Configuration Model for Evolvable Assembly Systems

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The assembly systems domain in recent years has been pressed to provide highly adaptable and quickly deployable solutions and deal with unpredictable changes according to market trends. Furthermore, the current decreasing product lifecycles provided the need for more reusable assembly systems to distribute the system costs across different products. In this context a new concept of Evolvable Assembly Systems has been introduced in this research domain to address these issues. The introduction of this approach presents new challenges but also opportunities for current modular assembly system configuration methods. While the focus on standardised process models makes more automatic configuration approaches more feasible, challenges of how to effectively manage such standards arise at the same time. Furthermore, higher and lower levels of granularity in assembly system modularisation require hierarchical decomposition and consequently synthesis which are notoriously challenging topics for automatic configuration methods. This paper reports on a new configuration method which use a process focused semantic model, as basis for assembly system configuration. The paper identifies all the necessary concepts that enable evolvable assembly systems, namely the assembly system requirements, equipment definition, capability models and overall evolvable assembly system operation process. The potential of this approach is shown to significantly reduce the system configuration and control deployment effort for agent-based modular assembly systems.

Keywords: Adaptive control, Agent, Assembly, Automation, Conceptual design, Emergent synthesis, Flexibility, Intelligent, Knowledge based system, Lifecycle, Mechatronic, Model, Modelling, Modular design, Module, Open architecture, Process, Reconfiguration, System architecture.

1. Introduction

An analysis of the current context of the assembly system domain and its trends has identified serious challenges [1] . Systems require an increasingly high level of responsiveness due to the market demand for increasing product diversity, shorter product lifecycles and shorter times to market while maintaining the cost at a minimum and quality at a maximum [2]. Nowadays, markets are truly global and are characterized by an intensive global competition which is conditioned by socio-economic aspects that influence the assembly systems. In addition to this, market have become increasingly dynamic and unpredictable, requiring product changes and adjustments which emphasises the need more flexible assembly systems.

These challenges have led to several technological advances targeting more flexible, agile and adaptable systems. Assembly shop floors with higher degrees of automation must therefore become as adaptable as their competitors who rely on the techno-economic flexibility of human labour. The concept of flexibility needs to be extended to enable the structure and layout of complex assembly systems to be rapidly built, adapted and enhanced on demand, thus drastically cutting time-to-market and new product introduction times. Shop floors, besides flexibility in terms of product variance and capacity, need to be easily reconfigured, changed and adapted to dynamic conditions with a high rate of variability. Consequently there is a need for a new generation of innovative, rapid deployable, self-configuring plug-and-produce assembly systems, which can be configured with minimal effort to meet a wide range of individual assembly requirements and are enhance-able without disrupting production.

Evolvable Assembly Systems (EAS) provide a new paradigm that takes advantage of the recent advances in modular assembly systems, enhancing them with the concept of evolvability [3]. The vision behind these system it to take advantage of the “Plug & Produce” concept, building highly adaptable mechanical and control solutions that target reusability and interoperability of modules, both logical and physical, enabling the extension of the modules lifespan, while providing shorter deployment times. This paradigm proposes the use of agent technology as the basis for controlling the assembly systems where each agent implements one or more assembly processes as so called skills. Skills represent the control equivalent to hardware modules and follow the object oriented approach of encapsulating reusable functionality. This combined with the agent technology provides a natural way for the devices to define clear sets of interchangeable and easy to configure control capabilities and allow their quick deployment into working systems.

This paper provides the definition of a skill concept, which allows for the description of the capabilities of different equipment and how these can be triggered and operated. Furthermore, the concept of skill recipes is introduced to provide the possibility to have deterministic systems using evolvable assembly systems. The paper provides an overall model that defines links to all the necessary concepts for the successful configuration of EAS.

2. Literature Review

An analysis of the current context of the assembly systems domain, quickly leads us to the growing need for higher levels of flexibility. The issue of flexibility in assembly systems is not new and has been one of the main research topics in the field of assembly, namely Flexible Assembly Systems (FAS), which provided the first concepts to introduce bigger flexibility through mainly the increase of the systems capabilities "just in case" and adding cost to the system[4, 5]. However, in realistic terms, these systems are still not common within industry. The fundamental reason behind this is, although technologically interesting, these systems fail to provide cost-effective solutions for industry as flexibility itself requires added capabilities in the system. This means that the system has components which are not always in use, which makes the system have high degree of redundancy [6].The concept does provide extra flexibility, but it is restricted to what can be predicted to be needed in the future. This raised other research questions on how to have a more flexible system that is able to deal with the market needs, without adding extensive amounts of redundant equipment that might never be used. It is in this context that notion of agility was introduced.

Traditionally, agility has been comprehended as the capability of an enterprise to operate in a "competitive environment of continually, and unpredictably, changing costumer opportunities" [7]. It is important to note that being agile is different from being flexible. Agility defines change as a normal process, which is quite complex to predict and plan for. Thus, in order to have truly agile systems one needs to incorporate the ability to adapt to change. This concept led to the emergence of several production paradigms: Bionic Manufacturing Systems (BMS) [8], Holonic Manufacturing Systems (HMS) [9][13], Reconfigurable Manufacturing Systems (RMS) [10] , Reconfigurable Assembly System (RAS) [11], Evolvable Assembly Systems (EAS) and Evolvable Production Systems (EPS) [3, 12, 13]. These paradigms denote the common concept of encapsulation of functionality in self-contained modules. These modules are then used as building blocks of the production system, thus taking advantage of the concept of "Plug & Produce" [14]. This modularisation of systems, provides significant advantages, namely adaptability for product changes, scalability for capacity changes, simplicity due to decoupled tasks, lead-time reduction, maintenance, repair and disposal, among others [15-17].

The modularisation of a system involves the analysis of the similarities among system components to establish modules, which should be kept as independent as possible from each other [11]. Once modules are defined under the context of a modular architecture, a finite set of modules can potentially deal with an almost infinite set of changes [18]. In the assembly domain there are two main types of modules, equipment modules and software modules. By definition modules are interchangeable and are connected by the flow of materials and information [19, 20]. Moreover, module combination and interaction provides the means for the emergence of new capabilities that result of module aggregations [6].

"Plug & Produce" targets the elimination of integration time. This significantly reduces the barrier for new system introductions and also together with interchangeability driven modularisation makes frequent system reconfiguration feasible. Hence the use of task-specific, process-oriented elements (modules) allows the continuous evolution of the assembly system. EAS paradigm is based on these concepts, defining process oriented modules as its basis for system adaptation. This paper reports on the configuration model for EAS paradigm developed under the research IDEAS research project [21].

3. Evolvable Assembly Systems Configuration Overview

The concept of evolvable assembly systems focuses on system adaptability. This adaptability will require an overall approach for the system lifecycle definition, which identifies fundamental concepts, their interrelationships and core characteristics. Very simplistically, the lifecycle of any assembly system can be divided into its design, its build and ramp-up, its operation, and its decommissioning phase. This basic lifecycle model is often extended by enabling a system to be reconfigured once its operational requirements change substantially enough to justify the required effort. EAS defines modularity as both physical and logical, thus establishing assembly processes as a

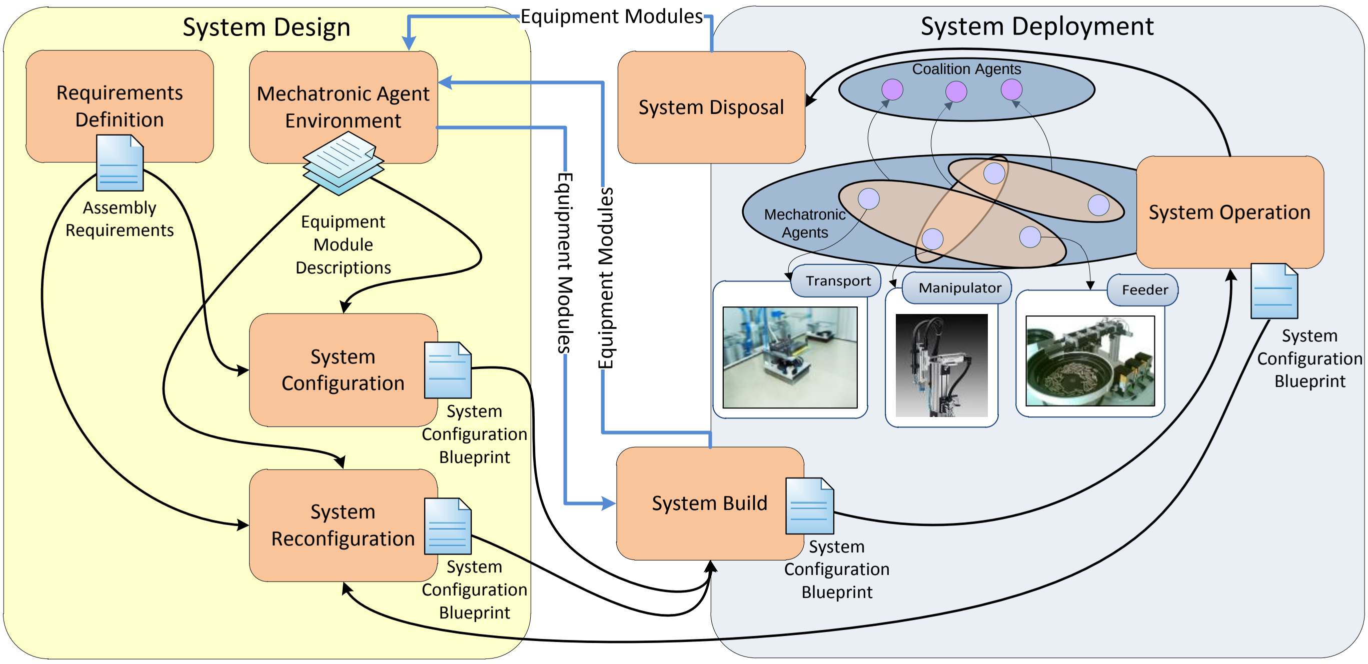

Figure 1. Overview of Assembly Process centred Configuration Method

basic logical block, the “skill”, which represents a capability.

The first step in the assembly process model definition is to understand the role and purpose of the model within the context of Mechatronic systems proposed by EAS. The Mechatronic agent concept proposed by the EAS paradigm, targets the reduction of the initial build and subsequent reconfiguration effort through the use of modular equipment with standardised interfaces and build-in control capabilities which allow modules (Mechatronic Agents) to be rapidly connected together and dynamically configured to achieve a wide range of assembly processes [13]. The Mechatronic Agent concept hence goes beyond the mere plug-ability of hardware building blocks, such as one would find in a LEGO system. The idea is to not only have the physical equipment modularity, but also create modules of the functional capabilities needed to execute an assembly process. These functional capabilities need to be directly related to the physical building blocks of the system. Hence when a Mechatronic Agent is plugged into the system is comes with its own process capabilities. These capabilities are the so called Skills.

Figure 1 shows an overview of the EAS methodology and how it impacts on the different lifecycle stages of an assembly system, identifying where and how the process model plays are role in this process. In the design stage the system requirements are defined and formalised. These are then input into the configuration stage along with the existing capabilities which are provided by the mechatronic agents. Once this process is completed the system is built using the blueprint that results from the configuration process. Then, the system is in operation with the agents (equipment units) collaborating in order to fulfil the requirements, under the constraints defined by the configuration process. In order to execute complex assembly processes it is expected that agents will create collaborations clusters. These collaborations with require a coalition leader that orchestrates the execution of the complex assembly process. The role of the assembly process (Skill) model is to formalise the concept of a Skill with all its characteristics and define how Skills are used to configure the process logic of Mechatronic assembly systems (MAS). In this role the model needs to support the planning/configuration of new or altered system as well as the execution of the assembly process within the agent control environment. Furthermore, the skill model should be defined such that it allows the capabilities of different agents to be defined by different equipment providers and yet still allow full interoperability.

4. Configuration Model for Evolvable Assembly Systems

The Skill concept is central to the Assembly Process centred Configuration Method presented in this paper. Skills define the process capabilities offered by the Agents (equipment units) to complete the required assembly process steps. Process skills take a similar role as methods in programming or services in SOA systems. Those Skill capabilities will be used to select and configure a new or re-configured assembly system. From a configuration and design point of view this implies that the available skill capabilities will be compared to a set of process/skill requirements. A similar match process would have to take place if a control system wants to support real time resource (skill) allocation. This makes it evident that a process model will need to include a Skill and Skill Requirement concepts.

Furthermore, it is expected that Skills will have some parameters which can be set either fixed for the operation of an assembly system or dynamically based on the outputs from other skills. Hence it will be necessary to define which parameter settings a Skill should be executed with to achieve the desired result either in advance or during run-time with. These settings can be defined in the form of a Skill Recipe concept which should prescribe how a Skill Requirement can be achieved by a Skill.

Finally, one of the key advantages of the Mechatronic Agent concept is that modules can be developed in parallel by different module providers. Consequently it will be necessary to control the definition of Skills and Skill Requirements to ensure interoperability. One mechanism to achieve the consistency of the definitions is the use of predefined templates. If the same set of templates is used to define both the Skills and the Skill Requirements, they can be directly compared and matched. Those templates will need to be linked to predefined types of skills and parameters.

4.1. Evolvable Assembly System Skill Concept

The skill concept describes and represents assembly processes in a clear object oriented control structure, which can easily be interpreted within the context of the proposed agent environment. Moreover, the skill concept will take advantage of existing concepts within the assembly domain which provide a hierarchical structure of assembly processes. The concept will provide the means to structure and define higher and lower level processes with the ability to describe their composition, inter-dependencies and parametric constraints.

The skill definition will be required to follow the function block concept (approach) allowing for its use within the Mechatronic Agent concept, enhancing the concept beyond the mere plug-ability of hardware building blocks. The key innovation is the composite definition which incorporates both the functional description and the actual execution definition of the assembly process. The agents will possess the definition of the skills, which enables it to provide information on its capabilities has well as having the recipe for their execution. Figure 2 provides a schematic overview of this concept using IEC 61499 notations.

The main requirements for the definition of a skill can be summarized into four main characteristics, namely the assembly process type, the level of granularity (which establishes if a skill is composite or atomic), the skill control ports and the skill parameter ports. The Control Ports represent the control elements, both inputs and outputs, for operating the assembly process (namely: Start, Interrupt, Finished, etc.). These are the basis for the definition of the process sequence since they establish the means to connect between different assembly processes (Skills). The role of the Parameter Ports is to provide the ability to specify the exchange of process data between different assembly processes (skills). These parameters are not mandatory for all skills, but some assembly sequences might require an information flow between different assembly processes. A typical use of these is a force feedback loop, where the value of the force would be passed on to other processes via a parameter port. In other words, this provides the means for information flow of a given assembly process configuration.

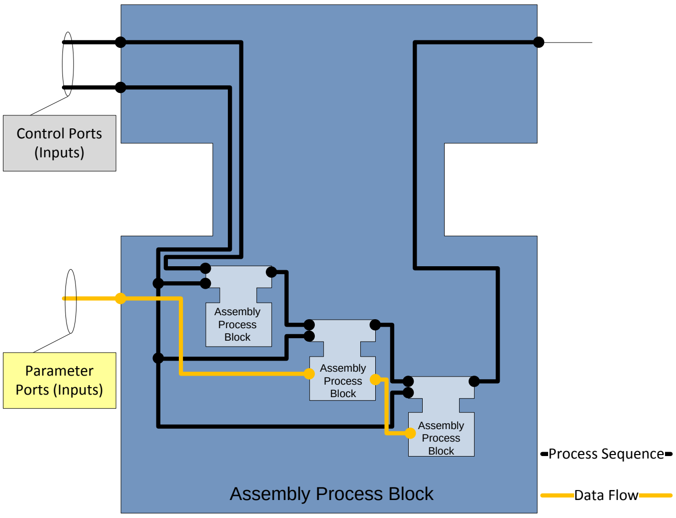

Figure 2. Overview of Composite Skill Concept

The assembly process type intends to provide the information of the capability in terms of its classification within the assembly domain. It is important to note that the naming of capabilities does not necessarily need to be standardised; however without a common agreed terminology between all the different actors across the whole configuration process, it would not be possible to use computer-based support mechanisms to ensure process consistency and allow automatic matching either during configuration or during dynamic skill allocation at runtime.

Another important requirement that should be catered for in the skill concept is the ability to establish complex skills that are defined as combinations of lower level skills. This introduces the need for the distinction between two types of skills: atomic, which are defined as elemental skills at the lowest level of granularity, and composite, which are defined as an ordered set of elemental or lower level composite skills. A composite skill should have exactly the same main characteristics as the atomic skill, in fact from an outside point of view there should be no difference. The difference consists in the existence of a structured definition for its lower level of granularity. This definition establishes both the internal process sequence and the information flow which results in the composite skill. Furthermore, this enables the high level definition of assembly processes and provides the basis for combining lower level assembly processes into new higher level and more complex assembly processes.

The composite assembly process also need to cater for the connectivity issues that arise from being composed of elementary assembly processes. Therefore, there is a need for a formalised structure that establishes how to connect the control and parameter ports. Another important aspect to consider is the possibility of a composite assembly process having alternative realizations, thus having different recipes for the execution of the capability.

4.2 Evolvable Assembly Systems Configuration Process

The concept of Skill Requirements has two functions. One is as discussed above for the definition of composite skills to bridge between different levels of granularity. The other one is for the specification of the assembly system requirements, which provide the product work flow. In order to understand these aspects one should analyse the configuration process, and see the role of the skill requirements. Figure 3 provides a three stage overview of the configuration process.

The first step in the configuration process is the specification of the assembly process requirements which will define the product work flow constraints (1). The product work flow needs to specify the required assembly process steps, their precedence constraints, and their required parameters. Once this is done, one can proceed to step two, which is the assignment of existing skills to a given requirements. Here there are two options, either these are left blank for a runtime assignment or one can assign one or more recipes for their execution (2). Therefore skill requirements model provides optional definition of recipes, which means that when these are not present the assignment of skills happens in runtime, otherwise the recipes are executed as defined. It is also important to note that one can have more than one recipe for each requirement, since it is easy to understand that depending on the available skills in a system a required skill could be executed in several ways while having the same output result.

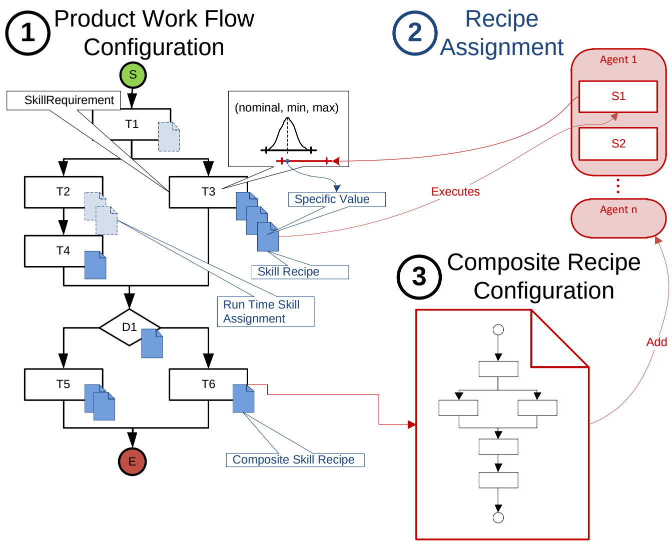

Figure 3. Conceptual Overview of Configuration Process

The third step, which caters for the scenario were the requirements cannot be performed by any of the existing skills. This is often due the different levels of granularity between the specific assembly requirements and the elementary skills implemented by the Mechatronic Agents. In this situation it is necessary to create new composite skills which break down the overall requirements into a set of lower level requirements, which can be matched to the available skills in the system.

5. Illustrative Example

This illustrative example is based on a real demonstrator form the IDEAS project. The demonstrator consists of a medical sector workstation that dispenses a liquid into a recipient. The process requirements are quite straightforward, the component for filling is retrieved, the liquid is handled into the component and the component is then stored. This provides an overview of the requirements; however one of these requirements is a composite skill, since it contains a set of requirements of its own. These consist on sucking the liquid, dispensing the liquid and testing to verify the properties of the liquid. Once these requirements are established and the physical system is built, a collation agent is created for managing the composite skill execution. This agent will advertise the requirements and establish a cluster for their execution. Figure 4 depicts this and shows the links between the mechatronic agents and the assembly system requirements for this example.

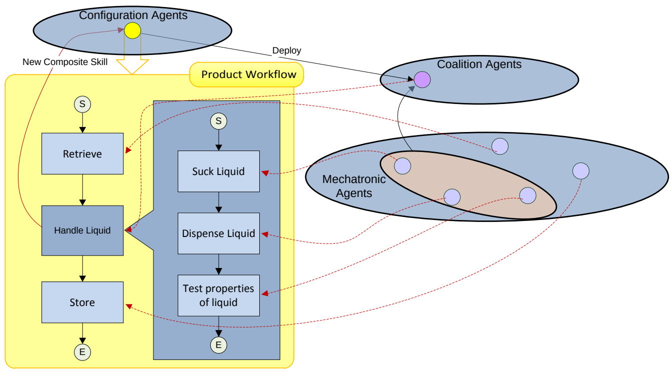

Figure 4. Assembly Process Focused Overview of Configuration Process

The design and implantation of the above process logic and corresponding agent system has been tested with very stable results. The configuration effort of the system could be reduced significantly.

6. Conclusion

This paper presented a new process-based configuration model for rapidly adaptable assembly systems using the EAS concept. An outline of the model has been given which identifies the representational requirements for such a configuration model. The developed model provides a clear and formal basis for development and rapid deployment of modular assembly systems. The process centred approach ensures that the functional integrity of the system can be achieved during system build and executed during runtime.

Further work will focus on more automatic means to support both the design process of EAS and their runtime behaviour. Semantic technology combined with configuration and synthesis methods provides a very promising direction to further explore this work.

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References

1. Jovane, F., E. Westkämper, and D. Williams, *The ManuFuture Road - Towards Competitive and Sustainable High-Adding-Value Manufacturing* 2009: Springer.
2. Kratochvíl, M. and C. Carson, *Growing Modular*2005, Berlin: Spinger
3. Onori, M. *Evolvable Assembly Systems – A New Paradigm?* in *Proceedings of the 33rd International Symposium on Robotics (ISR)*. 2002. Stockholm, Sweden.
4. Shen, W., D.H. Norrie, and J.-P.A. Barthès, *Multi-Agent Systems for Concurrent Intelligent Design and Manufacturing*2001, London and New York: Taylor & Francies.
5. Monostori, L., J. Váncza, and S.R.T. Kumara, *Agent-Based Systems for Manufacturing.* CIRP Annals, 55.EU FP6 NoE IPROMS (www.iproms.org). Cluster PAC (Production Automation and Control), 2006.
6. Ferreira, P., *An Agent-based Self-Configuration Methodology for Modular Assembly Systems*, in *Department of Mechanical, Materials and Manufacturing Engineering*2011, The University of Nottingham: Nottingham.
7. Goldman, S.L., R.N. Nagel, and K. Preiss, *Agile competitors and virtual organizations: strategies for enriching the customer*. Vol. 414. 1995: Van Nostrand Reinhold New York.
8. Ueda, K., *A concept for bionic manufacturing systems based on DNA-type information*, in *PROLAMAT*1992, IFIP: Tokyo.
9. Babiceanu, R. and F. Chen, *Development and applications of holonic manufacturing systems: a survey.* Journal of Intelligent Manufacturing,, 2006. **17**: p. 111–131.
10. Bi, Z.M., et al., *Reconfigurable Manufacturing Systems: the state of the art.* International Journal of Production Research, 2007. **46**(4): p. 967-992.
11. Bi, Z.M., L. Wang, and S.Y.T. Lang, *Current status of reconfigurable assembly systems.* International Journal of Manufacturing Research, 2007. **2**(3): p. 303 - 328.
12. Barata, J., et al., *Evolvable Production Systems: Enabling Research Domains*, in *International Conference on Changeable, Agile, Reconfigurable and Virtual Production*2007: Toronto, Canada.
13. Onori, M., H. Alsterman, and J. Barata. *An architecture development approach for evolvable assembly systems*. in *International Symposium on Assembly and Task Planning: From Nano to Macro Assembly and Manufacturing*. 2005. Montréal, Canada: IEEE.
14. Arai, T., et al., *Agile Assembly System by "Plug and Produce".* CIRP Annals - Manufacturing Technology, 2000. **49**(1): p. 1 - 4.
15. Martin, M.V. and K. Ishii, *Design for Variety: Developing Standardized and Modularized Product Platform Architectures.* Research in Engineering Design 2002. **13**: p. 213-233.
16. Gunnar, E., *Modular function deployment – a method for product modularisation*, 1998, Royal Institute of Technology: Stockholm.
17. Blackenfelt, M. and R.B. Stake. *Modularity in the context of product structuring – a survey*. in *The Second Nord Design Seminar, KTH, Stockholm*. 1998.
18. Bi, Z.M. and W.J. Zhang, *Flexible fixture design and automation: review, issues, and future directions.* International Journal of Production Research, 2001. **39**(13): p. 2867-2894.
19. Feldmann, K. and S. Slama, *Highly flexible assembly – scope and justification.* Annals of the CIRP, 2001. **50**(2): p. 489–498.
20. Heisel, U. and M. Meitzner, *Process in reconfigurable manufacturing systems*, in *Second International CAMT Conference*2003: Wroclaw. p. 129-136.
21. IDEAS, *Instantly Deployable Evolvable Assembly Systems.* 2010.