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DEVELOPMENT OF A VENDING MACHINE USING VIRTUAL COLLABORATION

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1. Introduction

Farming is no longer so closely connected with the traditional way of life in the countryside; it is increasingly becoming business-oriented. An entrepreneurial spirit and new products are therefore important, especially on small and medium-sized family-owned farms, because the costs of the traditional methods are too high. In Slovenia, farms that use a minimum of 1 ha and a maximum of 6 ha of agricultural land or raise at least 2 and not more than 30 livestock units are considered small and medium-sized farms [Krznar and Belec 2004], and stockbreeding is the main agricultural activity on these farms. The reorientation or diversification of these farms, which is necessary to strengthen the welfare of rural communities, is taking place too slowly. Recognizing new, profitable opportunities in a systematic way is, therefore, of even greater importance [Benedičič et al. 2011].

The first author is a researcher who also became the owner of a mountain farm situated in a hilly area at an altitude of 780 m. The farming conditions there are quite difficult. Therefore, the farm can be economically viable only if it develops agricultural products having a high economic, nutritional, social and health value.

Using the method of searching for opportunities [Benedičič et al. 2011], various options were recognized, including milk production with simultaneous maximised use of the natural resources available at the farm. Focusing on milk production will yield products of higher quality, which can be sold at a higher price on the market. In the case of milk, higher quality means hay milk and the use of ecological farming methods. To produce such milk, hay production needs to be adjusted as well, because only high-quality feed ensures cost-effective production of high-quality milk. Another essential aspect of this farm's development is its reorientation towards direct sales (i.e. without any intermediaries), which will enable increased revenues at relatively unchanged costs.

The farm's reorientation is therefore based on the process of feed production and sale of raw hay milk. To perform this process, appropriate technical systems (i.e. products) are needed, namely seeding machines, manure spreaders, mowers, grass transporters, hay drying chamber, hay distributors, milking machines, milk transporters and automatic vending machines (as part of an automatic marketplace for agricultural products from local farms). The above-mentioned process therefore offers us an opportunity to develop such products.

The paper describes virtual development of an automatic vending machine for milk (with emphasis on the percentages of using various communication technologies), which will serve as one of independent modules of a future automatic marketplace. The decision to develop a new vending machine for milk is based on the fact that existing vending machines cannot be integrated in such an automatic marketplace. The devised concept of an automatic marketplace is based on modular software (control software and graphical user interface) and a common payment module.

It was decided to use virtual development done by a team that would also include a couple of students, as the authors have had much positive experience with the use of such an approach. For formal reasons, the participating students performed their work outside of their regular study commitments.

2. Process of development of a vending machine

The first author proposed a model of the vending machine development process (Figure 1). It was later found that the development process in fact consists of a highly simplified Gausemaier's 3-Cycle-Model [Gausemaier et al. 2011] with emphasised iterative developmental steps.

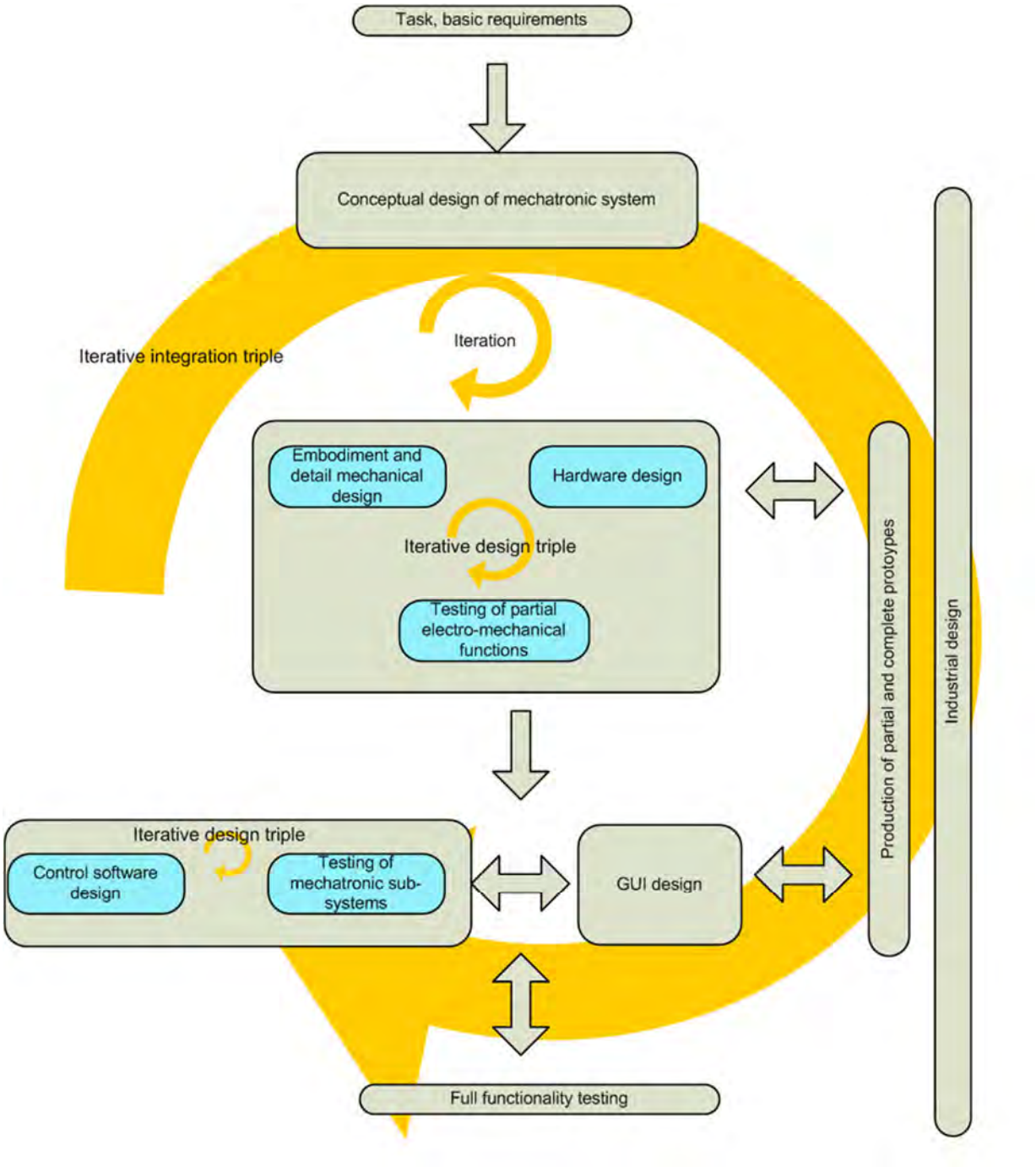

Figure 1. Model of the vending machine development process

2.1 Task and basic requirements

The developmental task is based on the results obtained (in our particular case) by using the method of searching for opportunities [Benedičič et al. 2011]. To begin with, in order to perform the process of producing hay and selling hay milk, a vending machine for three types of drinks (raw hay milk, skimmed hay milk and yoghurt) was selected from a set of products. The said vending machine was supposed to enable remote monitoring and interventions, and it had to be in line with the concept of automatic marketplace, which is based on modular software (control software and graphical user interface) and a joint payment module.
This was followed by the selection of functions to be performed by individual modules and the generation of alternative principle solutions for these modules. In this phase, the basic structure of control was also designed.

2.2 Iterative design triple

The design (embodiment and detail) of individual modules affects their behaviour. Therefore, it is closely associated with testing, while testing is further associated with the manufacture of partial prototypes. This iterative process is characterised by intense cooperation between the members of an interdisciplinary team. Based on the results of testing, it was necessary to make appropriate minor and major changes or even to find principle solutions. All modules were processed in this way.
Subsequently, iterative development of individual modules was done, in the following sequence:

- Development of and searching for (commercially available) mechanical components.
- Development of and searching for (commercially available electrical and electronic components.
- Checking and supplementing of the control process for the mechatronic module.
- Development of a graphical user interface.
- Production of partial prototypes.
- Testing of the behaviour of developed modules.

2.3 Iterative integration triple

Through physical and software integration of all modules, the functionality of the entire mechatronic product (i.e. vending machine) has to be achieved. Such integration is followed by comprehensive testing (by system developers and test users), which has to show the actual behaviour of the mechatronic product as a whole. More or less extensive changes and supplements of the individual modules, the controllers and/or the user interface are based on the findings of a thorough analysis of the causes for any differences between the required and actual behaviours.

3. Forming of a development team

It is of paramount importance that members of a development team are from the fields which cover all phases of the product being developed. A wide range of knowledge and different viewpoints stimulate team creativity [Pečjak 2001] and the end result is a product of a higher quality.
The development of communication technologies has led to the possibility of forming virtual development teams. These teams are supposed to provide many advantages over traditional ones, including the ability to bridge time and space (e.g. “follow-the-sun” product development), better utilization of distributed human resources without physical relocation of employees, ability to hire the best people regardless of their location, and organizational flexibility [e.g. Lipnack and Stamps 2000], [Paul et al. 2004]. The reduced need for constant physical presence means lower development costs and quicker development. There is less face to face communication and more virtual meetings of the team or individual team members; furthermore, experts who for various reasons would find it difficult to participate in usual development teams are able to get involved in teams of this type.
Members of a virtual team can also come from different geographical and cultural settings. Different cultural backgrounds of team members can sometimes prove to be an obstacle due to different views on a problem [Kayworth and Leidner 2000], [Fain et al. 2011]. Basically, different views on a problem

should add to the team's creativity, but creativity can sometimes be impeded due to disagreements related to the cultural positioning of a new product within a particular environment.
Students also hold a special place in virtual development groups, as they are able to participate in development teams within the framework of their studies and can perform their tasks on an equal basis to other team members. It was already shown in virtual teams composed exclusively of students [Žavbi and Tavčar 2005] that virtual communication within a development team does not impair the results of development. Rather, it enables an interdisciplinary approach and participation of students from different cultural, language and social environments.
Student collaboration within real-life product development as a concept of product development education provides a good dose of reality and exposes stakeholders to the challenges of the business environment. It also stimulates learning motivation by relating technical knowledge to its applications [Allan and Chisholm 2008]. This also increases the preparedness of students for assuming developmental tasks directly after the completion of their studies.

4. Further development of vending machine and means of communication within the virtual team

The vending machine for milk (Figure 2) constitutes one of the modules of a future automatic marketplace that performs one of the phases of the process ranging from hay production to the sale of milk.

Figure 2. Developed mechatronic system – vending machine for milk

Based on various analyses (market analysis, trend analysis and analysis of competitive vending machines), the first author designed a mechatronic system whose functions are to be performed by the following modules:

- **Module for pouring drinks**: This module comprises a cooling system, a container for storing drinks, a pump with a volume meter and a pouring site. The cooling system and the pouring site are common to all types of drinks, while the container with the pump and volume meter for measuring the poured quantities is separate for each type of drink. This vending machine can simultaneously contain 3 different types of drink (currently only raw hay milk is available);
- **Module for itemised products**: This module comprises a container and a mechanism for dispensing itemised products (i.e. plastic bottles).
- **Control module**: Contains control electronics with software that connects all other modules into a functional whole and ensures their appropriate functioning.
- **Communication module**: Provides for (remote) communication with the user and supervisor.

- **Payment module**: Enables payment with cash or with special USB sticks.
- **Housing**: Enables mechanical positioning in space and provides protection from the elements and other external influences. The outer design is an integral part of its shape, which has to be both appealing and functional.

Considering the functions of individual modules, it is evident that an interdisciplinary approach was necessary (Table 1). The necessary (generic) knowledge had been identified: mechanical engineering, electronics, control engineering, computer engineering and industrial design. From this standpoint, an interdisciplinary team was composed, which also included two postgraduate students. Student participation was chosen because such involvement of students has already been successfully used previously for product portfolio expansion of a metal-processing company [Žavbi et al. 2010].

Table 1. Competences of virtual team members

Team members	Specific competences
member 1 from a farm (owner)	team management, product development processes, mechanical concept, embodiment and detail design, strength analysis
member 2 from a company A	web management, PIC software, web tools for control engineering and testing
member 3 from a company B	CCA design, manufacturing and testing, MDB protocol, payment software
postgraduate student	visual communication software design, PHP, applications of remote access protocols
undergraduate student	wiring assembly design, selection of electronic components
extended team member from a company C	industrial design

4.1 Module for pouring drinks

The module for pouring drinks was designed as an independent module which can be included in various combinations with other modules. Electrically and informationally, this module is connected to the control module, while mechanically it represents a complete whole, which is inserted in the housing. The module for pouring drinks enables the basic functionality of a vending machine (Figure 2).

During the development process, communication was largely done via virtual communication means. There was only 25% of face to face communication, which took place at the initial, intermediary and final joint meeting and during individual partial tests. The most optimal form of communication considering both time and costs was communication via Skype with scanning support (when free hand sketches were necessary for discussions) and sending via e-mail (Table 2). The module for pouring drinks was developed by three members of the development team from the farm, commercial companies and a postgraduate student who conducted an independent task within the module development process. The leader of module development was a team member from the farm who was responsible for mechanical solutions and the development of the basic functionality.

4.2 Module for itemised products

The mechanics of the module for itemised products (i.e. plastic bottles) are designed so that they can be used either together with the module for pouring drinks or independently. They are composed of a container which comprises stock checking, a motorised dispenser and a drawer from which buyers receive the purchased plastic bottles.

As with the module for pouring drinks, slightly more face to face communication was needed in the phase of testing the basic functionality. Communication for all of the other development activities was done mainly via Skype (Table 2). Three development team members from commercial companies participated in the development of the module for itemised products. The leader of module development was a team member from a commercial company responsible for mechanical solutions and for development of the basic functionality.

4.3 Control module

The control module comprises the development of a processor panel with several series of input and output cards. If there is a need for increasing or reducing the number of inputs for switches and sensors, and motor outputs, the panel can be simply upgraded by adding several input and output cards. The system is planned in such a way that the basic processor panel is used for controlling simple mechatronic subsystems, while for more complex mechatronic subsystems a higher capacity computer is added via a USB connection.

The control module consists of a microcontroller and a mini computer running the Linux operation system. The microcontroller performs the task of reading various sensors and controlling the electromechanical part. The two computers communicate via a USB interface. The computer runs the background processes connecting the microcontroller, business logic and user interfaces. The computer is also connected in the network and enables remote access for users (i.e. system supervisors) via various interfaces (e.g. WEB, VNC and terminal access). Users are also able to sign in the system from a remote location and to monitor its functioning, i.e. help local users (i.e. buyers at the vending machine) in the case of any technical problems. The key parameters necessary for system operation are displayed to the user on the remote panel with LCD graphic display. The entire system is designed in such a way that practically all software errors can be eliminated through remote access.

At the beginning of planning, an introductory face to face meeting was held, at which the role of the control module was confirmed and a rough design thereof was produced. A part of the development team then continued with independent work (Table 2). The majority of communication was conducted via Skype. It was necessary to harmonise the possibilities for producing electronic circuits and soldering technology with the needed communications between individual parts of the software. Two team members from commercial companies and a postgraduate student participated in the development of this module. The leader of module development was a team member from a commercial company who was an expert in control software.

4.4 Communication module

The communication between the buyer and the vending machine is done via a touch screen and software installed on the machine. This software offers users simple communication with the vending machine, leading them through the entire process of purchase, payment and dispensing of products. The development of the communication module comprised the development of the procedure for selecting products, procedure for payment of selected products and the procedure for their dispensing (for liquids and plastic bottles).

The designing of the communication procedure between the user and the vending machine comprised the determination of the necessary communication steps, individual information from the vending machine's user for each step and possible connections between these steps. After these procedures were designed, visualisation of the user interface was done for individual steps of the procedure in the form of screen pictures in PPT form. It comprised the general set-up of the interface's functionality (data presentation and possible actions in the form of buttons). The second step of designing the user interface was the design of a simple virtual vending machine: a user interface was made in the form of a web page and a monitoring module to be used for determining the current state of the virtual vending machine. By using the virtual vending machine, it was possible for us to test the functioning of the user interface before its installation on the vending machine for all anticipated states of the vending machine. The third and last step of designing the user interface was its installation in the vending machine and its testing on the machine.

The user interface was customised specifically for use in the vending machine and was also tested by test users prior to its installation on the machine. The test users were chosen with respect to the target groups of vending machine users. The advantage of the customised user interface lies in its adjustment to individual vending machine requirements and the resulting simpler and improved user experience.

The main purpose of developing the above-mentioned virtual vending machine as part of user interface development was to reduce the time required for user interface testing on the machine due to concurrent development of the user interface and other parts of the machine. Another reason was the

possibility to perform prompt testing of any corrections and supplements made on the user interface before its installation on the vending machine, which shortened the time of the machine's downtime.
Two team members from commercial companies and a postgraduate student participated in the development of this module. The postgraduate student was the leader of module development. Several different types of complementary knowledge were required. The entire development process, as well as the testing and elimination of any errors, were conducted using various forms of virtual communication. The majority of communication was done via Skype (Table 2).

4.5 Payment module

The payment module was composed of a coin receiving device, which also served for returning cash, and a payment unit for USB sticks. Communication between them and the control module was done via an MDB protocol. MDB (Multi-Drop Bus) is a protocol intended for communication between various payment systems via a single bus. Communication is sequential with a constant speed of 9600 bits per second. A command sent to the common bus is visible to all machines, but only the one whose address was sent in package with the said command will respond. A single MDB controller can communicate via the bus with a maximum of 32 machines. The MDB protocol is standardised and is regularly updated so as to keep up with the development of new payment systems. Integration of the MDB protocol with the control module's software was done so that each payment system would operate independently, but they may also complement each other if necessary.
A team member from a commercial company, who was also the leader of module development, and a postgraduate student participated in the development of this module. The entire development process, as well as the testing and elimination of any errors, were conducted via various forms of virtual communication. As usual, communication via Skype was used the most (Table 2).

4.6 Housing

The development of the housing was done concurrently with the development of the other modules. An industrial designer produced several variants of shapes and details and then the most optimal one was chosen based on the functionality, design guidelines and integration in the local environment.
A team member from the company, who was also the leader of module development, an undergraduate student and an external associate in charge of industrial design participated in the development of this module. In the initial part of development, communication was conducted partially virtually and partially face to face. ICT was used for communication during core development of the module, while face to face communication prevailed during choosing the final industrial design alternative, prototype testing and installation (Table 2).

5. Discussion and conclusion

The result of the virtual development process described above was an automatic vending machine for raw hay milk, which in terms of its specifications and its innovative design (the solutions have been patented) ranks among the best vending machines of this type. Its significant advantages and unique features compared to existing automatic vending machines lie in the dosing system, which achieves a precision of ± 0.5%, in communication with the buyer and supervisor, in the unified payment module which serves all other modules of the automatic marketplace, and in its modular structure. The currently used manufacturing technologies were selected primarily by anticipating small batches.
Development was conducted according to the process shown in Figure 1, which is a very simplified variant of the Gausemaier's 3-Cycle-Model [Gausemaier et al. 2011]. The model in Figure 1 emphasises the iterative nature of individual process phases and the entire development process.
The process was performed by a virtual interdisciplinary team whose members had the necessary technical and professional competencies. The majority of communication within the team (86%, Table 2) that was necessary for development was conducted via the use of ICT. This is understandable, as it is necessary to provide an appropriate substitute for communication that is normally characteristic of collocated teams. The predominant percentage of using video and voice calls (44% of all the communication during the developmental process for the vending machine as a whole; done via Skype) is also understandable, as they represent the synchronous type of communication, which is the

best approximation for face-to-face communication. E-mails (asynchronous type of communication) were used only in 8%. This is in line with Kock's work on media naturalness of various communication means; synchronicity is one of the key elements of media naturalness, especially when communication of knowledge is the goal [Kock 2008]. Naturally, this only applies under the assumption that high-quality communication infrastructure is available, along with mastery of the relevant ICT tools. However, regardless of the intense use of communication technologies, primarily video/audio calls, these could not fully replace standard face-to-face interaction. It should be noted that individual team members had previously successfully cooperated on other projects. This was important, as one of the necessary conditions to achieve and maintain a high level of team creativity is the trust amongst all team members. For example, Thompson [1967] has shown that in uncertain and complex conditions requiring mutual adjustment (which is characteristic for product development), effective and sustained action is only possible where there is mutual trust [Dayan and Di Benedetto 2010]. Similarly, IJsendoorf found out that personal acquaintances before the beginning of collaboration are regarded as stimulative for virtual teams in industrial environments [IJsendoorf 2002].

It was very important that basic communication practices, work attitude, observance of time limits, responsibility for adopted decisions, and commitment to team goals were consistently high. The same was true of team member motivation.

The greatest percentage of video/voice calls and the absence of face-to-face meetings were recorded in the development of the communication and payment modules. The reason for this is primarily the possibility of remote access to these modules (e.g. remote control, installation/running applications, transferring files and analyzing log files) which was actually used.

The smallest percentage of video/voice calls and the greatest percentage of face-to-face meetings were recorded in the development of the housing. This can be explained by the fact that the evaluation of industrial design was highly subjective (detailed requirements were not given) and associated with communication rich interactions between the industrial designer and farm owner while making the decision on one of the proposed alternative solutions. Besides, final physical integration of the modules into the housing was done during this phase.

The authors believe that a systematic development process is also one of the key elements to achieve expected results via the use of virtual teams, and it includes: appropriate preparation of the requirements list, development of the technical process and function structure, and prompt reporting of any encountered problems/outcomes/decisions. Good planning facilitates the designing/assigning of tasks and the management/autonomy of (sub)teams [Oguntebi 2009], [Daim et al. 2010].

Use of ICT significantly reduced the negative effects of geographic dispersion of individual team members. Therefore, the two students were also able to participate on an entirely equal basis and it was only necessary to adjust the timing of virtual meetings in order not to interfere with their study obligations.

Table 2. Percentages of individual types of communication in the module and the entire vending machine development process

	Face to face [%]	Skype – video and voice call [%]	Skype – messages [%]	E-mail [%]	Cellular phone [%]
Module for pouring drinks	25	45	20	5	5
Module for itemised products	15	45	30	5	5
Control module	15	40	25	10	10
Communication module	0	50	25	15	10
Payment module	0	55	25	5	15
Housing	30	25	20	10	15
Vending machine as a whole	14	44	24	8	10

In short, the presented case indicates that virtual team members should have appropriate technical and professional competencies. They should have an introductory face-to-face meeting (if they have not collaborated previously), they should have good command of ICT use and should follow a systematic developmental process. These findings (although based on a limited case) are in line with the findings of many virtual team studies e.g. [IJsendoorf 2002], [Rezgui 2007], [Oguntebi 2009]. The above-mentioned limitations of the case most likely originate from the fact that there were no cultural differences between virtual team members, no time differences in terms of time zones and no foreign language issues. It has been indeed reported that these types of issues create barriers within virtual teams [Daim et al. 2010].

Figure 3. Modules for the sale of eggs and bread added

Selling milk via the developed automatic vending machine has enabled the farm owner to achieve higher milk prices than he would be able to get by selling it to the dairy as usual (EUR 1 instead of EUR 0.35). The farm's owner has already expanded this automatic marketplace with modules for the sale of eggs and bread by local farmers (Figure 3). Both of these modules were also developed by the interdisciplinary virtual team in the same way.

References

Allan, M., Chisholm, C. U., "The Development of Competencies for Engineers within a Global Context", Proceedings of the Conference on Innovation, Good Practice and Research in Engineering Education, retrieved on 14 August 2013 from http://www.heacademy.ac.uk/assets/documents/subjects/engineering/EE2008/p001-allan.pdf, 2008.

Benedičič, J., Duhovnik, J., Žavbi, R., "Innovations for Future Development of Farms: a Case Study of the Implementation of an Opportunity Search Method on a Farm", Transactions of the ASABE, Vol. 54, No. 2., 2011, pp. 743-752.

Daim, T. U., Ha, A., Reutiman, S., Hughes, B., Pathak, U., Bynum, W., Bhatla, A., "Exploring the communication breakdown in global virtual teams", International Journal of Project Management, Vol. 39, No. 2, 2010, pp. 199-212.

Dayan, M., Di Benedetto, A., "The impact of structural and contextual factors on trust formation in product development teams", Industrial Marketing Management, Vol. 39, No. 4, 2010, pp. 691-703.

Fain, N., Kline, M., Duhovnik, J., "Is new product development culturally bound?", Proceedings of the International conference on engineering and product design education, 2011, pp. 715-720.

Gausemeier, J., Dumitrescu, R., Kahl, S., Norsiek, D., "Integrative development of product and production system for mechatronic products", Robotics and Computer-Integrated Manufacturing, Vol. 27, No. 4, 2011, pp. 772–778.

IJsendoorf, H., "Application of computer aided systems", PD&E Automotive, E-GPR_Industrial case study, 2002.

Kayworth, T., Leidner, D., "The global virtual manager: A prescription for success", European Management Journal, Vol. 18, No.2, 2000, pp. 183–194.

Kock, N., "Designing E-Collaboration Technologies to Facilitate Compensatory Adaption, Information Systems Management", Vol. 25, No. 1, 2008, pp. 14-19.

Krznar, J. J., Belec, A. "Sampling of cultivated areas and livestock: methodology", No. 7., Statistical Office of the Republic of Slovenia, 2004.

Lipnack, J., Stamps, J., "Virtual teams: People working across boundaries with technology", 2nd ed., Wiley New York, 2000.

Oguntebi, J. O., "Creating Effective Global Virtual Teams: A Transactive Memory Perspective", Doctoral Dissertation, The University of Michigan, 2009.

Paul, S., Seetharaman, P., Samarah, I., Mykytyna, P. P., "Impact of heterogeneity and collaborative conflict management style on the performance of synchronous global virtual teams", Information and Management, Vol. 41, No. 3, 2004, pp. 303–321.

Pečjak, V., "Ideation: creative techniques in companies, schools and elsewhere", self-published, 1990 (in Slovenian).

Rezgui, Y., "Exploring virtual team-work effectiveness in the construction sector", Interacting with Computers, Vol. 19, No. 1, pp. 96-112.

Thompson, J. D., "Organizations in action", McGraw-Hill New York, 1967.

Žavbi, R., Tavčar, J., "Preparing undergraduate students for work in virtual product development teams", Computers&Education, Vol. 44, No. 4, 2005, pp.357-376.

Žavbi, R., Benedičič, J., Duhovnik, J., "Use of mixed academic-industrial teams for new product development: delivering educational and industrial value", International Journal of Engineering Education., 2010, 26(1), pp. 178-194.

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