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Project title:
Internet Of Things (IOT) innovation space labs
Final Report

4TU. CENTRE FOR ENGINEERING EDUCATION

1 Introduction

This report provides information about the implementation and evaluation of the project *Internet of Things (IOT) innovation space labs* which was awarded to the Electrical Engineering department in December, 2017 by the 4TUE Centre for Engineering Education Innovation Funds.

In the coming sections we report about the learning objectives achieved, the implementation of the project itself, the evaluation of the project, the dissemination phase and the different involvement of the stakeholders.

2 The context of this project

The interest to take up the initiative to carry out this project was based on enhancing hands-on education within the Electrical Engineering department on the one hand. On the other hand, it became essential to focus on the field of Internet of Things (IoT) as a promising and relevant area of expertise requested nowadays in the Electrical Engineering arena.

3 Objectives and expected outcomes of the project

The objectives of this project were:

- To create an IoT innovative space DBL course within the EE bachelor program to enable students to acquire IoT skills. The DBL course will be an elective course in the 2^{nd} year. The EE-educational management supports the creation of this new DBL course.
- To develop hands-on assignments in which students work in multidisciplinary teams in a DBL lab environment. In this lab environment students prepare a sustainable basis/toolchain and test bed on IoT and related hardware, software and applications.
- To build the infrastructure/facilities for the new IoT DBL course.
- To collaborate with other TU/e departments, namely Computer Science and Industrial Engineering & Innovation Sciences, so that also the multidisciplinary aspects IoT are handled. The teaching staff of Computer Science and Industrial Engineering & Innovation Sciences departments will be also involved in giving form to the content of IoT assignments.

Regarding the expected outcomes we have achieved the following:

- A new DBL method is developed for hands-on and innovation and multidisciplinary lab projects.

Within the framework of this project, a DBL project oriented course has been designed for second year students. This course is elective and is open to all TU/e students. Within the EE department there are DBL projects aiming at having students to apply knowledge and practice the professional skills. However, this IoT project was devoted to develop experience to acquire knowledge in each iteration in the design process and having them run new applications, hosting various sensors and other hardware.

- IoT skills such as machine-to-machine communications, embedded programming, data processing, web design are taught.

The DBL project-oriented course is a hands-on project aiming at having students work in multi-disciplinary teams in which students learn how a large pool of IoT devices, connected to form an intelligent network can be used to solve practical engineering problems relating to emerging applications such as autonomous driving and in building navigation and localization. The essence of this project course was to engage students in the design and optimization of the wireless network connecting the IoT nodes, the establishing of algorithms and protocols for data exchange as well as the introduction of appropriate sensors to collect essential data for performing the project.

- Infrastructure and facilities for the IoT DBL project are built and a sustainable basis/toolchain for the DBL course is prepared.

The infrastructure necessary to run students' projects have been developed in FLUX building. We provide below some imagines of the infrastructure.

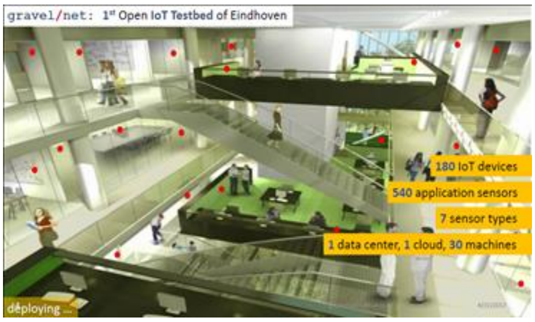

Fig. 1:

Fig. 2:

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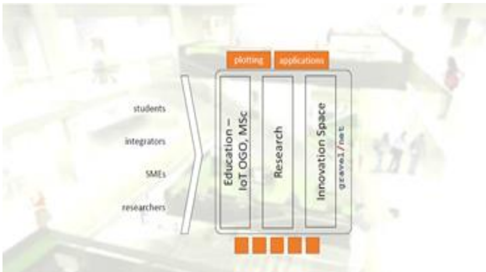

Fig. 4:

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- It is expected that students from other TU/e departments, and mainly from Industrial Design and Computer Science will choose this IoT DBL elective course.

During the project implementation we have held contact with the IE&IS department mainly, in order to promote this project among the students. A preliminary meeting took place with the adjunct-director of IE, Monique Janssen, in order to include this courses in first year students' choices regarding second and third year elective courses. As a result there were two IE&IS students registered in this course and one ID student. Although no promotion was made at the ID and other TU/e departments the fact that an ID student enrolled in this course was promising. In total twenty students registered in the IoT project oriented course. Most of the students were EE and AU students.

In addition, there are also plans to promote further this course within the IE&IS and CS departments among teachers through teachers' meetings. This activity has not yet been carried out as the course has been implemented in quarter 1 and results of students' questionnaires were not made available until mid-December.

Finally, and it was announced in the project proposal, the first step towards linking with the industry was to have the involvement of a company. i.e. Genexis. This company has been involved in the mid-term and final review of students' final projects and products.

4. IoT Project results

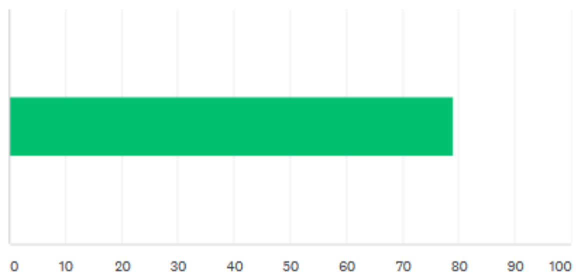
This is the first time the IoT project oriented course has been implemented. Therefore, we were keen on gaining feedback from students on particular issues besides the regular feedback gathered through the course evaluations. Regarding the regular course evaluations, unfortunately and due to some logistic problems with the new EvaSys system, the evaluations recorded only a few answers.

In terms of students' appreciation for the course we observe that the students are highly satisfied (Q2 below)

Q2

Did the course meet your expectations? (1 - not at all; 5 - very much)

Beantwoord: 16 Overgeslagen: 0



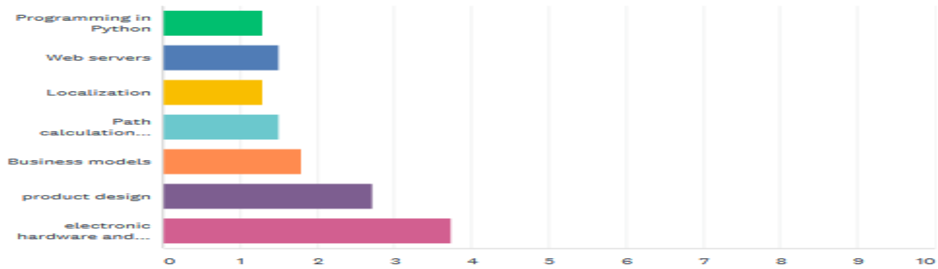
ANTWOORDKEUZEN	GEMIDDELD AANTAL	TOTALE AANTAL	REACTIES
	79	1,264	16
Total Respondents: 16			

In addition, we also were keen on to know to what extend students gained skills with this course in comparison to the starting level (see Q 3 and 4 below)

Q3

For the following skills please rate your starting level

Beantwoord: 16 Overgeslagen: 0



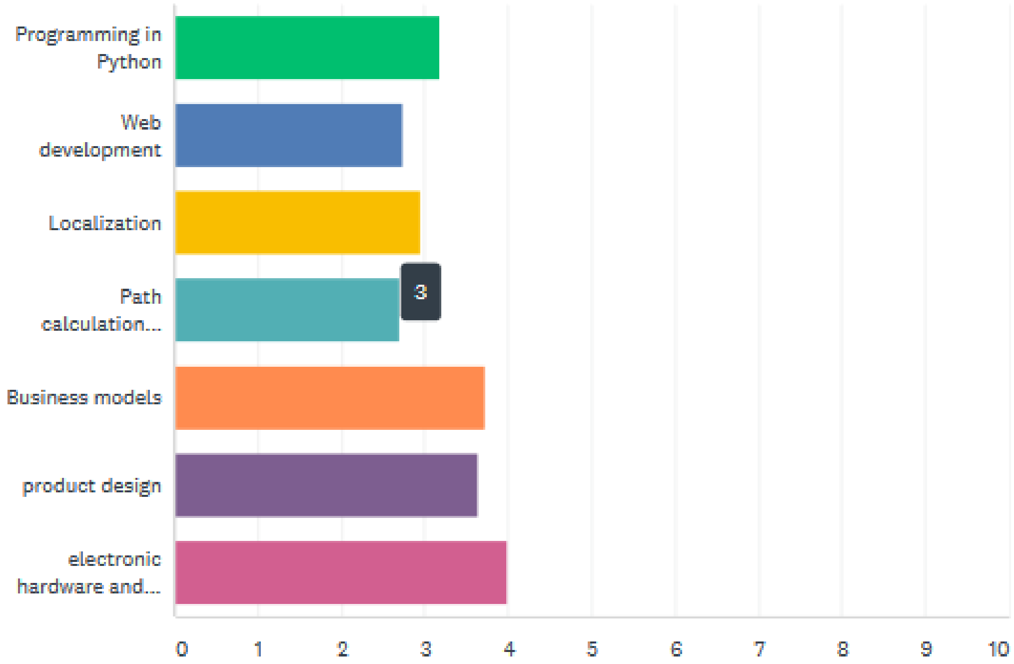
	1	2	3	4	5	N/A	TOTAAL	GEWOGEN GEMIDDELDE
Programming in Python	75.00% 12	0.00% 0	12.50% 2	0.00% 0	0.00% 0	12.50% 2	16	1.29
Web servers	56.25% 9	18.75% 3	12.50% 2	0.00% 0	0.00% 0	12.50% 2	16	1.50
Localization	62.50% 10	25.00% 4	0.00% 0	0.00% 0	0.00% 0	12.50% 2	16	1.29
Path calculation algorithms	56.25% 9	18.75% 3	12.50% 2	0.00% 0	0.00% 0	12.50% 2	16	1.50
Business models	43.75% 7	31.25% 5	6.25% 1	0.00% 0	6.25% 1	12.50% 2	16	1.79
product design	12.50% 2	31.25% 5	25.00% 4	18.75% 3	6.25% 1	6.25% 1	16	2.73
electronic hardware and assembly	6.25% 1	6.25% 1	18.75% 3	43.75% 7	25.00% 4	0.00% 0	16	3.75

We are satisfied to observe that students score higher at the end of the course regarding the same skills (Q4)

Q4

For the following skills please rate your ending level

Beantwoord: 16   Overgeslagen: 0



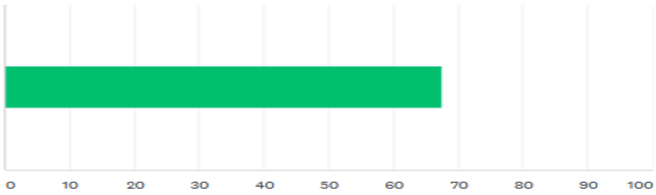
	1	2	3	4	5	N/A	TOTAAL	GEWOGEN GEMIDDELDE
Programming in Python	12.50% 2	12.50% 2	25.00% 4	43.75% 7	6.25% 1	0.00% 0	16	3.19
Web development	25.00% 4	12.50% 2	31.25% 5	25.00% 4	6.25% 1	0.00% 0	16	2.75
Localization	18.75% 3	12.50% 2	31.25% 5	31.25% 5	6.25% 1	0.00% 0	16	2.94
Path calculation algorithms	18.75% 3	18.75% 3	37.50% 6	25.00% 4	0.00% 0	0.00% 0	16	2.69
Business models	0.00% 0	6.25% 1	43.75% 7	12.50% 2	31.25% 5	6.25% 1	16	3.73
product design	0.00% 0	6.25% 1	31.25% 5	56.25% 9	6.25% 1	0.00% 0	16	3.63
electronic hardware and assembly	0.00% 0	6.25% 1	0.00% 0	81.25% 13	12.50% 2	0.00% 0	16	4.00

In addition, we were interested to learn whether students' found this course challenging enough at the first lecture. Following results, we feel pretty confident about the challenging content and structure given to this course.

Q5

Was the challange given to you at the first lecture clear enough?

Beantwoord: 16 Overgeslagen: 0



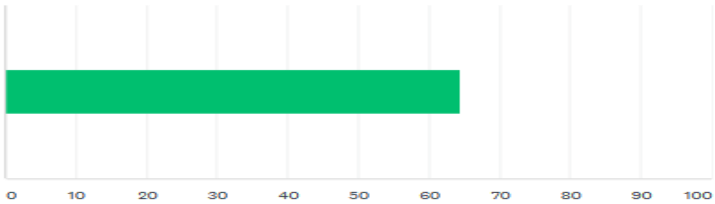
ANTWOORDKEUZEN	GEMIDDELD AANTAL	TOTALE AANTAL	REACTIES
	68	1,081	16
Total Respondents: 16			

The students' rates regarding quality of lecturers is also high as well as this of the student assistant (see Q 6, 7, 8 and 9)

Q6

Was the lecture by Prof. Johan Lukkien an impotant addition to the course?

Beantwoord: 15 Overgeslagen: 1

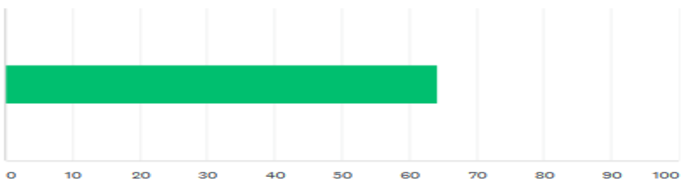


ANTWOORDKEUZEN	GEMIDDELD AANTAL	TOTALE AANTAL	REACTIES
	64	967	15
Total Respondents: 15			

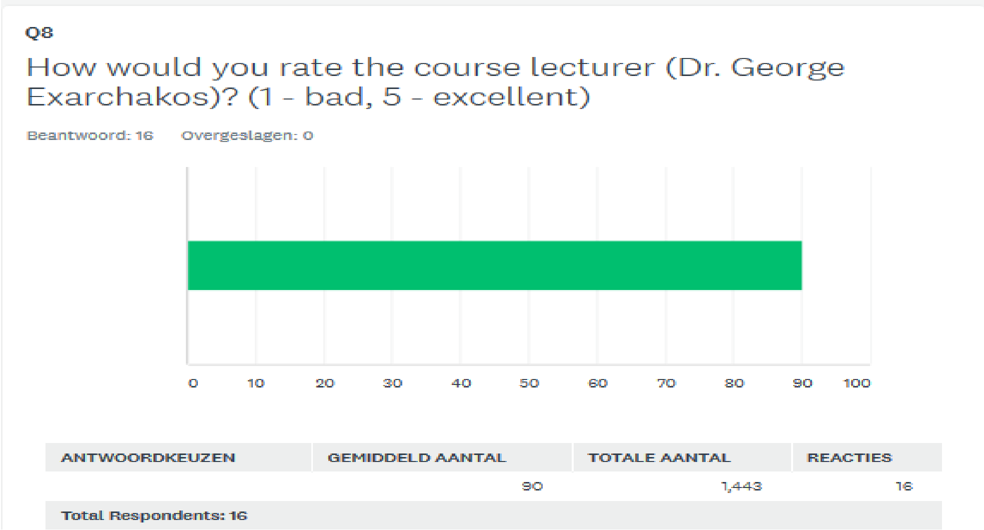
Q7

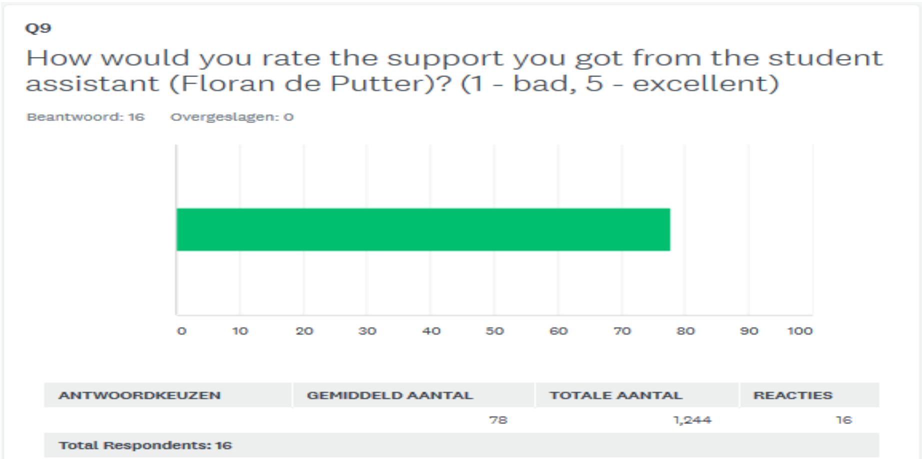
Was the lecture by Dr. Bert Sadowski an impotant addition to the course?

Beantwoord: 15 Overgeslagen: 1



ANTWOORDKEUZEN	GEMIDDELD AANTAL	TOTALE AANTAL	REACTIES
	64	964	15
Total Respondents: 15			





5. Dissemination

The dissemination of this project has taken place in different forms:

- Presentations at the TU/e organized by the 4TU/e CEE Innovation Funds;
- Presentation at international conferences, i.e. SEFI (Azores, Portugal, September 2017) – See paper.
- Presentation at the Data Science Summit (the Netherlands, December 2017). Students' presentation in the form of a demo based on the results of the IoT course.

There are also other means for dissemination (still in progress)*:

- EE Education day and lunch meeting;
- Meetings with teachers from IE&IS and CS departments.

*Since the IoT project-oriented course has been implemented in quarter 1 (till the beginning of November, 2017) and the results of the students' evaluations were not yet available till December, 2017, the above mentioned dissemination activities have not been implemented yet. These are in the pipe-line.

45th SEFI Conference, 18-21 September 2017, Azores, Portugal

Connecting the world with Internet of Things

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ABSTRACT

The abstract should summarize the contents of the paper and should contain at least 70 and at most 200 words. It should be set in Arial font 12-point font size and justified.

Conference Key Areas: Curriculum Development; Skills and Engineering Education; Continuing Engineering Education and Lifelong Learning

INTRODUCTION

Imaging a connected world is easy although the potential of the IoT application is still to discover. Connecting the world sounds like a very challenging undertaking when it comes to gathering information, analysing and distributing data. Possibilities for applications are manifold to connect multiple systems while using the shared data for industrial and economic purposes or for empowering citizens and communities, among others. Internet of things (IoT) is more than just a buzzer word that can be applied to a wide range of devices, technologies and situations. IoT is the concept of connecting any device to the internet while internetworking with for instance cellphones, connected vehicles, wearable devices or buildings by the use of sensors, actuators, and software of network connections as a whole [1].

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At the Electrical Engineering (EE) department at the Eindhoven University of Technology (TU/e) the topic of IoT is starting to boom up. The motivation to integrate IoT in the EE curriculum is driven by the fact that IoT is quickly gaining an industrial foothold in The Netherlands and internationally. In addition, engineers with IoT expertise are already required by many companies. Furthermore, while a need for this expertise is evident, there are no hands-on specific courses or lab environments where students can be exposed to the IoT experience within the TU/e. The main aim of this project proposal is to create the required IoT innovation space and educate students via practical assignments on all aspects of IoT devices, networks and applications. Therefore, the motivation for the development of an IoT project within the EE curriculum is to create an IoT innovation space around gravel**/**net, the expandable wireless IoT network of 50 nodes deployed inside *FLUX*, which is the name of the building of the EE department at the TU/e.

In this paper, we give an overview of the IoT project assignment in the EE curriculum. In this IoT project, students explore the relation between signal noise ratio and channel capacity, the design of low energy systems by the use of algorithms of localization. In addition, we also provide an outline of the multidisciplinary components of this project to develop new insights into possible business applications of the IoT project case.

4 the context of internet of things

4.1 The rationale for the development of a IoT project in *FLUX*

Internet of Things (IoT) is the internetworking of physical devices, vehicles, buildings and other items. IoT enable devices including electronics, software, sensors, actuators, and network connectivity modules in order to collect and exchange data. IoT is becoming a growing market making a stand in the industrial world in the Netherlands and internationally.

At the TU/e (the Netherlands) there are courses at the Computer Science and Industrial Engineering that cattle the need to educate engineers to use applications for the potential to exploit industry, society and business solutions. These courses are devoted to teach students the technological aspects of IoT, among others, architectures, device classes, protocols, application patterns and application examples. In addition, courses also focus on developing business models and business cases on the products students make. However, the industry needs engineers with hands-on skills able to innovate and implement applications to match customer value needs and businesses.

The second year design-based learning sophomore project course *Internet of Things* at the Electrical Engineering (EE) department aims at teaching students to learn to use the applications of IoT around gravel**/**net, the expandable wireless IoT network of 50 nodes deployed inside of the EE department, the ultra-modern and recently-constructed building *'FLUX'* (See Figure 1). Moreover, our purpose for the development of this hands-on project is to make possible to run new applications, hosting various sensors and other hardware. This network is the result of several past and ongoing research programs, however it is not yet big and mature enough to be used for educational purposes. It should in principal scale to 180-200 nodes and become robust and easy to use allowing both teachers and students to focus on learning objectives rather than solving technical issues.

Within this project, students learn how to design wireless links (including basic concepts of antenna design), and to optimize end-to-end latency over an IoT network. Likewise, students become familiar with different wireless protocols.

The project has a multidisciplinary character as elements of architectures from the computer science field and the economic values from the business world are integrated in the cases of the students to complement the electrical engineering knowledge that students will gain through the implementation. In addition, students from other departments, mainly Computer Science and Innovation Sciences are part of the EE project teams.

4.2 Innovation space and the Engineers for the future

The Internet of Things project is a pilot which has potential to expand and link with the newly initiated concept of Innovation Space at the TU/e. Since 2016 the idea of the TU/e Innovation Space (still under construction) is built upon the rationale to have students work on hands-on engineering assignments in multidisciplinary teams while dealing with challenging and *complex societal and industrial challenges, create prototypes and develop innovations in collaboration with researchers, businesses and other stakeholders...*[2]. The added value of this initiative is the strong scientific collaboration that the TU/e has with the surrounding industry, with researchers and businesses.

The concept of Innovation Space does not stand alone in the world. Looking at other initiatives overseas, for instance, the Design Factory at the Finnish Aalto University, this has been an inspiring example to adjust that model into the TU/e pattern. The experience of Design factory illustrates and leads the TU/e project to make possible and give form to a space in which the physical and mental working environment for product developers and researchers come together to encourage and to enable fruitful interaction between students, researchers, and professional practitioners. Following the already 10-year old Finnish model, the TU/e innovation space provides a setting to inspire teaching staff and students for which lectures and workshops are organized. In addition, the fact that the Innovation Space provides a scenario for the implementation of multidisciplinary engineering projects encourages the engineering thinking of creating prototypes and transforming those into products, services for the society in order to stimulate businesses. Moreover, the TU/e innovation space model has also a specific accent which lies on encouraging the cross-fertilization between departments as well as the cooperation with the business community. The operationalization of such an ambitious undertaking is actually a step ahead in realizing the vision of the TU/e to educate the Engineers for the Future [3].

5 Instructional design in engineering education

5.1 The Design-based learning approach of the Internet of Things project

Design-based learning (DBL) is an active learning teaching method similar to Problem-based learning [4] and Project-based learning [5] engaging students in solving real-life design problems while reflecting on the design and learning process [6].The unique element of DBL is that it is grounded in the *process of inquiry and reasoning towards generating innovative artifacts, systems and solutions* [7]. DBL emphasizes the engineering design process resembling authentic engineering settings in which students make decisions during the design cognitive thinking processes as they go through iterations in generating specifications, making predictions, experiencing and creating solutions, testing and communicating [7].

Resembling the DBL model from empirical literature, we have included the features of DBL [8], i.e. *open-ended, hands-on, authentic* and *multidisciplinary* aspects in the in the instruction design Internet of Things second year bachelor project. The *open-ended* character of the project is featured by the fact that students get an ill-defined description of the cases to solve. As an instance, students are to trace people in buildings, workers in a factory, patients in a hospital or just lab equipment. Besides the description of the use case with incomplete information and some specifications of the final systems they are to produce, students' teams are to experiment iteratively with different architectures to be able to choose the appropriate one that matches the technology selected for the design. Within this experiencing phase and following the common engineering design process, students make a throughout analysis of the use cases and requirements and choose some criteria to select the proper architecture. In addition, students' teams analyse the business aspects and make priorities of the requirements and features of the system to be developed.

As in the engineering design cycle, students formulate own design plan, and seek for alternatives in the design of the architecture and integration of existing architectures and communication technologies. In the integration process, it should be included the selection and assembly of the required hardware, installation of software, modules and libraries, etc. The next steps in the design process are to test iteratively the prototypes and experiencing repeatedly various architectures in order to design a minimum viable product, i.e. a prototype which is not the final product. The design and testing phases should be in iterations so that students can expand the design with different features of each specific case. A relevant element within the design process is the feedback to support the construction of a viable product so that this can be sold and become profitable. These project assignments provide students the opportunity to experience a typical production development process from the organization of working from a traditional waterfall production and design work into a much more *Agile* type of work consisting of short iterations allowing companies to realise new products in short time.

The fact that the assignments are embedded in *real life* industry tasks make the cases more *authentic* resembling jobs students my get in companies and business. The teaching staff from the Computer Science and Industrial Engineering departments will be also providing feedback as part of the customers' roles they will be playing. Moreover, the *hands-on* component of this project is actually inserted in the generation of knowledge from each iteration in the design process which is afterwards applied in a new iteration producing new information on the prototype to make.

In this *hands-on* project students are asked to work in *multi-disciplinary* groups to address a challenge concerning how a large pool of IoT devices connected to form an intelligent network can be used to solve practical engineering problems relating to emerging applications such as autonomous driving and in building navigation and localization. The rationale for multidisciplinary lies in that students from the different three departments, i.e. Electrical Engineering, Computer Science, and Industrial Engineering will be working together and share expertise in working on different applications and making different business models of these. As a matter of fact the involvement of Computer Science in this project is related to the architectures of a system.

6 Tthe assignment

6.1 Description of the Internet of Things project

The objectives of this DBL IoT project are:

- To optimized wireless links (including basic concepts of antenna design)
- To optimize end-to-end latency over an IoT network
- To get familiar with different wireless protocols
- To create and analyse relations between signal noise ratio and channel capacity
- To design for low energy systems
- To apply algorithms of localization
- To conduct analysis of large data sets
- To develop new insights into possible business application of the IoT case

The motivation behind this project course is to introduce students in the world of the Internet of Things by applying technology, architecture and business models by tracing people and objects in indoor localization functionally assignments.

3.2 Internet of Things: examples and dimensions use cases

The end purpose of the IoT project assignment is to have students to solve open-ended and realistic use cases as they would be tackling complex problems of a real world industry. The assignment is based on tracing people in a factory, or patients in a hospital, or expensive equipment in the university, for instance as students go from lab to lab and transfer important pieces of lab instruments from one lab to another. All assignments have a common denominator, i.e. indoor location functionality. However, each of these cases has different requirements. As an example, workers in a factory have very stringent requirements of delay of notifications and this is a danger that a human can run into it. Within this scenario students have too set an alarm immediately in order to avoid a bigger damage. Regarding the assignment of tracing patients in a hospital the main problem is that patients cannot be reached as they are moved to a surgery room where the walls are thick because the signal communication is not possible to go through thick walls.

The open-ended character is a scenario with no clear specifications as the students can choose architectures which match the technology. The motivation is that students can described a fully automized industrial floor which a location system with cotations and tool kits for one or two technologies. This implies that students will use their creativity to locate the floor plant to learn to combine technologies and architectures (See *Fig. 2*). Architectures are general mechanisms or a hardware unit in an IoT system that include a piece of software such as sensors and actuators, processing units, storage units or communication units. The idea behind is that students learn to apply technologies, selecting adequate architectures while building a business case.

The project assignment leads students to experiment with different architectures each one focusing on a different optimization. The motivation to introduce the architecture part in this course is to have students practice with features of architectures and tools and write the codes from the implementation. The students will engage in the design and optimization of the wireless network connecting the IoT nodes, the establishing of algorithms and protocols for data exchange as well as the introduction of appropriate sensors to collect essential data for performing the project (See *Fig. 3* and *Fig. 4*). Optimization in this regard is considered from two different criteria, flexibility and reliability. When it comes to flexibility, students can change, for instance, any type of data from the sensor or run an application which may be installed in any environment. In terms of reliability of optimization, however, the students focus on the network part, i.e. data are delivered on time in 100 milliseconds as applications do so. These networks, however, do not match with bigger networks, while the flexible ones do match indeed.

Moreover, for industrial applications with coordination with robots, these have to be coordinated precisely one product to the other. When it goes about robots issues such as people and safety or alarm are key important elements. At the end of the course, the students will demonstrate that their solution can indeed solve the challenge taking into consideration specifications such as speed and efficient use of energy (See *Fig. 5*).

Fig. 1:

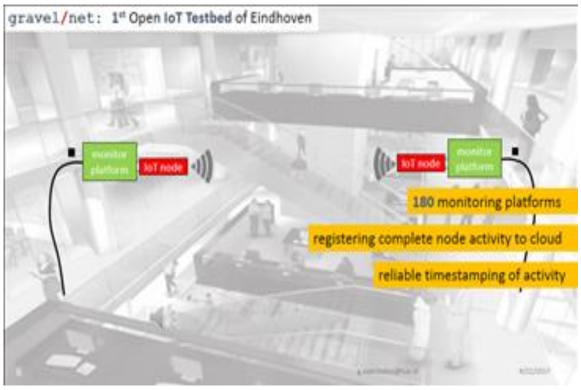

Fig. 2:

Fig. 3:

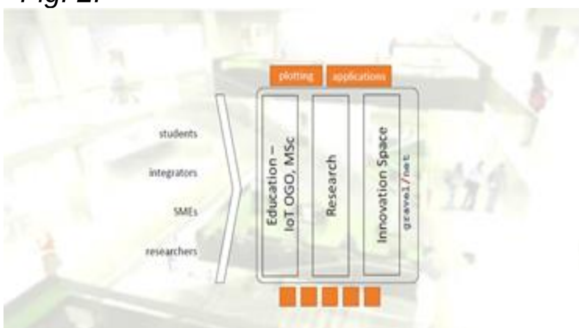

Fig. 4:

Fig. 5:

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3.3 Business case and business models in the Internet of Things project

Next to the technical challenges also the business aspects of the project will be explored within the students' groups. Students make use of a business case and models to notify in the production line. The added element of including business models and cases is to have students to get involved in real live assignments in which they have to gather information on crowd sensing applications to be able to understand how crowd works, for instance, for safety and business purposes while deploying the necessary application. The key element is that students see the product development part of such as real-life case as they may work in a small company with similar challenges.

7 The structure of the DBL IoT project

The structure of the project consists of seven weeks and eight contact hours in which students carry out the project activities. Besides an introductory meeting on the Internet of Things assignments, students get two support lectures on the two main multidisciplinary topics in this project, i.e. architectures, and business models and cases. These support lectures are given by lecturers from the Computer Science and Innovation Sciences departments. In addition, the Electrical Engineering lecturers are also involved in the direct supervision of the teachers.

Following the educational principles of problem-based and project-based learning, students work in teams together throughout seven weeks. The groups are led by a supervisor or project leaders. These are older bachelor or master students with broad knowledge on the Internet of things as they have been involved in the construction of the network. The groups are made out up to 6 students and the tasks are divided among them.

The follow-up of the project activities and interim products is based on mid-term presentations in which students report about the progress of the project, main obstacles but also the challenges ahead and how these will be solved. In these mid-term presentations the interim products and prototypes, and progress are assessed and students receive feedback from the experts on how to make improvements. The presentations and final report are assessed against quality of final products.

8 Discussion

The Internet of Things project is a pilot project that has been developed to introduce students in the world of communication technology and to learn them the application of technology, architecture and business models by tracing people and objects through indoor localization functionally assignments. The added value of this project is that is a pioneer course within the Eindhoven University of Technology as it is devoted to promote *hands-on* application of a connected world rather than in a lecture-type course. The relevance of this project is therefore twofold: first of all, the IoT project is devoted to promote practical applications of content; secondly, the project aims at integrating different disciplines as a realistic scenario of what the engineers for the future will be dealing with in the industry. The future challenges of this project will be to include elements of value for money in the design review in order to fine-tune the assignments and students' products according to the clients. In order to embrace the value for money component it will be necessary to make the project sustainable and gain financial support to be able to buy sensors, actuators and missing parts upon which students will make choices based on the technology and architectures they are planning to use. The need to link with the Innovation Space university project becomes also relevant.

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