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ENGINEERING INTERACTIONS AND WORKFLOWS IN PRODUCT
DEVELOPMENT**

Frederick Rowell

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EXPLORATION OF COLLABORATIVE DESIGN SPACES: ENGINEERING
INTERACTIONS AND WORKFLOWS IN PRODUCT DEVELOPMENT

A Thesis
Presented to
the Honors College of
Clemson University

In Partial Fulfillment
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Mechanical Engineering

by
Frederick Rowell
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ABSTRACT

Product Lifecycle Management (PLM) initiatives can improve an enterprise's efficiency by increasing collaborative design opportunities within its business structure. PLM solutions provide digital mediums to collaborate on all aspects of a company's workflow, including engineering, testing, manufacturing, marketing, business, and field support services. This paper examines the major PLM tools and software used to establish a collaborative engineering design space; computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), and product data management (PDM). The interactions between these PLM tools and a design team's organizational structure are analyzed to determine some of the most effective PLM integration strategies to improve collaboration for all business functions. Engineering enterprises may split their work functions into technical and non-technical categories and match them with PLM solutions to create a collaborative design space that integrates all departments. A case study presents a university design team whose objective was collaborative creation of a digital twin for a scale tracked vehicle. The Siemens Teamcenter software tool was integrated within the team's design procedures to improve the process. The results of integrating advanced PDM software into their workflow, including troubleshooting issues and problems, were explored in this paper. PDM and workflow interactions throughout the case study produced many unique outcomes that require additional PLM engineering solutions. Overall, advanced PDM software increased collaboration and efficiency of their design process.

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CHAPTER ONE

INTRODUCTION

Over the 21st century, product lifecycle management (PLM) initiatives have swept the engineering industry, with more companies transitioning to digital collaborative design methods over existing engineering design strategies. With enterprises realizing the wealth of possibilities for PLM systems and how they will change their organizational structure and capabilities, engineering design processes have changed dramatically, from a traditionally closed environment to incorporating multiple departments into a collaborative design space. The shift in mindset towards a collaborative design process produces many issues, such as engineering productive workflows to include all aspects of a business. Integrating PLM initiatives into an existing engineering design process can also cause problems due to poor assimilation into the current business structure. Some of the issues associated with integrating PLM into current product development processes are analyzed in this paper, with a few of the most critical obstacles studied further in an educational case study. The resulting analysis features research on PLM tools and how they assimilate into engineering design processes to form a collaborative design space.

Product Lifecycle Management is a virtual thread for an enterprise's workflow, bringing together all business functions to increase the efficiency of a company's operations. A business may implement a PLM system for many reasons with multiple objectives and goals. At its core, PLM is a product management system that incorporates a business' entire product portfolio into a central operating system. One main objective of implementing PLM into a business' workflow is to improve product performance by

developing efficient relationships between its functions, such as human resources, marketing, engineering, manufacturing, and field service. A product's lifecycle, ranging from its design to testing and manufacturing, is displayed in Figure 1.1.

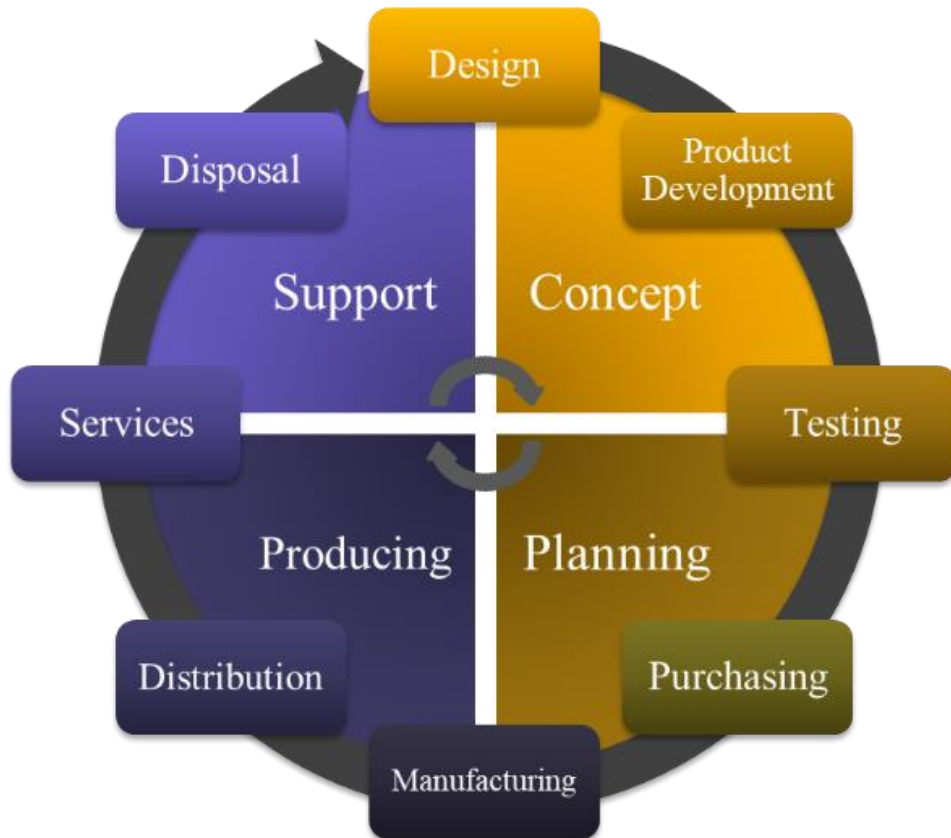


FIGURE 1.1: Common tasks comprising the lifecycle of a product

The product's lifecycle contains numerous supplements from multiple different business functions. The goal of PLM is to manage these stages of a product's lifecycle, decrease product cost, increase product revenue, and maximize the value of a business's product portfolio for the customer. PLM solutions provide a range of management and

engineering tools that are utilized by all business departments to increase the efficiency of product management and reach their long-term goals [1].

PLM initiatives have applications in many different industries. An essential aspect of using PLM software in the aviation industry is the optimization benefits for servicing and repairing aircraft to ensure airline and passenger safety [2]. In the energy sector, Failla *et al.* [3] researched how oil and gas businesses use PLM solutions to manage manufacturing bills of materials for turbomachinery. Product management tools such as the bill of materials are a vital aspect of PDM software that is discussed further in this paper. A key outcome of utilizing PLM software for product development is the creation of a digital twin. In the production of electric vehicles, digital twins of lithium-ion battery packs are used to simulate extreme conditions and “improve the safety and service life of the battery packs” [4]. Pollard *et al.* [5] describe how the electrical and electronic (E&E) sector was subjected to research on how PLM initiatives fit into the circular economy paradigm. Many common themes involved in PLM, such as resource management, product-life extension, reuse, and waste management, are also involved in developing circularity indicators for “measuring and monitoring the circularity of E&E products” [5]. In addition to PLM’s application to physical products, virtual engineering research by Morshedzadeh *et al.* [6] uses PLM systems to create a new information model to house virtual models of historical artifacts from an automotive company. With an extensive network of applications for PLM systems, researchers are focusing on how to implement PLM solutions in engineering enterprises.

Implementing PLM solutions into an existing business infrastructure can come with its challenges. For example, Anandavel *et al.* [7] discuss how migrating data and information from existing storage networks to cloud PLM solutions is “a challenging task which demands overall change management in the organization.” Incorporating change management into an enterprise is an important issue that will be examined in the case study later in this work. Another problem with implementing PLM systems is providing proper data access to all contributors to an enterprise’s collaborative design space [8]. Data access management requires a mapped network of all employees and certain privileges granted to each in all PLM software. Conlon [9] shares how the traceability of changes within a workflow allows a business to track fundamental alterations and the present status of a product. PLM solutions use traceability systems to manage a product’s versions, so all departments of an enterprise can utilize current product data and track previous versions to use in upcoming product development [9]. An additional critical issue with implementing PLM systems into a business’ infrastructure is integrating each of the PLM software to form a cohesive network. Information technology experts are required to tackle the complete setup of these systems while integrating them within the existing data framework. Several of these challenges will be examined and discussed in the case study section of this work.

An essential aspect of implementing PLM systems into a business’ engineering design process is understanding how each department within the organization can interact to achieve their financial, performance, and customer goals. An enterprise’s organizational structure is what changes its PLM initiatives. For example, certain businesses may need

more PLM solutions than others, ranging from computer-aided design and engineering software to product data management software. The organization's structure also dictates how each PLM tool integrates with others within each department. Figure 1.2 visually represents the main aspects of an enterprise's organizational structure. Within the organization model, some departments cover every part of a company's needs, including engineering, manufacturing, and marketing. Similarly, to Figure 1.1, these departments encompass aspects of the engineering design process and product lifecycles such as design, testing, manufacturing, and services.

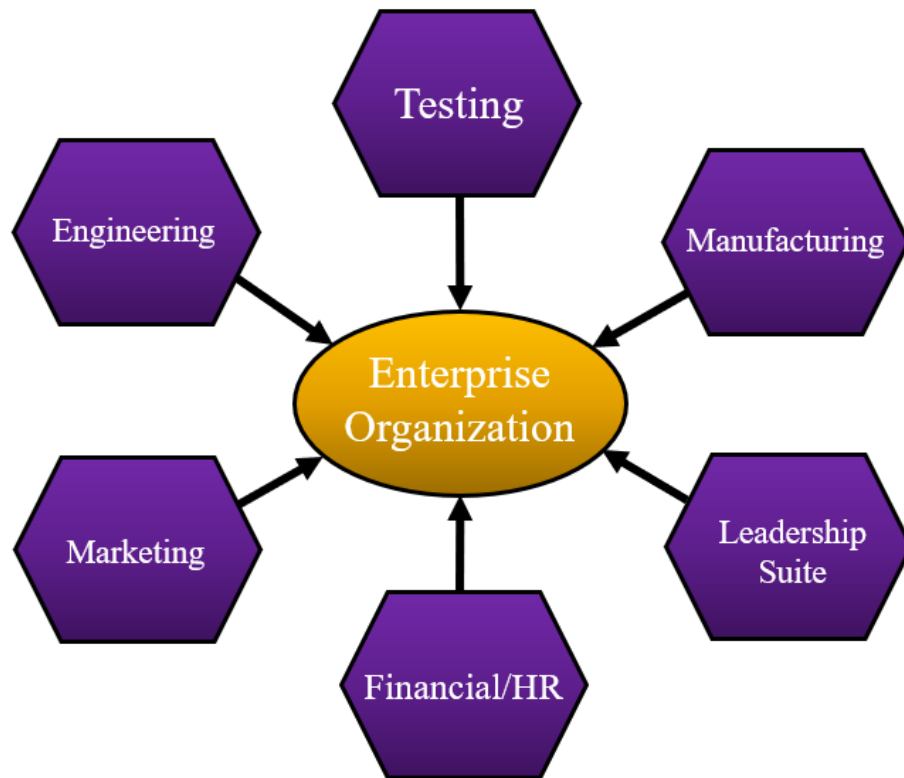


FIGURE 1.2: Traditional departmental roles within an enterprise before PLM implementation

Before the early 21st century PLM initiatives, the business structure looked very similar to Figure 1.2. Each department contributed individually to the overall success of the enterprise, with limited collaboration between them. Each aspect of the business, from product development to manufacturing, to distribution and services, was tackled by individual departments. With limited collaboration between departments, business functions often transpired slower and less efficiently than after PLM implementation. PLM initiatives changed how businesses were structured by integrating all departments into a common thread to collaborate on each business function. Many improvements to companies' business functions were made from PLM initiatives, including increased communication and collaboration on every aspect of the product development process. PLM initiatives combine some of the responsibilities in each department to create a collaborative design space that improves the efficiency of the engineering design process and decreases overall product cost. As Stark [1] described, PLM initiatives involve "the activities of managing a company's products ... in cross-functional business processes across the product lifecycle." The idea of transforming a business from an individualistic, functional unit to a "cross-functional business" has made them successful across all business units.

As PLM initiatives were frequently implemented across the engineering and product industry, the organizational structure changed dramatically from enterprise to enterprise. Companies implemented different PLM solutions based on their needs. As a result of these changes, collaboration amongst departments within businesses increased. Some of the most significant alterations of an enterprise’s organizational structure are shown in Figure 1.3.

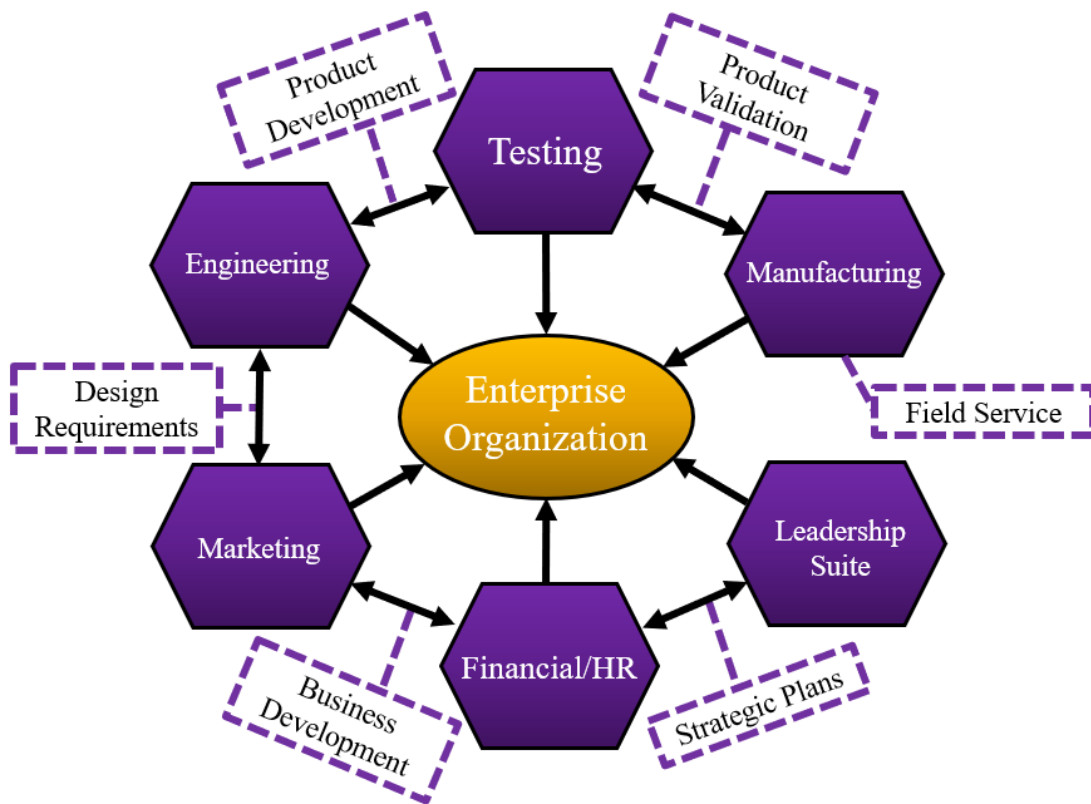


FIGURE 1.3: Post-PLM implementation within an enterprise based on the digital background to enhance department interactions

The main differences between Figure 1.2 and Figure 1.3 are the bi-directional arrows between each business unit and the purple dashed boxes attached to each of the arrows. The purple dashed boxes represent standard business processes that occur between departments. These business processes range from product development and validation to

business development and strategic planning. PLM solutions increase the efficiency of these business processes by improving collaboration of all aspects of the enterprise. For example, product data management software allows engineering, testing, manufacturing, and marketing departments to collaborate on design requirements for any product. Also, computer-aided design software improves product development and validation collaboration by engineering, testing, and manufacturing departments. The other key difference between Figure 1.2 and Figure 1.3 is the bi-directional arrows between each business unit, representing the collaborative design strategies between all departments within an enterprise. PLM initiatives drive collaboration by linking all departments into a virtual thread through the different PLM tools discussed in the next section of this paper.

CHAPTER TWO

PLM TOOLS

A business may utilize many PLM resources to achieve its long-term goals. PLM resources include methods, facilities, data management, applications, and people. The resources most consistent with use in engineering design are product data management (PDM) and PLM applications. Figure 2.1 displays the digital backbone of many PLM applications used in industry.

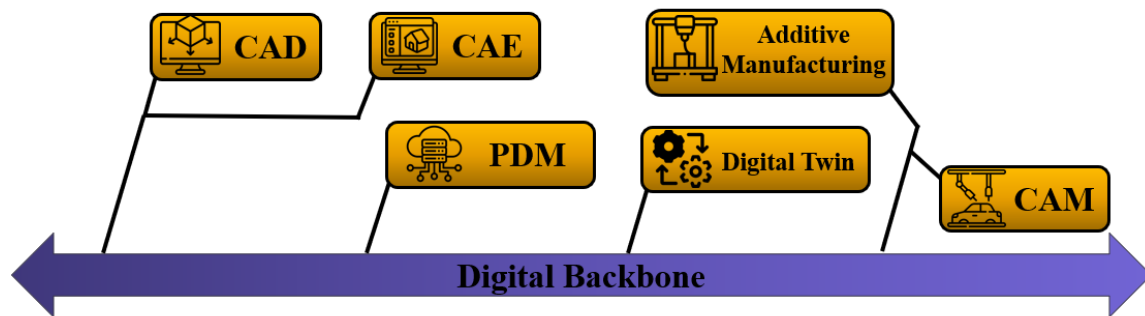


FIGURE 2.1: PLM digital backbone with select virtual engineering functions displayed, including AM, CAD, CAE, CAM, and PDM

The digital backbone comprises typical design applications such as computer-aided design (CAD) and computer-aided engineering (CAE) software. In addition, computer-aided manufacturing (CAM) and additive manufacturing are critical resources that improve a company's manufacturing processes' accuracy and efficiency. The combination of these applications and the addition of some others make up the bulk of a digital twin, a virtual tool composed of a database of computer models to be used in addition to a physical model to estimate the behavior of a product. To store all the product files from the other PLM resources, a product data management (PDM) application is necessary. PDM systems are

among the most critical elements in a business' PLM resources. PDM systems provide the correct information for all business functions whenever required. In stark contrast to the engineering design process of the 20th century, PDM systems integrate departments into the design process that have had limited involvement before.

2.1 Computer-Aided Design (CAD)

Computer-Aided Design (CAD) software is critical to the success of PLM systems and solutions, as it forms the basis for product development. CAD is a software tool used in engineering for digital design, drafting, and prototyping. The primary purpose of CAD software is to assist designers in the engineering design process by allowing them to create accurate 3D models, designs, and drawings. CAD software also supports increased collaboration amongst engineering teams on graphics and procedures, which improves the efficiency of the engineering design process in the industry. The software enables engineers to explore contrasting designs and make changes to meet the requirements of the product and customer. Nzetchou et al. [10] explore semantic enrichment methods of CAD models in PLM systems and their degrees of industrial implementation. CAD enrichment gives engineering collaborators an additional layer of metadata to improve their designs and the efficiency of the engineering design process.

In addition to the design process, CAD software plays a prominent role in manufacturing, including prototyping and iterative manufacturing. Rapid prototyping is essential for a business because it boosts efficiency and minimizes waste. CAD models aid engineers in rapid prototyping by providing a digital, readable file of any part or assembly

that can be prototyped through additive manufacturing or machine fabrication. Also, CAD software has allowed a new, adaptive form of iterative manufacturing by creating a shared, central repository for product data that can be utilized by engineering, manufacturing, marketing, and many other departments to boost the efficiency of the engineering design process. Paul et al. [11] employed CAD models to develop a "predictive tool based on machine learning" that can improve the yield efficiency of their simulation models and, in turn, advance the additive manufacturing methods they use for rapid prototyping. CAD software is critical in every engineering design process stage and a crucial tool to the PLM infrastructure.

2.2 Computer-Aided Engineering (CAE)

Computer-Aided Engineering (CAE) software is another crucial design tool used to simulate and analyze the behavior of products and designs under different environments. There is a range of additional CAE software, including finite element analysis (FEA), fatigue and structural analysis, computational fluid dynamics (CFD), electromagnetic simulation, and multibody dynamics (MBD). Each software package focuses on a specific environment under which a design would be subjected. One of the primary purposes of CAE software is to reduce prototyping costs, as it allows engineers to test their strategies under contrasting loading conditions before building expensive prototypes. Also, CAE software can improve product design performance through optimization tools, as defined by Murthy et al. [12] in their chain load optimization of fuel pump lobe phasing for a BS6 diesel engine.

One of the main applications of CAE software in PLM systems is the creation of a digital twin. A digital twin is a digital representation of a physical product whose primary purpose is to improve the efficiency of the engineering design process by creating a digital model that can be controlled and optimized through real-time simulations. The primary purpose of creating a digital twin is to reduce the cost of the concept and detailed design stage in the design process, as explained by Kolbachev et al. [13]. In addition to the cost-saving benefits of creating a digital twin, another main advantage includes creating a high-accuracy model of an object or system that is too complex or dangerous to test in a physical situation. These intricate designs could require expensive, controlled environments to test them in, which would further increase the cost of the prototyping and testing stages of the design process. Overall, CAE software is essential to PLM software and collaborative design tools.

2.3 Computer-Aided Manufacturing (CAM)

Computer-Aided Manufacturing (CAM) software plays a vital role in the automation of manufacturing processes. CAM software works with CAD software to convert a 3D model into a set of instructions that a machine can use to manufacture a product. CAM software has many benefits, ranging from increased manufacturing efficiency to improved quality control. CAM software increases the accuracy and consistency of manufacturing processes, all while decreasing the cost of manual integration of CAD drawings with machines. Another benefit of using CAM software is that it can optimize manufacturing processes. As Nikolov et al. [14] describe, CAM systems are critical in generating optimal

technological strategies for machining mold elements using CNC machines. The optimization strategies utilized by CAM software can increase efficiency and reduce the overall cost of engineering design processes.

In addition to integrating CAM and other digital tools in the engineering design process, CAM software can integrate with additive manufacturing (AM) to further enhance the manufacturing process and increase production efficiency. Additive manufacturing is a process that involves designing and creating a product by layering material incrementally on a base structure. Additive manufacturing has many advantages, including increased efficiency and quality of rapid prototypes in industrial and research settings. CAM software can integrate with additive manufacturing to optimize the manufacturing process. Feldhausen et al. [15] explore how "various CAM strategies could be deployed for AM to improve process efficiency or enable localized control over part performance." With the introduction of CAM software into the industry, digital tools have successfully integrated into the engineering design process, creating a collaborative environment that improves overall product quality.

2.4 Product Data Management (PDM)

Product Data Management (PDM) is a system used to store and manage product lifecycle data. PDM software is critical in developing an efficient Product Lifecycle Management system. It maintains data regarding many aspects of a product's development, such as CAD models, CAE simulations, bill of materials information, CAM models, and pricing and manufacturing data. The primary purpose of PDM software is to increase

collaboration amongst all departments of an enterprise by allowing them access to data from other departments that they would not usually have access to. In addition, PDM software helps reduce costs and improve the quality of product designs as it optimizes the engineering design process by integrating software mentioned in the previous subsections, including CAD, CAE, and CAM software. Lucky et al. [16] discuss how the construction industry integrates Product Data Templates (PDT) and Product Data Sheets (PDS) into their PDM environment to create a shared information model that improves collaboration among stakeholders and designers. Implementing integrated applications allows PDM systems to manage product data effectively.

Another essential aspect of PDM systems is the creation and tracking of workflows. Workflows are tasks that replicate business processes to reach a specific objective or goal. Workflows automate standard functions such as assigning tasks, change management, design reviews, and prototype fabrication processes. In a traditional PDM system, workflows can be managed and changed internally, with templates guiding each process from start to finish. Workflows drive the engineering design process by increasing the efficiency of standard design processes and simplifying complicated processes to flowcharts that all departments of an enterprise can utilize. Bruun et al. [17] explore the functional workflow capabilities of PDM and PLM systems in modular product design. Overall, PDM systems and workflows improve the efficiency of engineering design processes and collaboration between multi-disciplinary teams.

CHAPTER THREE

COLLABORATIVE OPPORTUNITIES

Over the 21st century, PLM initiatives have integrated into existing business infrastructures to create digital collaborative design spaces. Digital collaborative design spaces differentiate from existing product development strategies by including all departments for product input related to design, manufacturing, and development. A digital collaborative design space can consist of many different things, including business functions, product development inputs, and PLM software. Figure 3.1 is a visual representation of all the various features of a collaborative design space, including those listed above. The shapes are color coded to match the categories discussed earlier. For example, each of the light orange circles and ovals represents inputs into the development of a product, including field data, CAD models, CAE analysis, customer feedback, requirements, bill of materials, and sales and marketing. In addition, the green diamonds separate the product inputs into separate business functions, testing, design, research, and business. Lastly, the purple boxes on the outside, denoted by arrows to dashed ovals, represent the PLM tools and software that would be used to improve collaboration within the business functions and product inputs. The PLM tools listed in each box are specific examples of software used for each application. Several other examples of software that could have been placed into each box, but the ones listed are some of the most prominent examples for each application. There are many collaborative opportunities in each facet of a business' operations. In the next two sections, collaborative opportunities are split into technical and non-technical categories and discussed further.

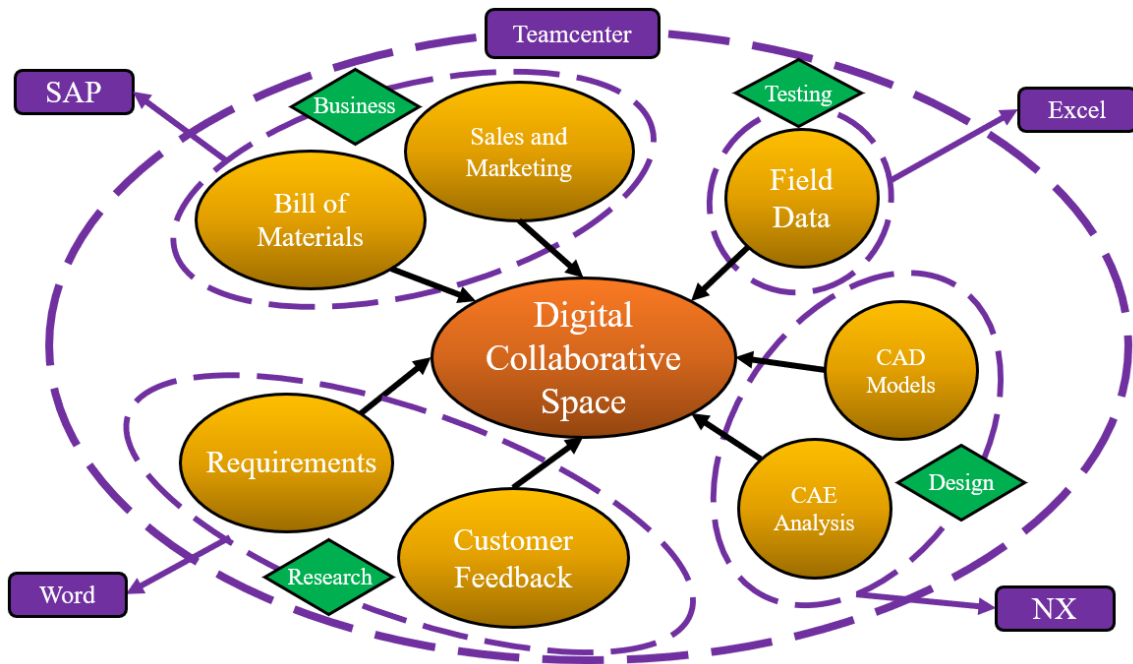


FIGURE 3.1: Collaborative digital design space with identification of software tools commonly applied

3.1 Technical (Engineering and Manufacturing)

There are many opportunities for collaboration in all technical aspects of a digital collaborative design space. In Figure 3.1, the technical inputs to the digital collaborative design space include "CAD Models," "CAE Analysis," "Field Data," and technical "Requirements," all falling under the "Testing," "Design," and "Research" business functions. CAD software has undergone many changes since its invention in the late 1950s, including additions of electrical and mechanical elements and integration features with CAE software. Collaborative CAD software has become a significant focus of industry development over the past couple of decades, with PLM initiatives leading the way. Deng et al. [18] explain how multi-user CAD (MUCAD) software allows "virtual, real-time collaboration, with the potential to expand the learning outcomes and teaching methods of

CAD." MUCAD systems allow for collaboration within engineering departments and other technical business units, such as manufacturing and testing [18]. An entire business can benefit from collaborative design using CAD software. Integrating CAD and CAE software can provide many new opportunities in a digital collaborative design space.

CAE analysis is a critical piece of the engineering design process and contributes to a product's success or failure. CAE primarily aims to reduce the design cycle time by running simulations of environments and loadings that a model or product may undergo in their normal operating conditions. Gathering CAE analysis from CAD models requires an integrated simulation package compatible with the CAD model file type. Many different CAE packages correspond to other loading conditions or applications, as described earlier, including finite element analysis (FEA), computational fluid dynamics (CFD), thermal analysis, and multibody dynamics. A collaborative opportunity in the CAE software space researched by Cramer et al. [19] is constructing a "Collaborative Architecture" for each CAE tool to integrate through a compatible CAD application. The purpose of this type of system is to "allow designers specializing in different CAE tools to access, view, or capture the functionality offered by other CAE applications in real-time without returning to the source CAD system" [19]. This system would contribute significantly to a digital collaborative design space by decreasing the design cycle time and increasing the efficiency of the engineering design process. In Figure 3.1, the example application encircling both the "CAD Models" and "CAE Analysis" circles in the "Design" business function is Siemens NX. NX is a CAD software offered by Siemens that includes many crucial design functions, including modeling, optimization, and finite element analysis

simulation. NX also integrates with other Siemens PLM solutions, including their PDM software Teamcenter, which will be discussed in the Case Study section of this paper.

Another critical technical input to a collaborative design space is field data and technical requirements. One of the primary purposes of gathering field data is to begin benchmarking research for use in the preliminary concept generation and design stage of the engineering design process. Storage of this data is a common problem for PLM solutions, with multiple solutions available. In Figure 3.1, the application listed as an example for storing field data is Microsoft Excel. Excel is a spreadsheet tool that can compute dataset's basic and advanced mathematical functions. Excel files can be easily shared across a business database through PDM software. Collaborative opportunities are available through PDM software, as they are commonly instantaneously updated for users to access all field data across an enterprise through a central repository. Another example of a collaborative opportunity in field data management is using a cloud digital twin. Research on cloud digital twins for metal additive manufacturing by Liu et al. [20] shows that collaborative data management solutions demonstrate "efficient data communications" and allow for "process optimization" throughout their business structure. Field data is also a key input to creating technical requirements for any product in the initial design stages. Technical requirements are generated through customer input and benchmarking research and can be stored in Microsoft Word documents. Similarly, these Word files can be added to PDM software to be easily accessible for all users in a business. Collaborative opportunities for creating technical requirements lie in the collective functions of PDM software. Stakeholders in the product design from every department in a business can

access and edit the technical requirements documents from the company's PDM software. All of these collaborative opportunities relating to the technical inputs of the engineering design process are incorporated into PLM initiatives of the 21st century.

3.2 Non-Technical (Business Functions)

In a digital collaborative design space, the non-technical inputs include "Sales and Marketing," "Bill of Materials," and "Customer Feedback," each a part of the "Business" and "Research" business functions. The first non-technical input discussed in further detail is "Customer Feedback." Customer feedback is a crucial facet of the engineering design process, as the customer can provide critical input to the construction of a product through design reviews. Prabhakaran et al. [21] discuss how collaborative opportunities exist in the communication of customer feedback through the creation of "an interactive and immersive virtual environment for design communication." Research on creating a virtual reality environment for furniture, fixture, and equipment (FFE) design communication for stakeholders reveals that "the presented framework can highly improve the efficiency, design coordination, and productivity" of the FFE design process [21]. Additionally, this prototypical VR system increases collaboration amongst all stakeholders for any design problem by allowing them to give feedback on particular design choices or methods instantaneously. Overall, collaborative initiatives in the communication of customer feedback can improve the efficiency of the engineering design process.

Next, the "Bill of Materials" and "Sales and Marketing" non-technical inputs to the digital collaborative design space in Figure 3.1 allow businesses to configure their

purchasing and marketing strategies for their product portfolio. A bill of materials (BOM) is a structured list of the components of a product, including materials, parts, and assemblies. A bill of materials is an essential source of information for the sales and marketing departments, as they can provide links to documentation and drawings of the most important aspects of products. One collaborative opportunity in using a bill of materials is the creation of a collaborative bill of materials (C-BOM) [22]. Shamsuzzoha et al. [22] relate how research on a collaborative bill of materials among manufacturing firms allows "companies [to] collaborate with each other from the early conceptual phase of the product, where necessary design and engineering are undertaken." Collaboration amongst businesses on product development would require a network of information and expertise through a standard bill of materials. For manufacturing firms, this collaborative tool would need to "facilitate frequent exchange of information" that "contributes to the collaborative product design" [22]. An example of a PLM tool that incorporates a bill of materials into a cloud-based setting is SAP ERP (enterprise resource planning). SAP is a software system that "helps run core processes in a single system for departments such as finance, manufacturing HR, supply chain, services, procurement, and others" [23]. The benefits of using a cloud-based system such as SAP ERP include the increased collaboration of all departments on specific aspects of the product department. Collaborative opportunities on non-technical inputs to the digital collaborative design space are vital to PLM initiatives, as they improve collaboration in all aspects of the engineering design process, including the non-technical parts, such as customer feedback, bill of materials, sales, and marketing.

CHAPTER FOUR

CASE STUDY

A case study was conducted with the PLM Processes Creative Inquiry (CI) team at Clemson University to implement ideas from the digital collaborative design space into an educational setting. The goal of the CI team is to develop a digital twin of a scaled, tracked robotic platform. In pursuit of this goal, industrial PLM concepts and tools will be utilized to improve collaboration amongst team members and the efficiency of the design process. The tracked vehicle the CI team attempts to recreate as a digital twin is a T'REX Robot Tank Chassis, shown in Figure 4.1. For PLM resources, the CI team already uses Siemens NX as their CAD software and Microsoft Excel as their PDM solution. To improve their design process's collaboration and efficiency, we will implement Siemens Teamcenter as an additional PDM tool. For the CI team, Teamcenter will be integrated into their existing design process as a database for NX CAD files and a facilitator for product development through the use of workflows. The following two sections will discuss the benefits of using advanced PDM software, including features such as CAD and PDM integration, engineering workflows, and collaborative design tools. Additionally, an overview of the difficulties encountered when integrating the software will be discussed, and some steps will be taken to troubleshoot these problems.

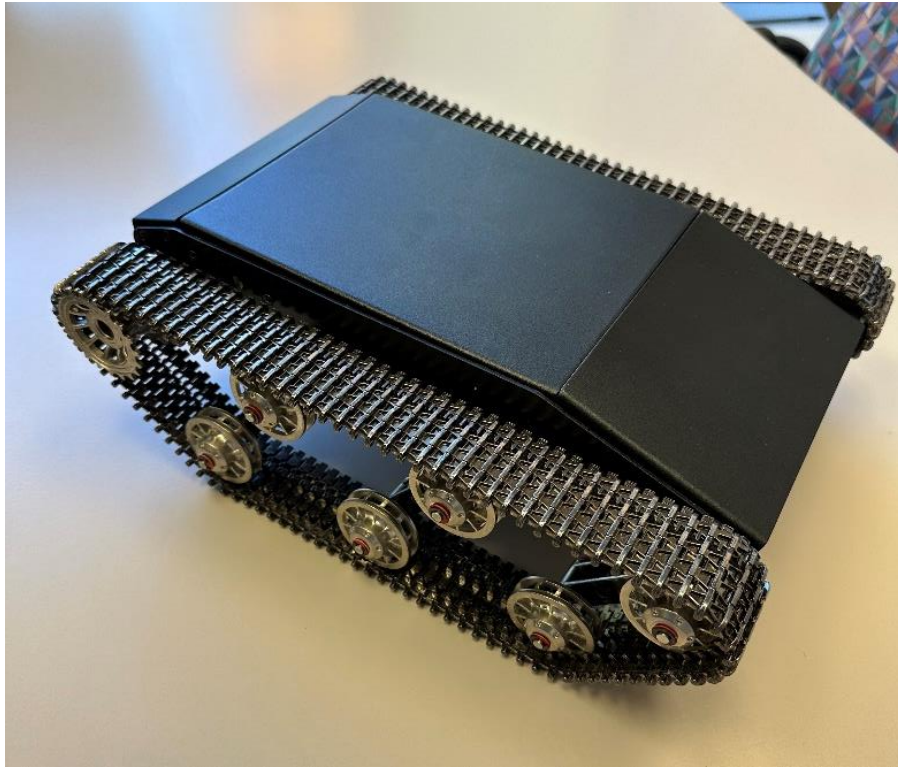


FIGURE 4.1: A scaled tracked vehicle serves as the basis for collaborative study with Creative Inquiry students

4.1 PDM Application

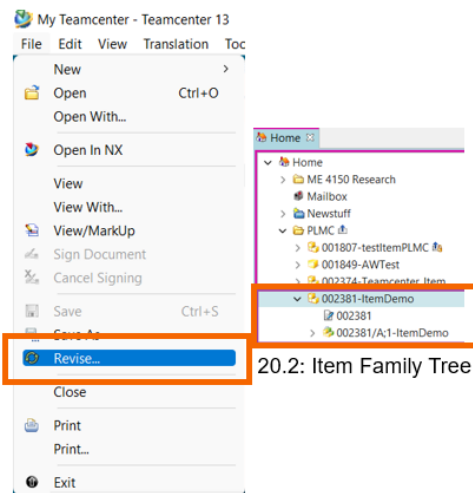
In Figure 3.1, the purple, dashed outer circle surrounding the entire digital collaborative design space is labeled "Teamcenter," a Siemens PDM software that incorporates all aspects of the digital collaborative design space into its functionalities. PDM software is one of the essential parts of the digital collaborative design space, as it facilitates all of the different PLM processes discussed earlier in this paper. Teamcenter can integrate CAD, CAE, and CAM software into its central database to create a repository for all product-related data. For the CI team, Teamcenter will be a foundation for building the tracked vehicle's digital twin. To introduce Teamcenter to the team, an introductory presentation was created and presented, showcasing some of the software's essential

features, including item creation, workflows, change management, and bill of materials. The presentation communicates information on the benefits of using an integrated PDM system like Teamcenter. The presentation also incorporated several demos on the basic functionality of Teamcenter, including items, workflows, change management, and bill of materials. An example presentation slide for an item creation demo is shown in Figure 4.2.



Item Demo: Item Revisions

- When a new item is created, it's revisions are listed below its parent using the drop-down bar
- To create a new item revision, select the most recent revision, and navigate through the **File** menu to create a revision
- Assign a revision ID to the object
- Newly created item revisions will be displayed below the parent item



20.1: Creating an Item Revision



FIGURE 4.2: Teamcenter software instruction - item demonstration

After the Teamcenter presentation was given to the CI team, Teamcenter 13 was installed and set up on the desktop computers in the Product Lifecycle Management Center's (PLMC) computer lab on Clemson University's main campus. Each member of the CI team was assigned a Teamcenter account that they could log into remotely using Teamcenter's active workspace or through a PLMC lab computer in the rich client. The

team would utilize the most crucial feature of Teamcenter throughout their design process is the NX/Teamcenter integration. The team used this integration to improve the efficiency of their engineering design process. It allowed them to navigate quickly through the list of parts, assemblies, and drawings for the tracked vehicle while easily downloading and uploading new versions of these files automatically. Teamcenter can open an NX part file from its central database through the Active Workspace and Rich Client. One problem the CI team encountered when trying to utilize the NX/Teamcenter integration was the difficulty in transferring existing part files from their Excel PDM file to Teamcenter's server. Figure 4.3 displays the solution to this problem, a screenshot of the dialog box that uploads NX part files into Teamcenter. This feature allows users to upload parts or assemblies from their local server or file database into Teamcenter's servers. The feature can be found in NX's "File" menu bar, titled "Import Assembly into Teamcenter." Teamcenter allows users to customize their import options within the dialog box, including the file name and revision, item type, and destination folder. Once the options for each uploaded part are configured, Teamcenter can validate the information in its database and perform a dry run of the upload. After confirming the uploaded parts, the files can be uploaded to Teamcenter's server. Figure 4.3 adds three of the CI team's original part files to the upload list. In the left-hand column, drop-down lists for the naming conventions of the items are available. Newly uploaded items can be named using their original file name or a different name based on the user's preference. Additionally, the items can be listed in Teamcenter with an identification and revision number. After the naming conventions are chosen, the user can specify the type of files that they are uploading. For the CI team's

application, the “Item” type was chosen, as it allows them to attach different types of data files to each specific item. Next, the user can change the destination folder that each item will be uploaded to. In Teamcenter, folders can be created for individual users to sort their items and documents based on different projects or products. Overall, Teamcenter’s import feature has allowed the CI team a seamless transition to Teamcenter from their previous system.

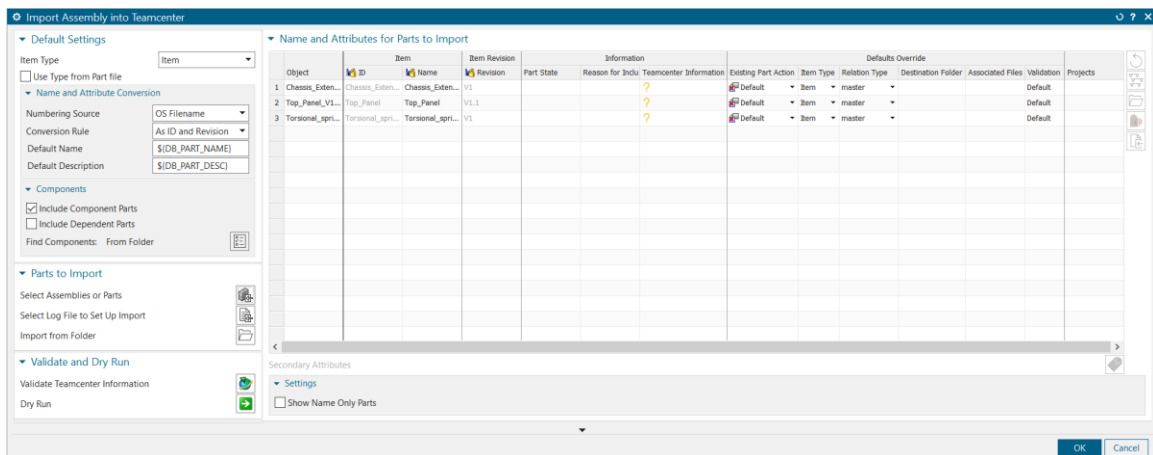


FIGURE 4.3: Import assembly into Teamcenter dialog box

The other significant features of Teamcenter that the CI team are utilizing in their design process are workflows. A workflow is a step-by-step release process that models many basic business functions. Workflows can route an item for design review and approval, manage the change management process, and track manufacturing and design processes. A block diagram of an example Change Review (CR) workflow in Teamcenter is shown in Figure 4.4. The Change Review workflow has many unique features, including assigning specialists and a review board to specific tasks. Workflows always begin with a

user assigning participants to each task and providing descriptions of the needed work. For this workflow, a plan for the change must be proposed by a specialist and checked by an engineer.

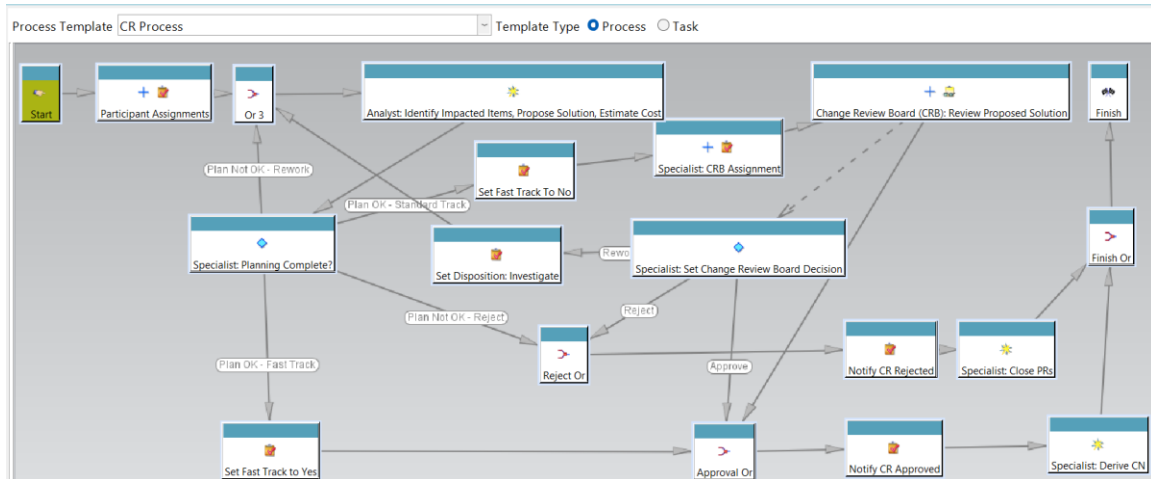


FIGURE 4.4: Change review workflow

If the proposed plan is approved, the workflow can be fast-tracked, or standard-tracked. If fast-tracked, the workflow then moves to the approval process, where the Change Review Board (CRB) reviews the proposed solution and either approves or rejects the proposed plan. This Change Review workflow would be ideal for large engineering companies with many stakeholders invested in the design process. However, for this case study, the workflow is too complex and intricate for many basic design processes the CI team will complete. Instead of this complicated review process, the CI team will employ a basic workflow that includes assigning a task to either a group or individual user,

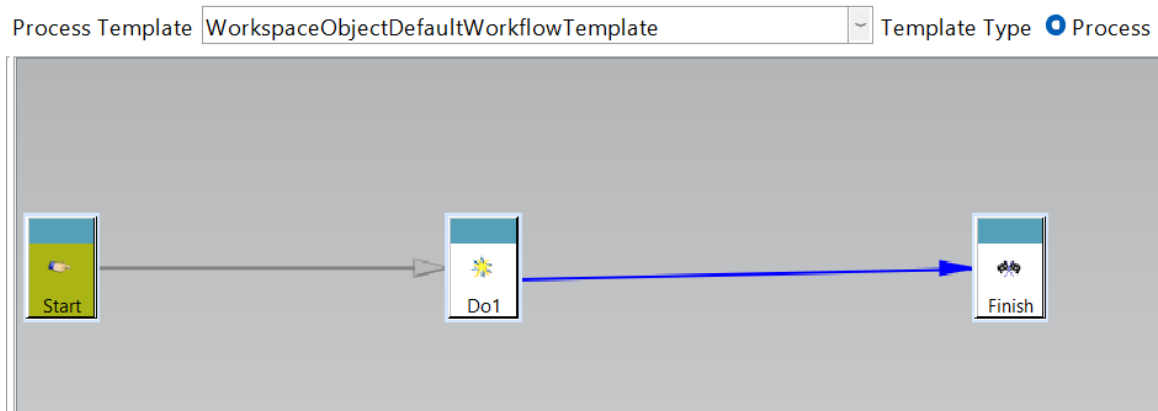


FIGURE 4.5: Workspace default workflow within Teamcenter

completing that task by the assigned user(s), and finalizing the workflow. A block diagram of this described workflow is displayed in Figure 4.5. The workflow consists of a single step, a "Do" task. Within the task, a description of the assignment is included, as well as options to edit or complete the task. Once a workflow is completed, each box in the block diagram is highlighted green, and the workflow is removed from a user's worklist. For the CI team, this simple workflow is ideal for the basic design processes they will complete. For example, a team member can assign a workflow to a part file that requires another member to create a 2D drawing of the part. In general, workflows allow team members to communicate and collaborate on different design aspects with a built-in digital process to guide them.

4.2 Troubleshooting and Results

Throughout the Teamcenter implementation process, the CI team encountered many problems integrating the software into their existing design process. One major problem

was connecting Teamcenter with NX using the Teamcenter/NX integration. After Teamcenter was installed on the PLMC lab computers, the link between the two software needed to be established, and the integration could not be utilized. After thorough troubleshooting, a Siemens software technician was contacted to help correct the issues. After weeks of communicating and collaborating with the technician, it was determined that an error in Teamcenter's preferences caused the disconnected link between NX and Teamcenter, which was quickly fixed after the solution was identified. Another issue the team faced was with the Workflow Designer perspective permissions in Teamcenter. The Workflow Designer perspective is a feature of Teamcenter that allows users to design their workflow processes, specifically for different business functions. An essential aspect of the CI team's digital twin development is creating scaled CAD models of other parts of the tracked vehicle. The team could benefit tremendously from a customized workflow replicating the design review process they already use for their CAD models. However, Teamcenter does not allow non-database administrators (non-DBA) to use the Workflow Designer perspective to design workflows. A screenshot of the error message received after attempting to use the perspective is shown in Figure 4.6.

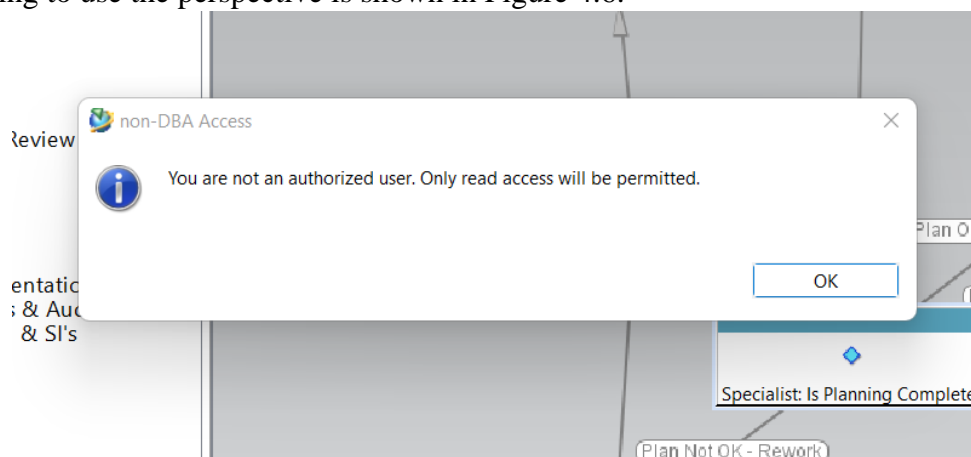


FIGURE 4.6: Workflow designer error

Unfortunately, this error could not be fixed, and due to server limitations, authorizations for certain users could not be granted to use this feature. However, the templates in Teamcenter cover most of the possible workflow processes the CI team will use. Therefore, the team will move forward with the workflow templates instead of the original designs.

Although the CI team has learned Teamcenter quickly and is utilizing it weekly to improve the efficiency of the engineering design process, it is still very early in the implementation of the PDM tool, and concrete results still need to be gathered. From conversations with members of the CI team, positive impressions of Teamcenter are a common theme. Teamcenter has allowed them to improve the speed and performance of their design process by utilizing the Teamcenter/NX integration. Also, the engineering workflows increased collaboration amongst team members on all design aspects of the digital twin. Overall, using advanced PDM software like Teamcenter provides many benefits to a company or design team. The specific benefits of implementing Teamcenter in the CI team will be researched further in future projects.

CHAPTER FOUR

CONCLUSION

PLM initiatives have positively contributed to the digital collaborative design space by increasing collaboration amongst all departments in the engineering design process. PLM tools such as CAD, CAE, CAM, and PDM software have provided a medium for collaboration on different aspects of the process, from design and simulation to manufacturing and data management. One of the essential PLM resources is advanced, digital PDM software that can integrate with other PLM tools to create a digital collaborative design space. Implementation of Siemens Teamcenter in a design group case study resulted in increased collaboration and efficiency of their design process.

APPENDICES

Appendix A

PLM Processes Creative Inquiry Tank

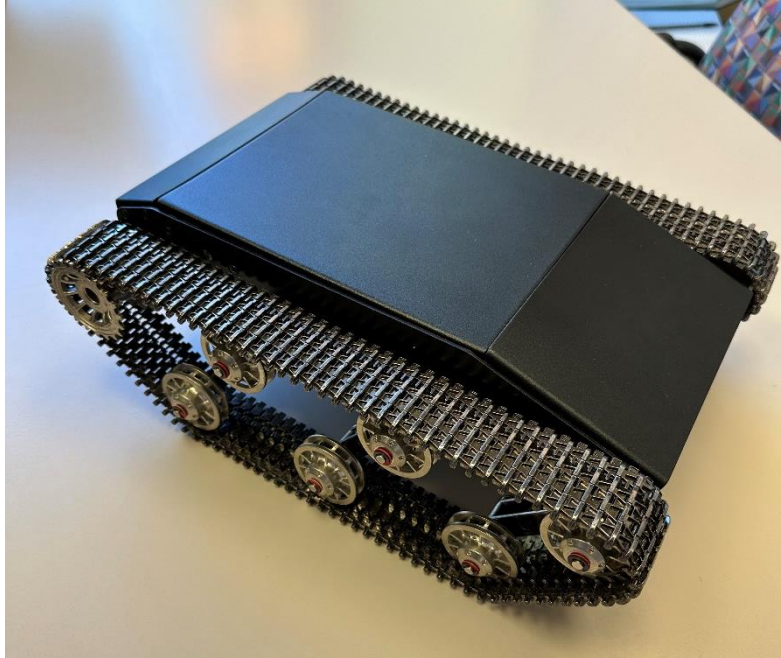


Figure A.1: Tank – Bottom View

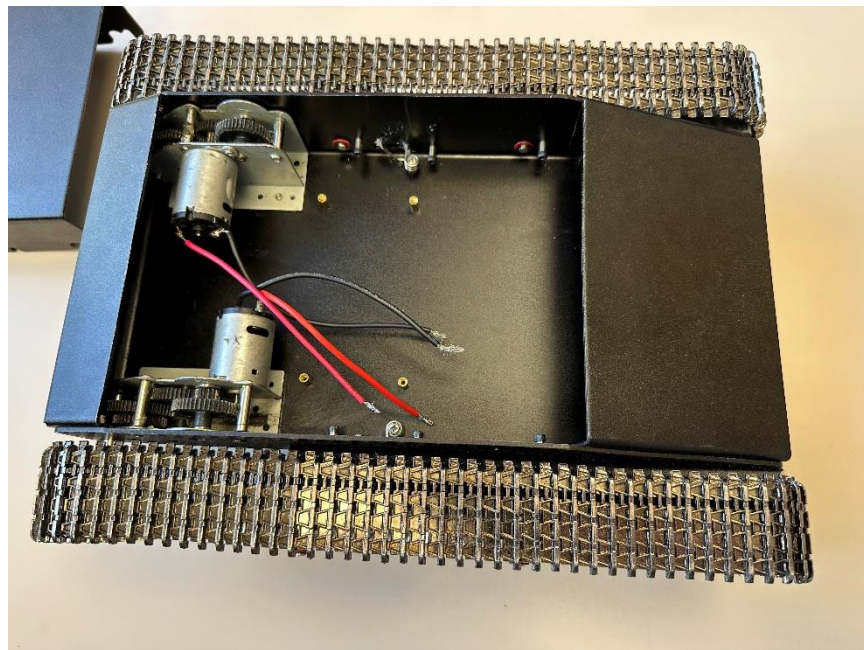


Figure A.2: Tank – Top View

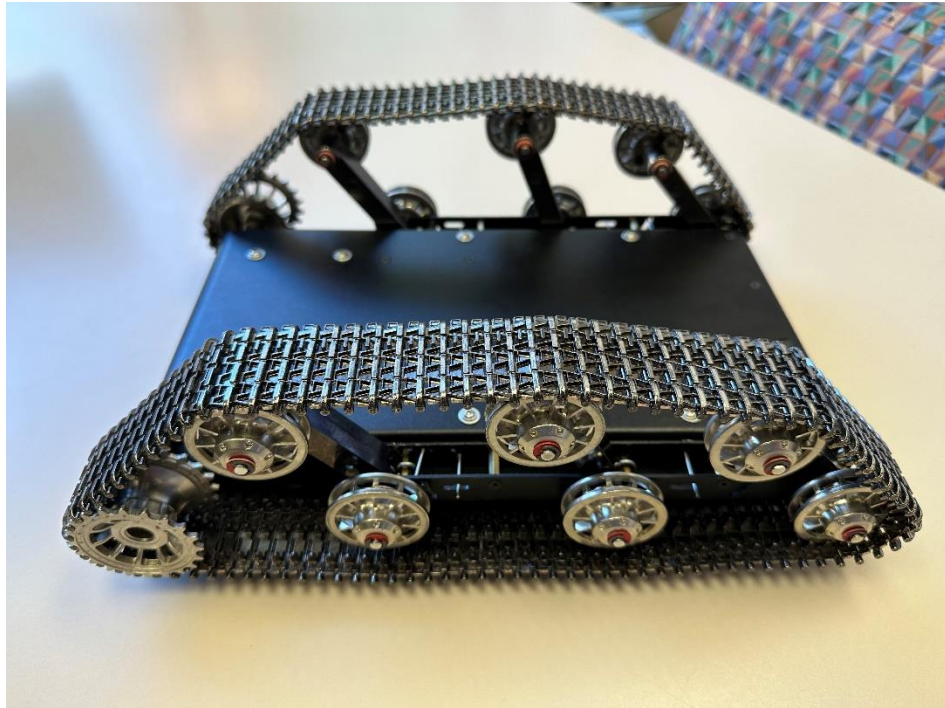


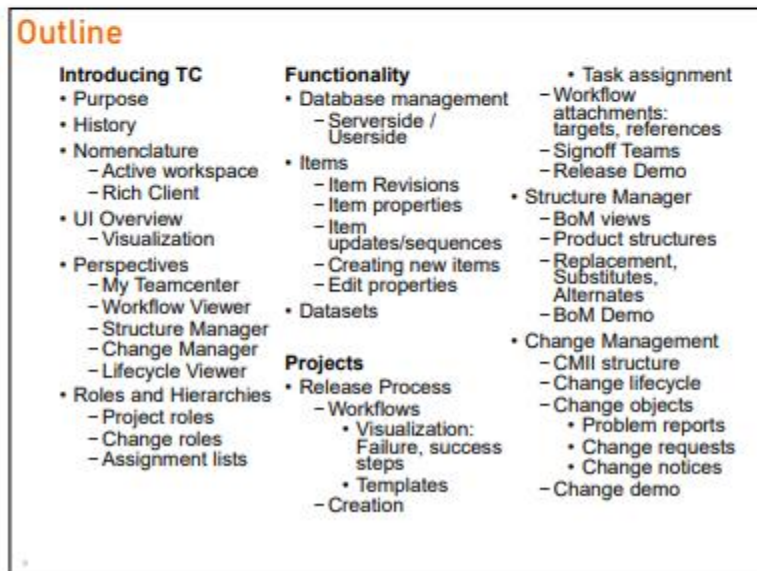
Figure A.3: Tank – Bottom View

Appendix B

Teamcenter Workshop Presentation Slides

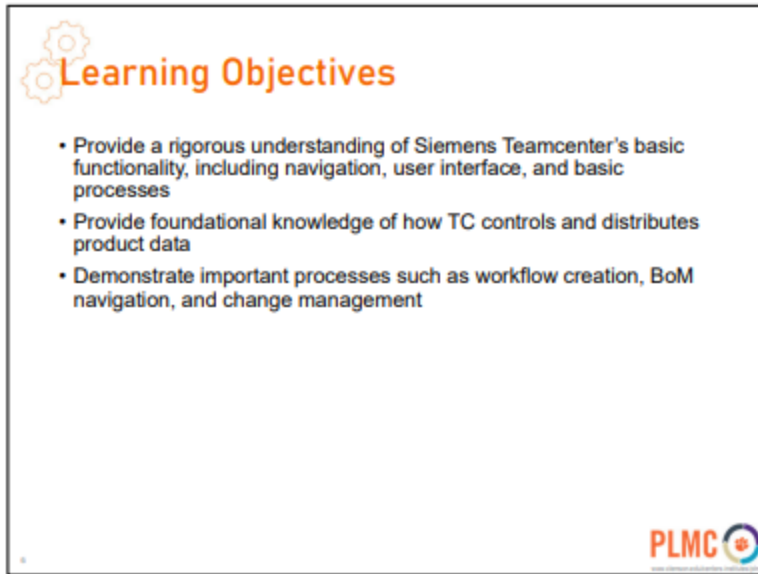



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Figure B.1: Teamcenter Slides (1)

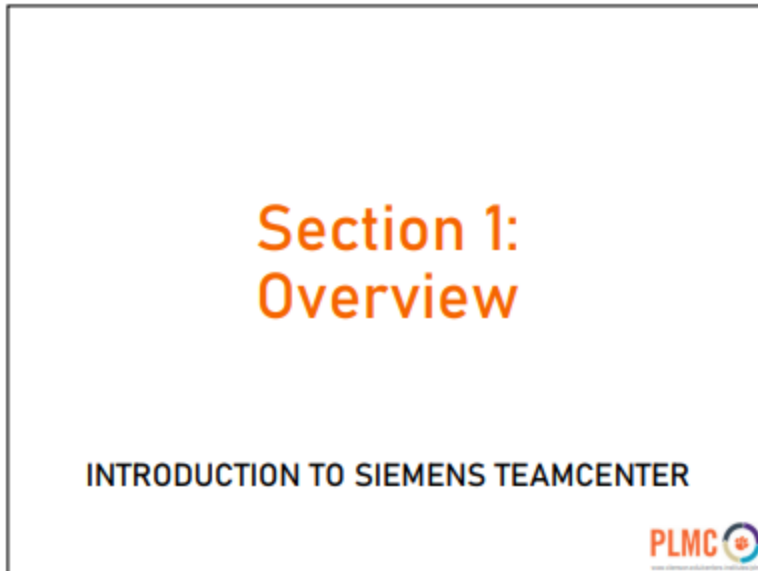


 **Learning Objectives**

- Provide a rigorous understanding of Siemens Teamcenter's basic functionality, including navigation, user interface, and basic processes
- Provide foundational knowledge of how TC controls and distributes product data
- Demonstrate important processes such as workflow creation, BoM navigation, and change management




6



**Section 1:
Overview**

INTRODUCTION TO SIEMENS TEAMCENTER




7


Figure B.2: Teamcenter Slides (2)

History/Intro to Siemens

- Headquarters in Munich, Germany
- Focus on electrification, automation, and digitalization
- Global Revenue exceeding \$100 billion
- Conglomeration of many distinct divisions:
 - Digital Industries
 - Financial Services
 - Mobility
 - Siemens Healthineers
 - Smart Infrastructure
 - Global Business Services




8.1: Siemens Headquarters in Munich, Germany
Siemens, 2016




8

Nomenclature


- **Active workspace**
 - Accessed via web browser
 - Designed for use on multiple different machines
 - Provides limited functions
- **Rich Client**
 - Desktop-based interface
 - Designed to fulfill advanced tasks and allow customization
 - Provides access to full Teamcenter functions



9.1: Teamcenter Active Workspace Interface



9.2: Teamcenter Rich Client Interface

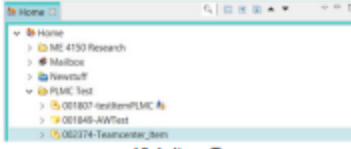


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Figure B.3: Teamcenter Slides (3)

Nomenclature


- **Item:** Holds product-related data that can be accessed throughout the product development process
 - Drawing, part, assembly files
 - Bill of Materials (BOM) info
 - Change management data
 - Engineering simulations
- **Workflow:** Set of actions used to make changes to product data
 - Require actions from individuals or groups to meet a set of criteria before the workflow is approved



10.1: Item Tree




10.2: Workflow Template




10

Perspectives

- Teamcenter perspectives allow users to access different features of the software by changing their view
 - My Teamcenter
 - Workflow Viewer
 - Structure Manager
 - Change Manager
 - Lifecycle Viewer
 - Organization
 - Workflow Designer
 - Project



11.1: Perspective Menu



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Figure B.4: Teamcenter Slides (4)

Perspectives

- Teamcenter contains around 45 different applications that can be added to the perspectives list using the navigation pane options
- Teamcenter Perspectives allow the software to become more flexible and customizable for different tasks

12.1: Application Navigation Pane

12

User Interface

- **Menus:** Located in the upper left bar, contains many useful functions
 - File
 - Edit
 - View
 - Translation
 - Tools
 - Window
 - Help

13.1: Tools Menu

13

Figure B.5: Teamcenter Slides (5)

Section 2: Functionality

INTRODUCTION TO SIEMENS TEAMCENTER



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Roles and Hierarchies

- **Organization:** Perspective that displays all groups on the local server, as well as their subgroups, roles, and users

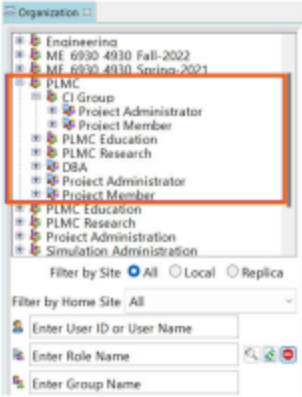
15.1: Organization Perspective

15

Figure B.6: Teamcenter Slides (6)

Roles and Hierarchies

- There are many different roles that users can be assigned:
 - **Project Administrator:** delegates tasks and facilitate project development
 - **Project Member:** creates and maintains product data
 - **Project Team Admin:** provides support for project members
 - **DBA (database administrator):** manages Teamcenter databases
- All users can be found using the search bars below the organization list




16.1: PLM Center Group

PLMC

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Database Management

- Teamcenter uses a centralized database to store information and data that can be accessed by users across different systems
- Teamcenter's server can either be hosted on-site or through the cloud
- Clemson hosts Teamcenter at their primary data center, the Information Technology Center (ITC)
- ITC is centered at the Advanced Materials Research Park in Anderson, SC



17.1: Database Storage System

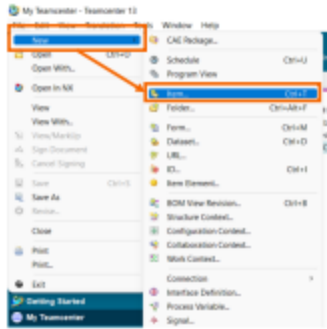
PLMC

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Figure B.7: Teamcenter Slides (7)

Item Demo: Create an Item

- Choose an existing folder to place the new item within
- Navigate through the **File** menu to create an item data asset that manages documents, drawings, or 3D models



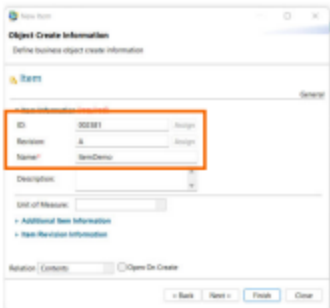
18.1: Creating an Item




18

Item Demo: Create an Item

- Create a sequential ID using the **Assign** feature, then provide a more understandable name to the part
- Once added, the item file will be saved to Teamcenter's database, and will appear inside the selected folder's family tree



19.1: Assigning an ID



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Figure B.8: Teamcenter Slides (8)

Item Demo: Item Revisions

- When a new item is created, it's revisions are listed below its parent using the drop-down bar
- To create a new item revision, select the most recent revision, and navigate through the **File** menu to create a revision
- Assign a revision ID to the object
- Newly created item revisions will be displayed below the parent item

20.1: Creating an Item Revision

20.2: Item Family Tree

PLMC

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Item Demo: Edit Properties

- **Edit Properties:** feature that allows a user to modify the metadata of a specific item
 - Revision number
 - Lifecycle state
 - Project workflow
- Navigate through the **Edit Properties** menu to make changes to an item's properties

21.1: Edit Properties

21.2: Edit Properties Dialog Box

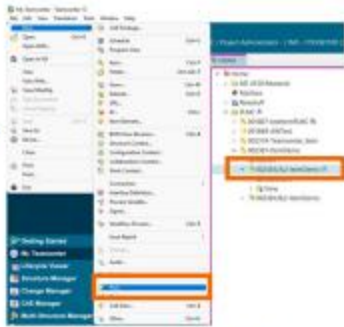
PLMC

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Figure B.9: Teamcenter Slides (9)

Item Demo: Create a Part

- Select an item to create a part file
 - If an item has multiple revisions, select the specific revision to create a part file
- Navigate through the File menu to create a part for the item revision




22.1: Part Creation




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Item Demo: Create a Part

- Create a sequential ID using the **Assign** feature, then provide a more understandable name to the part
- Proceed through the steps in the New Part box to attach files, define workflows, enter additional information, and assign to a project
- Newly created parts will display below the parent item revision in its family tree

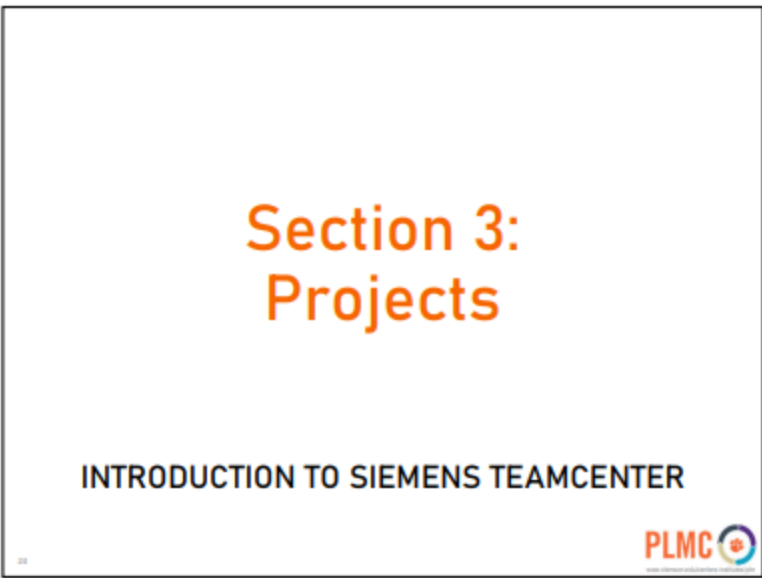


23.1: New Part Dialog Box

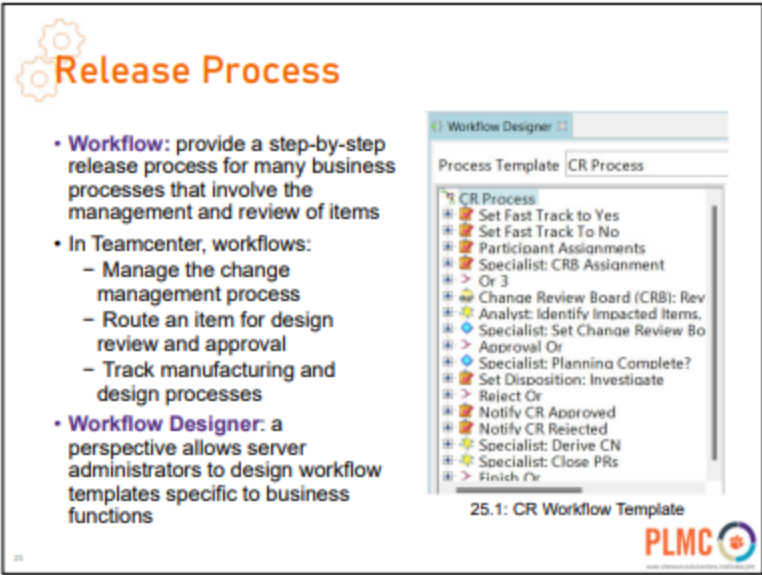


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Figure B.10: Teamcenter Slides (10)



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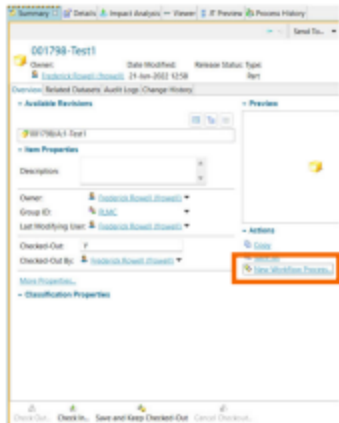


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Figure B.11: Teamcenter Slides (11)

Workflow Demo

- To create a workflow process:
 - Check out a part
 - On the part's **Summary** page, find the **New Workflow Process** option




26.1: New Workflow Process




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Workflow Demo

- There are several options within the **New Process** dialog box to customize a workflow
 - Different process templates can be applied to replicate business processes
 - Tasks can be assigned to anyone within the organization
 - Process templates can be viewed and altered
- Workflow Viewer**: a perspective used to view a workflow's progress



27.1: New Process Dialog Box

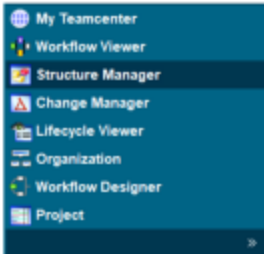


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Figure B.12: Teamcenter Slides (12)

Structure Manager

- Preview item relationships
 - Allows the user to view and edit a product's bill of materials (BOM), including its components and sub-assemblies
- Analyze product dependencies
 - Contains impact analysis, which displays an item's relationship with other products or projects
- Collaboration
 - Improves collaboration among teams by providing a shared, centralized repository for product data



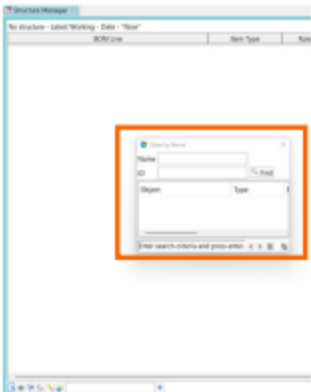
28.1: Structure Manager

PLMC

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BoM Demo - Using Structure Manager

- Locate the Structure Manager perspective from the Perspectives tab
- Search an item, part, or assembly to add it to the BOM line at the top
- An item's properties and details will be listed horizontally across the screen
 - Item type
 - Revision status
 - Units
 - Variant conditions
 - All notes



29.1: Structure Manager Search Box

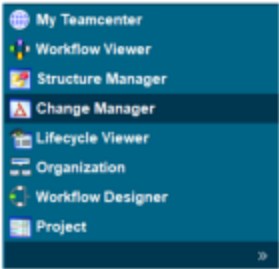
PLMC

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Figure B.13: Teamcenter Slides (13)

Change Management

- Change Management is a tool used to track changes to product data in the development process
- A change lifecycle normally consists of many of the following features:
 - Creation and submission of change requests
 - Review and approval of changes
 - Implementation and documentation of changes
- Allows for more efficient collaboration amongst team members



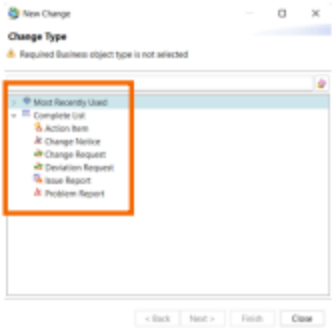
30.1: Change Manager

PLMC

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Change Management

- Change objects are used to manage changes to product data and items
 - **Change Request:** A request for modification of an item
 - **Change Order:** A document that implements a change request
 - **Change Notice:** A document that illustrates a change to an item
 - **Problem Report:** A document that describes potential problems with a requested change



31.1: New Change Dialog Box

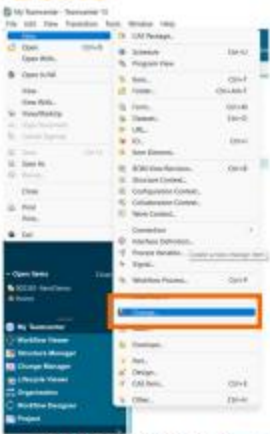
PLMC

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Figure B.14: Teamcenter Slides (14)

Change Management Demo

- Navigate through the **File** menu and select the **Change** option
- Choose a change type that accurately reflects the type of procedure that you would like to complete
- Assign an ID to the proposed change, and provided a synopsis and description of the change
- If the change is part of an in-progress workflow, add it to the correct stage in the workflow



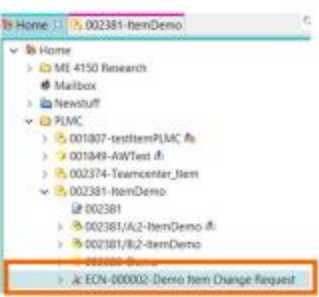
32.1: New Change Demo

PLMC

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Change Management Demo

- The change will be displayed below its parent item in the family tree
- The change can be viewed and edited using the Change Manager perspective



33.1: New Change Item Tree


PLMC

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Figure B.15: Teamcenter Slides (15)

Siemens Xcelerator Academy

- Siemens gives Clemson personnel access to their online learning academy
- Follow the QR code below to be added to Clemson's license list and be given to access to the Xcelerator Academy
- Afterwards create a Siemens account using your ClemsonID@clemson.edu email

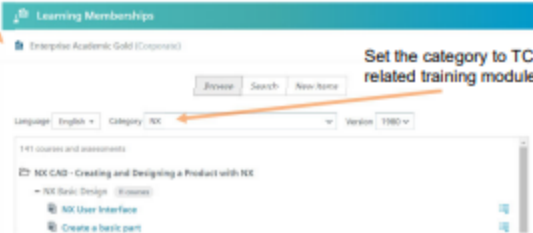


PLMC

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Siemens Xcelerator Academy

Once you have been added to the system the *Enterprise Academic Gold* membership will show up here



Set the category to TC to find related training modules


There a dozens of courses you can take, including 11 for basic design in TC

You can also export a transcript of your work, a useful record to show employers!

PLMC


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Figure B.16: Teamcenter Slides (16)

 **Summary**

- Siemens Teamcenter is a product lifecycle management (PLM) software that is designed to manage and process any data associated with the design of a product
- Teamcenter is a comprehensive system that includes product data management (PDM), engineering, simulation, and manufacturing tools
- Teamcenter provides integration between CAD, CAE, CAM, and PDM software to allow teams to collaborate in a virtual design space

SIEMENS
Ingenuity for life



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 **Request Course Content**

Send an email to plmcenter@clmson.edu to request access to today's presentation, or other information on Product Data Management





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Figure B.17: Teamcenter Slides (17)



Contact Info

Fritz Rowell
 Phone: 865-605-5731
 Email: frowell@clemson.edu

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INTRO TO SIEMENS TEAMCENTER

PLMC

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Figure B.18: Teamcenter Slides (18)

Appendix C

Departmental Honors Presentation Slides




Exploration of Collaborative Design Spaces – Engineering Interactions and Workflows in a Product’s Lifecycle

4/25/2023
Frederick (Fritz) Rowell
Dr. John Wagner, Clemson University
PLM Center




1



Research Objectives and Goals

- Objectives
 - RO1 - Explore engineering interactions with collaborative tools on product design
 - RO2 - Investigate use of Teamcenter in Creative Inquiry design projects and Deep Orange vehicle designs
- Goals
 - G1 - Integrate Siemens NX and Teamcenter to create a virtual toolbox (RO1)
 - G2 - Collaborate with Creative Inquiry class on rudimentary application (RO2)
 - G3 - Join Deep Orange 14 design team at CU-ICAR (RO2)
 - G4 - Complete case studies to document processes and challenges (RO2)
 - G5 – Trailblazing use of Teamcenter in PLM Center at Clemson University and overcome problems (RO1)



2

Figure C.1: Final Presentation (1)

Agenda

- PLM Concepts
- PLM Tools
- Collaborative Design Space
- Case Studies

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3

PLM Concepts

CLEMSON UNIVERSITY

4

Figure C.2: Final Presentation (2)



Product Lifecycle Management (PLM) Concepts

- PLM is a virtual thread for workflow within an enterprise, bringing together all business functions
- Encompasses human resources, business, engineering, manufacturing, field service
- All team members need to buy into digital design, documentation, and manufacturing to be successful
- Number of commercial PLM software vendors exist
- Goal: Decrease product cost, increase product revenue, maximize value of product portfolio for customer



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5



Product Lifecycle Management Benefits


- Optimization
 - Guraksin et. al. analyzes the **optimization** benefits for servicing and repairing aircraft to ensure passenger safety [1]
- Traceability
 - Conlon shares how the **traceability** of changes within a workflow allows a business to **track** fundamental alterations and the present **status** of a product [2]



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6


Figure C.3: Final Presentation (3)




Product Lifecycle Management Benefits

- Software Integration
 - Nikolov et al. discusses the benefits of **integrating** CAD and CAM software for **manufacturing** purposes
- Access Management
 - Ngo et al. researches different ways to delegate **access** to data for all **users** in an organization in the medical sector [4]






7



Traditional Enterprise Organization

- Individual departments contributing to the overall success of the enterprise
- Limited collaboration
- Slow, less efficient product development



Enterprise Organization (Pre-PLM)



8

Figure C.4: Final Presentation (4)



Post-PLM Enterprise Organization

- Increased collaboration
 - Arrows and dashed boxes between departments represent collaborative business processes
- Faster, more efficient product development
- Digital collaborative design space



Enterprise Organization (Post-PLM)



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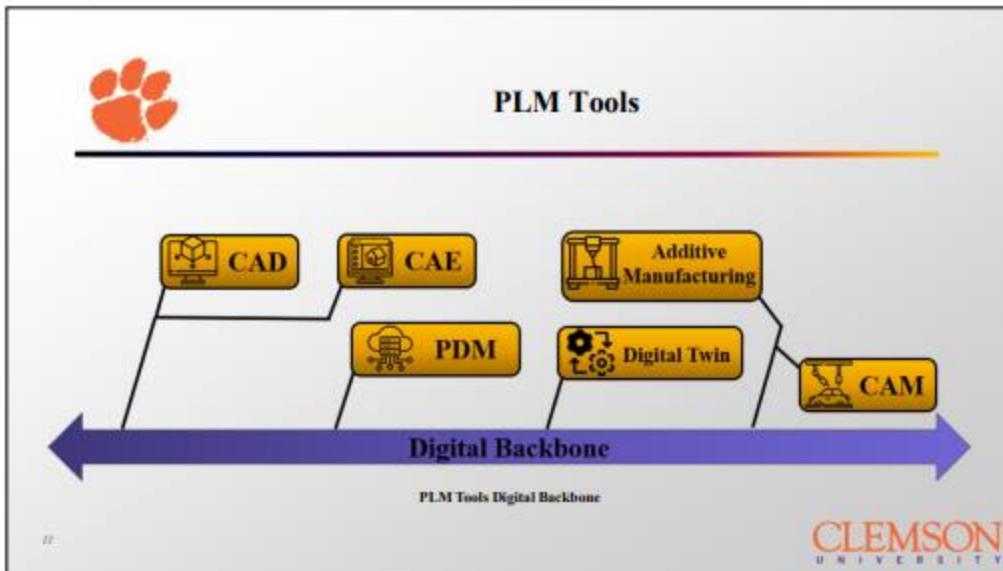


PLM Tools

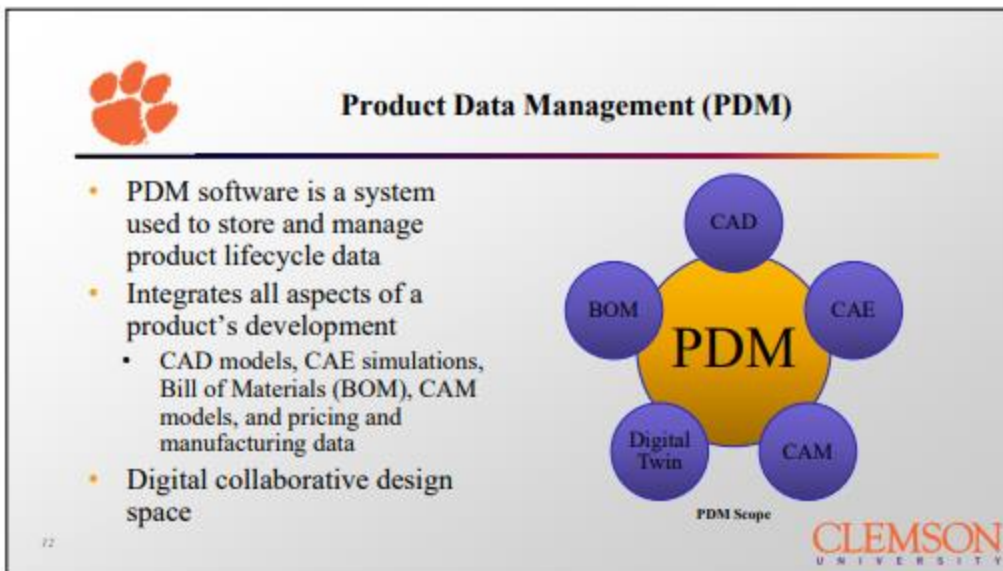


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Figure C.5: Final Presentation (5)



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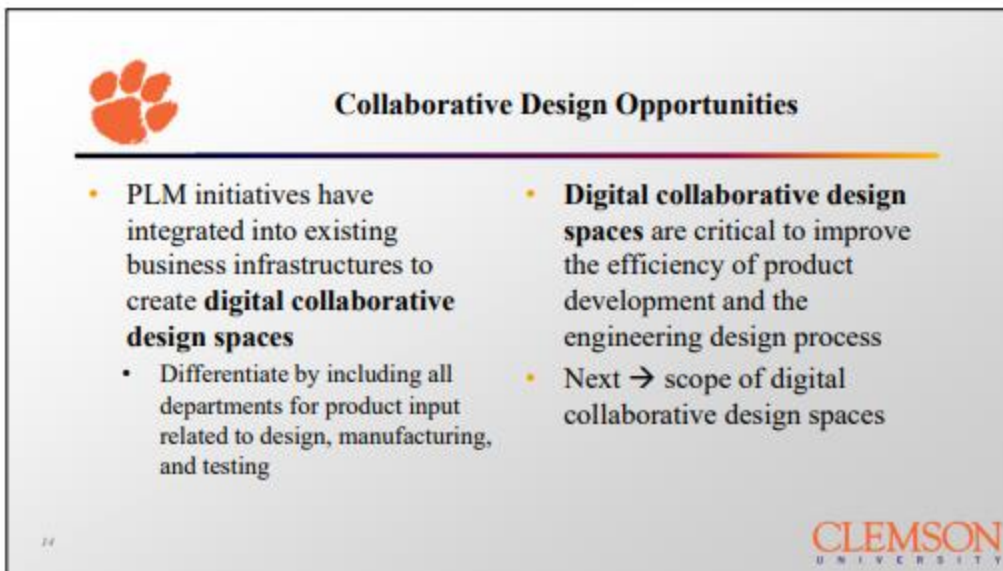


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Figure C.6: Final Presentation (6)

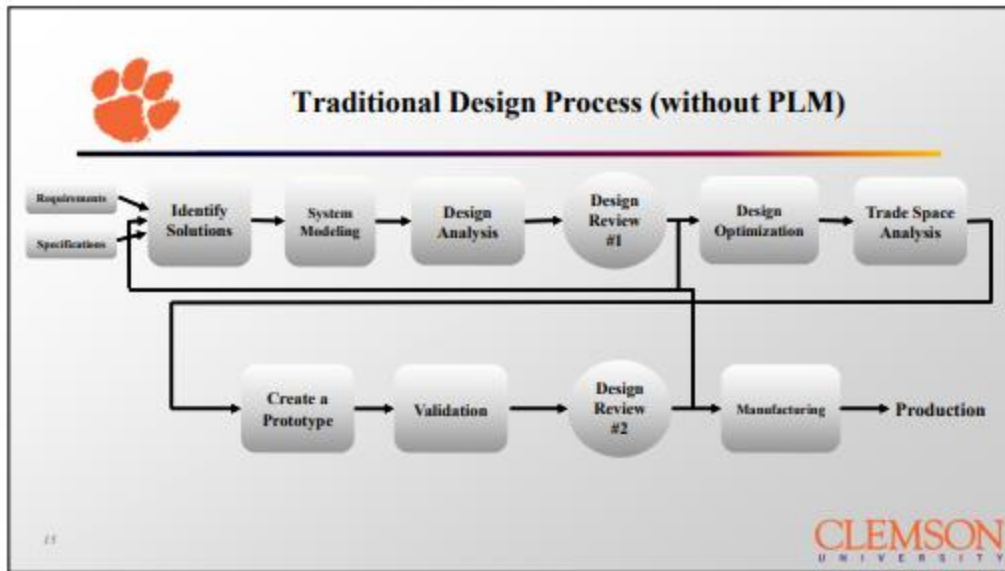


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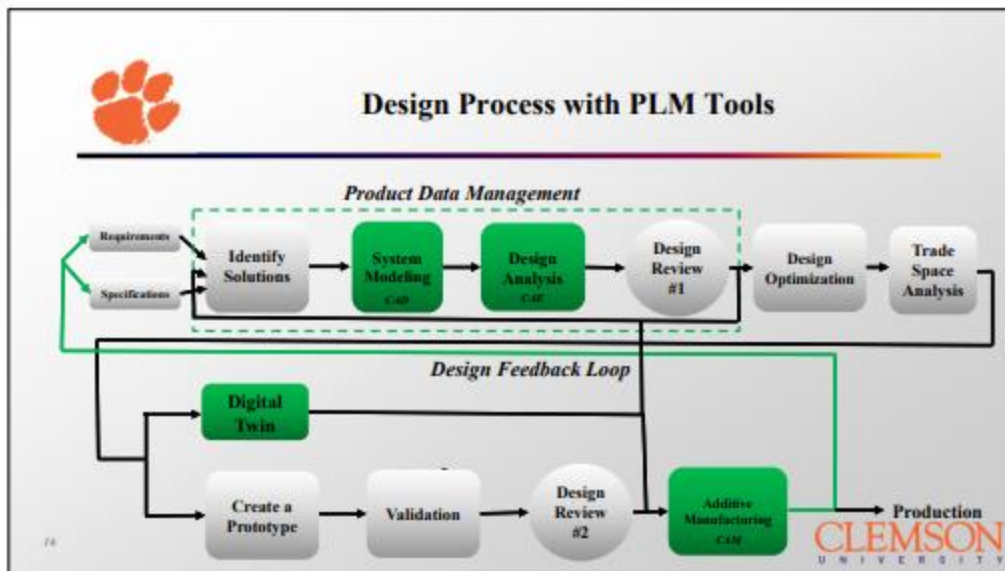


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Figure C.7: Final Presentation (7)

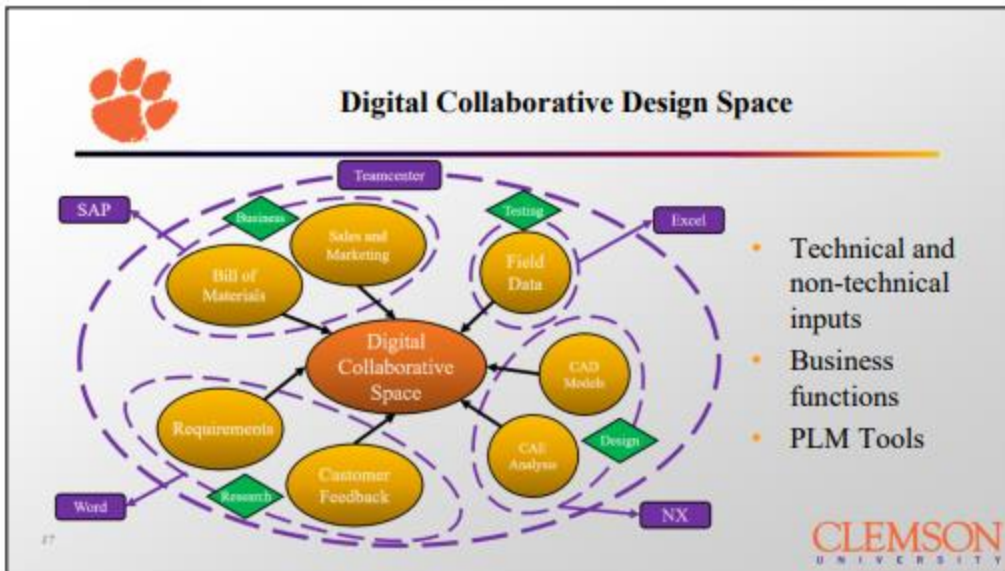


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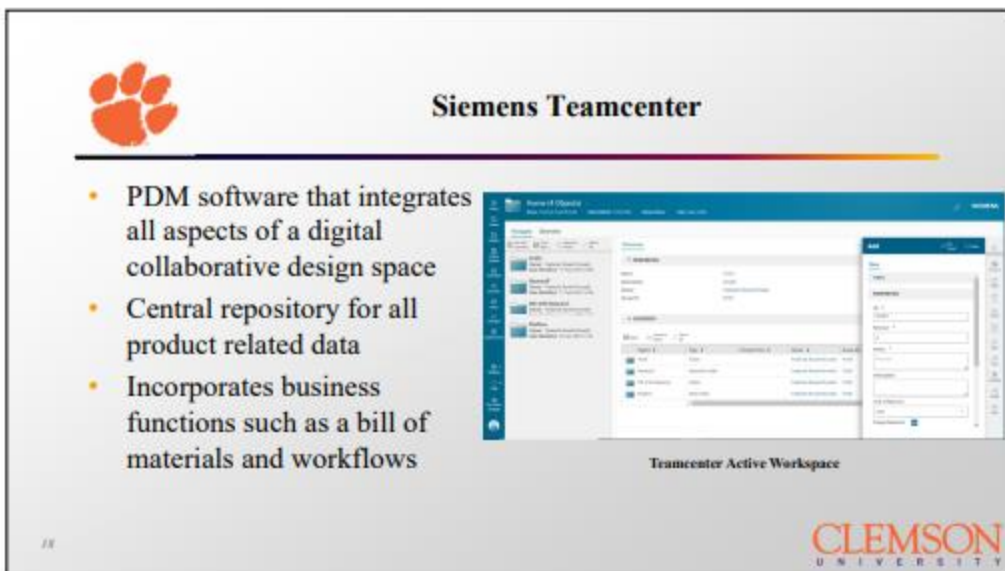


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Figure C.8: Final Presentation (8)

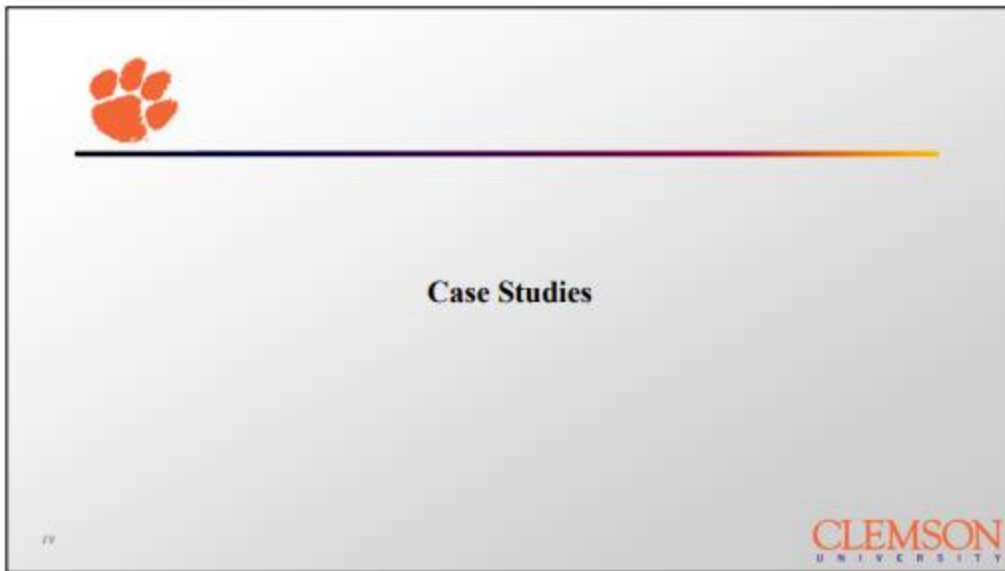


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Figure C.9: Final Presentation (9)



19

20

CLEMSON UNIVERSITY

This slide features the Clemson University paw print logo in the top left corner. A horizontal line with a color gradient from purple to yellow spans across the slide. The text "Creative Inquiry Case Study" is centered in the middle. Below the title is a bulleted list of three points. To the right of the list are three images showing different views of a tracked robotic tank chassis. The slide number "20" is in the bottom left, and the "CLEMSON UNIVERSITY" logo is in the bottom right.

- PLM Processes Creative Inquiry team
- Goal is to develop a digital twin of a scaled, tracked robotic platform
- Use PLM concepts and tools to improve collaboration amongst team members

T-REX Robotic Tank Chassis

20

Figure C.10: Final Presentation (10)



Teamcenter Application

- Created an introductory presentation to discuss the benefits of an integrated PDM system such as Teamcenter
- Included basic features and demos of key processes
 - Item creation
 - Change management
 - Bill of materials

Item Demo: Item Revisions

- When a new item is created, it's revisions are listed below its parent using the drop-down bar
- To create a new item revision, select the most recent revision, and navigate through the File menu to create a revision
- Assign a revision ID to the object
- Newly created item revisions will be displayed below the parent item

20.1: Creating an Item Revision

20.2: Item Family Tree

Item Demo Example Slide



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NX/Teamcenter Integration

Import Assembly into Teamcenter

Item ID	Item Name	Item Status	Item Date	Revision	Revision ID	Revision Date	Revision Description	Revision Type	Revision Status	Revision Owner	Revision Created	Revision Modified	Revision Deleted	Revision Deleted Date	Revision Deleted Reason	Revision Deleted By	Revision Deleted Date
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NX Import Assembly into Teamcenter

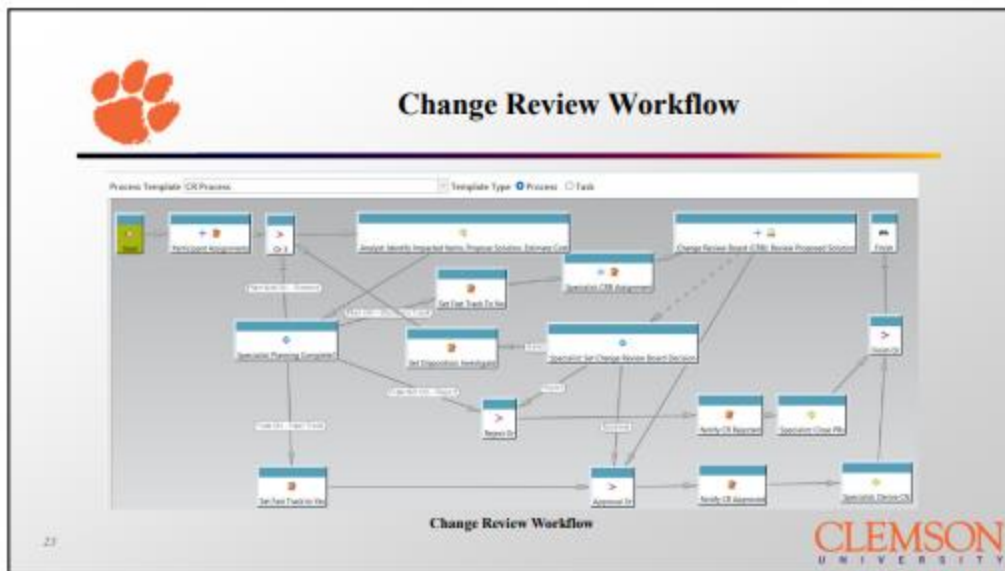


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Figure C.11: Final Presentation (11)



Change Review Workflow



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Workflow Designer Error

- Access to Workflow Designer perspective isn't allowed for non-DBA users
- Transition to existing workflow templates

Workflow Access Error

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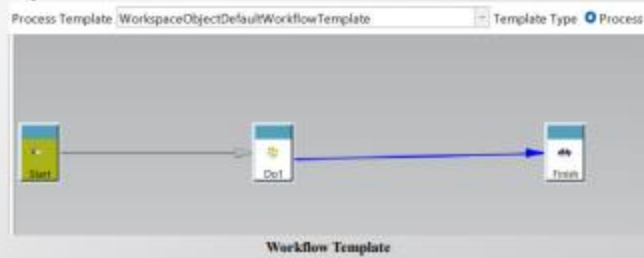
24

Figure C.12: Final Presentation (12)



CI Workflow

- Simplified workflow that contains a “Do” task
- Can assign users to each part of a task and provide information to complete the tasks



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CI Results

- Although the CI team has learned Teamcenter quickly, it is still early to gather concrete results from its application
- Received positive impressions of the NX/Teamcenter integration as a whole
- Continue utilizing Teamcenter to create the digital twin
- Analyze the structure of Teamcenter to fit the team's needs



26



26

Figure C.13: Final Presentation (13)



Deep Orange Case Study

- Presented the introductory presentation to the Deep Orange design team at ICAR campus in Greenville
- General interest, but no use this year
 - Too late to apply



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Next Steps

- Work with Deep Orange team to bring Teamcenter into its existing infrastructure
- Finish an ASME conference paper that is in the revision stage
- Start Graduate School!

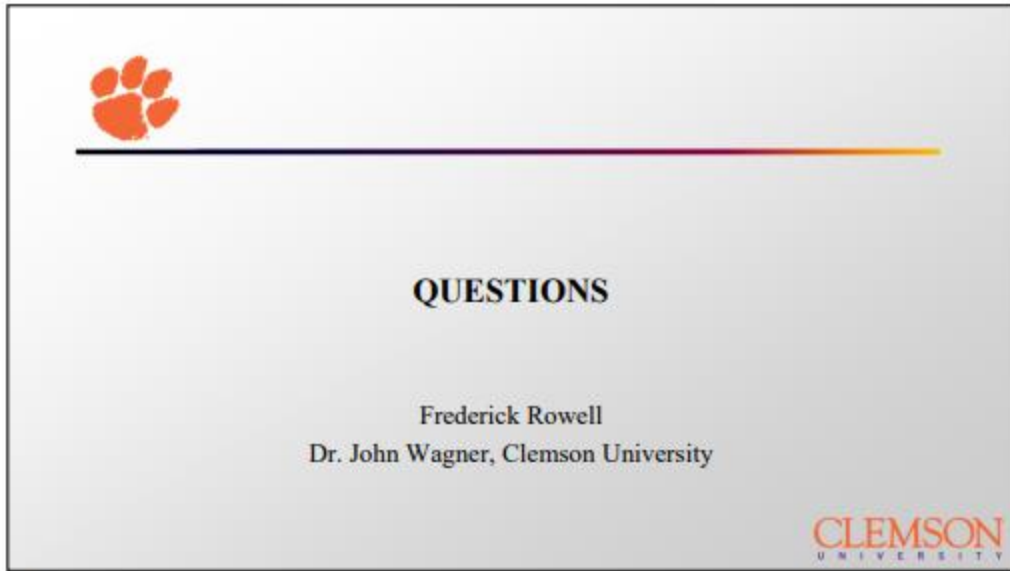


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Figure C.14: Final Presentation (14)



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Figure C.15: Final Presentation (15)

Appendix C

Teamcenter Presentation



Figure D.1: Teamcenter Presentation

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