The Development of Knowledge-Shelf to Support the Generation of a Set-Based Design of Surface Jet Pump

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Abstract: - Set-based Concurrent Engineering (SBCE) is advocated in order to provide an environment where design space is explored thoroughly leading to enhanced innovation. This is achieved by considering an alternative set of solutions after gaining knowledge to narrow down the solutions until the optimal solution is reached. Knowledge provision is essential in SBCE application. Hence there is a need for a tool that provides appropriate knowledge environment to enable SBCE and supports it in taking right decisions. At the same time there is a need to capture the rationale of the alternative design decisions taken during the process of narrowing down the set of the design in the SBCE environment. These decision rationales constitute important knowledge to be re-used in developing new products. In this research the tool designed to address this research rationale is called Knowledge-Shelf (K-Shelf). This paper and its outcome serve the groundwork for the development of K-Shelf software that captures knowledge and in generating the first design set in SBCE environment based on previous knowledge documented. This paper is a collaborative work from a case study of Surface Jet Pump (SJP) between the LeanPPD research group in Cranfield University and Caltec Ltd, a company that provides engineering solutions to the oil and gas industry. The K-Shelf was developed using rapid web application development tool – Oracle APEX.

Key-Words: - set-based concurrent engineering, knowledge-shelf, design rationale, knowledge provision, product development, project summary report, service jet pump

1 Introduction

Product development (PD) strategy at the moment has been the eminence factor accordingly to the rapid growth of manufacturing sectors, advancement in technology and a shift in customer needs for cheaper quality products [1], [2]. Research in PD has reached a vertex as industries are willing to invest vast amount of money. Many studies have shown that 70-80% of lifecycle cost of any product is determined in the conceptual design phase itself [3], [4]. Hence, a better PD strategy could save resources and provide companies with this extra competitive edge to take over their respective market.

Toyota is the world leading automotive manufacturer and its PD process has been sought after and researched by many competitors [5]. It was first described by [6], where its principles were identified by [7]. Toyota's product development is based on three main principles as following: a focus on system design, the use of knowledge and the work with sets simultaneously. This set of principles was translated to a framework known as Set-Based Concurrent Engineering (SBCE) [8]. Industrial applications of SBCE was evolved into a detail SBCE process model with a guide of its implementation [9], [10] and the model was refined and implemented to other industries [11] which consider the entire product lifecycle. **Fig. 1** is the SBCE process model that has been developed [9], [11]. It is the one used for this research to demonstrate the concept of K-Shelf.

In SBCE, the assortment of conceptual design is delayed as the design set is gradually narrowed based on the knowledge available to support decision taking [6], [8], [9], [11]. It is also generally accepted that managing knowledge in SBCE is essential since design works are distributed across designers and customers as advocated by [12]. However, it has to be taken into account that knowledge within SBCE environment does not necessarily exist; it has to be created and provided since the beginning of SBCE process, i.e. generation of set of conceptual design.

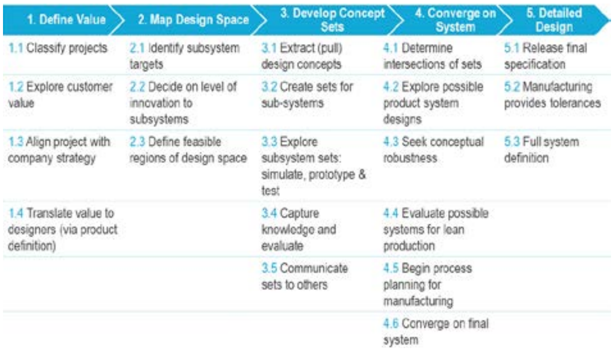

Fig. 1 SBCE process model [9], [11]

SBCE is a representation of a Lean PD (Khan, 2012) as it is form a process that should be followed to develop a product. SBCE is a PD in a knowledge base environment; therefore there is a need to a tool that captures design rationale and support decision taking throughout PD process. This paper presents a software application of the Knowledge-Shelf (K-Shelf) concept which has been developed for the purpose of providing the adequate knowledge environment to enable SBCE application.

The K-Shelf is designed as a software application which provides support and enables SBCE. It is fairly new concept, still under scrutiny, and is currently being developed to be an integral part of SBCE. It mainly addressed the second principle of Toyota automotive PD – the use of knowledge – to capture, compare and reuse key project design information to support designers with the knowledge they need throughout the SBCE process. The work presented in this paper is a demonstration of the K-Shelf concept using an industrial case study from Caltec Ltd, based on the Surface Jet Pump.

2 Knowledge Provision in Set-Based Concurrent Engineering Environment

Managing knowledge in Set-Based Concurrent Engineering (SBCE) is important since design works are distributed across designers and customers [13]. However, relatively limited research has been carried out on knowledge provision in SBCE. Although knowledge is considered as an important element of SBCE, very few publications address this issue, of which none provide any detailed knowledge provision. The one that might be mentioned is in Lean KLC framework to support Lean PD [14] which addresses the baseline model of knowledge management practices in PD.

During the conceptual design phase, knowledge-rich key information is taken into account, e.g., stakeholder requirements, preliminary product definition, key value attributes, functional capabilities, and to some extent level of innovations. Managing vast amounts of knowledge within this phase potentially leads to challenges. Pertaining to this phenomenon, [14] points out that 79% of all conceptual design problems could have been prevented by the correct knowledge being provided in the right place at the right time, i.e. knowledge provision. It is also recognised as one of the industrial challenges in managing product development, as well as in SBCE, particularly in the form of knowledge provision for targeted group of product designers and engineers [15].

Although the literature covers the use of sets in the conceptual and preliminary design phases [8], [12], it remains unclear how these sets of information are formatted, classified, retrieved, dispatched, compared, and archived during an SBCE process. Researchers strove to address these indeterminate methods by advising a number of computer based software tools flavoured with particular knowledge format to facilitate certain aspect of SBCE [16]–[18]. Generally, the tools can be categorised in two general groups; the one that integrated to Product Lifecycle Management (PLM)/Product Data Management (PDM) solutions and the other one that is stand-alone – designed to be operated independently. [16] discuss a preference set-based design in which a set is generated based upon a designer's preference, through the integration of external computer aided design (CAD) images as its knowledge that can be stored for the future projects. In addition, [17] proposed an approach to multiply set of conceptual design in the form of 3D representation of a product together with its product structure and attributes (Digital Mock-Up/DMU). This DMU with its attribute information represent design knowledge which is nested in a Product Data Management (PDM) system for reuse within project and the future projects. Furthermore, Computer Aided Synthesis (CAS) approach was suggested to be used in supporting the implementation of SBCE principles in the way of increasing the number of candidate solutions and in the same time generating spaces of feasible solution in the injection moulding cooling case by employing expert knowledge [18]. Most of the aforementioned tools solely addressing set of design in ad-hoc manner and was generated manually. However, the documentation of individual design has been done with extra information e.g. CAD, digital mockup. This extra information is considered and adding value because of the representation of certain knowledge.

In addition, considerable research efforts have been put into developing design rationale software. However, it appears mostly that the developed design rationale software are not in widespread use in industry, and challenges still exist regarding effectively deploying the software in industry [19]. A significant task is to capture the design rationale whilst making the design decisions. Usually, this parallel working is difficult to achieve. A main reason is that the software often enables capturing design rationale after making the decisions or even when the product is already designed. While capturing design rationale is a significant task, simply accessing the design rationale is at the same level of importance. As [20] mention, around 20% of the designer's time is spent searching for information and only 40% of design information requirements are met by documentation sources. This implies that design information and knowledge is not often represented in a simply accessible knowledge base.

2 Knowledge-Shelf Concept

Knowledge-Shelf (K-Shelf) can be delineated as a tool which captures key design project information and provide designers with relevant knowledge throughout the set-based concurrent engineering (SBCE) process. From the previous research, some initial requirements of the K-Shelf have been defined [21]. It should have the following capabilities: 1) dynamic knowledge capture; 2) store the captured knowledge in a well-structured manner; 3) generate project summary report obtained from previous projects, research and development and novel concepts; 4) support the generation of a set of designs; 5) support the comparison of sets of solutions (e.g., trade-off curves), 6) knowledge reuse within the same project and 7) knowledge reuse for another project. **Fig. 2** illustrates the overall concept of the K-Shelf. The idea is to have a knowledge-base that is structured into several shelves to capture different levels of project information and design decision rationale. The main objective is to enable the application of SBCE by supporting the generation of a set of alternative conceptual designs. The sources of these alternative conceptual designs are; previous projects, R&D projects and newly generated conceptual designs.

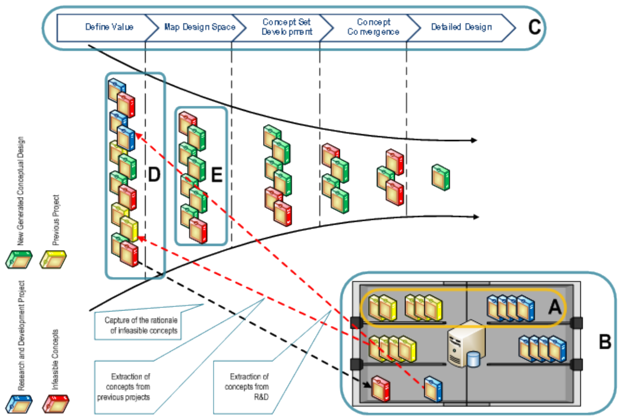

Fig. 2 Overall concept of Knowledge-Shelf

A project summary report (PSR) template as described in Fig. 3 has been designed in order to capture the key information of the previous projects along with its rationale for selection. This information represents the required knowledge to support design decision taken in the SBCE environment. Examples of key information that should be captured in the PSR are; key value attribute, design space, requirements, features, geometry, performance, configuration, manufacturability, technology readiness level, cost, feasibility and design rationale.

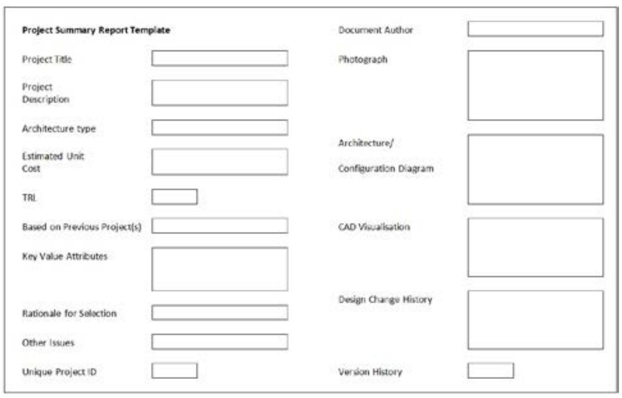
Project Summary Report Template
Project Title
Project Description
Architecture type
Estimated Unit Cost
TRL
Based on Previous Project(s)
Key Value Attributes
Rationale for Selection
Other Issues
Unique Project ID
Document Author
Photograph
Architecture/ Configuration Diagram
CAD Visualisation
Design Change History
Version History

Fig. 3 Example of project summary report template

PSR represents previous projects and R&D projects as shown in **Fig. 2.A** and retained in the K-Shelf (**Fig. 2.B**). **Fig. 2.C** represents the SBCE process model [9], [11] that provides an innovative working environment by reasoning, developing, communicating about a set of design and engineering solutions in parallel. **Fig. 2.D** illustrates the generation of the first conceptual design set as follows: the blue coloured PSR represents design that was pulled from R&D projects, the yellow one represents design that was pulled from previous projects and the green one represents design that was new conceptual design generated during the project under consideration.

In SBCE process, as the design progressed, the set is gradually narrowed based on the knowledge gained due to simulation, prototyping, testing and other engineering evaluations. Therefore, several design solutions need to be removed from the set, as shown in the red coloured container (see **Fig. 2**). Here, where the K-Shelf will play an important role in capturing the design rationales of these weak or infeasible solutions. The reason behind that is although solutions are not good for the project under considerations; they might be useful for other projects. Trade-off curves (TOC) could be used in order to provide comparisons among sets of solutions then to narrow them down [22]. This approach has been identified in the literature review and was advocated by [23]. However, method to integrate trade-off curves to meet capability of comparing sets of solution is equally lacking.

Fig. 2.E shows the second set of conceptual design after narrowing down as a result of the application of SBCE. This means this second set is not generated from the K-Shelf. Again, as the design progresses, the set is gradually narrowed based on the knowledge gained and again the design rationale of the weak or infeasible solutions are also captured until the final optimised design solution is obtained.

3 The Surface Jet Pump Case Study

Case study aims to enhance the performance of the surface jet pump (SJP) which is used to increase production rate and to revive dead oil-wells; low pressure (LP) – using pressure difference between the latter and a live oil-well; high pressure (HP) as shown in **Fig. 4**. In order to demonstrate the capability of K-Shelf in this case study, there are a number of activities of SBCE process that must be implemented. **Fig. 5** shows the selected activities of SBCE that have been used in the SJP case study and K-Shelf procedure to support the generation of the first design set of SJP.

The SJP project should be classified in order to map Caltec's projects against a number of projects attributes. Some of the benefits of this classification are to give an overview of projects, providing an opportunity to make comparisons between projects or to check specific information from a project in a simple and effective manner. K-Shelf has to be able to capture all the relevant information and documents within this activity. The attributes considered in this activity are the following:

1. Project name
2. Client details
3. Geographical location
4. Duration of project
5. Technology readiness level
6. Product name
7. Application type
8. Field application
9. LP phase and HP phase
10. Material
11. Operating temperature
12. Pressures
13. Corrosion
14. Lesson(s) learnt

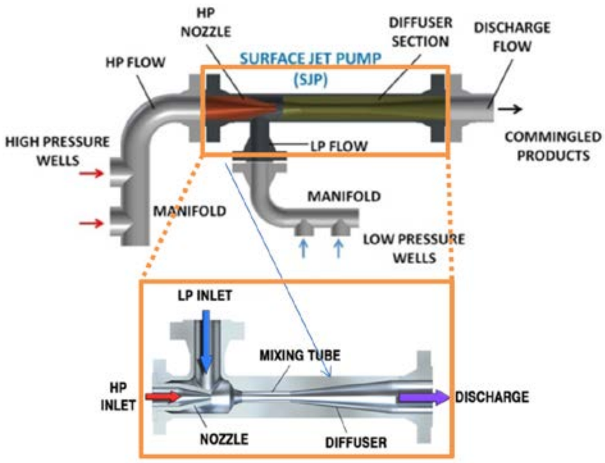

Fig. 4 General configuration of Surface Jet Pump (SJP)

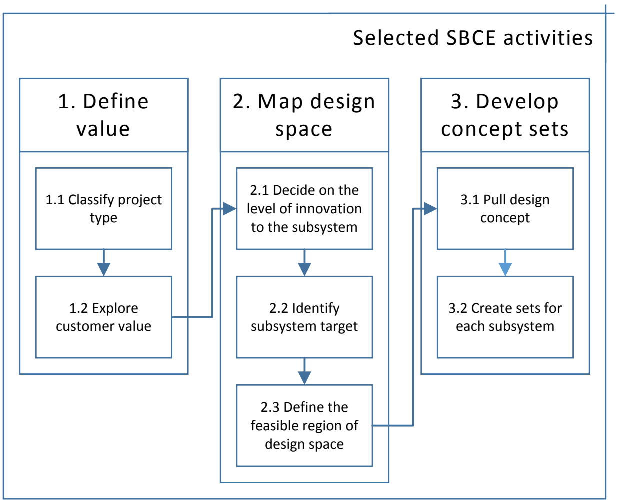

Fig. 5 SBCE activities implemented in K-Shelf

A database has been developed to relate the entities of SBCE process model, e.g. key value attributes, requirements, sub-systems, design sets to their attributes aforementioned to define its project classification. This classification was created for Caltec project as the first relational database of K-Shelf. The relationship design is done using an entity relation diagram as shown in **Fig. 6**. It is important for the relationship of each entity and its respective attributes to be properly defined as this is the framework of the database. An example from this would be the entity “Project” has tree attributes which are “Clients, ID and Cost”, e.g the entity “project” has can only have one “cost” attribute. The interface of new project in K-Shelf is illustrated in **Fig. 7**.

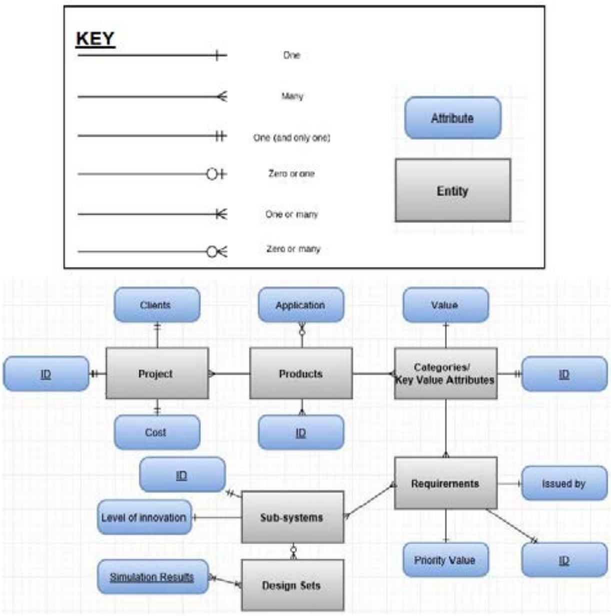

Fig. 6 Entitiy relationship diagram of K-Shelf relational database

Customer needs must be comprehended to accurately define system targets specifically related to the increment of the design performance of SJP. To identify the key value attribute (KVA) of SJP, the result of analytical hierarchy process (AHP) which is calculated outside of the K-Shelf has to be inputted manually. K-Shelf then generates a bar chart shows the AHP percentage of value attributes from the SBCE process model and is interactive (see **Fig. 8**). Clicking on any bar chart segment will take the user to where the information originates which add to the traceability of information, one of the requirements of K-Shelf. Generation of the first set of design can be realised by applying particular constraint of attributes in ‘classify project type’ interface that correspond to predefined design space. In the K-Shelf software, this retrieval feature of particular relations of entities and attributes is demonstrated as shown in **Fig. 9**.

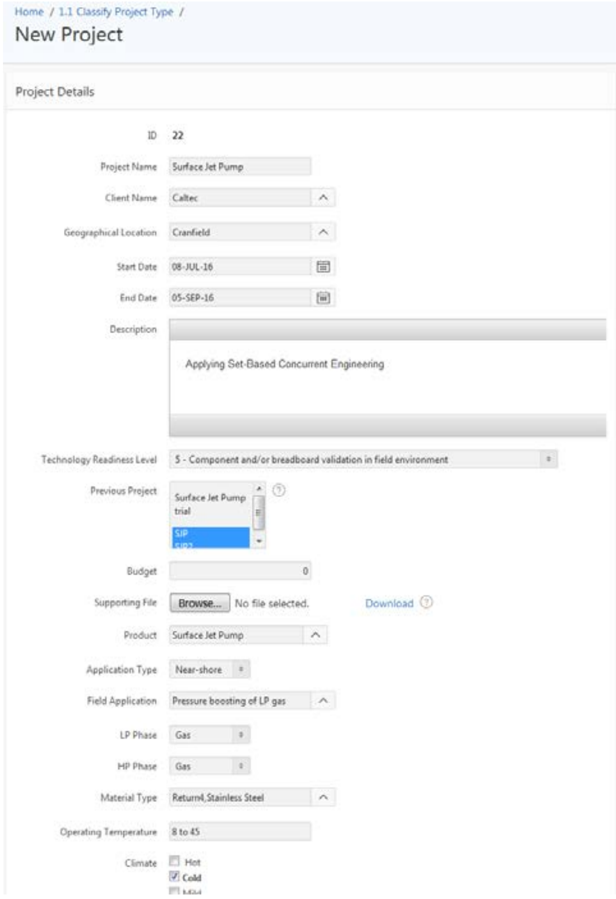

Fig. 7 New project interface of K-Shelf

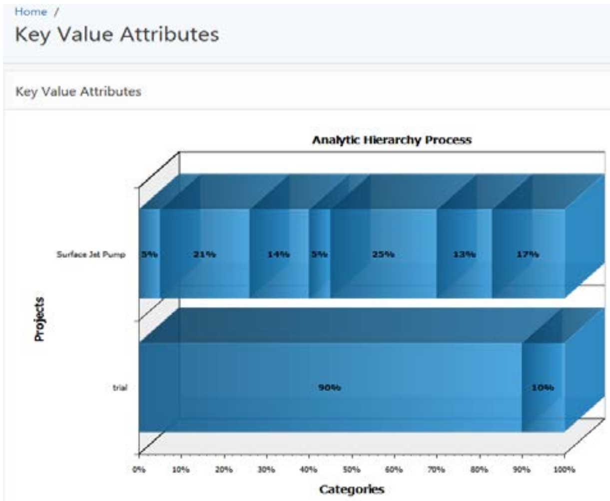

Fig. 8 Key value attributes interface of K-Shelf software

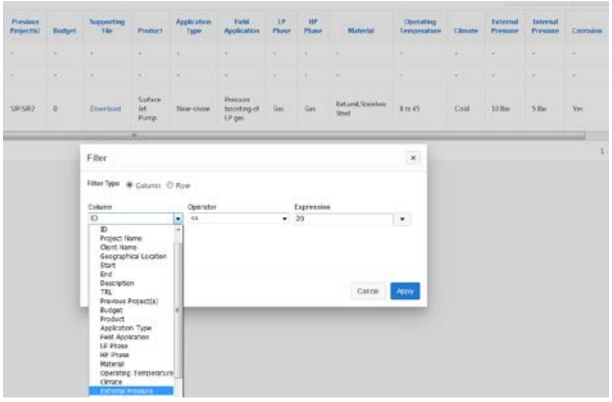

Fig. 9 Classify project type user interface in the K-Shelf

After applying some constrains to filter the range of available SJP designs, both from the previous project or newly developed one, K-Shelf is able to promote a set of first conceptual design of SJP which is later on will be narrowed down following the SBCE process.

4 Conclusion

The focus of the research presented in this paper was on developing Knowledge-Shelf (K-Shelf) software that captures knowledge and in generating the first design set in SBCE environment from previous projects and newly developed conceptual designs. The Surface Jet Pump case study was validated successfully and the software is promising in terms of knowledge re-use and storage. The database is well-structured, providing an integration and support to the SBCE process model activities. However, it has to be testes and validated with a larger amount of knowledge and data.

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