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Collaborative Design Aspects in the European Global Product Realization Project*

AHMED BUFARDI, PAUL XIROUCHAKIS
Institute of Production and Robotics (IPR), Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland. E-mail: ahmed.bufardi@epfl.ch

JOŽE DUHOVNIK
Faculty of Mechanical Engineering, University of Ljubljana, Slovenia.

IMRE HORVÁTH
Faculty of Design, Engineering and Production, Delft University of Technology, The Netherlands.

The European Global Product Realization (E-GPR) project represents the main practical part of the E-GPR course organized by 3 European universities: the Swiss Federal Institute of Technology of Lausanne, the Technical University of Delft and the University of Ljubljana. It is defined in collaboration with the industrial partner(s) of the E-GPR course and consists of developing a global product that can be sold in Europe and other markets. The project provides the teams of participating students with an opportunity to put into practice the knowledge learned throughout the E-GPR course and during other related courses undertaken at their universities. In this paper we investigate how the collaborative design aspects are incorporated in the E-GPR project. There are two main activities in collaborative design to focus on: (i) concepts generation and (ii) concept selection. We noted that in the E-GPR project the concepts generation activity is well structured and organized to some extent whereas the concept selection activity is dealt with in an informal way. We show that in the concepts generation activity of the E-GPR project the students experiment with almost all the collaborative design aspects they have learnt during the E-GPR lectures. The concept selection activity is dealt with in an informal way whereas it is known that inefficient decisions during the concept selection activity can seriously affect the next stages of the product development. That is why we describe a group decision-making framework that allows structuring and formalizing the concept selection activity in order to improve its efficiency.

INTRODUCTION

NOWADAYS, product development is occurring in an environment characterized by various constraining factors such as expansion of global marketplace, multiplication of competitors, multiplication and rapid development of technologies, rapid obsolescence of products, varying and increasing requirements of customers, increasing pressure of national and international norms about safety and environmental issues, etc. Consequently, companies are striving to provide highly customized products with a shorter dilevery time and at lower cost. To this end, new trends in product development research have appeared among which we can quote collaborative product development which provides a relevant solution to the increasing complexity of product development problems, the time pressure and the need of different expertise from a variety of engineering fields. More often, the expertise and knowledge needed in collaborative product development are situated in geographically distributed places.

At the design level, it is evident that a single designer would not be able to face alone all these constraints and to satisfy all the design requirements within a reasonable design timeframe. That is why collaborative design is emerging as a promising alternative to classical design approaches. Collaborative design can be defined as a process where a product is defined through the collective and joint effort of two or more designers [1]. Several factors such as the increasing complexity of design problems (needs for collaborative design), the rapid developments in multimedia and network technologies (means enabling collaborative design) have favoured the emergence of collaborative design as an important trend in design research. Collaborative design has been investigated in the literature from various perspectives. Different collaborative design issues such as team and infrastructure organization, communication, modelling of interaction betweem team members, sharing of data, information and knowledge, conflict resolution, decision making, etc.

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reflect its complexity. Various disciplines such as decision theory, social science, operation management, computer science etc. have been used to deal with the different issues of collaborative design.

The significant developments realized in the domain of information technology allow the future CAD systems to move towards supporting distributed and collaborative design, in which geographically dispersed systems can be integrated and a virtual design team can be set up within an Internet/intranet environment [2]. The E-GPR course lies within the general scope of distributed collaborative product development in a virtual enterprise environment [3].

At the academic level, engineering education should enable students to get the necessary skills that allow them when they become professional engineers to face the challenges yielded by the new trends in current real-world design problems. Engineering students should be prepared to follow the emerging trend in industry that consists of using virtual teams [4]. The E-GPR course that works as an academic virtual enterprise is an initiative that contributes to achieving this goal. The involvement of an industrial partner with the intention of exploiting the results of the E-GPR project provides the participating students with an as-professional environment to practice collaborative global product realization. Wiersma [5] representing a company that has participated in the E-GPR course expects that the design concepts developed by the different teams should provide a strong basis for the development of target future products.

The main objective of the E-GPR course is to lay down the foundations of an academic virtual enterprise between universities from different European countries where the students who act as evolving young engineers work in distributed teams in order to collaborate in solving a global product development project using: (i) the knowledge acquired throughout the E-GPR course period, (ii) the knowledge learned during different courses at their universities (iii) information and data provided by the industrial partner(s) and (iv) their own contribution.

The teams are initiated to the various facets of global product realisation through selected lectures of experts from both academic and industry sectors. This course involves 3 main types of actors: knowledge providers, project providers and students (see Fig. 1). The knowledge providers are professors, experts, collaborators from the universities involved in the E-GPR course and from outside when needed. They give academic lectures and industrial case studies to students via videoconferencing. The objective of these lectures is to complete the knowledge acquired by the students via regular courses about design, manufacturing and related issues, by focusing on specific subjects related to global product realization such as virtual enterprise, prototyping, collaborative design, etc. The lectures balance between the practical and theoretical issues in order to provide the students with efficient tools to deal with a global product development project in a structured way.

The project providers are industrial partner(s) whose role is to define the problem to be solved by the students during the E-GPR project and to provide the necessary information and data. The objective of this project is to conceptualise, design, engineer, make a prototype, and prepare for manufacturing a global product to be sold in Europe and other parts of the world. The industrial partners define product specifications for the global products to be developed, and provide the information and data about the existing models in the same families of products. Their contribution is very important since it enables the students to put into practice the knowledge accumulated during the E-GPR course and during the basic courses in their curricula. The practice of product development allows the students to deepen their understanding of product development process and to improve their professional skills. The students are the main actors of the E-GPR course as they form the bridge between the academic knowledge and the industrial application. They are both knowledge consumers and knowledge providers since a simple application of the knowledge acquired can rarely yield a successful realization of a global product unless it is impregnated by their ingenuity and personal implementation.

In educational projects considering virtual teams as in the E-GPR project it is often assumed that

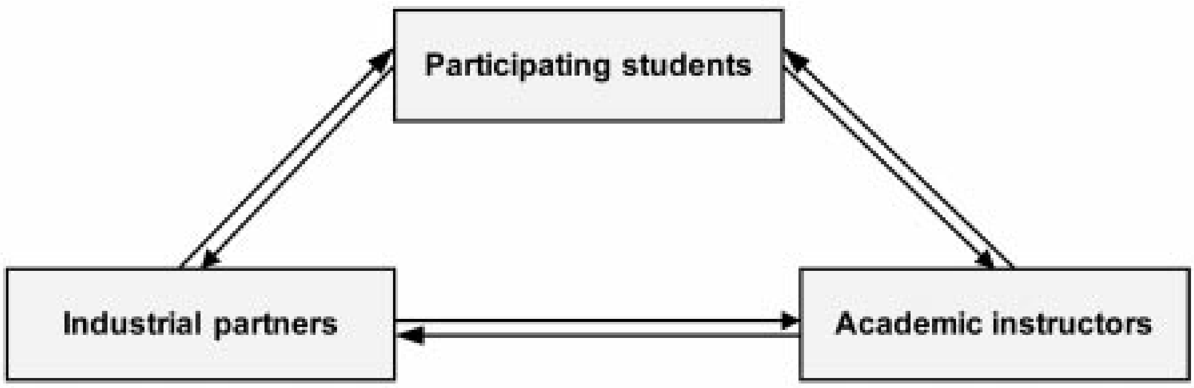

Fig. 1. Main actors in the E-GPR course.

the participating students know their responsibility, how to interact with other team members, how to contribute efficiently to the team work, etc. however more often this is not the case [6]. That is why it is also important [6] to include in the program course instructional material about team effectiveness, formation, planning and facilitation in order to overcome many practical and technical problems generally faced by virtual teams of students.

An important issue related to virtual teams is that of computer-supported collaborative (cooperative) work (CSCW). CSCW examines the different ways in which people work together in groups and how groupeware technologies can support group works where groupeware designates the set of computer-based systems designed to support people working together in groups such as e-mail, bulletin boards, group decision support systems, videoconferencing, etc. [7]. These tools provide efficient means for communication and data exchange, retrieval, storage, sharing and use between geographically dispersed team members. Most developments realized in the domain of CSCW are mainly concerned with technical issues such as data processing and transmission, groupware functions, software development, multimedia tools etc. and there are few studies about the role of CSCW in product development and design and its effect on problem-solving activities or processes [8].

The main application of CSCW is to support collaboration between geographically dispersed team members for which the conditions of a physical face to face environment requires traveling for some of them which implies several negative impacts related to time, travelling expences, effort, organization, etc. Kamel and Davison [9] claim that CSCW allows to overcome some probelms in face to face group interactions related to time, distance and space, and behaviour.

Not only the technical aspects of the collaborative work are important but also the content-based aspects. At the laboratory of computer-aided design and production (LICP) at EPFL, we developed a research area about the content-based aspects of the collaborative conceptual design. Two main activities are concerned: concepts generation and concept selection. The concepts generation activity cannot be fully supported by decision-making tools and methods since it involves creativity; an activity that cannot be formalized. However, the concept selection activity can be fully supported by decision-making tools and methods since it can be formalized as a pure decision-making activity. An essential problem in concepts generation is the aggregation of individual solutions of sub-problems into a global solution taking into account the constraints linking the different sub-problems, see [10] for the case of a single designer and [11–12] for the case of multiple designers.

For the concept selection problem, a common set of concepts is considered by all the individuals participating in the selection process as the set of alternatives to compare and from which the solution is to be selected. Each individual may have his own set of criteria depending on his interests and priorities. An essential problem here is to transform for each individual the evaluations of concepts on criteria into individual preferences reflecting the value system of the individual concerned [13]. In the case of a pairwise comparison of the alternatives, the preferences are usually given in the form of preference relations such as the indifference relation which indicates if two alternatives are indifferent or not, the strict preference relation which indicates if an alternative is strictly preferred to another or not, etc. Some lectures about Design for X aspects such as design for manufacturing and design for environment given by experts from EPFL can be seen as a contribution to the teaching of the content-based aspects of collaborative conceptual design in the E-GPR course as they allow to consider at the design stage, life cycle issues such as manufacturing and environmental performance of the product to be developed.

In this paper we investigate the collaborative design aspects in the concepts generation and concept selection activities of the E-GPR project. We show that in the E-GPR project the concepts generation activity is well structured and organized to some extent since the participating students experiment almost all the collaborative design aspects they have learnt during the E-GPR lectures even if some issues such as team effectiveness, team formation, planning and facilitation, etc. need more improvement through both specialized lectures and a follow-up on the ground. The concept selection activity is dealt with in an informal way which can weaken the overall design process since it is recognized that inefficient decisions during the concept selection activity can seriously affect the next stages of the product development. That is why a group decision making framework is proposed in order to allow structuring and formalizing the concept selection activity in order to improve its efficiency.

The links between the different topics addressed in this paper are shown in Figure 2.

THE E-GPR PROJECT

An important component of the E-GPR course is the E-GPR project (Fig. 3) where teams of students from three European universities are formed in order to solve real-life problems related to the development of global products as proposed by the industrial partner(s) involved in the E-GPR course. The E-GPR project is a one-semester project (4 months, 12 hours per week) intended for master of science level students. It comprises several steps among which we can quote: market analysis (present products on the market, competition, trends, market opportunities), financial

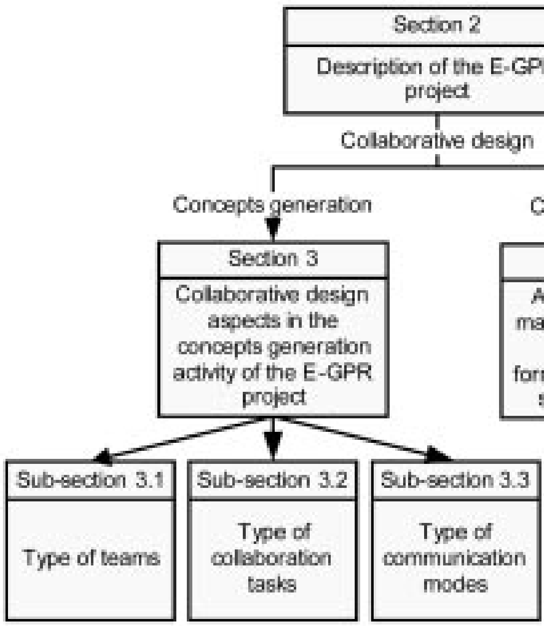

Fig. 2. Links between the different topics addressed in the paper.

issues, product specifications, concepts generation, concept selection, materialization and prototyping (see Fig. 4). In this paper we mainly focus on the concepts generation and concept selection activities of the E-GPR project and investigate the related collaborative design aspects.

The E-GPR course and its working environment is built around the E-GPR project [5]. This fact reflects the great importance of the E-GPR project within the E-GPR course. In this project as in any problem-based learning environment, it is the problem that drives the learning process. The content of lectures and case studies of the associated course is aimed to support the students in solving the problem they are given. The fact that the knowledge learned from the E-GPR course is used in parallel to solve the problem under consideration provides an efficient way to develop professional skills of the participating students.

Each team comprises two or three students from each of the three participating universities: the Swiss Federal Institute of Technology of Lausanne (from Switzerland), the Technical University of Delft (from The Netherlands) and the University of Ljubljana (from Slovenia). The students from the three universities present completely different profiles [3]. On the one hand this has the advantage of providing complementary knowledge and

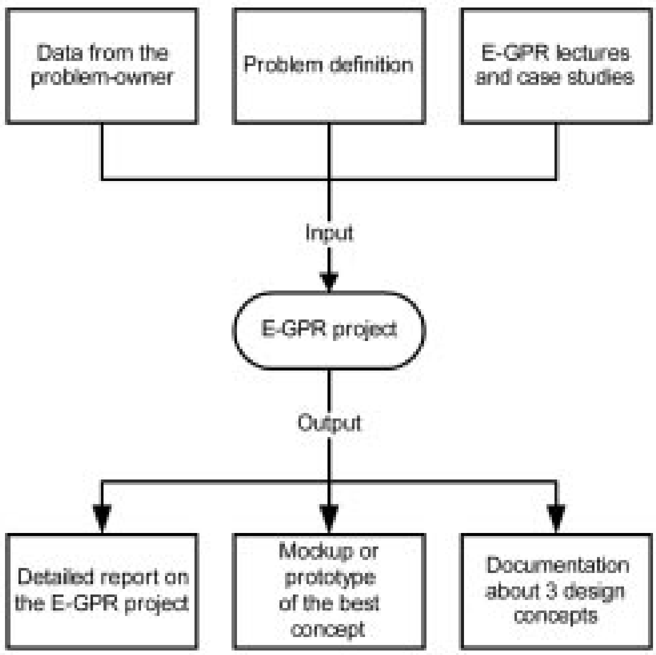

Fig. 3. The general framework of the E-GPR project.

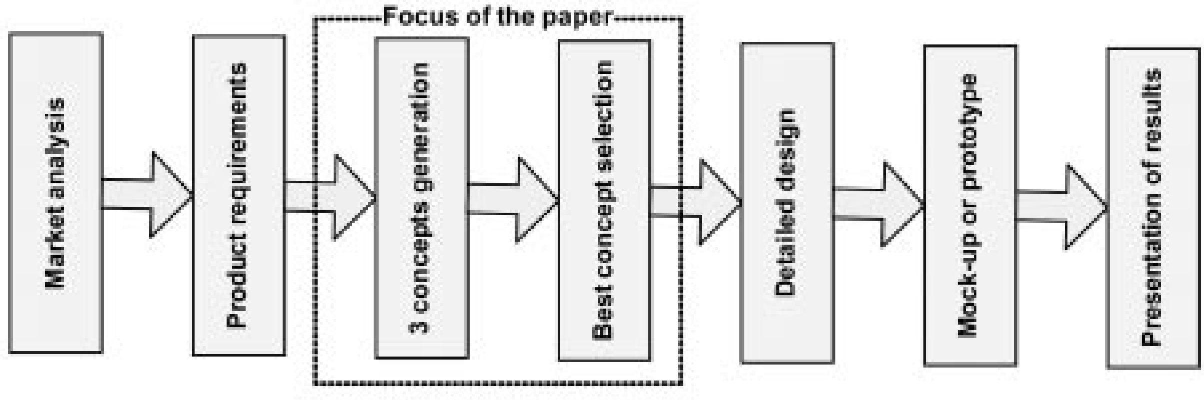

Fig. 4. The main steps of the E-GPR project.

expertise that are needed for the development of a global product and on other hand it poses the problem of handling the variety not only in skills and expertise but also in viewpoints about the same subjects. Hence, multidisciplinary teams with competence in various domains such as industrial design engineering, mechanical design and engineering, micro-engineering, electrical engineering, etc. are formed to collaborate on developing a global product.

Before the start of the project, the students are informed about its objectives, the timing for its realization and the deliverables to be provided at specific dates. Throughout the project duration, the students attend via videoconferencing academic lectures and industrial case studies about issues related to global product realization which can assist them during the project development. For example in the 2003 edition of the E-GPR course, the E-GPR project consisted of the development of personal protective means for the welding industry as proposed by the industrial partner of the E-GPR course for this edition: the Vlamboog company.

Instructors from the three universities monitor the progress of each team on a regular base and ensure that the rhythm at which developments are being made can lead to the expected deliverables and respect the due dates. They also provide technical and knowledge support and advice to the teams whenever needed and ensure that the developments made are compliant with the project objectives and requirements. It can happen sometimes that the instructors act as mediators in case of strong disagreements between members of a team or a lack of participation of some members of a team and so on. Their role is not only technical but also social.

Concerning the formation of teams, students from the three universities do not join the project at the same time because of the differences in the starting dates of each university. The first cells of teams are formed at the Technical University of Delft then students from the two other universities are free to join the team they want; the only constraint to take into account is that each team should comprise at least two students from each university. From previous experiences, the formation of teams does not pose any significant problem. Each team chooses a name and sometimes develops a logo. These aspects contribute to the socializing between the members of each team.

For the communication between the members of a team, the main tool used is NetMeeting but other tools such as AOL instant messenger, ICQ, Yahoo-chat, E-mail are also available and are occasionally used [3]. A blackboard hosted by the Technical University of Delft is used by students, instructors and lecturers for storing documents and results, sharing information and making announcements. It can also be used to monitor the progress of the work of the different teams.

Teams such as the E-GPR project teams with little common experience but with high willingness to work together to achieve specific goals are called future teams [14]. The members of a future team such as a newly formed project team show a great motivation for interaction and communication as they anticipate a future together [14]. Cohen and Bailey [15] distinguished four types of teams which are: work teams, parallel teams, project teams, and management teams. According to this classification the teams of students involved in the E-GPR project are project teams. Quoting Mankin, et al. [16], they defined project teams as being limited in time and producing one-time output. Cohen and Bailey [15] described project teams' tasks as being non-repetitive in nature and involving considerable application of knowledge, judgment, and expertise.

As in professional collaborative teams, students participating in the E-GPR project may differ in attributes such as domain knowledge and task and may have different cultures, preferences, ways of thinking, etc. However, since they share the responsibility for the final results of the project, the team works in a friendly and trusting manner and does the best for the success of the project.

A number of computer-aided design (CAD), computer-aided engineering (CAE) and computer-aided manufacturing (CAM) packages are available for the participating students [3]. Each team is free to select what it considers as suitable.

However, problems of incompatibility when exchanging data and when integrating results from different packages should be avoided.

Until now the students participating in the E-GPR project are not taught how to deal with complex decision-making problems such as concept selection. A systematic approach to decision making allows students to learn how to act in a logical and organized way when they face decision making. A proposal to improve the E-GPR project from this viewpoint is presented below. Lectures about decision-making tools and methods that are relevant to the needs of the E-GPR project are highly recommended. Moreover these methods and tools when well understood can be used for dealing with similar decision-making situations in other projects and disciplines which can enhance the decision-making skills of the participating students.

COLLABORATIVE DESIGN ASPECTS IN THE CONCEPTS GENERATION ACTIVITY OF THE E-GPR PROJECT

Design, from an educational point of view, is mainly characterized by the lack of a clear separation between theoretical knowledge and practical skills [17]. That is why teaching design should adapt a strategy paralleling theory and application. Students should learn both what is design and how to do design. This strategy is respected in the E-GPR course since it parallels academic lectures with strong theoretical knowledge and the development of the E-GPR project that involves the application of intensive practical skills.

There are two main activities in the conceptual design phase: (i) generation of design concepts and (ii) selection of the best design concept(s). In the E-GPR project, due to the limitation in time, the participating teams are requested to generate only 3 different design concepts. Until now the selection activity is done informally by the professors of the three involved universities and the representative(s) of the industrial partner(s) during the review meeting preceding the closing workshop. The collaborative design aspects raised in this section concern mainly the design concepts generation activity. The concept selection activity is considered below.

On the one hand, moving from classical conceptual design (with a single designer) to a collaborative conceptual design environment where two or more individuals are involved introduces a great deal of complexity into the design process since several issues such as the organization of the participants, their communication, distribution of tasks, their interaction, conflict resolution, decision making, etc., should be dealt with and on the other hand collaborative conceptual design may benefit from the developments made over several years on various disciplines such as design, group decision making, CSCW, team theory, social science, activity theory, etc. (see Fig. 5).

Traditionally, a designer faces alone a design problem and was assumed to have eclectic knowledge about a variety of disciplines. The rapid growth in knowledge in all engineering fields leads to more specialization in the curriculum of engineering programs and renders the education of engineers with a broad range of competencies more difficult, even impossible [18]. A single designer

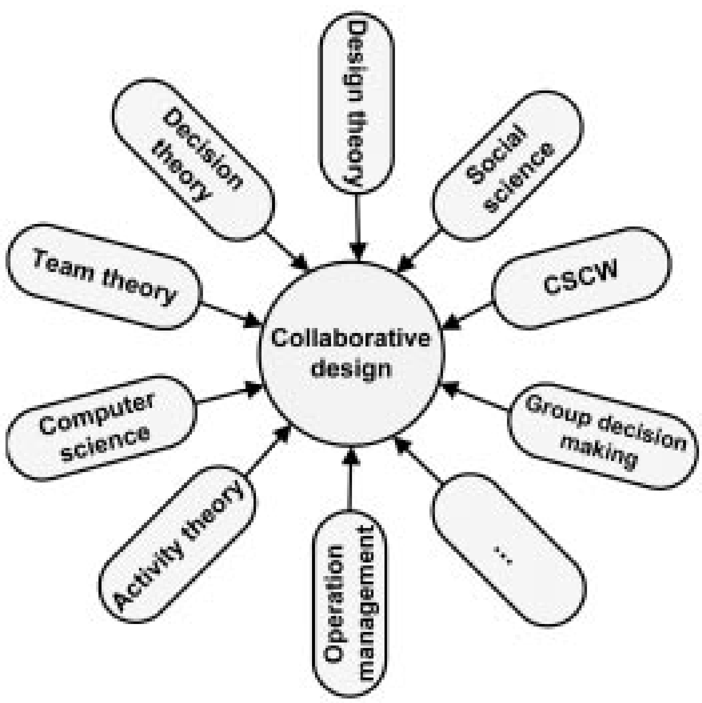

Fig. 5. Disciplines from which collaborative design can benefit.

does not have to deal with problems such as conflict resolution and mutual agreement but will not have the advantage of collaboration [19].

With the increasing complexity of products, the rapid development of technology and time pressure, collaborative design becomes an efficient alternative to classical design (without collaboration). For very complex design problems that necessitate knowledge and expertise from a variety of engineering fields, collaboration is not a matter of choice but becomes a necessity. The collaborating designers bring their individual resources in terms of knowledge, experience, motivation, etc. into the design situation. Complementarities between the participants in the design process due to the differences and variety in their skills and background, and interaction due to different viewpoints about common skills are very beneficial for collaborative design [20].

The way in which the team deals with issues such as discussions, conflict resolution, decision making etc. affects positively or negatively the performance of each team member [21]. Johnson, et al. [6], pointed out other problems that can arise in virtual teams such as the lack of willingness to participate (of some participants), lack of planning (of tasks and meeting sessions), conflicting schedules, and individual disagreements. Consequently the prerequisites of the group have a great influence on the design process and its results since they affect the performance of the group members [21]. This was one of the issues reported by Wiersma [5] concerning the experiences of the Vlamboog company within the E-GPR project. He remarked that some teams were more motivated and performed better than others and within the same team some members performed better than others.

The 'multidisciplinarity' in the background of the different team members is a strong factor of motivation for students to work together. Another factor of motivation can be driven from the way in which the project is defined. A project involving a high level of innovation and having multidisciplinary objectives is always attractive for students and allows an optimal exploitation of the knowledge and expertise of the different team members. From past experience of the E-GPR projects, there were often some innovative solutions proposed by students coming from other disciplines than mechanical design, such as telecommunications, informatics, etc.

Collaborative conceptual design research involves several important issues among which we can quote: type of distribution of the team (traditional vs. virtual), type of collaboration between team members (single task collaboration vs. multiple task collaboration), type of communication mode (synchronous vs. asynchronous).

In this section we show that various aspects of design collaboration are covered by the concepts generation activity of the E-GPR project in a more or less formal way.

Traditional team versus virtual team

Lurey and Raisinghani [22] cited references defining teams as groups of individuals sharing a common purpose or goal and interacting interdependently within a larger organizational setting.

Two types of teams can be distinguished in collaborative design depending if all the participants in the design process are located at the same physical location or not. These are traditional teams and virtual teams.

Traditional (co-located) team is a term used to designate a team whose members are all located at the same physical location and communicating without using technological support. A traditional teaming approach is commonly used in engineering education to prepare the students for team-oriented workplace in engineering jobs since team projects are a usual practice on many courses in engineering curricula [23].

A distributed team that is also called a virtual team is a term used to designate a team whose members are geographically distributed (dispersed) in different locations usually connected together by means of communication technologies.

Etter and Orsak [23] consider a virtual team as an extension of the traditional team that enables to include geographically dispersed partners through the use of advanced technology. They claim that the adoption of virtual teaming approaches in engineering education provides a better preparation of the students to the new trends in teamwork in industry where working in virtual teams is becoming in vogue.

Each team participating in the E-GPR project involves at least two students from each university. The members from the same university (often from the same section and knowing very well each other) and belonging to the same team form a sub-team or a local team. Depending on each university, there could be an instructor for each sub-team or an instructor for several sub-teams.

The team members in each university work together as a traditional team either because they work on the same task or because they share the same infrastructure which is in general limited in the universities.

The teams in the E-GPR project are virtual teams since they include students from three different locations. According to Fig. 6, the teams in the E-GPR project can be seen as virtual teams composed of co-located (traditional) sub-teams.

The intensive interactions within traditional local sub-teams and the harmonized complementarities between the different local sub-teams within the virtual team are a key success factor of the E-GPR project.

Single task collaboration versus multiple task collaboration

Nowadays, design problems are becoming more and more complex. To deal with this complexity, the most used strategy consists in dividing the design problem into sub-problems of lower

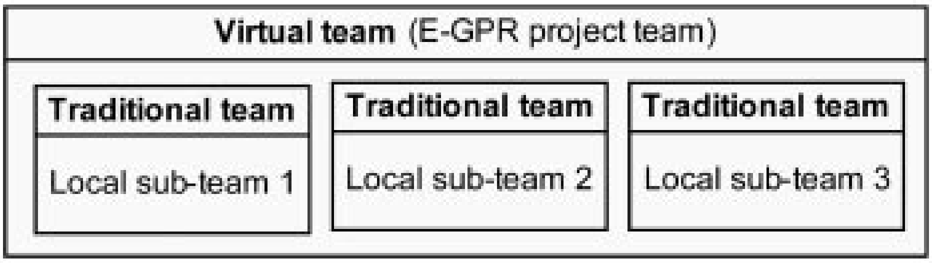

Fig. 6. Virtual and traditional characteristics of the E-GPR project teams.

complexity. The functional decomposition method of Pahl and Beitz [24] may provide an efficient way to define the individual design tasks by considering the search for concept solutions for each sub-function as an individual design task. In such a case, each individual design task is developed in parallel by a single designer or a design team. Then the solutions to the individual sub-functions have to be combined to provide global solutions to the overall function by taking into account the constraints linking the different sub-functions.

In collaborative design, two types of design collaboration can be distinguished: single task collaboration and multiple task collaboration. The type of design collaboration reflects the way in which the design tasks are dealt with by the participants in the design process.

In the single task collaboration, several designers work together on the same task. In such types of collaborative design, whenever a designer has a new idea he or she uses one of the available means such as drawings, gestures, lists, physical prototypes, etc., to convey it to the other collaborating designers [20]. The conceptual design process progresses in a such a way that collaborating designers construct on each other's ideas by adding new propositions, pointing out constraints, making comments, etc. This case where the participants act as a unitary entity is similar to the case of a single designer except that the involvement of several individuals in the realization of the same task may allow for the generation of several and various alternatives.

In the multiple task collaboration, the different design tasks are assigned to different designers or design teams, i.e. each designer or design team has a specific design objective or work on a specific sub-function. In this type of collaboration, there could exist dependencies between different design tasks. The dependent (also called coupled) tasks may be a source of conflict between the different designers or design teams. To avoid this and ensure the consistency and coherence of the whole design these dependencies should be taken into account during the design process.

In the E-GPR project, most often the members of a local sub-team work on the same task which means that the resulting type of collaboration is a single task collaboration. Each local sub-team works generally on a different task than other local sub-teams which means that the type of collaboration of the whole team is a multiple task collaboration (see Figure 7). There often are dependencies between the different tasks on which the sub-teams work on. The state of progress of each sub-team is regularly communicated to other sub-teams in order to allow them to take into account the constraints generated by the new developments in their future work.

In the 2003 edition of the E-GPR project, a local sub-team from the Swiss Federal Institute of Technology mentored by the first author worked as a single task team on the development of a new concept of a protective system of welders based on the use of two cameras placed on the welding helmet as shown in Fig. 8.

The other local sub-teams worked together as single task teams to design the other parts of the whole system comprising a helmet, a blower unit and a hose [5]. The whole team acted as a multiple task design team and provided the integrated solution in Fig. 9 (see Viersma [5])

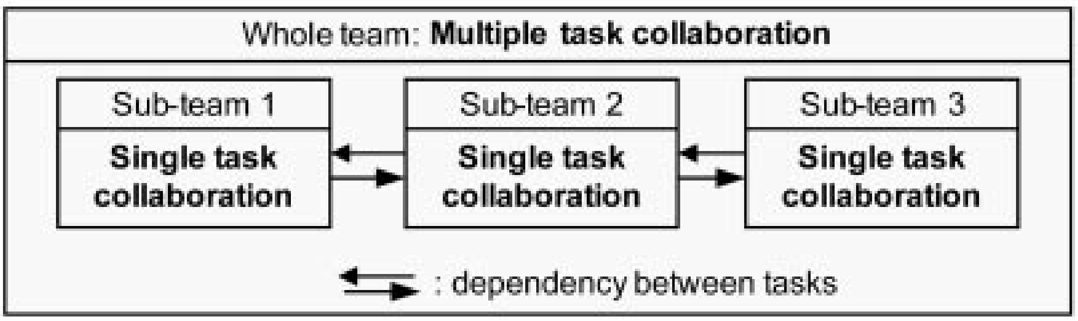

Fig. 7. Single task collaboration and multiple task collaboration in the E-GPR project.

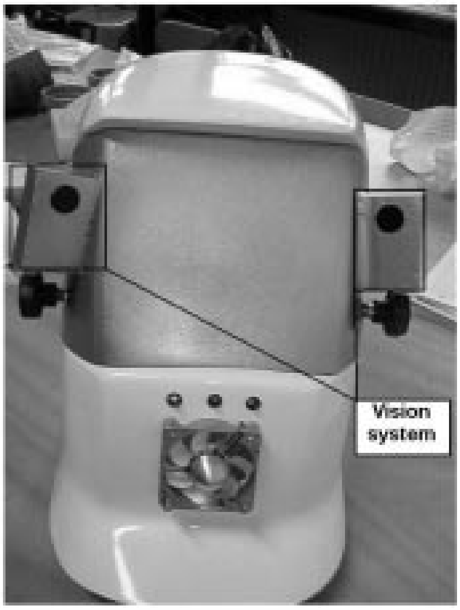

Fig. 8. Vision system for protecting the welders.

Synchronous communication versus asynchronous communication

There exist two main communication modes that can be considered in collaborative work such as collaborative design: the synchronous communication mode and the asynchronous communication mode. For each communication mode, there exist a number of communication tools that enable it.

The communication tool to be used depends on the type of distribution of the communicating persons (co-located or distributed) and the type of communication mode (asynchronous or synchronous). Table 1 provides some communication tools according to the type of distribution and communication mode. This list of communication tools is not exhaustive and is just used for illustration.

The E-GPR project requires intensive communication between the members of each team. Various communication means in both synchronous and asynchronous modes are provided to the teams participating in the E-GPR project. The sub-local teams use in the synchronous communication, face-to-face communication when they meet together and the phone when they are not together. In the asynchronous mode, e-mail is the most used. For the whole team, several NetMeeting sessions are planned during the E-GPR period as the main synchronous way of communication. When necessary videoconferencing sessions are organized. For the asynchronous communication, e-mail is the most used.

As it can be seen from this section, almost all aspects of collaborative design are involved to some extent in the concepts generation activity of the E-GPR project.

A GROUP DECISION-MAKING FRAMEWORK TO STRUCTURE AND FORMALIZE THE CONCEPT SELECTION ACTIVITY IN THE E-GPR PROJECT

In the E-GPR project, each team is asked to develop three different concepts for the global product under consideration and the best design concept is to be selected among these three design concepts during the final review meeting that takes place before the closing workshop that concludes the E-GPR course and project.

The concept selection problem in conceptual design consists of selecting one (or more) design concept(s) to be further refined in the following stages of the design process. The concept selection problem is important because the selection of a poor design concept can rarely be compensated for at later design stages and incurs great expense of redesign cost [25]. Each concept selection method in conceptual design belongs to the class of unstructured approaches or to the class of structured approaches [26]. In the previous editions of the E-GPR project, the concept selection activity was made in an unstructured way, which can

Fig. 9. A comprehensive solution for protecting welders.

Table 1. Examples of means of communication according to the type of distribution and mode of communication

	Type of distribution	
	Co-located	Distributed
Mode of communication		
Synchronous	• Face to face communication • Phone	• Chat • Videoconferencing • Teleconferencing • AOL instant messenger
Asynchronous	• E-mail	• Regular mail • E-mail • Use Net

deprive of the benefits of using a structured approach such as the multiple criteria group decision making approach.

One way of reinforcing the collaborative conceptual design process in the E-GPR project is to use a structured approach for the concept selection activity. Such an approach has many advantages:

- consideration of objective criteria for the comparison of design concepts,
- acting in a logical and organized manner,
- avoidance of personal influence,
- documentation and argumentation of the results of the selection activity, etc.

The selection of the ‘best’ design concept(s) from a given set of design concepts is recognized to be a multiple criteria decision-making problem because the participants in the concept selection activity need to consider not only the required product functionality, but also other life-cycle criteria such as manufacturability, assemblability, reliability, maintainability, etc. [25]. These criteria are often conflicting and since they should be considered

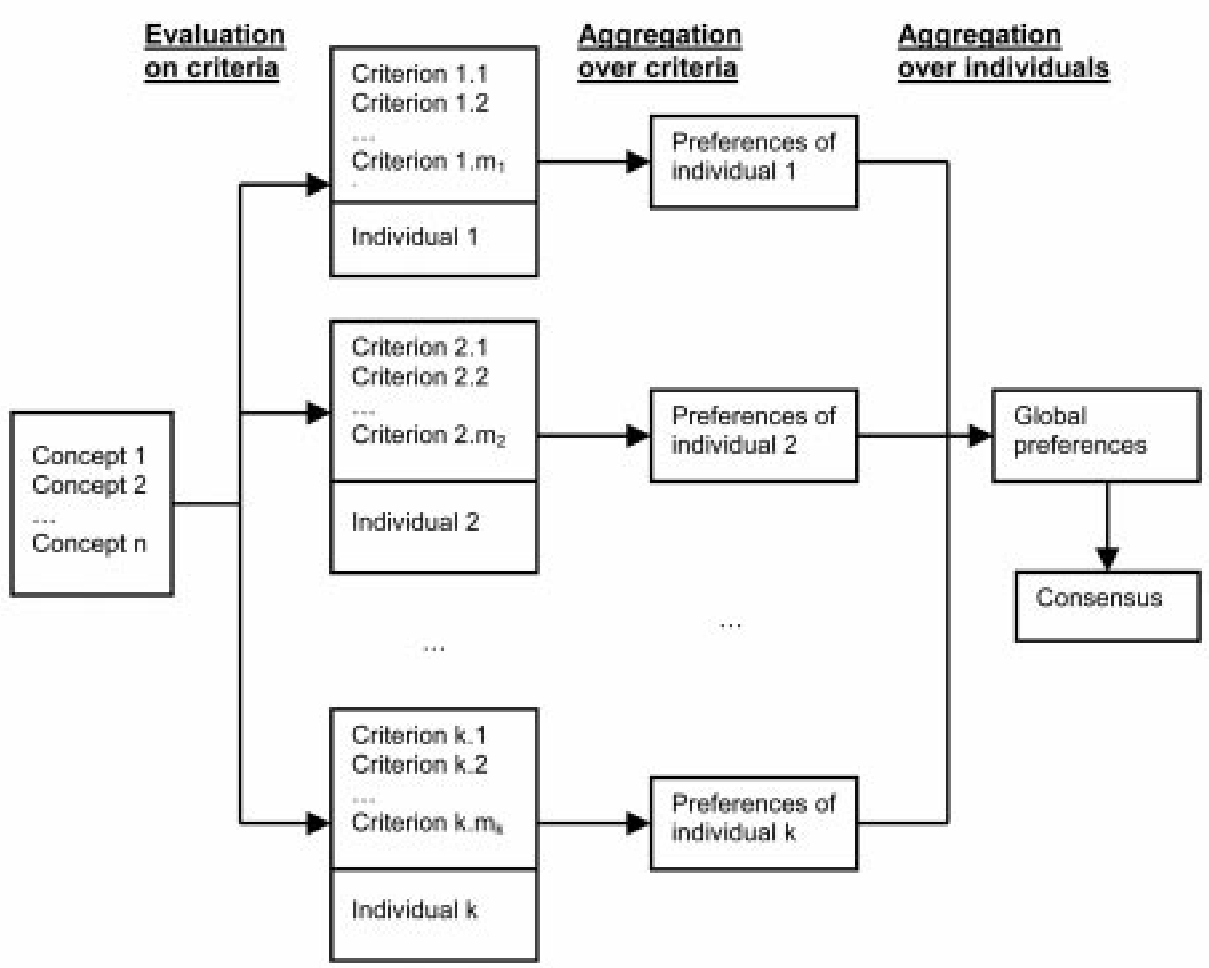

Fig. 10. An MCGDM framework for the concept selection activity in the E-GPR project.

simultaneously, there will rarely exist a solution that is optimal with respect to all criteria. That is why the decision makers should analyze the trade-offs between the different criteria and make a selection from the set of available alternatives.

Based on the fact that the set of alternatives (design concepts) is finite and given explicitly then a multiple criteria decision making methodology (with one or more decision makers) should be used instead of a multiple objective optimization methodology where the set of alternatives is implicitly defined by means of satisfaction of a number of mathematical equations. For the concept selection problem in the E-GPR project several individuals are involved in the decision-making process hence a multiple criteria group decision-making method (MCGDM) is suitable.

Until now the concept selection activity is done in an ad-hoc manner and no serious evaluation of concepts is performed. Consequently, the decisions made are very subjective. The laboratory of computer-aided design and production (LICP) at EPFL intends to integrate in the E-GPR project an MCGDM approach to enable a suitable formalization of the selection activity.

Since the individuals participating in the decision making process have different expertise, backgrounds and skills, it is normal to assume that each individual may consider only the criteria that are related to this activity and which can be evaluated more objectively. Consequently, the decision makers can share none, some or all the criteria. However, the set of alternatives (design concepts in the E-GPR project) should be common to all individuals in the group (see Fig. 10). This prerequisite seems to be reasonable because it is difficult to reach a global consensus among the group if the members do not consider the same set of alternatives [27].

There exist several MCGDM methods. They differ in the way the alternatives are evaluated on criteria, the way the monocriterion preferences are aggregated for each individual, the way the individual preferences are aggregated, the way the consensus is determined from the global preferences etc. The most suitable MCGDM methods for concept selection at the conceptual design stage are those that do not need accurate quantitative inputs for the evaluation of design concepts. They should allow the participants in the selection process to describe the performance of a concept with respect to a criterion qualitatively or in a fuzzy way if a precise and accurate evaluation cannot be provided as in Table 2 (the criteria and

Table 2. An example of model for concepts evaluation

Category	Criterion	Type (qualitative / quantitative)	Evaluation scale	Unit	Preference direction (maximize / minimize)	Weight of criterion (in [0,1])	Evaluation		
							Concept 1	Concept 2	Concept 3
Technical	Manufacturability	qualitative	very easy, easy, average, difficult, very difficult	—	min	0.7	difficult	easy	average
	Assemblability								
	other								
Functional	Autonomy 1	quantitative	—	hours	max	0.5	24	8	12
	Autonomy 2	qualitative	very low, low, average, high, very high	—	max	0.5	very high	low	average
	other								
Economical	Global cost to manufacture 1	qualitative	very low, low, average, high, very high	—	min	0.7	average	high	average
	Global cost to manufacture 2	quantitative	—	€	min	0.7	[150, 200]	[200,250]	[100,150]
	other								
Ergonomical	Comfort	qualitative	very bad, bad, average, good, very good,	—	max	0.4	bad	good	very good
	Mobility in movements	qualitative	very reduced, reduced, average, good, very good	—	max	0.4	very good	very good	reduced
	Weight	qualitative	very light, light, average, heavy, very heavy	—	min	0.3	light	average	light
	other								
Environmental	Recyclability	qualitative	very low, low, average, high, very high	—	max	0.2	low	low	high
Other categories									

related values and attributes given in this table are just for illustration and do not correspond to an existing case study).

The consensus reaching process is a necessity for all group decision-making processes because the achievement of a general consensus about the selected alternatives is a desirable goal [28]. Initially the individuals forming the group have often disagreeing opinions about the set of alternatives. Hence the issue of measurement of consensus inside the group is of major concern in group decision-making environments. The MCGDM methods provide procedures to determine the group consensus.

The use of a structured MCGDM method in the selection activity is essential in the E-GPR project. We also believe that the introduction of decision making theory in engineering courses will enhance the decision-making capabilities of students that will be very useful in their professional life.

CONCLUSION

The E-GPR project provides an efficient way for teaching collaborative conceptual design issues since it adopts a strategy paralleling theoretical knowledge and practical skills. Indeed, on the one hand to develop it, the participating students need specialized lectures initiating them to various aspects of the collaborative design activity and on the other hand during the development of the project the students learn to put into practice the techniques learned from these lectures by dealing with real cases of design collaboration provided by the industrial partner(s) of the E-GPR course. Hence the students act as knowledge consumers by applying the knowledge learned from the E-GPR lectures in solving a real life engineering problem and as knowledge providers since a successful realization of the project cannot be achieved without their own contribution, ingenuity and personal involvement.

In this paper we have shown that the E-GPR project involves several aspects of collaborative design in a more or less formal way especially in the concepts generation activity such as type of distribution of the team (co-located vs. distributed), type of collaboration between team members (single task collaboration vs. multiple task collaboration), type of communication mode (synchronous vs. asynchronous). Most of these issues are dealt with in an informal way without knowing what are the advantages, drawbacks, constraints, etc. To enable the participating students to deal efficiently with these issues the E-GPR course should provide not only lectures showing what is design collaboration and related issues but also lectures showing how to do efficiently design collaboration including communication and organization issues.

Each team is assumed to develop three different design concepts for the product under consideration and only one design concept is to be retained for further refinements in the following phases of the E-GPR project. Consequently, the participants in the E-GPR project find themselves confronted with a selection problem which involves the evaluation of design concepts with respect to relevant criteria reflecting various facets and processes and lifecycle phases of the product, the comparion of the design concepts and the selection of the 'best' one by a group of experts. Until now the selection activity is done in an unstructured way which deprives of the benefits of using a structured MCGDM approach that is suitable for such selection problem. We believe that if we adopt a structured selection approach such as an MCGDM approach we will teach the students a new way for dealing with complex decision making problems in a logical and organized manner and enhance the outcomes of the E-GPR project.

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Ahmed Bufardi holds a Ph.D. in Science from the Université Libre de Bruxelles in April 2000. He joined the laboratory of computer-aided design and production (LICP) at Ecole Polytechnique Fédérale de Lausanne (EPFL) in March 2001 and developed research activities on group decision making in collaborative design, decision making-based approaches in conceptual design, fuzzy sets-based methods for modelling uncertainty in conceptual design and multiple criteria decision making methods for product end of life treatment. Among his activities the teaching of a doctoral course titled ‘decision making-based approaches in conceptual and collaborative design’.

Paul Xirouchakis is a Doctor Professor directing the computer-aided design and computer-aided manufacturing (CAD/CAM) laboratory, institute of production and robotics at the Swiss Federal Institute of Technology in Lausanne, Switzerland. His research interests are in the areas of (i) product modelling and reasoning for manufacture/assembly/remanufacture, (ii) manufacturing information systems, and (iii) informatics for planning and scheduling for manufacture/assembly/remanufacture. Current project activities include: CAD tools for conceptual design of mechanical assemblies, geometrically intelligent NC-controllers built on feature-based post-processors and planning and scheduling of remanufacturing systems. Professor Xirouchakis is a full member of IFIP Working Group 5.3: Computer Aided Manufacturing. Professor Xirouchakis has industrial experience with CAD industries in the USA where he directed computer-aided simulation-based design projects. He has been a professor at the National Technical University of Athens and the

Massachusetts Institute of Technology in the area of Structural Mechanics. He obtained his Ph.D. in Structural Mechanics in 1978 from Massachusetts Institute of Technology.

Jože Duhovnik is a full professor of computer-aided design at the Faculty of Mechanical Engineering, University of Ljubljana, Slovenia. His pedagogic and research work is oriented towards design theory, development technique, project management, information flow in CAD, PDM/PLM and geometric modeling. He is the founder and head of the CAD Laboratory (LECAD) at the Faculty of Mechanical Engineering since 1983. He is leading the LECAD Group laboratories in some countries since 2004. He received a BS, a MS and a Ph.D. in mechanical engineering design in 1972, 1974 and 1980, respectively. His postdoctoral study took place at the Department of Precision Machinery Engineering at the University of Tokyo, Japan. He also has more than 14 years of engineering design experience in industry (COLOR—Medvode, SAVA—Kranj, SCT—Ljubljana, LITOS-TROJ—Ljubljana, etc). He is a member of VDI, IFToMM, Eurographics, New York Science Academy and ZSiT (national society of mechanical engineers). He is currently professor at University of Ljubljana, University of Zenica and Sstrossmayer University in Osijek.

Imre Horvàth (1954) is a full professor of Computer Aided Design and Manufacturing. He received his M.S.c in mechanical engineering (1978) and in engineering education (1980) from the Technical University of Budapest. He was working for the Hungarian Shipyards and Crane Factory between 1978 and 1984. He has had faculty positions at the Technical University of Budapest between 1985 and 1997. He earned a dr. univ. title (1987) and a PhD title (1994) from the TU Budapest, and a CDS title from the Hungarian Academy of Sciences (1993). His affiliation with the Delft University of Technology started in 1997. His primary research interests are in computer support of conceptual design, vague shape modelling, free-form fabrication of editable physical concept models, shape conceptualization knowledge and shape information content/entropy.