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Procedia Manufacturing 21 (2018) 18–25

Procedia MANUFACTURING

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15th Global Conference on Sustainable Manufacturing

Sustainable Innovation in a Multi-University Master Course

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Abstract

Mobility, multi-locality, and transnational migration are current social developments among the population of the European Union. These social developments in society and companies, linked to the challenges of sustainability, lead to new requirements for working in the European Union. Teaching and learning in higher education needs to adapt to these requirements. As a result, new and innovative teaching and learning practices in higher education should provide competencies for transnational teamwork in the curriculum of tomorrow's engineers in order to ensure their competitiveness in the job market and advantage in their future careers. Thirteen European students from four countries participated in a new project-based course, called the "European Engineering Team". Students focused on the development of two innovative and sustainable products. The goal of this paper is to present the thermal pallet cover, which is the result of the first one-year transnational and sustainability-oriented project. This paper also aims to present the process of performing the project. It provides the overview and discussion of engineering and management tasks that students completed in the transnational environment, working remotely at their own campuses between scheduled transnational meetings. The work contributes to project-oriented learning that may constitute a basis for teaching holistic engineering courses at mechanical and industrial engineering departments.

Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).

Keywords: sustainable innovation; sustainable development; engineering education;

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2351-9789
Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).
10.1016/j.promfg.2018.02.090

1. Introduction

Conventional classroom teaching methods are sometimes considered inadequate for preparing graduates for facing problems that require their knowledge application to new domains [1]. Graduates should be prepared to perform in a turbulent, European- and world-wide, transnational and multicultural environment, which is coined continuously by new social, economic, and environmental trends promoted by globalization. This dynamism is reflected in the EU's strategy EUROPE 2020 [2] with its focus on the importance of economic growth and creating new jobs, energy and climate change, welfare and social security. Vernon [3] concludes that an effective learning program in engineering education should (i) be student-centered; (ii) be project-oriented, and (iii) include some elements of economy and management. There are a number of initiatives related to new forms of collaboration with industry [4], including education of future engineers. Ziemian and Sharma [5] address possibilities of utilization of so-called Learning Factories to develop the competencies of engineers in Europe and give the necessary priority to the transfer of technology from science to production, but they do not address the initial phases of inventing innovations. Another approach is called Experiential Learning resulting from works of John Dewey [6], Kurt Lewin [7], Jean Piaget [8], David Kolb [9,10] and others. However, there are not so many multi-university and education-oriented initiatives.

With the intention of filling this gap, a new multi-university master course focused on action-based as well as on blended teaching and learning in transnational and interdisciplinary project teams has been developed and implemented at the university master's level. The European Engineering Team (EET) is a unique transnational course based on experimental learning and teaching in Europe, which expands sustainable engineering to competitive technological innovations for empowering a global sustainable development. The uniqueness of the EET course relies upon its holistic approach incorporating areas of management, mechanical and industrial engineering, and oriented toward sustainability challenges.

Examples of similar multi-university and education-oriented initiatives in the scope of the European Engineering Team are e.g.:

- "POLE – ON track" [11] from FH Nordwestschweiz is an international and interdisciplinary project-oriented study platform that permits the development of projects in cooperation with industry partners.
- "Global Engineering Teams" [12] managed by Global Education Team UG is an international and interdisciplinary project-oriented study course specifically for engineers. Students from universities in different countries such as the USA, South Africa, and Brazil form one Global Engineering Team. The international and interdisciplinary group of students works throughout the course on a project provided by an industrial partner.

2. Concept of the master course

Each university brings in three to four master students, one professor as a supervisor, and one PhD, PostDoc, or assistant professor as an assistant supervisor to the course. The students of this European Engineering Team jointly work on a sustainable, technology-based innovation. The applied approach to this first cohort could be referred to as a seemingly random walk. The idea behind it was to see how the students following a regular university education path could organize and establish a structured team. The unguided team building phase resulted in freedom in the following activities:

- Free to organize work, groups for tackling the sub-problems, restructuration of the groups for better self-empowerment and management,
- Free to make wrong decisions,
- Free to select their own topic within sustainability.

The freedom enabled the students to feel much more the authors of the engineering topic, be the authors of the scope of work and responsible for wrong or missing project assumptions. From the supervisor's side, the students' preparatory activities gave an insight into a process of organization of a team of people who meet for the first time and have to start collaborating. The supervisors are university teachers and these observations are useful for organizing project-oriented learning in the future. The price for this freedom is a longer process for setting project objectives and specifying requirements for a product.

Four transnational project meetings took place at each partner university. Between meetings, students worked at their own campuses, cooperating virtually with other students and supervisors. Students were grouped in smaller topic-or subject-oriented teams guided by one or two supervisors depending on the scope and merits of the planned work. More details on the EET concept are available in [13] and the systems engineering / systems thinking perspective can be found in [14].The EET project has been embedded into each student curriculum and prepared as a separate curriculum master program unit at each university and faculty. The project supervisors are responsible for this. This means that each student participating in the project continues his education, follows his field of specialization and supplements it with the project oriented learning unit. The number of ECTS a student is credited depends upon his faculty authorities and the individual base master course structure.

3. Results

The first team of 13 students decided to focus on waste prevention in the logistics supply chain and devised concepts for two complementary sustainable innovations; a quarter-pallet and the thermal cover, discussed here. The development of the innovation follows the framework present in [15]. This framework provided a structure for the students for developing the business model as well as the related product with its mechanical and ICT components. Students defined problem domain, designed business model and a prototype of the thermal cover. They were also taught how to cooperate virtually and physically in a transnational environment requiring short period and frequent mobility.

3.1. Domain background

The mandate of the Food and Agriculture Organization of the United Nations since 1945 has been to reduce food losses. Nonetheless, it is estimated that still half of the food grown is lost or wasted before and after it reaches the consumer [16]. Only 10% of worldwide perishable foods are refrigerated, yet refrigeration is the best technology, with no associated risks, to prolong the shelf life of perishable food [17]. Consequently, research efforts address different aspects of food loss prevention in the cold supply chain. The role of food packaging in the supply chain has been explored [18] and new solutions for traceability have been developed [19]. At the same time, some innovations go towards an integrated solution that aims at finding the best trade-off between food quality, energy use and global warming impact in cold chains [20]. The need for action in this field comes also from the expected compound annual growth rate of the refrigerated transports for perishables, which is assessed around 2.53% by 2020 against a volume of 3,010 mln tons [21]. Aligned with this growth, also the respective fuel consumption is significant. Today, a refrigerating unit of a 13.4 m semi-trailer consumes ca. 3-4 dm^3/h of fuel [22].

The students' selection of the project for their EET coincides with the food lost prevention. The product they decided to research and develop is an integrated product that tackles both problems of food loss: prevention and energy consumption. The product consists of a modular insulation cover for a pallet that aims reducing the thermal exchange between the external environment and goods on the pallet itself. The application of the pallet and the cover is for transportation of goods that require their temperature to be controlled during the transport, e.g., food or specific medication. Due to the insulation, the temperature of the transported products will increase more slowly, thus reducing the need for using refrigerated vans for short distance transport, and avoiding the effort to keep the goods in refrigerated logistic bays when loading and unloading on different transportation vehicles. In addition, the insulation reduces the energy needed by refrigerated vehicles to guarantee that the temperature does not increase above a given threshold.

The proposed design is made up of an insulated cover, with a metal structure to increase its rigidity and one or more embedded temperature sensors. The metal structure aims at protecting the goods from damages, while the sensors aim at exchanging information on the temperature with external controlling devices to provide monitoring and support advanced management of a truck refrigeration system.

3.2. Thermal pallet cover as a sustainable innovation

The thermal pallet cover contribution to innovation with respect to current practices in the logistics of goods is two folded. The first one is the structure of the cover, which is designed to be used together with the standard euro pallet, covering the goods and, thanks to the structural reinforcements, allowing them to be stacked. The second one relies on the use of embedded sensors enabling monitoring the temperature of the goods, and interact with the external environment to support advanced management policies of refrigeration systems to reduce the energy consumption and, consequently, the associated cost of transportation.

3.2.1. Business model

To support the feasibility of the idea of the thermal pallet cover from a business point of view, the students participating in the project carried out an analysis of the market to identify business niches where the thermal cover could be attractive for the customers. The main benefits of application of the thermal cover are:

- Reduction of the energy consumed in refrigerated transportation;
- Capability of guaranteeing a customer thermal controlled transportation thanks to the monitoring system;
- Mitigation of the risk of product damages.

In addition, a three-step analysis has been done to identify business opportunities. The first step concerns an identification of potential competitors. This analysis shows that the available commercial solutions can only partially cover the above-mentioned benefits. Existing products or solutions provide insulation or sensors to be placed in the truck for temperature monitoring. No solution exists which would provide the two features in an integrated solution and whose degree of protection would be comparable to the proposed one. The second step draws attention to potential customers, basically all the participants of "cold chain" logistics, transporting frozen or cold goods, e.g. supermarkets, distribution centers, transportation companies, etc. The last step addresses the identification of potential use cases, which could be derived and provided to a business sector where a pilot case could be implemented and tested also at the operational level.

This process has been supported through a structured canvas representation of the business model, developed during the meeting in Berlin, with the support of the Centre for Entrepreneurship from the TU Berlin [23]. Hence, the business idea focused on having logistic providers as the main customers, with the objective of regulating the refrigeration devices and respecting the temperature constraints, while protecting the load from damages.

Under these hypotheses, some drawbacks and critical points were identified initially, particularly at the operational level, due to the trade-off between the increasing complexity of the logistic operations (e.g., toggling the cover multiple times) and the benefits obtained. Further business analysis suggested the solution of using the thermal cover for the last mile delivery only, with the aim of avoiding the usage of refrigerated trucks at all. This hypothesis was also supported by testing using a prototype and simulating its usage in realistic applications, showing that the cover is likely to guarantee a proper temperature during the whole transportation. In addition to the changes at the business model level, the product design was incrementally improved to reduce the cost of the product and simplify its utilization in a real environment.

3.2.2. Mechanical components

The design of the thermal cover is organized such that it possesses a modular structure. The assembling of the different module in the thermal cover is shown in Fig. 1a. The following main functional modules were identified and designed:

- *Floor*. Allowing the handling using a forklift;
- *Walls*. Enveloping and protecting the transported goods;
- *Connection band*. Used to adjust the height of the cover in relation to the transported goods;
- *Roof*. Supporting the stacking of multiple pallets;
- *Tech*. Embedding the sensors for the monitoring and recording of temperature.

Based on the modules described above, different configurations have been analyzed to provide the customer with the flexibility of choosing one with the best fit for their operational and market needs. To enable the modules to be combined, proper interfaces have been also designed. Three main requirements have been taken into consideration. The first is avoiding coat processing, leading to an irreversible joint. Second, fasteners have to be quickly applicable and robust, considering the typical application environment. The selected fasteners were *Velcro Hook & Loop* [24] for connecting the *Floo*r with the *Connection band* and both this last and the *Tech* with the *Walls*. A zipper was employed to connect the *Roof* and the *Walls*, while a magnet band was used to pin the *Walls* on themselves.

Finally, the problem of material selection was divided into three sub-problems: the metallic structure, the insulating material and the textile covering. For the first two, aluminum and glass wool have been selected, satisfying the trade-off between sustainability, capability and price. For the textile covering, the *Roof* together with the *Floor* (Group 1) and *Walls*, *Tech* and *Connection band* (Group 2) together were associated to different materials:

- Group 1 (Interior + Exterior) – PVC Heavy protecting layer (560 g/m^2), to face exposure to mechanical damages and thermal exchanges.
- Group 2 (Interior) – PVC Light protecting layer (100 g/m^2) aiming at granting foldability and lightness.
- Group 2 (Exterior) – PVC Mid-density protecting layer (300 g/m^2), combining foldability and exposure to mechanical stresses.

3.2.3. ICT component

For the design and development of the ICT component of the thermal cover, a theoretical framework and a decision-making tool were adopted. Firstly, system design analysis [25] was applied for the simplification of the solution and its decomposition into relevant sub-components and sub-functional elements. Secondly, a morphology table [26] was used to list and compare all alternative options.

The main function of the ICT design was to carry information on the cargo's temperature to either an automatic or a human decision maker, to act as a temperature regulator. The cargo could be any product that needs thermal protection during transportation. The black box with the cargo temperature as an input and refrigerator regulation as an output was divided into sub-functions, each corresponding to a hardware or software component. These sub-functions are as follows: sensors, gateway, database and server, product information carrier and control algorithm. Finally, for each of the sub-systems, requirements in terms of input, process and output were made explicit. General architecture of an ICT component is shown on Fig. 1b.

Once all the sub-functions of the system had been clearly defined, a list of alternative options was made in the form of a morphology table. Both physical and software components were considered and a number of combinations were identified. Each time, communication issues were considered. For this reason, an additional area of interest was added, regarding the communication protocol among the system components. The combinations of components identified through the morphology table were compared based on their performance as well as their influence on the development of the solution. The business perspective motivated estimating the economic aspects of buying and using the various combinations.

The description of the chosen components follows the logical data flow of the final design. First, the Texas Instruments CC2650 SensorTag [27] was selected for its ability to read not only temperature, but also pressure, humidity and other parameters. Product data could be saved in an NFC tag. Both these pieces of information would be conveyed to the gateway, which was chosen to be an Android smartphone. Its ability to use a wide range of communication protocols was a decisive characteristic which drove the choice: Bluetooth Low Energy (BLE) could be used with the sensor, NFC with the information tag, internet protocols (like http) with the server infrastructure.

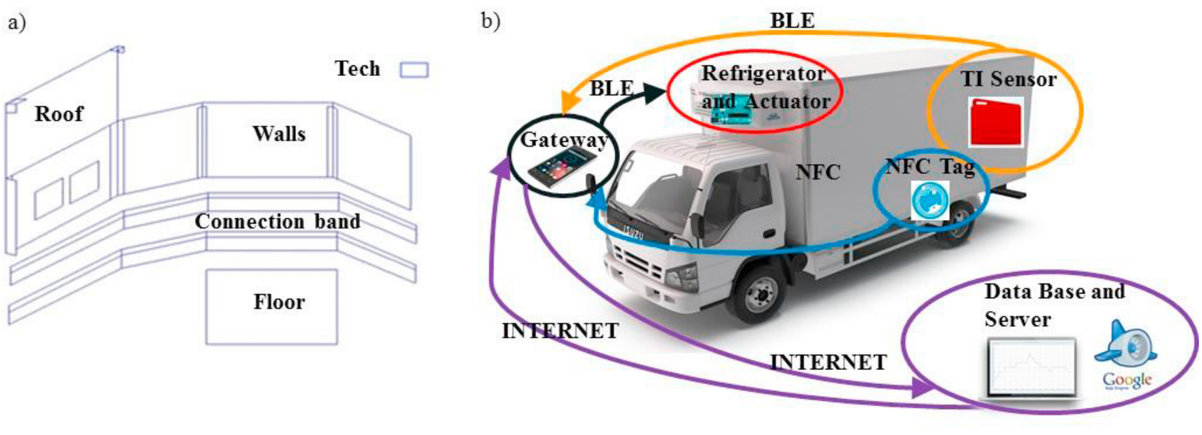

Fig. 1. a) Thermal cover – assembly ; b) ICT component – general architecture.

Google App Engine [28] was adopted as a platform to regulate any type of data flow coming from the gateway: from user information, to temperature readings, product data, journey information. On the other side, an Android application served as a data collector and distributor, as brain for the temperature control and as main user interface for the truck driver. The smartphone itself, with the EET application, was able to receive the temperature data and give alerts or specific signals whenever the temperature was out of range. Finally, an Arduino [29] board was used as an actuator, receiving information from the smartphone via BLE on the decision to switch the refrigerator on or off.

The resulting system is fully automated, it enables making decisions on temperature regulation, collecting and saving a great amount of data during the truck journey and providing the proof of a product safety through continuous monitoring. In case of component failure, an alarm notifies both the driver and the human operator.

3.2.4. Prototyping and experimenting

A final prototype of the Winter Cover was completed and tested at TU Berlin during a project meeting (Fig. 2a). The prototype was designed to fit a quarter pallet with a base of 60 x 40 cm, and a height of 75 cm. The complete prototype (with both hardware and software components) was tested while carrying water bottles. The experiments mainly aimed at analysing two aspects. Firstly, the thermal behaviour of the pallet load inside the cover, secondly the way the sensor can measure the temperature. In order to accomplish the first goal, some bottles were left outside, to represent a transportation without the cover. Concerning the second goal, the same experiment was replicated twice, varying the external temperature. The temperature of the bottles outside and inside the cover were recorded every 10 minutes during a 150 min. period. Table 1 presents the results of the preliminary experiments for the water temperature, showing that the temperature of the water inside the cover increased ca. 40% slower than the water left outside while Fig. 2b reports the graph of the temperature inside the cover.

A model of the heat transfer was developed in ANSYS Fluent to evaluate the behaviour of the thermal coat in different conditions, summarized in Table 2. The model consisted of a water box, with the thermal coat on the external surface. Both 2D and 3D finite elements models were created and analyzed whereof the 3D model proved having a higher fidelity. Starting from different initial water temperatures, the model has been used to calculate the time needed to fall out of the acceptable temperature range [+4°C, +20°C], that was assumed as required condition for a proper storage of water. As can be seen in Fig. 3, the temperature decreases and increases almost linearly under the given conditions. The slope in the 3D model is lower than in the 2D simulation, resulting in a longer time of temperature conservation. In Fig. 3 (left), case 3 is depicted: starting from a temperature of +20°C, water cools down because of the cold external temperature (-10°C) until it reaches the lower bound of the range (+4°C) after 11.5 hours. Fig. 3 (right) shows case 4: starting from a temperature of +4°C, the water is heated by the external air at +30°C until it reaches the upper bound +20°C) after 11 hours.

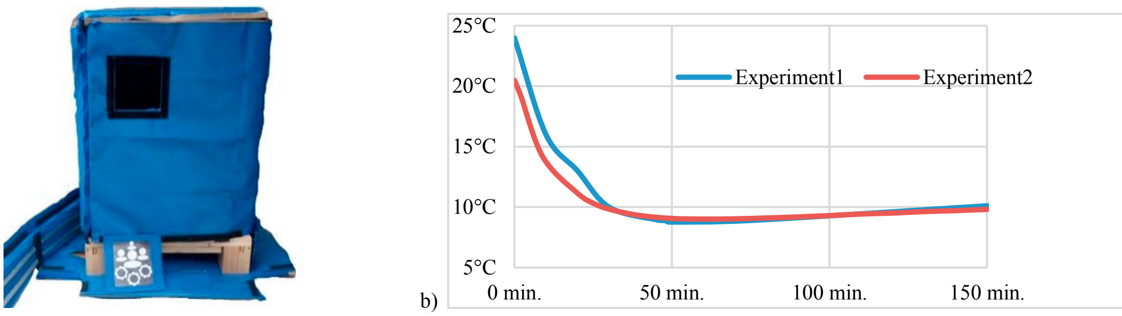

Fig. 2. a) A prototype of the thermal cover; b) Initial experiments – records of a temperature inside the cover.

Table 1. Results of preliminary experiments.

Ambient temperature	Initial temperature	Final temperature – Out / In	Change of temperature – Out / In
24.0°C	4.1°C	16.5°C / 11.7°C	12.4°C / 7.6°C
20.4°C	3.7°C	13.4°C / 9.3°C	9.7°C / 5.6 °C

Table 2. Heat transfer simulations

Parameters	Case 1 (2D)	Case 2 (2D)	Case 3 (3D)	Case 4 (3D)
Temperature outside / Temperature of water	-10.0°C / +20.0°C	30.0°C / 4.0°C	-10.0°C / +20.0°C	30.0°C / 4.0°C
Time within the range	8.0 h	7.5 h	11.5 h	11.0 h

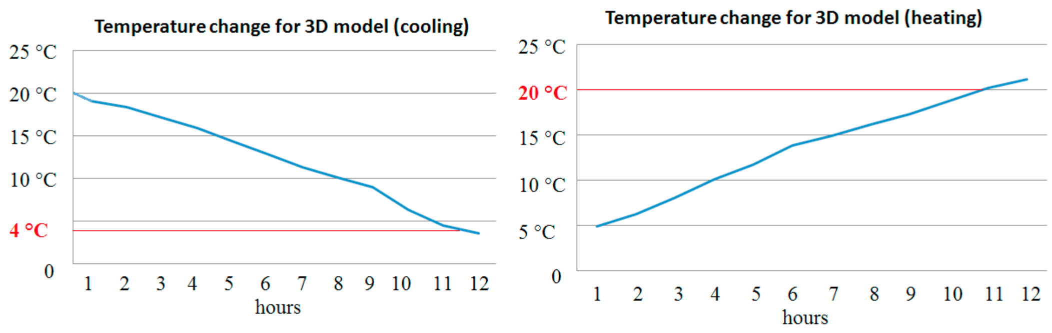

Fig. 3. Heat transfer simulations.

3.2.5. Future development

From the very beginning of the course, it was stressed that the engineering design needs to be concurrent with business model development. Students worked using business model canvas and presented their achievements to business-oriented audience during two business pitches. Finally, students prepared a roadmap for the future development of the thermal cover. They took into considerations further improvements of mechanical and ICT (hardware, software and temperature control algorithm) components, materials used for the thermal coat and customization, as well as business issues related to funding and investments.

4. Conclusions

Engineers today must be able to work in a transnational environment and cope with challenges of working in a team, able to cooperate, and interact with colleagues remotely. The aim of the EET project is to provide engineering students an action-based learning experience where they become familiar with the these aspects. In the described activities, students were given the freedom of self-organizing their work and learning from their decisions and mistakes. Cooperating with international colleagues (both physically and virtually) has been the only viable way to be successful. During the activities, they were taught in an environment simulating real-life on-the-job conditions and followed the process of innovation and new product development from the very beginning. The focus on sustainable development was put from the beginning of the project. Therefore, students were considering sustainability aspects when defining domain, building business model, designing hardware and software components.

The experience of the first cohort provides a strong evidence of the interest and benefits coming from this approach to learning engineering skills, moreover, the aim at achieving a result that could become a business opportunity has been strongly appreciated by the students. For the second cohort of EET, this aspect will be more structured to strengthen engineering skills applied by students during the project.

Acknowledgements

This research was supported by the ERASMUS+ Strategic Partnerships Project “New Culture in Higher Education: Project-Oriented Learning Beyond Borders” funded by the European Union, project number 2015-1-DE01-KA203-002207. Authors thank all the participants of the initiative, see engineering-team.net.

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