CASE STUDY

RAPID PRODUCT DEVELOPMENT OF AN AIRCRAFT COMPONENT THROUGH KNOWLEDGE BASED ENGINEERING (KBE)

Abstract

Engineering product development is very knowledge intensive and a significant part of this involves routine design activities that is mostly carried out manually by experienced designers. There exists enormous scope for improving the productivity and cycle time by automating these product development activities. The knowledge of the product and its design process can be translated into software applications which can then be used for the design of the product. Moreover, by adapting Knowledge based engineering (KBE) methodologies, engineering knowledge and related software applications can be made re-usable for the development of future similar products.

This case study presents an automation approach adapted for the design of an aircraft structural component that reduced the cycle time and effort by more than 30%. The paper elaborates the approach followed and the key lessons learnt for the execution of similar projects.

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Introduction

In a conventional engineering product development scenario, most of the design activities are planned to carry out manually using in-house or commercial third party CAD / CAE / PLM systems. Obviously, this requires significant amount of time and effort of all concerned engineers and subject matter experts (SMEs) to develop any new product; even though they have the prior experience of developing similar products. Many instances, majority of the design activities are routine in nature and SMEs spend enormous amount of time and effort in carrying out these activities. These activities can be automated through software applications by embedding the knowledge of the product and its design process.

This case study presents KBE based approach used for the design and development of floor beams for a major passenger aircraft program of an US based OEM. Floor beams are one of the critical structural components that support the payloads and interior components. Each floor beam is an assembly of several sub-components such as upper chord, lower chord, web and stiffener. The start of the floor beam development program was delayed by about 10 months and the approach described here has helped overcoming the scheduled slippage by completing the development well ahead of the time. This is the first of its kind of project that adapted KBE process upfront in the product development (PD) cycle and for the complete work-package covering both stress / sizing as well as design.

The project consisted integration of design and analysis data of floor beams involving multiple iterations till a final acceptable sized configuration is arrived, while meeting the strength, stiffness, and stability, design, manufacturing and assembly requirements. It required smooth, accurate and consistent data flow between analysis and design teams over multiple design iterations for the entire duration of the project.

Next section gives an overview of the scope of the project. Subsequent section describes the approach followed to execute this project. It gives an overview of the process flow and also explains various phases of the project. It also highlights various other automations carried out to improve the productivity. Finally, this case study shares the benefits and savings realized as well as the key lessons learnt from this KBE approach that can help in execution of similar projects in the future.

Overview of the project

The scope of this project was to design and develop about 70 floor beams for a major passenger aircraft, through KBE approach. This included following key activities:

1. Understand the existing product development (PD) process for floor beam and analyze to identify the automation opportunities.
2. Define the KBE based PD process and identify the scope of various software applications for automating various PD activities.
3. Detail out the scope and requirements for various applications to be used in KBE process.
4. Development of all the identified software applications.
5. Generation of 70 floor beam designs using KBE process using software applications.

The KBE based PD process was required to cover analysis / sizing and detailed design comprising the following activities:

- Analysis and sizing of the floor beam and its components such as upper chord, lower chord, web, stiffener etc.
  - Identifying the various checks to be considered for various components of the floor beam assembly.
  - Sizing of various components and arriving at the final sized floor beam components.
- Detail design of every floor beam to generate the following.
  - 3D Part Models for all the components of floor beam such as upper chord, lower chord, Web, stiffener etc.
  - 2D detail drawings for each of the components
  - 3D Assembly models for the floor beam
  - 2D Installation drawings with all the required parts including the standard parts.

It was required to have all the final design data in CATIA V4, and to use the client specific tool to perform sizing calculation. The initial configuration of the floor beam is taken as that of the previous aircraft variant.

Multiple sets of load data were expected to arrive at various stages during the execution of this project and it was required to ensure that the KBE process re-generates the floor beam design consistently with the latest set of loads, without any overheads.

Approach

This being the first of its kind of project where KBE based approach has been planned for the complete design and development of floor beams, a pilot phase was taken up initially to establish the feasibility of the KBE based approach.

1. **Pilot Phase:** The objective of this phase was to define and establish the KBE process with all the identified software applications; and pilot it on few floor beams. About 50% of the PD activities that are applicable for all the 70 floor beams were automated during this phase; and the remaining automations were planned to be taken up during deployment phase.
2. **Deployment Phase:** The objective of this phase was to deploy the KBE process for the design of all the floor beams over multiple load cycles. In addition, the enhancements of all the software applications were carried out to handle specific features that are applicable to specific floor beams. Almost 80% of the PD activities were automated during this phase.

Pilot Phase

The project started with the pilot phase wherein the existing floor beam design process was studied and understood. The objective here was to arrive at the generic design methodology, process, rules, heuristics and algorithms that are applicable for all the 70 floor beams. The design process, various rules, heuristics were analyzed and enhanced to arrive at KBE based process wherein significant proportion of design activities could be automated. After defining the scope for every automation area, requirements were detailed out to develop software applications for all the identified areas. The software applications with the identified core functionalities have been developed and then deployed on few pilot beams to generate the floor beam design successfully, thus establishing the KBE process. Hence at the end of pilot phase, about 50% of the design activities were automated and the rest of the functionalities were addressed in the deployment phase.

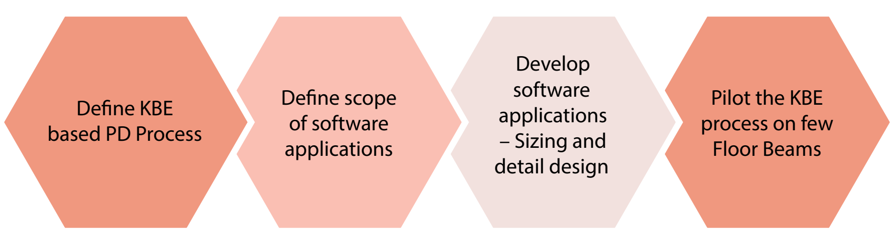

Figure 1: Various stages of Pilot Phase.

Figure 1 shows various stages of the pilot phase. Each of these stages has been described in the following sub-section.

A. Define KBE based PD process:

At this stage, the existing PD process for the floor beam development has been understood along with the related client specific tools used for the development. There were basically two broad areas – analysis / sizing and detail design. One important observation in the traditional as-Is process is that there was no standard mode of exchange of floor beam geometry data between sizing and detail design process. This involved significant overheads with lot of routine manual interventions for data exchange between sizing and detail design. The existing process was also prone to many errors and hence this was one of the key areas of automation addressed in the KBE based process. Few of other points that have been considered in defining the KBE process are:

1. Leveraging existing set of tools, utilities, and KBE applications already available with the client. This was to ensure that the existing applications are re-used to the maximum extent.

2. Understanding of the geometric complexities, shape variability, rules and heuristics related to sizing, detail design as well manufacturing processes of all the floor beams. Based on this, arrive at the generic functionalities or features or logic that needs to be developed that can address all the 70 floor beams.

3. Evaluate various modes of automations available on CATIA V4 as well as CATIA V5 and understand the relative advantages and disadvantages from the floor beam requirements perspective.

Figure 2 shows an overview of KBE process for floor beam development that has been arrived at for both analysis as well as detail design.

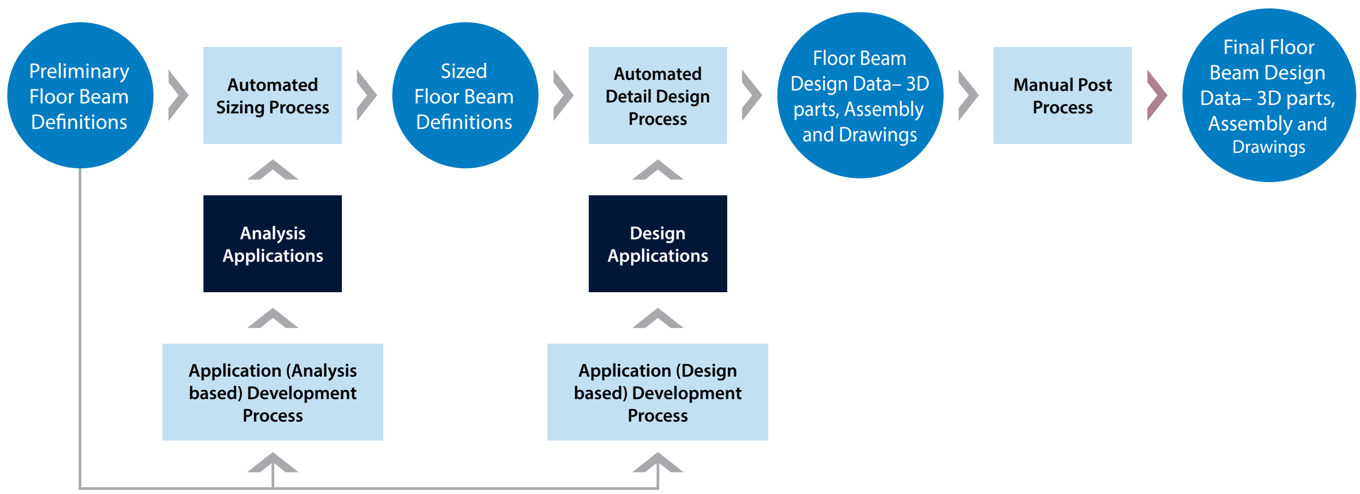

Figure 2: Overview of KBE based PD process

Following are few key aspects of KBE based PD process for floor beam development.

1. Identified about 6 automation opportunities with corresponding software applications (3 for sizing and 3 for detail design) that can automate more than 80% of the floor beam design process.

2. Though significant proportion of sizing and detail design activities have been identified for automation, some of the activities are planned for manual execution only. This is because of the fact that they are specific requirements (that may not be required for every floor beam) or the effort required for automation is high compared to the effort required for manual execution.

3. Establishing the common format for the floor beam definitions, both for preliminary as well as sized floor beams. The geometry, rules, material definition information, which is common data for both sizing and detail design, is captured in the form of tables in an excel workbook and this forms the common input to both the sub-processes. This has helped significantly in reducing the iteration overheads.

4. The final drawings, solids and assemblies were required to be made available in CATIA V4 platform. But programming in CATIA V4 was complex for wireframe operations and hence it was decided to adopt a CATIA V5 – V4 Hybrid approach to take advantage of the excellent wireframe programming capability in CATIA V5. This Hybrid approach resulted in a set of design applications both in CATIA V5 as well as in CATIA V4 platforms.

After defining the KBE Process for the floor beam development, detailing of the scope and requirements for various sizing and detail design KBE applications have been carried out in the next stage of this pilot phase.

B.Define the scope of various software applications:

As mentioned in the previous section, there have been six automation opportunities and related software applications have been identified in the overall KBE process. These key automation areas have been briefly outlined in the below table.

Sl. No.	Automated Design Activity	Input	Output
1	Analysis Pre-processing	Geometry definition Material definition Load definition	Batch file for running the core analysis application
2	Carrying out various analysis checks for all the components of floor beam.	Batch file containing Geometry definition Material definition Load definition	Margin values for each of the checks.
3	Analysis Post-Processing	Margin values for each of the checks.	Critical margin summary report
4	2D Geometry profile creation for various components in CATIA V5	Sized floor beam geometry definition. Detail design rules for upper chord, lower chord, web and assembly. Manufacturing rules for tolerances.	2D profiles for upper chord (UC), lower chord (LC) and web. Assembly part definition. Fastener layout information.
5	Generation of CATIA V4 3D models and Drawings for various components	2D profiles for upper chord (UC), lower chord (LC) and web.	3D Detail parts for UC, LC and Web 2D Drawings for UC, LC and Web
6	Generation of CATIA V4 3D Assembly models and Installation Drawing.	Assembly part definition. Fastener layout information. 3D Detail parts for UC, LC and Web	3D Floor beam Assembly. 2D Installation Drawing.

C. Development of identified software applications for sizing and detail design:

All the identified sizing and detail design applications listed in the previous section were developed using the appropriate programming languages and as applicable either in UNIX or Windows platforms and on CATIA V5 and CATIA V4 environments..

One of the key considerations in developing all the KBE applications is to ensure that the logic/algorithms/ methodologies implemented are generic in nature to cater to the needs of all the 70 floor beams. The design of a floor beam involves in designing the individual sub-structural components (such as upper chord, lower chord, web, stiffeners etc) as well as floor beam assembly. There exists lots of variability in the geometrical shapes of various sub-components across different floor beams. Each floor beam is different from the other (except for the high level shape and structure) and hence no two floor beams are exactly alike. The KBE applications were required to generate the design for every floor beam irrespective of its shape and had to handle different and complex shapes as well as features of all the sub-components. There also exist lots of design rules (both for sub-component specific as well as assembly specific) that are interdependent and were to be evaluated while creating the geometry. Accordingly, a unique and innovative approach has been developed to enable the creation of a family of profiles through a single, modular and efficient algorithm. As per this sketch based algorithm, every shape of floor beam components is made up of a combination of two types of sketches – generic sketch and unitized sketch. Depending upon the shape of the floor beam component, the algorithm involves in arriving at the right combination of generic and unitized sketches. Figure 3 illustrates the generic and unitized sketch.

- **Generic sketches:** Generic sketches are super set sketches, whose one or more parameter(s) can be set to zero to realize different shapes of the component. The exact parameter(s) that needs to be set to zero to achieve a particular shape was based on engineering rules. In all there were 15 generic sketches that could be used to generate a large number of shapes of wireframes.

- **Unitization of sketches:** Unit or elementary sketches are those that form a unit of larger shape. These unit sketches can be used repeatedly in a specific order to realize the overall shape. The order and the choice of unit shape that is to be used were based on engineering rules.

This approach has helped in generating varieties of shapes of the floor beams using single set of KBE applications that are applicable for this family of floor beam.

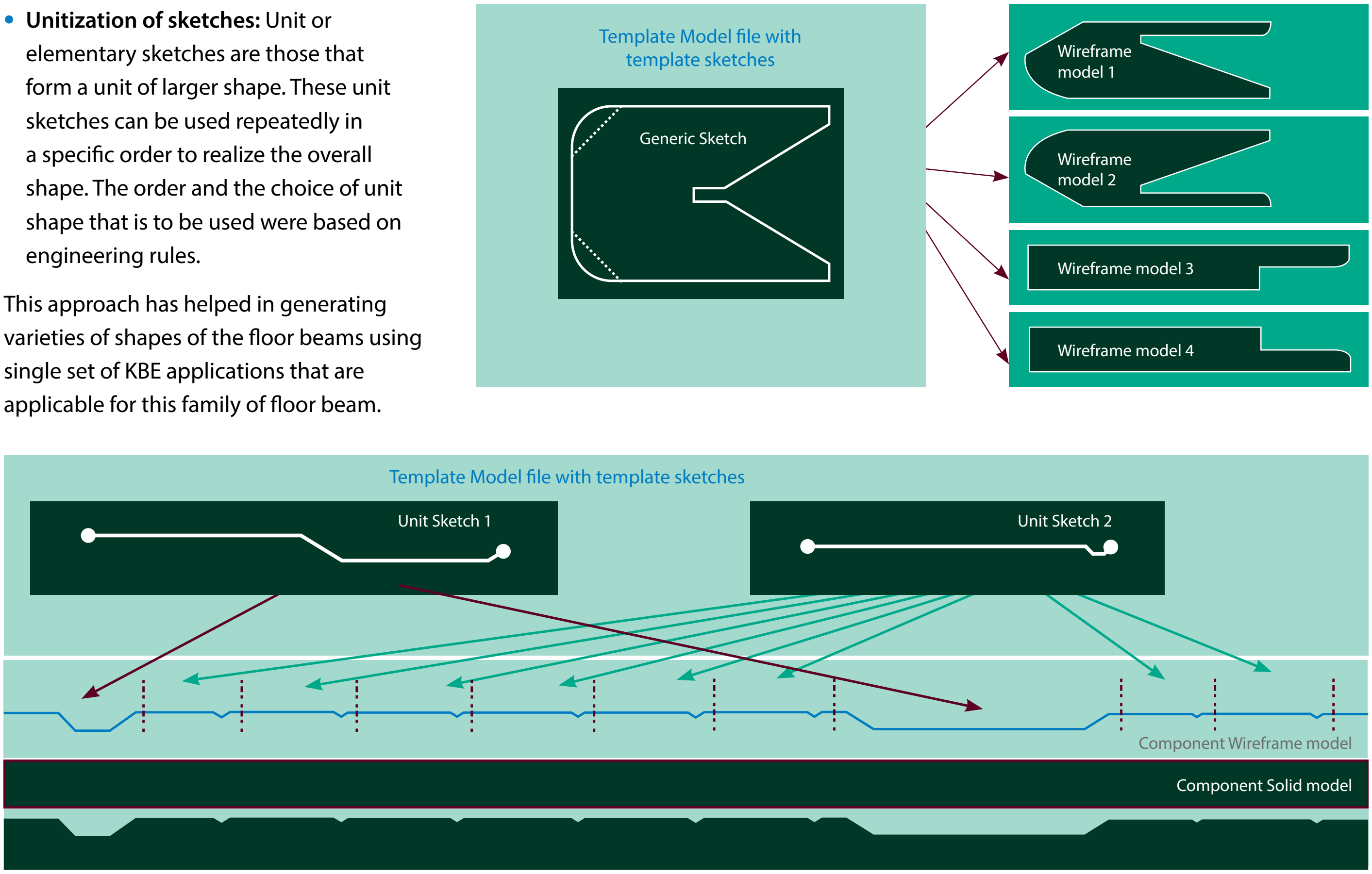

Figure 3: Illustration of generic sketch and unitized sketch

D. Piloting the KBE process on few floor beams:

The developed applications are piloted on 10 floor beams to generate the design. Almost 50% of the detail design and analysis activities were automated with all the sizing and detail design applications developed in this phase of the project. The technical feasibility of automating various design activities with the hybrid approach was successfully completed and this approach has been established. The sketch based approach has generated all the 10 floor beams with varieties of shapes. Hence it was decided to go ahead with the enhancement and deployment of this KBE process for the complete floor beam program.

Deployment Phase

Having established the KBE process with all the identified software applications in place, this phase involved in deploying these applications to design all the floor beams. As mentioned in the previous section, the scope of the automation in sizing and detail design were very much limited in the pilot phase and thus only 50% of the design activities were automated in the previous phase.

i. Though most of the design methodologies, rules, heuristics and requirements have been implemented in the pilot phase, some of these were still evolving during the initial stages and refined based on the initial design outcomes. Hence, it was required to enhance the software applications to take care of modified rules/methodologies.

ii. The generic sketch based approach was capable of handling all types of features that are applicable for all 70 floor beams. However, in the pilot phase, the implementation of this was done considering the features of only 10 beams. Hence, it was required to implement for the features, functionalities and geometric complexities applicable for all the remaining floor beams.

Ideally, prior to deployment of any software application, it is required to complete the development and testing on all the functionalities of all the application. Since the timelines were stringent, it was decided to go ahead with two parallel tracks, as described below.

A. Track 1 - Application Development:
Development and enhancement of sizing and detail design applications to expand the scope of automations and incorporate additional features of the floor beams.

B. Track 2 - Floor beam Development:
Deploying the KBE process with all the applications to generate floor beams design. While application enhancements are happening for the next version; the previous version of the same applications are deployed to generate the floor beam design.

In order to accommodate the schedule of delivery of floor beams, it was decided to adapt a staged development and deployment approach. In this approach, the floor beams have been categorized into several groups based on the complexity and extent of automation covered. Each of these groups comprised of about 3 to 5 floor beams of similar features and complexities. Each stage involved in the enhancement of specific versions of the software applications for the additional requirements of specific group of floor beams; and then deploying these software applications on those floor beams to generate the design. The scope of application enhancement at every stage was limited to one particular group of floor beams and hence the cycle time to make these applications deployable was relatively shorter.

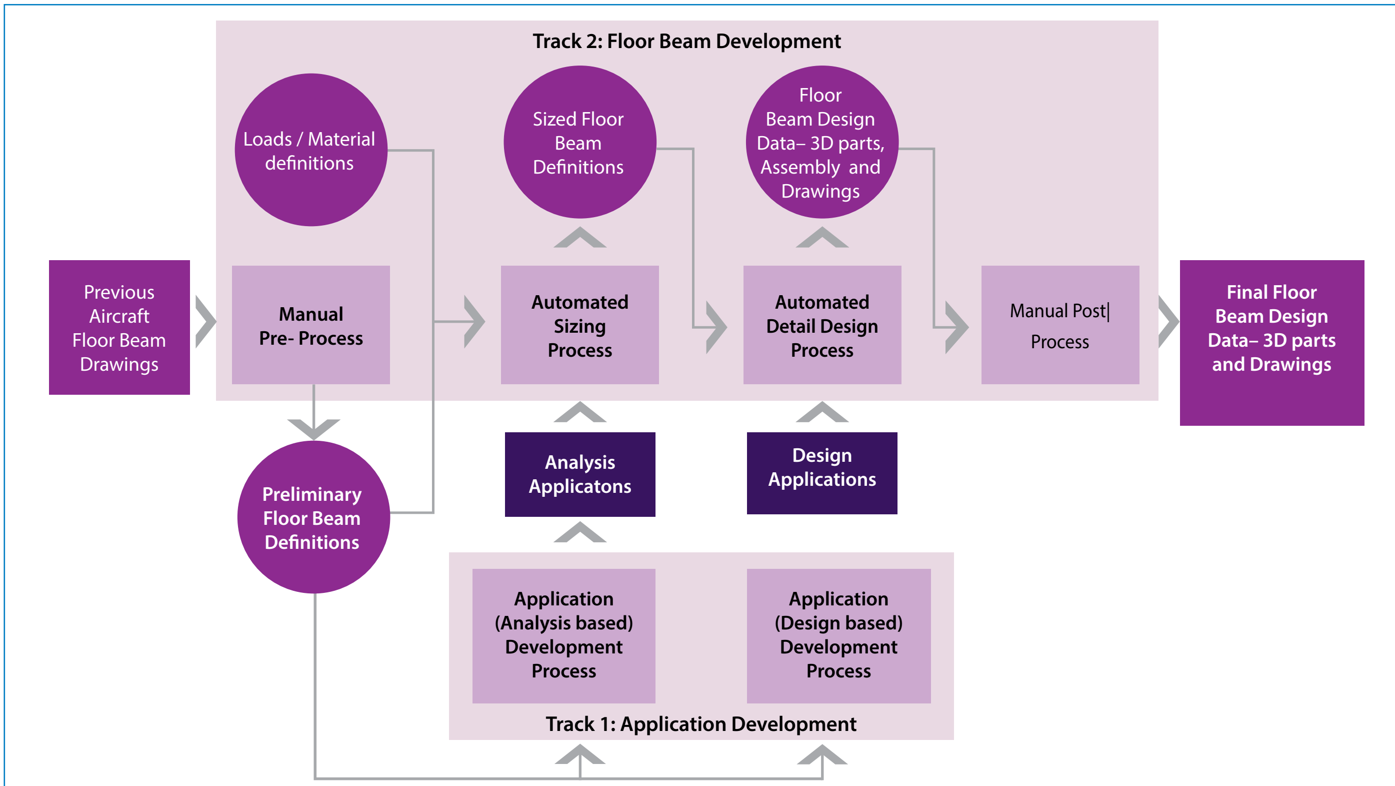

Figure 4: Multiple Tracks in Deployment Phase

Figure 4 illustrates the process flow with various tracks. Track 1 is involved in the enhancement of all the analysis and design applications considering the identified group of floor beams. These applications are used in Track 2 for the generation of design of this group of floor beam.

Other Automation tools developed

In addition to various sizing and detail design applications, good number of other automation tools has been developed to improve the productivity. These productivity improvement opportunities have been identified and respective tools have been developed and deployed. Some of the automated activities have been shown in Figure 5.

Figure 5: Productivity improvement tools to automate various activities

Most of these automation tools helped in reducing the effort by an average of 20%. Automation tools for the testing of the application have helped to reduce the testing effort by almost 50%. In addition, batch running capability of running all the detail design applications in sequence to generate floor beam design for all the 70 floor beams has significantly helped the designers to improve their productivity.

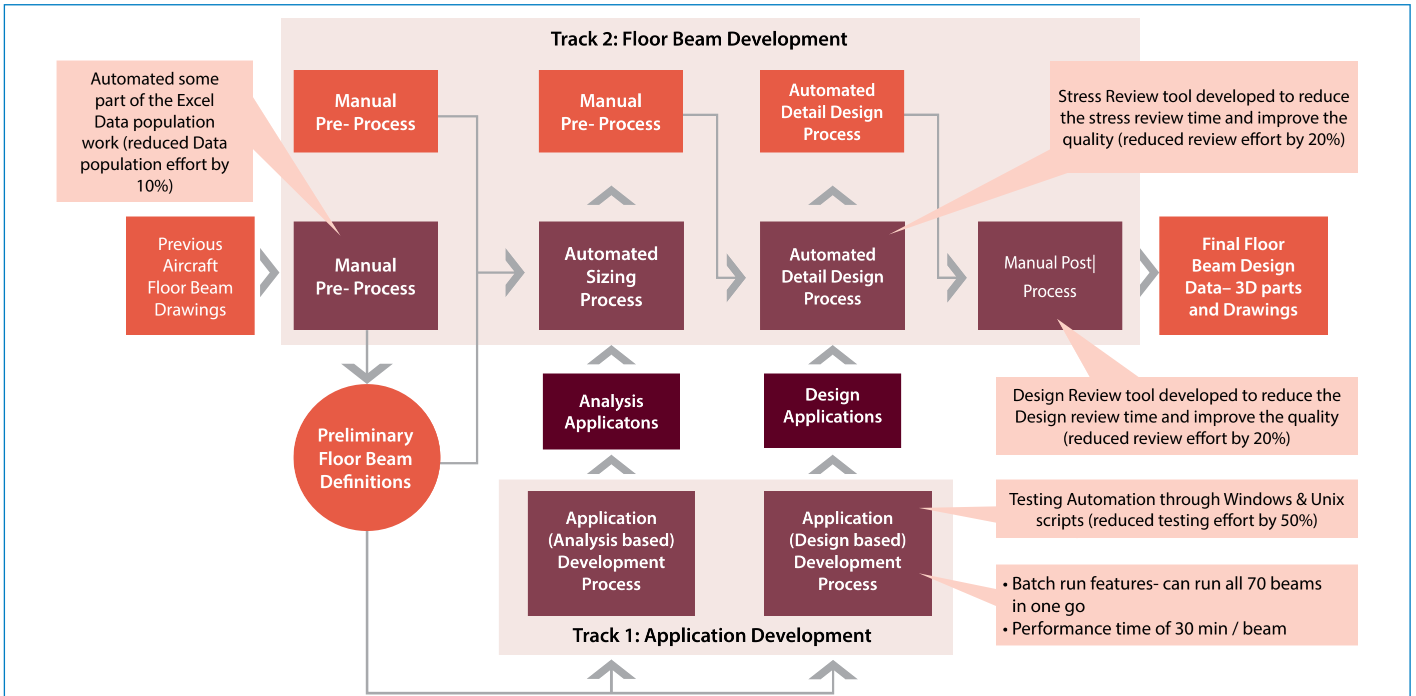

Figure 5: Productivity improvement tools to automate various activities

Benefits realized

As compared to conventional PD approach, several benefits have been realized through this KBE based approach for the floor beam development. Following are some of the key benefits of this approach.

1. Effort Savings: KBE based development of floor beams took only 67 % of total estimated effort with conventional PD process, leading to an overall savings of 33% in effort for all the 70 floor beams. This effort includes the effort spent on developing all the KBE applications for sizing and detail design. Figure 6 shows the comparison of the effort of estimated conventional PD approach with the current approach.

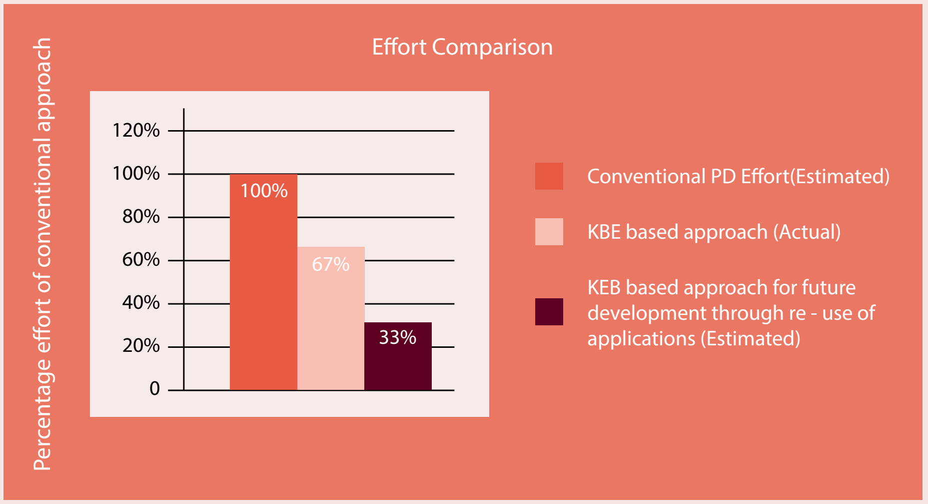

Figure 6: Comparison of effort

2. Turnaround time: As compared to traditional PD approach, this KBE based approach has resulted in more than 30% savings in time. With this approach, it was possible to complete the development well within the original schedule (estimated as per traditional PD) even though it started late by 10 months.

3. Quality improvement: Since most of the design activities were automated in this KBE based approach, probability of mistakes has been significantly lower and results were consistent irrespective of the person carrying out the design. Large number of sizing iterations could be performed for a given period of time because of automated process.

4. Re-usability of KBE process and applications for future similar programs: There have been three broad areas of activities in this floor beam development i.e. automated sizing with pre-processing; automated detail design with manual post processing; and software application development. The effort break-up amongst these three broad areas of activities are shown in Figure 7. Almost 51% of the effort was spent on the development KBE process and all the software applications for sizing and detail design. These software applications are generic in nature to be used for future similar floor beam designs and hence are re-usable. Hence for the future similar floor beam development, the effort and time gets further reduced by almost 50%, provided there are no changes in CAD platforms and other software technologies of these applications. Figure 6 shows the comparison of this estimated effort for future programs.

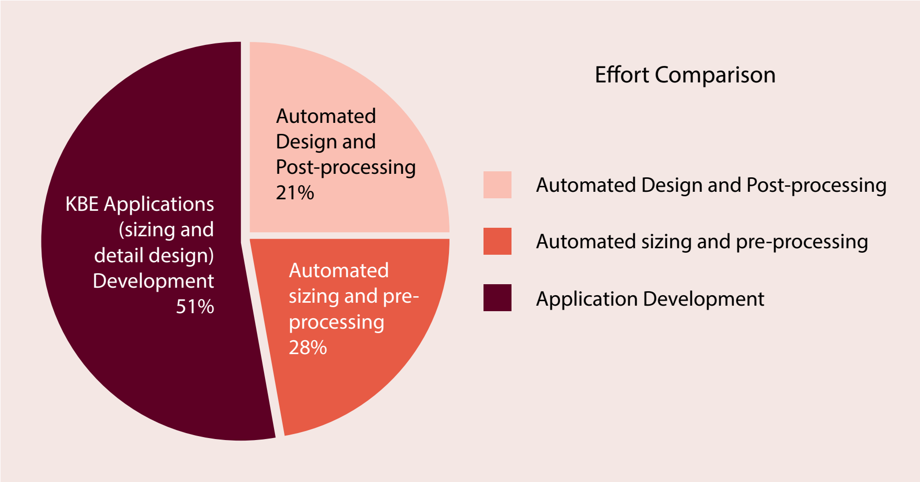

Figure 7: Effort distribution in KBE based approach

Key Lessons Learnt

Following are some of the key lessons learnt from this project that can help realize the same benefits for future similar programs.

1. Most of the automations of this project were planned upfront in the PD cycle before the start of the floor beam design. This has helped in faster development of required software applications. In most of the conventional PD projects automations are not planned early in the PD cycle and are being considered more as a tactical steps to improve the productivity. Maximum benefits can be realized if KBE is leveraged upfront of the PD process and plan for automations.

2. The deployment phase of this project had two tracks running in parallel – Application development for the next version of the applications and Floor beam development using previous version of the same set applications. This required significant collaboration and co-ordination between these two tracks apart from enormous effort spent for testing various versions of the application. It is suggested that the methodologies and processes are completely defined and frozen before development and deployment of KBE applications for the design of floor beams. Though the changes at the later stage are inevitable and cannot be completely avoided, those changes needs to be kept as minimum as possible. This will help to reduce the overheads significantly.

Conclusion

This project has been one of its kinds that have been executed through KBE based approach. In this program KBE approach has been adapted in the early stages of the PD cycle and end to end covering both sizing as well as detail design. This is one of the key differentiators of this project that has helped in realizing effort and time savings of 30%. Moreover, KBE technologies help to ensure that these software applications that have been developed are generic in nature to be used for future similar products; thus the resulting savings will get multiplied over several instances of use for similar product developments.

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This project was executed by Infosys with the involvement of many of designers, stress analysts, KBE engineers working at multiple locations and executed as a single integrated team. The project required enormous amount of co-ordination among all these teams and the contributions of each and every team member have been very crucial for the success of this project. We take this opportunity to acknowledge the contributions of key technical leads who have contributed to this program. Susikar Sigamani and Veera Venkata Satyanarayana Sirigina were the key stress leads contributed significantly to this program with the support from Sachin Kaledhonkar, Rafiq Raja, C H V Veerabhadram and Amol Patil. Abhishek N Sharma, Venkatesan Mahalingam and Lalitha Karanth were the key design leads contributing the success of this program with the support from Pradeep Ramanand, Saurabh Mishra and Guru Naga Sounder. Guhanathan S and Rohit Agrawal were leading various modules of design automation track with support from Kailash Umale V and Anand Parashuram Niranjan. In addition to the technical leads, we also would like to acknowledge the contributions of all the team members supporting these key technical leads. The other contributors to the project are Aman Tripathi, Ambarish S., Anup Kumar, Anup Ravi Panthayil, Ashish Agrawal, Ashok Kumar Viswanathan, Ashwin Babu, Brijesh V., Dinesh Bharathi, James Poonnolly, Kamaljit Saha, Nikhil Hariharan, Nutan Bhattiprolu, Pavan Kumar Medapati, RaviKiran Dasireddy, Renosh Mathai, Sagar Ashok Shahane, Salil Choudhary, Satish Mahabaleshwar Pattanashetti, Shweta Singh, Srikanth Kurumaddali, Srinivas Pendyala, Tejo Ram Bhagavathula and Theertha Prasad Pradeep. This project was executed with the guidance and support from Dr. Ravikumar G.V.V., Sundaresh Shankaran and Ramanath Suryaprakash.

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