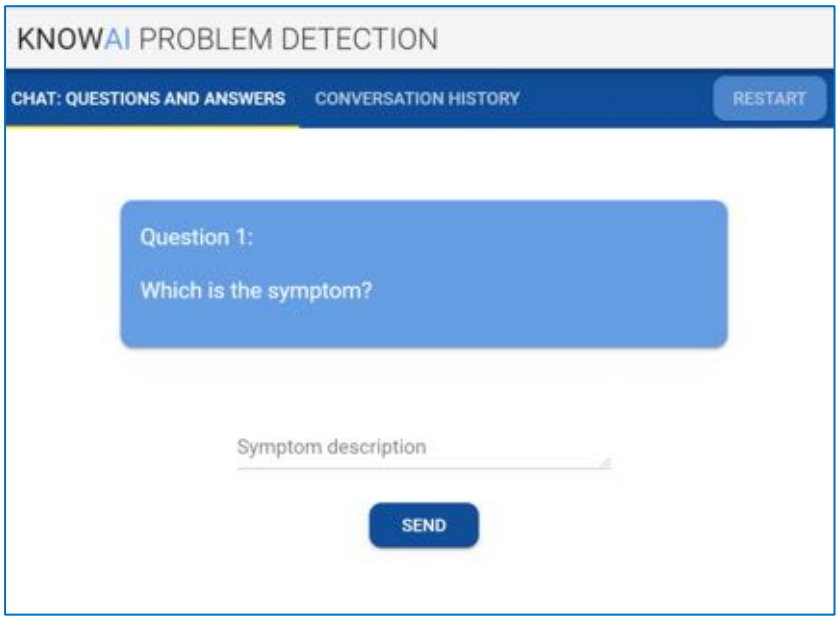

Figure 4: Operator Interface (used to report a new issue observed and to enter a discussion with an expert, who will in turn identify the cause of the issue).

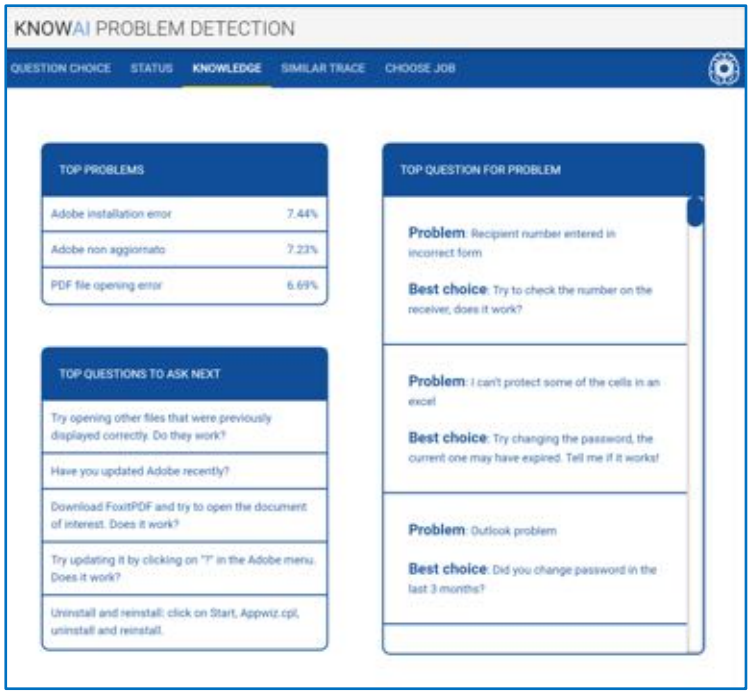

Figure 5: System Knowledge Base Interface. It provides a more in-depth description of the current point in the problem identification process regarding the currently selected job.

Main bibliographic references

K. Ellingrud, 2018, "The Upside of Automation: New Jobs, Increased Productivity and Changing Roles for Workers", *Forbes*.

Panopto Workplace Knowledge and Productivity Report, 2018, "Inefficient Knowledge Sharing Costs Businesses $47 Million Per Year", *Panopto*

J. Devlin et al. (2018), "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding", *Computer Science - Computation and Language*

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Andrea Biancini, Reti SpA

OFFICEMOTION

Introduction: the office space and its current state

Despite places where people carried out intellectual tasks always existed, the "office" is an invention of the 19th century, which adapted to the organizational of companies along the 20th. The recent financial crisis and the development of technologies changed the concept of work on several levels mining the centrality of the office on the economic scheme. People do not spend the same amount of time on the workplace anymore since most activities do not require a specific physical space to be performed and the static idea of offices is in crisis, giving space to new concepts like desk sharing or hot desking.

Herman Miller Corporation

The partner of our project is Herman Miller, one of the major companies for the design and production of office furniture since the beginning of the 20th century. It recently launched on the market the "Living Office", a new set of furniture showing the company's interest in adapting to users' new needs.

Design inspiration and background research: the emotions

Offices used to be designed to host specific work tasks, but since that economic model is no longer valid so it is that design thinking. The worker does not need a specific place to *be able* to carry out an activity, so how can the office be a place where that activity can be executed *better*? The focus of the design process needs to change from an activity-centered perspective to a user-oriented one.

Product design based on users' emotions is a recent trend, whose results proved to be effective and successful, however the application in architecture and interior design are still scarce.

User-oriented and emotion-driven design led to Officemotion, introducing the study of emotions in the office space, allowing the workers to find in the workplace the best atmosphere to perform their tasks.

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Layouts design process

The design has been approached by breaking down the office life to its fundamental activities. Each of them has been subsequently associated to a set of positive and negative emotions, deploying existing tools applied before only in product design. The physical architectural elements have been studied separately to arouse (or to avoid) the emotions linked to each activity and then combined in the final layouts. The furniture was selected among the catalogue of Herman Miller and its partners.

Flexible application

The key aspect of the layouts is the interchangeability of most of them among each other by adding or removing some of the elements composing the set. This leads to a great flexibility of uses during the working hours of the week overcoming the static of traditional offices.

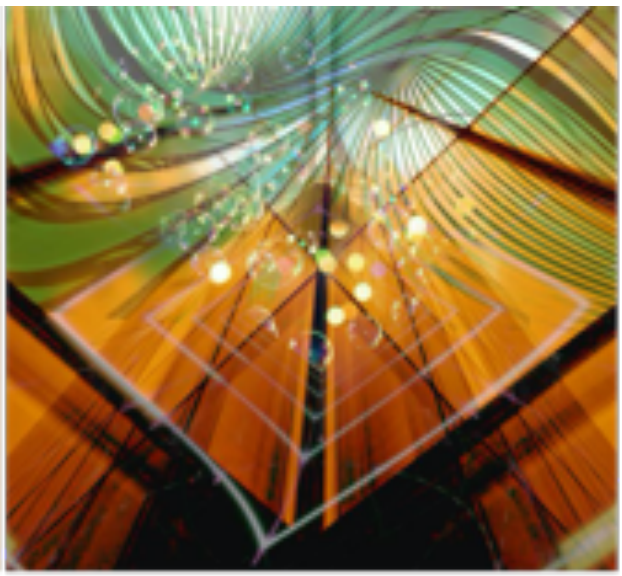
The physical combination rules of the layouts transported into an app and the fact that design of them deployed recurrent elements will allow the re-arrangement of the space according to managerial demands.

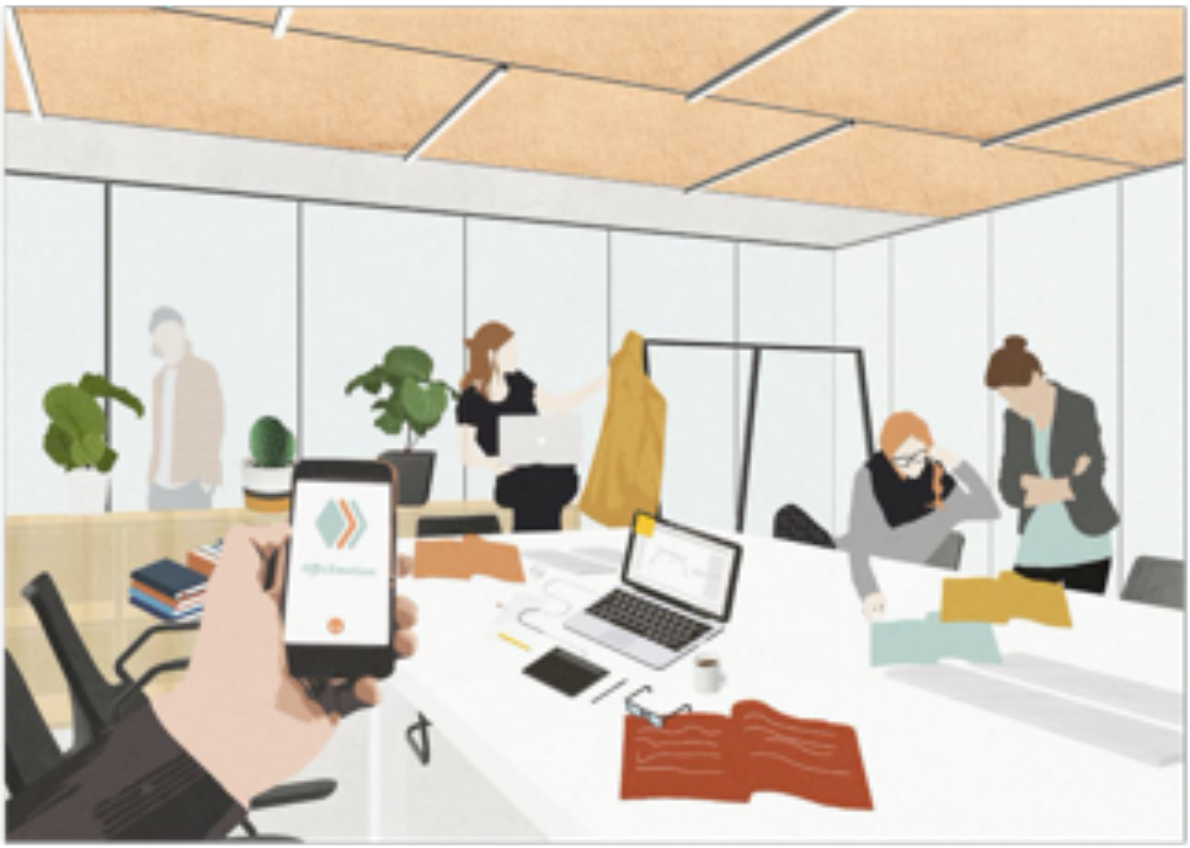
Key Words

Office, emotions, work, activity, design, worker.

OfficEmotion

Figure 1: OfficEmotion representative logo





Project description written by the Principal Academic Tutor

In all the contexts, interactions between actors play a central role. When we think in terms of interactions, we tend to underestimate the size of interplays occurring between actors and the environment they are immersed in. This is true also when modelling spaces that harbour productivity, learning and creativity. Especially for service companies, working offices are going through a Deep transformation that is increasingly mixing production activities, learning spaces and creative oasis.

We can observe that the design of working offices is increasingly taking into consideration how to transform the traditional concepts about space to better support diverse and heterogeneous interactions. We are convinced that art and beauty, together with technology, can be elements to be added in this process to permit the design of spaces that can sustain the different working activities but also inspire and sustain various emotions and emotional states.

With the work of this project it will be possible to model spaces and furniture to sustain the different interactions required in contemporary workspaces. The main dimensions taken into consideration within this project will be strongly interdisciplinary. To design the offices of the future it will be fundamental to take into consideration all the following dimensions: the spatial places and the furniture to sustain interactions, learning and creativity; the emotional dimension to create spaces where emotions can be exploited and expanded; art and beauty to help reinforce the desired emotions and eventually mitigate negative ones; technology to create living spaces that can sense, adapt and transform themselves.

Team description by skill

The Officemotion team is composed by seven students from the fields of architecture, building engineering and design. To each component a specific role was assigned in order to develop a strategic topic:

Adriano Aimar (MsC in Architecture, Politecnico di Torino) the management of the research on emotions and how they affect office work.

Juan Pablo Alvarez Buitrago (MsC in Architecture, Politecnico di Milano) the complementary research on how to translate the research done into the design phase.

Elena Busoni (MsC in Architecture, Politecnico di Milano) the design and final detailing of the spaces designed.

Francesca Calloni (Msc in Communication Design, Politecnico di Milano) the structure of the mobile app and the final communication strategy for the project presentation.

Maja Kopanja (Msc in Interior Design, Politecnico di Milano) the digital rendering and postproduction of the layouts designed.

Luga Lagorio (Msc in Architecture, Politecnico di Torino) the planning of the clusters of layouts and their composition rules.

Michele Maritano (Msc in Architectural and Building Engineering, Politecnico di Milano) the state of the art research and the economic and group management regarding the workflow overview.

Goal

The Officemotion project goal is to design a new concept of office space, in which the dimension of the emotions is added to the traditional values regarding office spaces. In order to make the office working experience more enjoyable by the worker as well as more productive for the employer, emotions are embedded into the design. At the same time, flexibility and the possibility to rearrange the spaces on demand make it possible for the company boss to fill empty or vacant spaces into the office floor, e.g. open spaces. In this order, the paradigm of working in offices is transformed, from the use of fixed and unifunctional spaces to layouts with more than one purpose, where owners can earn space to develop the required functions, and also where users have different options to appropriate a space and make work time something more pleasant.

Understanding the problem

Working is an almost daily activity that has been constantly thriving, showing specific lineaments along the story. The concept of a working space, since 19th century, has evolved according to different requirements by users as well as the perception of place and architecture in different periods of time. Factors of contemporary lifestyle such as technological revolutions have a great impact on the way people behave and deploy certain functions, and afterwards in the spatial configuration and interior design, which tends to embrace the concepts of flexibility and identity.

In this order, working spaces have evolved from an evangelist and individual model with confined spaces that pretended to insulate the worker from the context giving privacy and concentration, passing through the industrial and taylorist models where individual work is replaced by offices that host groups following a hierarchy, to the contemporary "liquid office", in which concepts like hot desking or co-working represent the temporality of space configurations and the free share of information. There are new working spaces where, for a few days or even hours, collectives with different specialties can work together with simultaneous inputs to a same goal. Therefore, human being has arrived to a new office concept where space and time compresses towards focusing in working efficiently as possible.

However, despite of the big influence of technological devices in nowadays society, the design concept used in several offices seems quite distant from representing this evolution, and some outputs do not fulfill users´ requirements to perform in a comfortable environment. Apart from the fact that many companies just omit the contributions of contemporary lifestyle in daily´s tasks and deploy outdated models, there is still one element which is not taken into account when it comes to design and configure working places, quite important to ensure workers´ satisfaction at workplaces and efficiency at developing activities; this neglected element is emotions. There is the need to deeply analyze in parallel the most frequent activities at offices and so the emotions evoked by workers while carrying out them. If designers were capable to finely understand how emotions work in certain spaces and their semiotic relationship with architecture, those final outputs might be more accurate towards people´s performance at work.

In this way, the commitment is to put users in the center of the design process, bringing out the precise elements that embody an atmosphere where the correct emotions can improve comfort, well-being and productivity to perform better. For this reason, offices must be rethought in the way that embrace working contemporary assets, and also meets not only capacity needs, but also the emotional ones.

Figure 2: Layout deployed for Analytical Work.

Figure 3: Layout deployed for Formal Events.

Exploring the opportunities

The positive aspect regarding contemporary office design and its relationship with workers´ emotional ambit is the plenty of tools to harness and exploit aiming at achieving a balance between productivity and wellness. Many tendencies and concepts in nowadays workplaces, as well as research documents about emotions and status, could be used in favor of finding the way emotions can influence a space or vice-versa and also to deploy layout options that can be easily applied in many offices to improve work quality. Workplaces are in constant transformation and seek for a robust structure that meets workers and bosses needs. In this order, the theoretical base and the final outputs made by the team can assess companies on how to materialize high quality offices that, by understanding and managing the emotions through flexible workplaces, are capable of reaching a scheme where production and enjoyment can be simultaneous and harmonic.

Generating a solution

The final solution consists in a set of workspace layouts that can be easily applicable and adaptable according to specific activities and workers´ requirements regarding them. To accomplish this, one of the main goals was to reach flexible and customizable working spaces, through a design methodology that improves the office settings that make it adjustable to different requirements around a certain activity. This methodology allows to find out the way an office can also adapt to different variations along functions´ development by using its own components and amenities, and consists in classifying different activities and their required elements in a spreadsheet that describes every layout per raw. After a process of overlapping activities and emotions in this spreadsheet, the first ones were finally embedded in four main clusters (working, meeting, gathering, relaxing) according to the features and components shared by two or more activities, each one representing a physical layout. Inside these clusters a physical space can be easily transformed from one layout to another according to facts like the layout components, the number of people or gadgets required.

According to the requirements established on the spreadsheet, the layouts are created following mainly the type of activity and the number of people, integrating the furniture pieces and accessories taken into account before, in order to complement the functions that happen inside. Whlie for some clusters like working or relaxing the furniture sets are simpler, consisting in some sitting elements and tables or desks where to put the different devices, plus some space delimiting elements such as partitions or greenery,for others (meeting and gathering) some other accessories like wardrobes and technological appliances take more importance; partitions and greenery have also stronger characteristics.

Adaptability and interchangeability of the layouts is fundamental for a successful application of the Officemotion design concept to real offices. For this main reason came the choice to design a digital application intended to help the user (mainly boss and owners) arranging the open spaces and workplaces. Indeed these activities and layouts require spaces that could adapt to changing needs quickly. Through the OfficeMotion app the user can quickly and effectively manage the required changes of space, by the possibility of designing the starting layouts with the assessment of specialised designers of Herman Miller, buying the required furniture and appliances to execute what is designed, and rearranging those layouts when needed though the same app´s interface.

Figure 4: Layout designed for Eating.

Main bibliographic references

- V. Crisp, F. Duffy, A. Laing, The Responsible Workplace: the redesign of work and offices, Architectural Press, London, 1993.

- A. Marmot, J. Elety, Office Space Planning. Designing for Tomorrow's Workplace, McGraw-Hill, USA, 2000.

- CABE, The impact of office design on business performance, Commission for Architecture & the Built Environment and the British Council for Offices, May 2005.

- J. van Meel, Y. Martens, H. Jan van Ree, Planning office spaces: a practical guide for managers and designers, Laurence King Publishing, London, 2010.

- Human-Computer Interaction: Towards Mobile and Intelligent Interaction Environments, 14th International Conference, HCI International 2011, Orlando, USA, 2011.

- I. Forino, Uffici, interni arredi e oggetti, Giulio Einaudi editore, Torino, 2011.

- K. Zumstein, H.Parton, Total office design: 50 Contemporary Workplaces, Thames & Hudson Ltd, London, 2011.

- J. Myerson, I. Privett, Life of Work - What office design can learn from the world around us, Black Dog Publishing, London, 2014.

- D.Plunkett, O. Reid, Detail in Contemporary Office Design, Laurence King Publishing, London, 2014.

- Cardello A.V., and S.R. Jaeger. Measurement of consumer product emotions using questionnaires. Elsevier Ltd. (2016).

- Russell J.A., A. Weiss, and G.A. Mendelsohn. "Affect grid: a single-item scale of pleasure and arousal", Journal of personality and social psychology, vol. 57, n. 3 (1989).

- Boer A.G.E.M. de, J.J.B. van Lanschot, P.F.M. Stalmeier, J.W. van Sandick, J.B.F. Hulscher, J.C.J.M. de Haes, and M.A.G. Sprangers. Is a single-item visual analogue scale as valid, reliable and responsive as multi-item scales in measuring quality of life? Kluwer Academic Publishers (2004).

- Schifferstein, H. N. J., and Desmet, P. M. A. "Hedonic asymmetry in emotional response to consumer products". Food Quality and Preference, (2010).

- Schifferstein, H. N. J., Fenko, A., Desmet, P. M. A., Labbe, D., & Martin, N. "Influence of package design on the dynamics of multisensory and emotional food experience".

- Quality and Preference (2013), 27(1), 18–25.

- Frijda, N. H. (1986). The emotions. Cambridge, UK: Cambridge University Press.

- Izard, E. E. (1979). The maximally discriminative facial movement coding system. Newark, DE: Instructional Resourses Centre, University of Delaware.

- Ekman, P. (1999). Basic emotions. In T. Daigleish & M. Power (Eds.), Handbook of cognition and emotion. Chichester, UK: John Wiley & Sons, Ltd.

- LivingOffice, Herman Miller, 2014.

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[kitCHUN]

Executive summary

Dementia is considered to be the fastest-growing major disease in China. Currently, there are more than 9 million diagnosed cases. Forecasts show that, by 2050, this number is expected to surpass 40 million patients. Moreover, the increase in the life expectancy of the Chinese from 40.8 years in 1955 to 75 years in 2013 and its predicted amelioration in the near future has shed the light on this issue.

People with dementia (PwD) suffer from a decline in mental ability which can ultimately interfere with daily life. This will eventually result in the loss of autonomy in the person's life and the need for a caretaker or/and support system becomes inevitable. This also means extra costs and pressure on the families of PwD.

The kitchen, being one of the most dangerous places in the house, can be off-limits for PwD. The project [kitCHUN] deals with providing PwD and the elderly with smart kitchen products that can improve their autonomy, increase safety, and provide their families with assistance and peace-of-mind while taking into consideration the cultural aspect of the Chinese society.

The developed products are collectively part of the *Balanced Living Integrated System for Seniors,* or *Bliss* for short. The kit can be distinguished into the basic version and the Help upgrade. The basic kit includes: a transparent pot holder called Fire which prevents the person from being in direct contact with the flame; an easy storage system called Box which provides flexible and modular storage spaces; a device named Lotus, which is an air quality monitor that alerts the family in critical conditions; a DIY module that allows to control humidity called Drop. The Help upgrade consists of an anxiety detection camera, a set of LEDs that recreate a peaceful lighting and atmosphere (Drop+) and a system that implements Smell&Sound therapy (Lotus+).

Key Words

dementia, elderly, kitchen, China, Alzheimer's

[kitCHUN] Bliss system representation in a traditional Chinese kitchen

kit[chun]
bliss

FIRE 火

Safety device
Pyrex and heat resistant silicone
Transparent in order to see the fire

BOX 箱

Easy storage
Wheels and brake system
Configurate your own space
Bamboo

LOTUS 蓮花

Air quality sensor system
Aestetically coordinated
Connection to a caregiver
Bamboo

DROP 降

Humidity system
DIY zhezhi module to cover the kitchen walls
Customizable decoration
Bamboo or Tyvek 4

Project description written by the Principal Academic Tutor

In this project, the design of the new intelligent kitchen home for aging society will be carried out to adapt to the characteristics of the new type of home-care for the elderly people in China and in Italy. We will face the daily needs of using kitchen for those older people who live alone or with form of disease, even brain disease (as Alzheimer). The target product should be intelligent, remotely assisted and based on the Internet, with the effective improvement on the structure and man-machine operation experience.

The main contents include: intelligent cabinets, smart kitchen home products, smart aging product design. Working methods: Politecnico di Torino and Politecnico di Milano, ASP, together with Nanjing University of Science and Technology and Nanjing Forestry University, build a double project team for the main design. Relying on the production strength and market scale of Nanjing Wulian Sensing Technology Co. Ltd. and Nanjing Dongbang Taitai Furniture Co. Ltd., the design and development of smart kitchen home products will be carried out. Experts from these companies will assist in engineering design, and in designing of prototype, in production and in processing. The project includes: industrial design, electronic circuit design, mechanical structure design, information and interaction design and so on. During the project time, Chinese companies will be invited, as Huawei, Xiaomi, Alibaba, NetEase, Suning Appliance and other domestic companies to conduct joint workshop design, formulate workshop topics, and jointly plan the project with both Chinese and Italian professors and business experts. Both teams of graduate students conduct joint research, design and development. The completed prototype design can be completed in Nanjing and cooperated with Shenzhen HAX Innovation Accelerator for product incubation and internet crowdfunding and promotion.

Team description by skill

The ASP team for this project is composed of 4 members:

- Alessandra Angelucci, a Biomedical Engineering student at Politecnico di Milano

- Lucia Di Terlizzi, a Communication Design student at Politecnico di Milano

-Camilla Mascia, an Architecture Construction City student at Politecnico di Torino

- Nour Saeed, a Mechatronics Engineering student at Poltecnico di Torino

Alessandra Angelucci was assigned as the Team Controller of the team whereas Lucia Di Terlizzi was appointed Communication Coordinator.

Goal

With the aging of the Chinese community, the problem of dementia becomes more evident. The main goal of this project is, by the use of technology, to provide the elderly and people with dementia with new means of home-care.

The technology must also embrace the Chinese kitchen experience. The presence of wooden utensils and cutlery is very common in Chinese culture. Another important aspect in the Chinese cuisine is the visible flame. It should also be flexible and customizable. This is important as the system must be adjustable to the needs of each patient.

Understanding the problem

Grasping the issue requires understanding the problems and needs of the elderly and PwD in general, and those of China in particular. Visits to Borgo Sostenibile in Figino have provided useful insights: in fact Grace, an Italian NGO, hosts there elderly with dementia in a controlled environment where they can become more autonomous and self-sufficient.

Furthermore, a huge dissimilarity exists between European and East-Asian kitchens. This is an outcome of the differences in culture. In order to better understand the problem, one needs to be aware of the cultural aspects of the Chinese community. A visit to China during November 2018 allowed gaining insights on the Chinese culture.

One important concept is the visible flame in the kitchen. In Chinese cooking, fire is used in the most traditional recipes and the elderly are used to see it clearly. However, this adds a risk factor especially for those with dementia. In order to allow for maximal autonomy, safety must be assured.

Another important aspect is the size of the kitchen. In China, a small space is usually allocated to cooking and, unlike in western kitchens, there is no space for dining together, also because the kitchen space is made uncomfortable by the fire and smoke produced during the traditional cooking procedures. This leads to two main issues. The first one is the poor air quality due to the emissions that happen during the cooking process. The other is the lack of space in the kitchen. This can lead to mobility difficulties for the elderly. Thus, an air quality monitor is needed in order to keep track of internal air condition. Also, modular storage units and flexible workspaces must be included in the kitchens.

An essential factor to take into consideration is the psychological one. Agitation and anxiety are two of the most difficult symptoms of ageing and dementia. Agitation and anxiety are characterized by various activities, such as wandering, repetitive and purposeless behavior, social inappropriate activities and physically and verbally aggressive and non-aggressive behaviors. Agitated people with dementia can harm themselves, their caregivers or other patients in a care facility. Automatic detection of anxiety can alert caregivers so that appropriate interventions are performed.

Lunch time at Hefei housing for elders (China)

The team and the professors at Huawei (China)

Exploring the opportunities

Various ideas were generated during team meetings and a workshop in China. Smart refrigeration systems, collapsible preparation platforms, water filtration systems and air monitoring were some of these ideas.

The team went to Nanjing, China, to take part in a workshop at Nanjing University of Science and Technology in cooperation with Nanjing Forestry University and Southeast University. Visits to companies as Bigtime and BLUM helped to provide insights to kitchen design and ideas for several mechanisms. Other visits to Huawei and Wulian Sensors introduced the ICT world in China along with sensors technology available.

In the end, three main project concepts were evaluated. The first one is a modular kitchen that is also customizable. The second is the redesign of the

Chinese kitchen. This solution is rigid with different components hidden inside the kitchen. The last one was an upgradable toolkit that contain several components which serve a purpose.

Various criteria must be considered. Flexibility and customization are important as each patient is different from the other. Being traditional can help in the acceptance of the system. The system should also be simple to use and economically available to the end-user. In the end, the concept of developing a kit of tools was chosen because of its greater flexibility and affordability.

Generating a solution

In order to increase autonomy and safety for PwD, the toolkit approach has been employed. The overall system has been named Bliss, Balanced Living Integrated System for Seniors. People with early stages of dementia were considered as primary users for the system. However, patients of different stages can also benefit from the system.

Bliss provides a basic kit and an upgraded kit.

The basic kit contains four components: A transparent pot holder (Fire) provides safety while keeping the flame visible. A multifunctional easy storage system (Box) is also proposed as part of the basic kit. Extendable joints permit the change of the storage into a workbench and add ergonomics. The third component is an indoor air monitoring device which provides caregivers information on the internal air quality (Lotus). This devices has the shape of a lotus flower and is made of bamboo. A humidity control panel (Drop) is added to the kit. This panel also serves as a mental training exercise as this solution is a DYI solution.

The upgraded kit, which introduces the Help function, includes an anxiety detection camera. The level of anxiety can be measured based on body movements and certain behaviors. The usage of an RGB-D camera can help in getting more information from the user and can be used in the dark. The same camera can be also used for fall detection. This camera can alert the caregivers and eventually intervene by activating other components of the upgraded kit. This kit incorporates a smell and sound diffuser (Lotus+) which uses sound and smell therapy to relax anxious PwD. Drop+ is another element of the Help kit: it consists of an upgrade of Drop which includes LEDs in order to perform light therapy to reduce anxiousness in PwD.

Main bibliographic references

E.C. Brawley, *Design Innovations for Ageing and Alzheimer's: Creating caring environments*. John Wiley & Sons, NJ, 2006.

M. Cassinaro, A. Setti, *Complexity as Key to Designing Cognitive-Friendly Environments for Older People*. Frontiers in Psychology, vol 30(7), 2016, pp. 1329.

Dementia Services Development Center. 10 Helpful Hints for Dementia Design at Home: Practical design solutions for carers living at home with somone who has dementia,. University of Stirling, SCT, 2014.

L. Fuggle, M. Marshall, J. Christie, *Design and Dementia: When Less is More.* Journal of Dementia Care, 2017, vol. 25(6), pp. 14-15.

M. R.. Keogh-Brown, H.T. Jensen, H.M. Arrighi and R.D. Smith, *The Impact of Alzheimer's Disease on the Chinese Economy.* EBioMedicine, 2016, vol. 4, pp. 184-190.

J. Van Hoof, H.S.M. Kort, M.S.H. Duijnstee, P.G.S. Rutten & J.L.M. Hensen, *The Indoor Environment and the Integrated Design of Homes for Older People with Dementia.* Building and Environment, 2010, vol. 45(5), pp. 1244-1261.

SORT - E

SEI: Automation and Robotics

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Executive Summary

Waste management is a huge, capillary and established problem with which every inhabited cluster is concerned.
Recently, recycling of waste has proved to be a good solution to give value back to a potentially consistent portion of produced waste, however each material requires a different process to be restored for reuse, hence the need for the differentiation of produced waste.
However, the responsibility of differentiating waste is currently left to the person producing the waste, which is not always willing to make any differentiation or is not aware of the specific differentiation rules reflecting the technical needs of the recycling plants (e.g. a very common mistake in Italy is throwing non-packaging plastic like plastic toys in the plastic bins).
Later differentiation in waste collection plants is possible but extremely slow and inaccurate as a manual job, and extremely complex and expensive to be automated.

As a solution to this problem within waste management, we propose to provide relatively cheap waste bins which can autonomously identify and segregate different waste categories by leveraging on the most recent advances in computer image classification.
Such method would solve the current paradox of leaving the responsibility of correct differentiation of waste to waste producers who are only indirectly affected by the quality of their contribution, while collecting data about waste production at the same time.
Collected data can themselves be used not only for data analytics about geographical consumption and waste production, with applications like waste logistics optimization, but they can also be used to improve the classification algorithm within every bin.
Moreover, the hardware components required to build a bin with image based waste classification capabilities are extremely cheap (the core electronics on our prototype are worth 50€ and they could be made cheaper), thus allowing for a competitive price over standard bins.

Key Words

Waste Management | Computer Image Classification | Smart Bin

AR SEI Team at the Inaguration day of the Italian Tech Week, Turin, 28 June 2019.

Project description from the academic tutor.

The project was developed by the team within the SEI Pioneer program in partnership with ASP. The goal of designing, prototyping and testing an innovative robotic product was pursued exploiting the entrepreneurial formation program, offered by SEI. During the project development, technical matters were successfully dealt with, together with start-up issues, like problem vision and ideation, lean startup methodology, customer definition and market validation.

The result is the development of the prototype of an innovative robotic waste bin (Sort-E), which can autonomously identify and separate different waste categories. The main strong point of the project from the technical point of view is the adoption of recent approaches of computer image classification for the waste identification. From the entrepreneurial side, the team has developed a solid structure for the work organization, suitable for exploiting the heterogeneous competencies of the members, and excellent presentation skills.

Future improvements of the current prototype have been already envisaged to enhance its potentialities and the application domain.

Team description by skill

The team includes five master students from the Universities of Politecnico di Milano and Politecnico di Torino.
First there is **Elena Giaccone** who is an student of architecture. Her contribution was fundamental to team as she is an expert in utilizing various CAD and design softwares, that were essential in the prototype design and assembly and all the presetations.
She also has a strong passion for sustainability and green solutions that was a driving force for the team direction and vision.
Next we have **Tomas Monopoli**. He is an electrical engineer whose expertise were essential for the dimensioning of Bin-e's mechanical and electrical components. He also has a passion for the innovation market and the launching of sustainibility driven ventures. This made him extremely valuable in finding contacts and enriching connnections with other players in the field and the experts.
Next we have **Giulia Piccitto**. She is an Architect with a very strong character and a lot to prove to herself and others. She has a strong desire to be successfull and recognized as a strong leader in the world of start-ups.
Finally we have **Luca Cavalli**. He is an ITC engineering with a master in Machine Learning Techniques. Thanks to his efforts it was possible to create the core of our product, i.e. the image recognition software. Everything "smart" about the bin was written by him. His technical council was also crucial for the design of the prototype.
Last but not least, **Francesco Pignatone** is a Master Student of Electrical Engineering. He has a strong passion for sustainability and green ventures that was important for the team vision and morale. He has a natural curiosity that was essential in the conception of the prototypes mechanical functioning and mechanisms.

Understanding the problem

Nowadays only 31% of trash is differentiated worldwide. This is due to the fact that we are producing more and more waste, and we still don't have the correct infrastructure system nor we educate people about how to perform waste separation correctly.

In Italy we reach a 53% of trash differentiation rate, meaning that the rest of waste, which is 65K tons, is left in landfills or burnt in incinerators: this corresponds to 30K extra tonnes of CO_2 released in the atmosphere every year.
In 2017, the amount of municipal waste collected in Italy was almost 500 kilos per inhabitant. The largest quantities were collected in the Northeast (549 kg/inhabitant) and in the Centre (548 kg/inhabitant). Production was lower in the Northwest (482 kg/inhabitant), the Islands (460 kg/inhabitant) and the South (444 kg/inhabitant).
In the Northeast, the highest percentage of separate waste collection was also found (66.6%, since it meets the target of 65% set by the regulations). It is slightly lower in the Northwest (62.3%). The levels of separate collection in the Centre (48.6%), the South (43.3%) and the Islands (26%) are very distant, although Sardinia exceeds 60%.
In 2018, 85% of households declare to collect plastic and paper separately, 84% of glass and over 74% of aluminum.
However, not all of the differentiated waste can actually be recycled.

Thanks to household interest in the problem, the indoor differentiated waste collection contamination rate is generally under 30%, thus it produces good enough waste for recycling plants, however the contamination rate of trash collected in public spaces is often higher than 80%, which clearly makes the material unsuitable for actual recycling. The reason for this difference is mostly associated with user behaviour in public spaces, however sometimes the lack of proper infrastructures can play a significant role (like inconsistencies on the category colors and differences in recycling rules).

Circo Massimo, Rome - The day after the Rolling Stones concert (2014).

Exploring the opportunities

Recently the consolidated system has been improved with many gradual innovations to cut costs and improve efficiency.
One of the simplest tech innovations is having IoT connected bins with embedded level monitoring, that allows logistics to know the filling level of each bin to better optimize the routes over time while ensuring that bins are rarely full.
Although very simple, this simple additional monitoring information can save a significant portion of the costs of logistics. The same principle has been applied to more all-around bin monitoring systems including fire risk detection, vibrations, operators performances, and GPS location for movable bins and stealth detection.
Sometimes coupled with filling level monitoring, another common small innovation is adding compression to bins: incoming waste is compressed to reduce its volume and increase the storage capacity of bins, at the cost of more complex mechanics and higher energy consumption.
Compression, however, is limited to reducing air spaces without actually compressing the material itself, which would change its physical properties and make it unsuitable for recycling.

A further improvement to bins has been proposed more recently with the explosion of artificial intelligence applications: bins equipped with extra sensors that can have a clue about the material are able to recognize the material of incoming waste through machine learning applied to all its sensor readings.
The main advantage of these AI-based solutions is that the designer of the system does not need to explicitly model the sensor readings for different materials on incoming trash, which would be a very complex problem due to the unpredictable conditions of the trash thrown in, instead data-driven machine learning techniques can learn such statistical model directly from data. Therefore, these bins are able to additionally classify trash categories autonomously within some level of confidence and with some accuracy that can ensure an average quality standard of collected trash.
AI based solutions have been also developed in a centralized framework, innovating in the waste sorting post-processing conventionally based on human labour. In particular, recent research on robotic manipulation and object recognition allowed proposing to substitute human sorters with robotic arms equipped with sensors to detect, locate and recognize individual objects in a waste stream. Available robotic solutions can be trained to perform different sorting tasks, proving to be a very flexible solution to the problem, while being much faster than humans and suitable for demanding sorting processes with sustained load.

Centralized solutions, however, must cope with the problem of physical waste separation: impurities in waste streams can be entangled, and much more difficult to be actually recognized and segregated with respect to localized single wastes.
This entails an increased complexity, thus cost and time to market, for reduced performances compared to decentralized solutions like smart bins. On the other side, light smart bins embedded with sensors for logistics optimization and risk prevention are not directly facing the core problem of incorrect waste differentiation: they contribute to reduce waste management costs but they do not increase the rate of effectively recyclable waste. As the increase in hardware complexity is much lower than the increase in actual value, we finally aim at developing a smart bin with automatic differentiation capabilities.

Generating Solutions

The development of our smart bin has been carried out in cycles, following the lean methodology, thus integrating different prototyping phases with potential users feedback collected at showcase events, producing variations on our concept each time.
Every concept of ours has a common feature, which is our core value, the value proposition we wanted to deliver: the ability to automatically differentiate waste.

On the other hand, there are a lot of different possibilities concerning the hardware of our product and some potentially additional features. The main design variables that we considered around differentiation are bin mobility for autonomous waste logistics, which was discarded at this initial stage of development, trash buffering to reduce processing time between consecutive uses of the bin, which is important only when there can be high usage peaks, and separation mechanics, which entail many tradeoffs in volume, weight, reliability, energy efficiency and cost.

Following the lean methodology, we developed subsequently more advanced prototypes of our main concept based on feedbacks from the previous prototype at different events. In particular we developed:

1. Idea demonstrator: the first prototype, very small, cheap and simplified to show the idea at the first Demo Day (16th November 2018) to SEI tutors and possible investors of the sector.

2. Full sized demonstrator: an improved version of the first prototype, with more robust materials, improved look, faster processing of trash and realistic size. This was exposed at the Mini Maker Faire (4-5th May 2019) at Fablab Torino to have usability feedback and general suggestions from technology enthusiasts.

3. MVP for Universities: the first prototype meant to be actually viable for a specific customer, i.e. universities. It is the first linear design prototype, allowing for much bigger storage. This was presented at the Torino Tech Week opening ceremony (24th June 2019) to possible investors in the sector.

Moment of prototyping, FabLab Torino, May 2019.

Main bibliographic references

https://www.statista.com/statistics/866887/vending-machines-distribution-by-place-in-italy/

https://www.letsdoitworld.org/about/overview/trash-facts/

http://www.isprambiente.gov.it/en/archive/news-and-other-events/ispra-news/year-2018/may/green-book-urban-waste-management-data-in-italy

www.sei.it

http://www.conai.org/notizie/firma-accordo-con-comune-di-torino/

https://www.gruppohera.it/gruppo/attivita_servizi/business_ambiente/raccolta_differenziata/conai/

http://www.arpa.veneto.it/temi-ambientali/rifiuti/rifiuti-1/consorzi-di-filiera

file:///C:/Users/nenna/Downloads/Accordo_ANCI_CONAI_2014-2019_Allegato_Plastica.pdf

http://www.conai.org/enti-locali/accordo-quadro-anci-conai/allegato-plastica/

http://www.conai.org/enti-locali/accordo-quadro-anci-conai/

https://linchpinseo.com/the-agile-method/

https://www.businessmodelcanvas.it

https://www.businessmodelcanvas.it/business-model-canvas/

https://www.coleyconsulting.co.uk/require.htm

https://www.wastehero.io/en/products/sensor/?gclid=CjwKCAjw1rnqBRAAEiwAr29I-IxmdyyiT4SU6iPKyDHy-7uVa-Ah-6ittst4hQwWJomBoewbmOzNTpQxoCrOYQAvD_BwE

https://iot.farsite.com/iot-explained/netbin-fill-level-monitoring-for-a-smart-bin/?gclid=CjwKCAjw1rnqBRAAEiwAr29II6OdGpCphSu-QMgHIdg8aEKIp1JhMum0dglh3Nv-GESenqfOSgOSiDBoCLwcQAvD_BwE

http://bine.world/

https://www.smartbin.com/

https://zenrobotics.com/

https://www.researchgate.net/profile/Sathish_Gundupalli/publication/308387565_A_review_on_automated_sorting_of_source-separated_municipal_solid_waste_for_recycling/links/59c9d9790f7e9bbfdc32fecc/A-review-on-automated-sorting-of-source-separated-municipal-solid-waste-for-recycling.pdf)

Main bibliographic references

Gundupalli, Sathish Paulraj, Subrata Hait, and Atul Thakur. “A review on automated sorting of source-separated municipal solid waste for recycling.” Waste management 60 (2017): 56-74.

Ang, Fitzwatler, et al. “Automated waste sorter with mobile robot delivery waste sstem.” De La Salle University Research Congress. 2013.

https://cleanrobotics.com/

https://intuitiveai.ca/

https://www.tritech.it/en/progetto-ecologico-tritech/

https://github.com/garythung/trashnet

http://robocraft.ru/files/datasheet/28BYJ-48.pdf

https://datasheetspdf.com/pdf/1245697/OSM/17HS08-1004S/1

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Fly-By-Sensor system for Photovoltaic energy plant monitoring (FBS-PV)

Executive summary

Photovoltaic (PV) electricity generation represents one of very few renewable energy sources with the potential to grow to very large scale. In recent years, it has experienced a significant growth, becoming one of the most prominent clean sources in the energy challenge. In order to counteract the degradation the PV plants are prone to, an effective Operations and Maintenance (O&M) represent a key aspect. Although, over the past few years, physical inspection of the PV panels by human workforce has represented the state of the art, today inspections are carried out normally thanks to the use of UAV (Unmanned Aerial Vehicle). The increasing reliability in autopilots and the development of interfaces for mission planning have encouraged the spreading of automatic systems for the UAV flight. These systems can drastically reduce the workload for the human operator, which can concentrate on the quality of the images captured and the scheduling of maintenance operations. On the other hand, the meter-level uncertainty of the Global Navigation Satellite System (GNSS) used for navigation purposes, as well as possible imperfections in the map used to plan the flight, make automatic systems not reliable and robust enough for the high accuracy tracking of the PV lines.

The FBS-PV concept regards the inclusion of on-board additional sensors to improve the UAVs' flight accuracy in trajectory during PV O&M procedures without the need of external compensation from human operators. Accuracy is guaranteed by the perfect overflight of the rows of photovoltaic panels thanks to the use of image vision-based controllers.

Key Words

Photovoltaic, Drone, Vision Control, Autonomous Flight

FBS-PV team participation at Dronitaly with Bruno Bajeli.

Project description written by the Principal Academic Tutor

Nowadays, photovoltaic (PV) plant monitoring performed with unmanned aerial vehicle (UAV) technologies is growing in the operation and maintenance market for the capability to provide a low cost and effective tool in maintenance. In this context, innovative hybrid UAV platforms, especially in the light segment, can be used as an effective tool to perform accurate data acquisition in multidisciplinary application fields.
In this frame, being able to improve the flight control system by means of sensors data and, consequently, to improve the image acquisition process, can be an important added value in the market: in fact, it can impact on the time required and especially on the quality of the provided service.
The focus of the project is to develop an innovative fly-by-sensor system tailored for the PV monitoring application, receiving information about the flight from onboard sensors or by means of a wireless ground network or station. It is envisaged that control technologies beyond the state of the art in small-scale multirotor UAVs might be needed, specifically involving on-board planning/re-planning and optimization, possibly coupled with learning algorithms. The historical data can be profitably used as a first test set for the proposed system, while new data can be specifically acquired in new flights performed during the project period.

The project can be composed in different phases in which the students acquire the relevant know-how and then can develop and test their own system. In particular the foreseen project phases are:

- Analysis of the state of the art, both for what concerns the flight procedures and the fly-by-sensor technologies: in this phase the team can analyze how UAV flights are presently performed and can identify the current technical and commercial gaps. In parallel they can investigate the fly-by-sensors systems identifying what can be included in the system they will develop. Moreover, the different kind of existing sensors should be investigated in order to find the most appropriate for the specific UAV platform.
- Development of an innovative system tailored on the application of PV plant monitoring. The system can include onboard sensors and on ground wireless sensors network. In this phase, the students can exploit the knowledge obtained in the previous stage and the support of the tutors to develop their own system.
- Test of the proposed system, using simulation tools with the data available or using laboratory equipment. In this phase the students can further improve the developed system.
- Possible on field test, performed if the results of the previous testing phase are satisfactory.

Team description by skill

Bruno Bajeli, project manager. His contribution consisted in work planning, time scheduling, meetings organization and documentation management, graphic design of project logo and promotional video

Fausto Lizzio, worked on requirements and need analysis, stakeholders interview.

Andrea Maiani, worked on problem definition, ideas generation, design of the solution.

Antonio Marangi, worked on computer vision and graphics development, on field interviewer.

Ivana Mirchevska, worked on state of the art, aerial camera analysis of PVs, final presentation.

Giacomo Ornati, software developer. Worked on concept formulation, simulation setup, image processing and algorithm implementation.

Massimo Perini, worked on project requirements, state of the art analysis, evaluation of alternatives and website development.

Gabriele Roggi, software developer. His main activities regarded problem formulation and algorithm implementation with focus on the integration between vision and flight control laws.

Goal

This project aims to explore and study innovative “fly by sensor” systems for Unmanned Aerial Systems (UASs) applied to energy plant monitoring with reference to photovoltaic power plant.
The main objective of this project is to develop an innovative system capable of automatically create an optimized flight plan exploiting data coming from a proper set of sensors, placed on the aircraft or on a ground control station.
The specific objectives of the project are:

- Analyze the existing fly-by-sensors technologies identifying the specific advantages and the disadvantages;
- On the basis of the state of the art, propose a specific system for the PV monitoring application;
- Analyze the performance of the proposed system using historical data previously acquired or coming from new flights performed by the selected industrial partner with specific attention to the group needs;
- Potential laboratory or in field testing of the proposed solution.

Understanding the problem

At present, the maintenance of photovoltaic systems using UAVs can be divided into two categories:

Manual flight: a pilot flies the drone in manual mode following it along the entire length of the photovoltaic plant. The images obtained are of excellent quality, but the time required to complete the operation is very long, so the costs are high. In addition, there is little repeatability of the photos as they are taken in manual mode.

Automatic Flight: In this case the operator relies on the autopilot software for overflight. His task is simply to create a trajectory thanks to the software in the ground control computer. Compared to manual flight, the time required for flight operations, as well as costs, significantly decrease. However, the trajectory of the UAV is often incorrect or misaligned with respect to the PV line to track, leading to poor quality images. This is mainly due to three factors:

1. Error in the positioning of waypoints during the mission planning phase
2. Error due to incorrectly geotagged maps
3. GNSS error during flight

Our goal is therefore to try to obtain the quality of the images taken in manual mode but using automatic flights to limit the time and cost of maintenance operations.

Mission planning in a ground station for automatic flight

Exploring the opportunities

To solve the mentioned problems of automatic flight, three possible solutions have been analyzed:

1. **Usage of RTK**: Real-time kinematic (RTK) positioning is a satellite navigation technique used to enhance the precision of position data derived from satellite-based positioning systems. It relies on a reference station and is able to provide up to centimeter-level accuracy. Adopting this technology would only improve the accuracy of the GNSS feed but would not eliminate imperfections in the mapped positions of the panels and imprecision in the setup of waypoints.
2. **Image recognition with tag**: Optical tags can be cheap passive devices located on ground or on the PV panels. Under the assumption of knowing the exact georeferenced position of these tags, the drone can exploit this information to reconstruct its position with respect to the panels themselves. This will lead to the correction of both GNSS and geotag error. However, this solution is characterized by a high invasiveness with respect to the plant since, before the actual maintenance operation, the plant must be suitably prepared through the installation of multiple devices.
3. **Vision-based solution**: A subsystem in the companion computer of the drones analyzes the real time video stream looking for errors in the flight plan caused by the GNSS and map inaccuracies and/or bad operator orders. Using a fly-by-sensor approach with only on-board devices makes this solution far more interesting for potential customers: they don't have to place and remove multiple tags every time or buy expensive external devices. The drone should use the information provided by the camera to correct the operator input in order to follow precisely the PV panels rows. Clearly, as drawback, it is worth noting that the development of such an algorithm requires a high effort from the software and hardware architecture point of view. However, both GNSS accuracy and waypoints setup problems are solved using only technologies bundled with the drone, therefore leading to a more effective solution.

Gabriele Roggi looking at the control station equipment during operations on the Lodi photovoltaic plant.

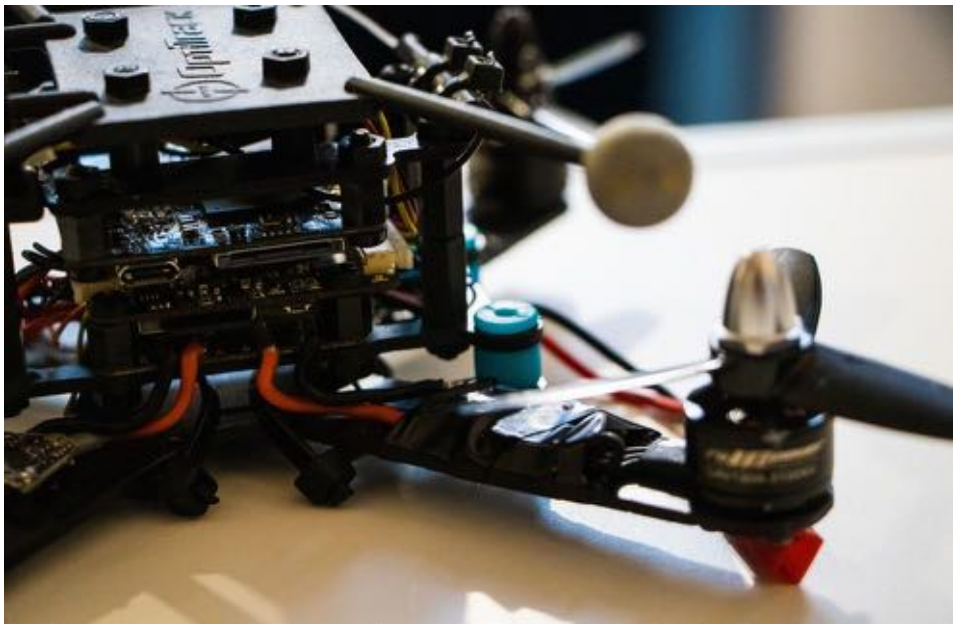
Generating a solution

The solution chosen is the third proposal. As previously mentioned, the development of an integrated algorithm on an UAV is a very delicate task. Bugs or wrong tuning of parameters can trigger hazardous behavior or induce crashes. To avoid such consequences, the software has been tested in a software-in-the-loop simulation environment for the open-source autopilot firmware PX4. It is

implemented using the Gazebo simulator and exploiting the Robotic Operating System (ROS) as an interface among the different architecture components. This simulator can replicate the entire UAV architecture, comprehensive of all the sensors, i.e., gyroscopes, accelerometers, range sensors, GNSS receivers and the camera the UAV is provided with. In this framework, the overall performance is appropriately quantified and compared with the state-of-the-art solution.

The FBS-PV concept regards the inclusion of on-board additional sensors' information to improve the UAVs' flight accuracy during PV O&M procedures without the need of external compensation from human operators. Among the sensors available, cameras have notably several advantages in terms of low weight, low power consumption and low price. Exploiting suitable techniques for image processing, these sensors can provide valuable information about the position and the attitude of the vehicle with respect to the target, in this case represented by the PV rows.

The results have highlighted excellent characteristics in terms of accuracy and robustness, and the software has shown itself as a valuable tool for improving the performance of PV O&M tasks. In particular, the computer vision techniques used can estimate the position of the UAV with respect to the PV panel with an error lower than 50 cm. At the same time, the correction inputs sent to the drone makes it align to the PV panels' rows with the same level of accuracy.



Details of FCU and Companion computer on a real drone at Dronitaly

Main bibliographic references

[1] F. Grimaccia, M. Aghaei, M. Mussetta, S. Leva, P. Bellezza Quater, (2015), Planning for PV plant performance monitoring by means of unmanned aerial systems (UAS), DOI 10.1007/s40095-014-0149-6, Springer.

[2] J. F. Canny, Finding edges and lines in images, Report AI-TR-720, MIT Artificial Intelligence Laboratory, Cambridge, MA, 1983.

[3] P. P. Acharjya, R. Das, D. Ghoshal, Study and Comparison of Different Edge Detectors for Image Segmentation, Global Journal of Computer Science and Technology Graphics & Vision, Volume 12, Issue 13, 2012.

[4] PX4, https://px4.io/.

[5] MAVROS, http://wiki.ros.org/mavros.

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Light&SENSEable city - triLIGHT

Executive summary
Our project investigates the **light** to help **cities** become **smarter** and more **sensible**. Our **multidisciplinary** team worked with Artemide S.p.A., a leader in light design, and with the consultancy of Deloitte.
We designed an **innovative**, **interactive urban system sustainable socially** (bringing closer the community promoting interactivity for the users' needs), **economically** (being feasible and implementable thanks to modularity), **environmentally** (reducing the energy footprint, generating healthy oasis inside polluted-busy cities). It valorizes the spaces trough **beautification** creating a **safer** and attractive atmosphere. It was developed a **modular flexible** structure for the valorization of urban spaces and of the daily people experience, a **system of devices**, whose configuration is **adaptable** to different scenarios. The module is a **triangular transparent unit** with a thin **opaque frame** with technological components. The triangle has been chosen to build any other shape for the specific site. Light is provided by the latest LED, increasing intensity according to natural conditions and the activity below, promoting its efficiency within the photovoltaic cells, while photocatalytic paint captures pollution. In a synergic union, the project is system of autonomous units, advantage for maintenance where even in complex structures, each problem can be located in a single unit.
Stazione Centrale (Mi) was chosen for contextualizing while always taking into account the objective of scalability. A multi-layered masterplan showed where to place the modules to maximize the benefits. Other scenarios and structures are conceivable using our modules just bringing minimal adjustments. Transparent base units may be assembled in dynamic facades of buildings or for pavilions. The takeaway is a marketable product, which opens a range of endless innovative solutions for cities. The objectives were achieved, while keeping it open to future implementation. The solution takes part in the transformation of critical urban areas into smart places: it could become part of a collective strategy towards new balances between society and urbanity.

Key Words
light | interaction | sensible device | urban environment | sustainability

3D representation during sunny days, cloudy ones, sunset and night


triLIGHT

Project description written by the Principal Academic Tutor

Light as smart energetic infrastructure

Tomorrow's city is a key topic for innovation research. It is a junction between many issues concerning people's lives: light, data transmission, mobility, safety and pollution, amongst others. Starting from an understanding of Light as a necessary infrastructure within the urban context, the course will aim to develop an innovative and sense-able network which, using energy in all its declinations, expands beyond the light field. As the human being is at the center of the SENSE-able city where different private and public actors share objectives and responsibilities. A cutting-edge design system that improves life quality for the city-ecosystem of the future, providing innovative services for urban spaces and their inhabitants.

The course had three main goals:

- **Creation of responsive and interactive spaces** in an urban context where the threshold between indoor and outdoor is increasingly blurred and where the interactions between different actors of the city are more and more dynamic.
- **Design of an open platform**, starting from light, where smart spaces are increasingly related thanks to the technological settings which enable the interaction amongst people.
- The emerged proposal is an applicable solution not only from a functional point of view, but also from an aesthetic, perceptive and social standpoint. It can be seen as a **lighting eco-system**, able to create a new generation of products in order to improve liveability in urban spaces, with a particular attention to crossroads of flows and people. **It starts from a clear context, as a site-specific project, but it becomes and Incremental infrastructure**, fluid, back compatible and upgradable in its performances.

Team description by skill

The group work has been structured according to the specific competences of each member and also respecting an internal distribution of roles and responsibilities. Interdisciplinarity allowed us to study the project from different points of view: from the most technological and detailed, to the impact it creates in the public space; from the aesthetic value, the beautification of the place, which is linked to the social value as characterizing the identity of a place, to its subsequent redevelopment; from environmental to economic sustainability. Individual and group work have both been of fundamental importance.

The team consists of the architects Riccardo Ronzani, team leader, Maria Stella Lux, responsible of technological details and prototyping and Aurora Maggio, finance and management responsible; a mechanical engineer, Satyesh Shanker Awasthi, that curated mostly the innovation and technologies part; a control engineer, Lorenzo Granata, the communication responsible; a biomedical engineer, Jacopo Paganelli, responsible of research and analysis phase;

A sensitive light for urban space was the theme of the project proposed by Artemide, an Italian company established in the field of lighting and design. In particular, we worked with Carlotta de Bevilacqua, Laura Pessoni and Fabio Zanola, respectively the CEO, designer and engineer of the Artemide group, for the first phase of theme analysis and concept design, and with professionals indicated by them for the development of the drawings, more technical systems and the prototype. The whole process was coordinated and followed by Professor Luisa Collina, dean of the design school of the Politecnico di Milano, with the support of Professor Venanzio Arquilla, Maurizio Vrenna, Ilaria Bollati, Research Fellow at Politecnico di Milano, and Professor Laura Daglio, for the technological-structural part.

Goal

Our project aims at investigating the potential of light and its use to develop a viable and feasible idea with light energy at its nucleus to help the cities become smarter and more sensible.

The project aims to design an innovative, interactive urban device that must respond to some fundamental requirements, that are:

- **Social Sustainability** The project has to bring the community and society closer, introducing inclusive interaction and promoting interactivity to cater to the needs of the users. Beautification and valorization of urban spaces should create a safer and more attractive environment.

- **Economic Sustainability** The project must be feasible and implementable immediately, while having a life-span able to accommodate possible future tweaks. In addition, modularity and scalability are essential objectives, in order to develop an adaptive universal solution.

- **Environmental Sustainability** The project should consciously work towards reducing the energy footprint and prevent degradation of the environment and its inhabitants; it should also generate a healthy oasis for the citizens inside polluted and busy urban environments.

Needs and requirements of the primary Actors and Stakeholders were mapped in order to enrich the list of objectives with more specific requirements. The innovative quotient of the project is bound to be high, with the goal of offering a system of feasible solutions to the complex and multilateral problems present today. Notwithstanding the fact that the project has its efficiency and effectiveness, it should be pleasing to the eye and enhance the aesthetic appeal of the locations where it is based, contributing to the creation of a valued and attractive city.

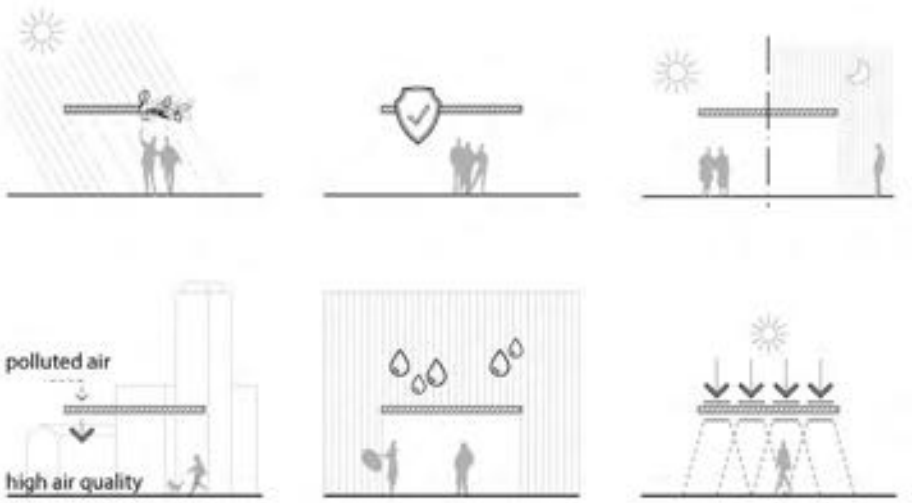
Understanding the problem

To achieve the objectives, a deep research of light in different contexts of science and engineering, society and culture, energy, environment and data transfer were performed at the beginning of the design process. The analysis phase proceeded in parallel with the identification of possible issues to be tackled specific to cities, as for example pollution, lack of safety, psychological impacts and loneliness, lack of inclusion, increasing population density and decreasing green coverage.

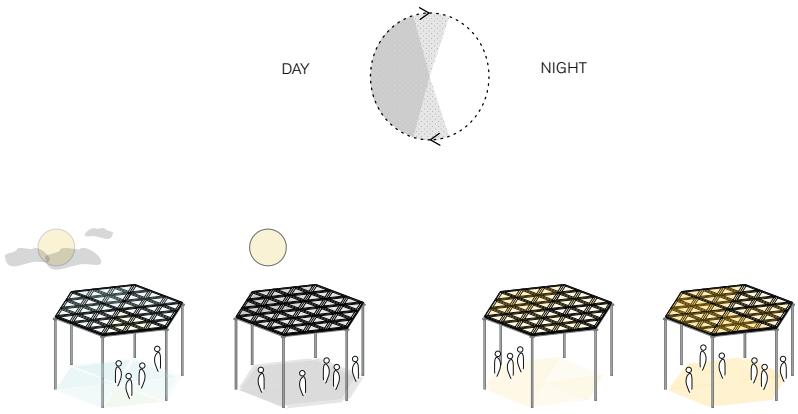
Cities of today are complex and problematic. Urban contexts are characterized by a casual overlapping of dynamics that often produce a chaotic perception in spaces, unable to respond to the real needs of citizens. Over the last decades, these issues have led to the conception of an innovative type of city: a city capable to be in touch with its inhabitants, producing positive synergic interactions. As a result of several academic studies and innovative urban experiences, the concept of smart city was born, and has ever since been growing in importance. For the purpose of a future smart city, a conscious and intelligent use of light plays a fundamental role. Along with responding to practical needs and that of safety, light can influence circadian rhythms of humans and plants, having an impact on the psychological well-being and the social behavior, and can play a key role in the maintenance of an ecosystem.

While dealing with a “light sense-able city”, the main stakeholders are Artemide and the municipality of Milano, so public utility and social value are required as final outcome while the company’s needs a luminous object that responds to its identity: the aesthetic quality, materials and classic line that have always characterized them, and the technological innovation towards which they aim. At the same time, economic feasibility must be taken into consideration, drawing up a plan that leads to a standardized, modular and scalable production.

The method of generating the design concept describes how the needs of the stakeholders were translated into project requirements. A precise definition of the problem was necessary both for the concept generation and for the definition of the product in detail: we followed a structured analysis, research, identification of problems and solutions, and definition of the final choice.



Concept schemes of the shelter functions



Sensibility and interactivity of the horizontal layer

Exploring the opportunities

Having a strong belief that interdisciplinarity could benefit the project, inspirations and references were sought in the world of nature and art. Sensible light and human centered design hypothesis developed, using in different ways light or technologies, were compared highlighting their potentials and weaknesses according the fundamental objectives or the problems to solve, the stakeholders involved, the specificity and scalability of the project. We wrote a manifesto containing the guidelines and the main objectives: L.I.G.H.T. (Light Interaction for Growing Human and Towns). Milan Stazione Centrale, at first, contextualized it in a frame of actual problems and users, while always taking into account the objective of a scalable project: a practical example of how to use the proposal in different scenario analyzing the location and its dynamics. A smart system for beautification and valorization of the environment through an adaptive modular structure.

Generating a solution

During the process we developed the idea of a modular adaptive structure for the valorization of urban spaces and the enrichment of the daily experiences of people. The idea was conceived as a modular system of devices, whose configuration can be developed and adapted in different scenarios. The module, the basic unit of a smart structure, is thus a tool to generate a series of possible urban outcomes.

The basic unit is a transparent triangle with a thin opaque frame that contains all technological and electrical components. The triangular shape has been chosen since it can be used to build any other shape, according to the specific project site. The key point of the idea is to instill dynamism in the module behaviour with respect to the natural light conditions and the presence of people. To accommodate for the variety of different seasons, the difference between usage during the day and night and the different end users, we provided a set of technologies to our structure.

Environmental sustainability is provided by photovoltaic cells and specific strategies for guaranteeing a good air quality, as for example photocatalytic paint, to capture pollution from the air. It gives color to the whole playground, an healthy oasis where everyone can live a personal experience of the urban space.

All the project choices are coherent with the principle of modularity and, according to the objective of economic sustainability, they ensure the possibility of standardized industrial production and advantages for maintenance issues where even in complex structures, each problem or malfunction can be located in a single unit.

The takeaway of our design experience is a feasible and marketable product, which opens up a range of potentially endless innovative solutions for cities. Thus, using light as a pivotal element in the project, the intended objectives were achieved, while keeping it open to future solutions and implementation. The solution presented, actively and innovatively takes part in the transformation of critical urban areas into smart places: it has the potential to become part of a collective strategy aimed at establishing new balances between society and urban spaces.

Main bibliographic references

Rossi Maurizio , *Design della luce*, Maggioli Editore, 2008.

Frova Maurizio*, Luce, colore, visione: perché si vede ciò che si vede*, Rizzoli, Milano, 2000

Basiago A.D., *Economic, social, and environmental sustainability in development theory and urban planning practice*, The Environmentalist 19, pages 145-161, 1999

Sloane Mona, Slater Don, Entwistle Joanne, *Tackling social inequalities in public lighting*, May 2016

European Commission, Directorate General for Regional Policy, *Cities of Tomorrow: Challenges, visions, ways forward*, Unit C.2 - Urban Development, Territorial Cohesion, October 2011

Stolterman Erik, Janlert Lars-Erik , *Things that keep us busy: the elements of interaction*, Mit Pr, 2017

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BE SEI | Wiseair

Executive summary

The SEI Bioengineering project was born from a clear challenge: to find an application on the market of an innovative technology studied within the IIT, the microbial fuel cell (MFC). Microbial Fuel Cell is an electrochemical system able to generate electricity from the oxidation of organic matter present into natural environments, such as in particular plants' soil. Despite its innovation potential, the technical limitations of such technology (above all the extremely low achievable power rate) still obstruct attempts to get it out of research centres and universities.

After a long phase of research and ideation, we decided to overcome the limits by leveraging the strengths of technology: (i) the ability to produce energy (albeit little) in a natural and continuous way (ii) the possibility to integrate technology into a familiar and design object like a balcony plant pot. This is how Arianna is born. Arianna is an IoT balcony pot, that exploits the energy produced by an integrated MFC to power an air quality sensor hidden inside.

Arianna was our way of applying MFCs to one of the biggest problems facing cities today: urban air pollution. Taking advantage of the technology, we invented a stand-alone sensor, which requires no network connections or batteries, and is presented as an object close to the end user.

From this idea was born a first prototype and then a real company called Wiseair. Today, Wiseair's mission is to create hyperlocal maps of air quality, giving urban communities of problem-sensitive citizens the opportunity to participate in the construction of capillary monitoring infrastructures by simply placing a vase on their balcony. The data collected by hundreds of Ariannas distributed in our cities will be the starting point to find the most effective solutions in the fight against pollution, promote them and certify their impact.

Key Words

Microbial Fuel Cells, Air Quality, Wireless Sensor Network, IoT, Smart Cities


UR
MISSION
Create real time detailed maps of urban air quality in polluted cities
HOW
Sunlight is naturally converted into chemical energy 1
The biochemical integrated system turns excess chemical energy into electricity 2
The electrical current produced by the system is used to power an AQ sensor 3
The measured data are wirelessly sent to an user device 4
The data from all the users are gathered in a dense urban data network 5
This network allows to always have a detailed urban air quality map in your pocket! 6

Project description written by the Principal Academic Tutor

The project involves the development of the application of Microbial Fuel Cells (MFC) for the power supply of sensors with application in the field of air monitoring. Microbial Fuel Cells are a technology designed to allow the exploitation of the exoelectronic activity of bacteria for power and energy production. Energy production takes place directly using fuels which are naturally present in the soil and related with the plant metabolism: these systems are therefore able to produce energy by working in direct contact with the roots of the plants. The idea of the team is to exploit this energy produced for the supply, operation and data transmission of a sensor system for monitoring air quality (in particular, particulate matter). The main focus of the project is product development, with a view to evolving the MFC system towards a real application able to penetrate the market and create value.

Team description by skill

The project team is composed of six engineering students with highly heterogeneous skills, both in the IT and in the industrial domain:

Fulvio Bambusi is a Computer Engineering student at Politecnico di Milano specialised in Big Data and software development.

Paolo Barbato is an Energy Engineering student at Politecnico di Milano specialised in renewable energy and system modelling.

Mateus dos Reis Barone is a Management Engineering student at Politecnico di Torino specialised in supply chain management and project management.

Carlo Alberto Gaetaniello is an Energy Engineering student at Politecnico di Milano specialised in energy management and efficiency.

Giulio Matarazzo is a Chemical Engineering student at Politecnico di Torino specialised in innovation processes design and oil & gas plant design.

Bernardita Stitic is a Electronic Engineering student at Politecnico di Torino specialised in microcontrollers and circuit design.

The whole team is characterised by a strong attitude towards entrepreneurship and innovation combined with solid scientific and technical skills.

Goal

Microbial Fuells Cells, with a TRL between 3 and 4 (Moro, et al., 2017), is still an immature technology for which further applied research must be carried out to overcome many technical limitations. Nevertheless, in such an early stage of development, a recognized and specific need is required capable of fostering its diffusion and industrial development and of attracting public and private stakeholders and investors.

In such a context, the project focuses on the following two main objectives:

- **Demonstrate the feasibility** of electricity generation from plants with MFC technology by developing a small-scale working prototype;

- **Find and innovative and market-ready business idea** leveraging on the potentialities of MFCs to push the technology out of the labs while solving an actual problem.

Understanding the problem

There are several technical limitations that make MFCs not competitive with other incumbent technologies. The first one is represented by the **low conversion yield** of the organic matter, which typically lies between 1% and 3%. In addition to that, the lack of any relevant real-world use case has significantly hindered the industrial development of the technology, which now is only studied and tested in lab-scale systems built for purely academic purposes. The low **reliability** and **stability** of these systems and their **high cost** are the main obstacles that, combined with the low energy output, challenged the team throughout the entire search for a viable solution.

Setup and Testing of the bio-electrochemical system at the ChiLab (research centre of the IIT)

Presentation of the project at the Party for Planet event in Milan

Exploring the opportunities

In the initial phases of the project we focused on a long research and classification work to understand what were the main applications currently feasible for Microbial Fuel Cell. The main ones we found were:

Access to electricity in remote areas. Thanks to MFC technology used as an energy harvesting technique, we are able to produce electric energy from many renewable and largely available sources of organic matters like human and animals' wastes, soil, water etc. .

Autonomous sensors. It is forecasted that autonomous sensors will replace battery-powered sensors in the next few years. In this context, due to their capability of continuously generating electric energy on-site, MFCs are a good potential candidate to overcome the old battery-centred paradigm and move towards the new concept of self-powered sensor.

The design phase was conducted with the idea of finding an application that could overcome the limits of the Microbial Fuel Call, leveraging instead the strengths. For years, attempts were made to find industrial applications for MFCs, such as energy production, but with poor results because the technology is still too immature and offers poor performance. We have therefore decided to focus instead on the energy harvesting sector and on the possibility of using the energy produced by the MFC to power autonomous sensors that require low consumption. We have produced more than 60 ideas, classifying them based on two main parameters: **value to the customer** and **effort**. Thanks to this analysis, we find a great potential in applying MFC in the field of air pollution monitoring

Generating a solution

In order to drive the design of our product we investigated the features that customers appreciate and evaluate the most.

We identified three main properties: **low maintenance**, **data intensity** and **aesthetic value**. Via the case study of smart citizens, we discovered that users perceive the maintenance of sensors as a low value-added activity, hence are not eager to perform it. On the other hand, the market of air quality data is expanding, and so it is vital that the the product produces a reliable stream of information.

Finally, in order to easily penetrate the market and spread in our cities, the pot must be extremely appealing to the consumers. We decided to enforce this property by leveraging two different strategies. First, we gave our sensor a familiar and friendly appearance. Moreover, we created a community to motivate and encourage our customers and to promote debate on the theme of air quality.

As far as the low maintenance is concerned, we designed the circuit to be autonomous from the energy point of view, and we enabled wireless transmission of data so as minimize the need of user intervention. Wireless, real time transmission of data does also address the requirement of high data intensity.

Main bibliographic references

A. Moro, F. J. Aycart Lazo, G. Bardizza, M. Bielewski, J. Lopez Garcia and N. Taylor, "Workshop on: Identification of Future Emerging Technologies for Low Carbon Energy Supply*" Publications Office of the European Union*, 2017.

S. Venkata, G. Velvizhi, J. Annie Modestra and S. Srikanth, "Microbial fuel cell: Critical factors regulating bio-catalyzed electrochemical process and recent advancements.," *Renewable and Sustainable Energy Reviews,* vol. 40, no. Dec 2014, pp. 779-797, 2014.

N. A. Bhatti, M. H. Alizai, A. A. Syed and L. Mottola, "Energy Harvesting and Wireless Transfer in Sensor Network Applications: Concepts and Experiences," *ACM Transactions in Embedded Computing Systems,* vol. 12, no. 3, p. 24, 2016.

C. Lightowlers, T. Nelson, E. Setton and P. C. Keller, "Determining the spatial scale for analysing mobile measurements of air pollution," *Atmospheric Environment,* vol. 42, no. 23, pp. 5933-5937, 2008.

R. Roy and N. Braathen, "The rising cost of ambient air pollution thus far in the 21th century: results from the BRIICS and the OECD Counties," *OECD Environment Working Papers,,* vol. 124, 2017.