A Contribution to Optimized Data Exchange Supporting Automotive Bodywork Engineering

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Abstract. Automotive manufacturers and suppliers are being challenged by increasing product variations, new drive technologies, the increasing significance of globalization and, at the same time, increased cost targets. In this way, the pressure exerted on the automotive industry requires the implementation of appropriate development and production measures. One important area includes the optimization of the entire vehicle body development process, which is to be supported by optimized data exchange processes between the different CAx environments. In order for this data exchange process to be optimized, the constantly changing boundary conditions in the area of body development must be taken into account. Additional challenges have to be handled in the supplier industry because different customer (car manufacturer) work with different data management strategies and tools. This paper introduces an optimized approach for data management between different CAD and CAE environments to support the entire vehicle body development process.

Keywords: Computer Aided Design, CAD-CAE Integration, Automotive Bodywork Development, CAx Information Exchange, Joining Technology, Knowledge-based Engineering, Process Optimization
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1 INTRODUCTION

Continuously varying boundary conditions in the automotive industry require constantly performed improvement of development processes. Besides propulsion technology and automation systems, the automotive body (BIW – Body-In-White) development, including the entire field of material and joining technology, represents an important field of investigation. Development targets include body stiffness and durability, optimized crash behavior and the reduction of body weight to decrease driving resistances and thus fuel consumption and exhaust emissions [16].

This reduction of vehicle body mass can be achieved by a variety of ways, whereby the use of different materials – respectively material combinations – plays a significant role. This means that joining technologies have to be adapted to the increasingly applied multi-material design solutions, which leads to new challenges in both areas, the creation and administration of joining technology data as well as the exchange of these data and metadata between different computer-aided design and engineering (CAx) disciplines and systems.

The present paper provides an overview of state-of-the-art automotive bodywork development processes and derives the enhanced requirements on the management of joining technology data, in particular on data creation, administration and exchange procedures. Finally, a new approach of optimized data management for joining technology is introduced.

2 PROBLEM STATEMENT – FROM THE VIEWPOINT OF AN AUTOMOTIVE TIER 1 SUPPLIER

Due to the fact that an automotive engineering service provider has to deal with a variety of different customers and OEMs (Original Equipment Manufacturers), each project differs from the other. In addition to some obvious differences, such as vehicle design, contract terms, etc., the projects also differ in the field of data management. This means that each customer or OEM has different requirements for the CAD-based data generation processes and the data exchange processes, on the one hand between the customer and the supplier and on the other hand in the supplier's internal environment. Due to these requirements, the boundary conditions for the data exchange process must be adapted in each project. In addition to the increased number of systems used for data exchange, this also leads to higher costs and higher expenses in the development process.

Management processes cover the full range of data lifecycle, starting with the creation of data, followed by administration and data processing, and ending with the distribution of the resulting information. To be able to describe the multitude of different customer requirements for the generation of data (especially CAD data) and the data exchange processes, they are summarized in this paper focusing on the following three types of projects. The boundary conditions of transferring CAD data from a CAD environment to the automotive supplier's internal CAE environment is the same for all three project types.

- Type I – Projects, where the main engineering workload takes place in the customer-specific (OEM-specific) CAD environment. In most cases, access to the customer-specific CAD environment is gained through the use of remote machines. In Type I projects, the customer provides all processes, tools and methods for the creation and administration of CAD data. For the data exchange process, this means that the data generated in the customer environment must be transferred to the internal environment. This requires that the supplier must be able to handle the specified processes, tools and methods of the customer. Furthermore, it means that the degrees of freedom in terms of data management are restricted.
- Type II – This type of projects is a mix between Type I and Type III projects. Typical Type II projects occur if some parts of data are already available in the customer-specific CAD environment. These data, created in the customer environment, are imported into the supplier-internal data environment, where the completion of the 3D CAD model is performed. Resulting CAD data are exported into the customer environment for evaluation, discussion processes and implementation into the customers full-vehicle data structure.
- Type III – In this type of projects, the complete engineering workload takes place internally, whereby internally developed processes, methods, tools and systems are used. In most cases there are no customer requirements related to the creation of CAD data, as well as the data exchange process. This fact leads to a higher degree of freedom in terms of data management but on the other hand specific (created) tools to support the entire data creation and exchange processes have to be provided. Typical Type III projects are for example cooperation projects with start-up companies, those do not have any internal development processes.

The above-mentioned classification of typical project types enables a segmentation of customer requirements and serves as a basis for the subsequently performed creation of enhanced data management processes. Target is to define a consistent process, which enables the exchange of development data of BIW joining technologies in all upcoming projects. The data formats and data structures that occur differently from customer to customer, both for geometry data and for joining technology data must be involved in the process.

3 STATE OF THE ART

3.1 Automotive Body Design

As previously mentioned, automotive BIW development has changed considerably in recent years. This paper focuses primarily on changes in material combinations and the different types of joining technologies used in car body construction [13], [23]. As discussed in the introduction, one main goal in the automotive industry is to reduce the total vehicle weight by reducing the BIW weight [18], [21], [24].

The background for the desired weight reduction is the achievement of emission limits imposed by legislation during recent years. In order to achieve these goals, new materials and material combinations are applied. For example, the application of a full aluminum body (e.g. Audi A8) is able to reduce the body weight up to 40 percent in comparison with a standard steel body [8]. Table 1 shows selected examples of currently used body material combinations. It should be noted that the different types of aluminum, steel, high strength steel and plastics (SMC – Sheet Molding Compound) are not distinguished here.

Material	*Volvo V90*	*Peugeot 3008*	*Aston Martin DB11*
aluminum	6%	5%	53%
standard steel	27%	27%	5%
high strength steel	67%	62%	
SMC		6%	42%

Table 1: Comparison of BIW material combinations of exemplary selected cars manufactured in 2016 [14], [19], [20].

Compared to the situation about twenty years ago, when a vehicle bodywork was mainly manufactured out of standard steel, the current situation is more complex. Besides standard steel bodies, which are mainly used in low-budget vehicles, different types of material – respectively material mixes – occur. As a result, the development of joining technologies becomes increasingly complex and the number of joining technologies used in a vehicle has increased [6].

Type of joining technology	*Volvo V90*	*Peugeot 3008*	*Aston Martin DB11*
spot weld	5250 pcs.	4157 pcs.	
rivets			1278 pcs.
clinches		14 pcs.	
weld stud	247 pcs.	83 pcs.	
screws			52 pcs.
hemming flanges		19,87 m	
seam weld	9,3 m	150,29 m	
adhesive line	79,4 m	20,22 m	152 m

Table 2: Comparison of different types of joining technologies of exemplary selected cars manufactured in 2016 [14], [19], [20].

One example represents the FIAT Uno (manufactured in 1986), which had a full standard steel body. The entire body with all components was joined by about 2700 spot welds in total [15]. As a difference, modern multi-material-based vehicle body design requires the implementation of several types of joining technologies. The complexity in view of modern vehicles is displayed in Table 2. Therefore, the numbers of the different applied types of joining technologies in three selected state-of-the-art cars (manufactured in 2016) are shown.

3.2 CAx in Automotive Industry & Data Exchange

Because of rising complexity in the fields of materials, manufacturing procedures and joining technology, the complexity and amount of data in the development of automotive bodywork are increasing. In this context, effective data management processes have to be introduced to ensure that all information is handled and transmitted between the different CAx environments effectively and without unwanted losses [9], [12]. These exchange processes of 3D CAD models incorporate the usual appropriate data formats [5], [7] and the applied tools that support the exchange processes [10]. For all further considerations, the term data is distinguished into the following two terms:

- Geometry data: Contain all the information, which is necessary to create sheets/parts in the CAD environment. This information includes all geometric dimensions (e.g. length, width, height, curves, bends) and metadata (e.g. thickness, weight, COG (Center of gravity)) of the parts.
- Joining technology data: Contain all the information required for creation of joining technology elements in the CAD environment. Each joining technology element is assigned a position vector (x, y, z coordinates), the type of joining technology (e.g. spot weld, rivet, bolt, seam weld), the parts to be joined (e.g. part number), and other parameters tailored to the joining technology element. Additional parameters can be, for example, a diameter of the spot weld, thickness of the weld seam, normal direction for rivets, or similar metadata (for further metadata, cf. [4]).

In the field of geometry and joining technology data exchange, there are two possibilities for exchanging CAD data. On the one hand it is possible to exchange the 3D CAD model in native file formats (e.g. "CATIA" [3] files). On the other hand, there is the possibility to convert the native file format into a neutral file format.

In comparison, the advantage of using native files is that all created information (e.g. design history, tolerance information, etc.) is available as well as that the depiction of parts (geometry and joining parts) is more precisely (exact definition of geometry is used). However, this leads to the disadvantage of larger file sizes, which further leads to the fact that the processed CAE models are larger (i.e. performance reduction in the CAE environment). Neutral file formats offer the advantage of a leaner file structure, which is primarily achieved by neglecting unneeded information (e.g. design history or exact geometry data). A further benefit of using neutral file formats is, that these formats are easier exchangeable between different CAx environments [1].

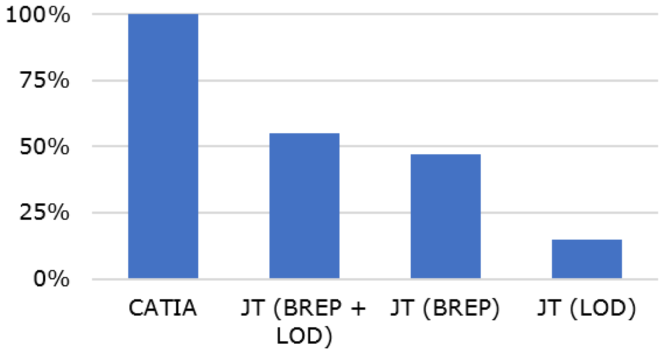


Figure 1: File size comparison – CATIA native file with JT files (different variants).

For the geometry data exchange between different CAx environments, only a limited amount of information available in the CAD environment is required. In case of data exchange between CAD and CAE environments, information such as exact geometry and specified metadata (e.g. thickness of components, material, etc.) must be available. Further information (e.g. sequence of design steps, geometric conditions, visualization levels) is not required for CAE simulation steps. This leads to a desired data reduction with simultaneous transfer of all information required in the CAE pre-processing system. Depending on the information levels contained in the JT files, different file sizes result. General statements about the reduction of the amount of data when converting a CAD file into a JT file are hardly possible and vary greatly due to the native factors.

Figure 1 exemplary shows a quantitative representation of the file size of a part used in the automotive industry. The left column shows the CATIA source file. The other three columns represent converted JT files (column 2 contains BREP (Boundary Representations) information and 3 LODs, column 3 contains BREP information but no LODs and column 4 contains no BREP information) of the source file. In addition, all JT files contain the metadata required for the simulations processes. In this case, the savings potential of the file size using the JT format including BREP and metadata is around 50 percent compared with the native "CATIA" file. In general, the saving potential may vary (25-90%), depending on the type of geometry model and the settings, defined in the applied JT converter [2].

4 SELECTION OF APPROPRIATE FILE FORMATS

The neutral file format JT is used for geometry data exchange in the exemplary internal supplier environment. Due to the requirements of the CAE environment to deliver exact geometry information to fulfil all pre-processing tasks, most neutral data formats cannot be used. However, the neutral file format JT is able to transfer geometry information with satisfying exactness by use of so-called BREPs [17]. It thus combines the advantages of a leaner file structure, easy exchangeability between different CAx environments and sufficient exact geometry description. Furthermore, JT is a standard that is widely used in the automotive industry. Besides, the conversion process already ensures that the required information (exact geometry and all necessary metadata) is available in the converted JT file.

While the JT file format is used for the exchange of geometry data, the situation is much more complex for the exchange of joining technology data including their metadata. In the field of joining data exchange, there are various ways in which these data can be transferred. Again, a selection can be made between native and neutral geometry data exchange formats. Due to the emerging variety of different data exchange formats in the field of joining technology (almost every customer uses a different one), the neutral file format xMCF is used here. The reason for this is that the xml-based, neutral exchange format xMCF combines the advantages of a smaller file size and easy readability in most CAx environments. Furthermore, it is flexible in a way that it is possible to transfer all kinds of meta information (e.g. diameter of spot welds, lengths of rivets, etc.) [4].

Besides these internally used file formats, different file formats have to be transferred by the customer (data exchange between customer and supplier-internal environment), which leads to complex data management procedures. A new and more efficient approach must consider that joining technology data have to be available (input file) either as CAD native files or as neutral files (e.g. list formats, e.g. Excel, xml). Furthermore, it must also be taken into account that the geometry data are always available in native files. Therefore, the entire data structure must be converted for the internal data exchange process.

5 APPROACH – DATA MODEL TO SUPPORT AN OPTIMIZED DATA EXCHANGE PROCESS

As previously mentioned, there is a variety of different file formats and ways how data can be transmitted between CAD and CAE environments (cf. [11]) In addition, existing data exchange processes have to be adapted in a way that they are suitable for different occurring projects (cf.

Type I, II and III). Furthermore, the data exchange process must be optimized in such a way that no unwanted information losses occur and a variety of data formats can be processed. Figure 2 shows an approach of an optimized data exchange process, which is supported by specific tools to guarantee a full working process. For a better understanding, the optimized process between CAD and CAE environment is divided into five areas, which are highlighted by different colors: CAD environment (yellow), data management (green), CAE environment (red), internal supporting tools environment (blue) and customer environment (purple).

CAD environment – The creation of both, geometry and joining technology data takes place in the CAD environment, whereby it does not matter if the CAD environment is placed internally (Type III), (partly) in the customer environment (Type II) or the access is enabled by a remote system (Type I). Various tools are used in the CAD environment to create and manage the data. Exemplary, "CATIA" and "Siemens NX" [22] (Figure 2 exemplary shows the optimized data exchange process by using "CATIA") are widespread in the automotive industry to create geometry data. The creation of joining technology data takes place partly or completely in the internal-developed tool "JoiningTec" or in any customer-specific tool, depending on the type of project. Besides the creation of data, the tool "JoiningTec" can also be used for exporting joining technology data. Therefore, an xMCF converter is integrated, which allows the direct export of joining technology data in xMCF file format [4].

Data management – The department of data management is responsible for managing the native data received from internal or customer-specific (CAD) environment. A PDM (Product Data Management) system is used to store and manage these data. By using standard converters, the stored geometry data are converted into the neutral data format JT [2]. The converted JT files used for the internal geometry data exchange are forwarded into the project exchange drive. As soon as the joining technology data are available in xMCF format (e.g. exported by the tools "JoiningTec" or "Joining Converter"), they are also transferred to the project exchange drive.

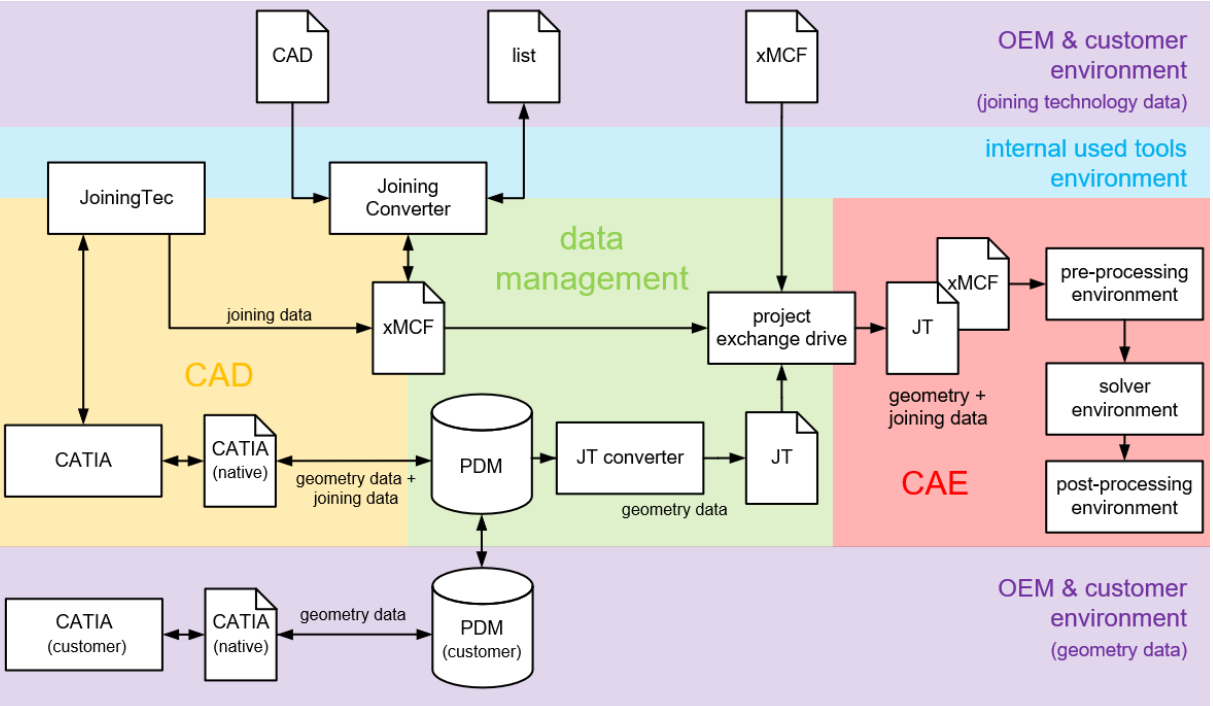
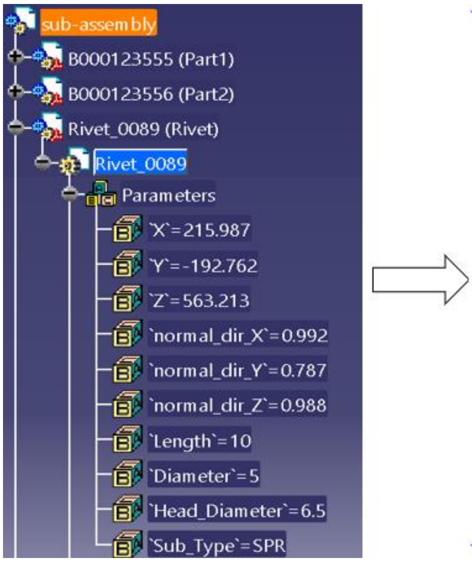


Figure 2: Approach of optimized data exchange process.

Customer environment – In case the customer already provides available geometry or joining technology data, the process enables an integration of these data into the development process at the supplier. In order to import the previously created customer data into the supplier environment, two PDM systems (one installed in the customer environment and a supplier internal one) serve as transmission path. The joining technology data, which are provided by the customer, may occur in different native CAD formats as well as several neutral list formats (e.g. Excel, xml). With the target to enable an integration of different data formats and structures delivered by different customers, the process provides a conversion into a uniform xMCF format that can be used for further processes.

Internal used tools environment – Besides the already mentioned tool "JoiningTec", used for administration and creation of joining technology data, another tool "Joining Converter" is necessary to guarantee a full working optimized data exchange process. This tool allows to convert any type of customer-specific joining technology data (list or CAD format) into an xMCF file (cf. Figure 3 for structure of these files). Therefore, this converter must have a high flexibility in the settings and guarantee that the created xMCF file always has the demanded file structure. Although, "JoiningTec" provides an internal xMCF converter, the tool "Joining Converter" is necessary for projects where "JoiningTec" cannot be used (e.g. Type I projects). In addition, the "Joining Converter" provides the function to convert an xMCF joining technology data file into a customary list joining technology data file. This might be necessary for the re-import of joining technology data into the customer-specific environment. On the left side of Figure 3, the "CATIA" structure tree of an exemplary rivet connection, including meta information (connecting the two parts B000123555 and B000123556) is displayed. The right side, shows the same rivet connection, including all meta information, displayed in the neutral xMCF format.

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```

Figure 3: Comparison of native CAD joining technology data structure and xMCF joining technology data; exemplary displayed for a rivet connection.

CAE environment – The last area that is included in the optimized data exchange process is the target zone, which receives both joining technology data (xMCF) and geometry data in JT format out of the project exchange drive. One boundary condition for the optimized data exchange is that geometry data are transferred in form of sufficiently exact geometry.

As already mentioned, the file format JT offers the possibility to transfer exact geometry, while all background information (e.g. design history) is deleted. As for geometry data, certain boundary conditions must be fulfilled for the transmitted joining technology data. This means that data of each joining technology element (e.g. linear and surface joinings are divided into several individual points with a defined distance) must contain the parts to be joined as well as the coordinates and certain parameters (e.g. diameter, thickness, height). Since each type of joining technology (can also be customer-depending) uses different parameters (e.g. spot welds require coordinates and diameter, rivets require coordinates, head diameter, length, type of rivet, etc. [4]), the xMCF format is very suitable for data transmission due to its flexibility.

After the import of all geometry and joining technology data files took place, the simulation tasks can be processed in the CAE environment, starting with the pre-processing step. In this step, a suitable CAE model is created by merging geometry data with joining technology data. The geometry files are first integrated into the pre-processor system and automatically positioned based on the transferred metadata. Subsequently, the integration of the joining technology data take place using the metadata provided in the xMCF file. Positioning of the individual joining technology elements is performed by using the location information contained in the metadata. In addition, the joining technology elements are automatically assigned to the components/parts to be joined, since this information is also transferred in xMCF file (so-called connectors). This merged CAE model is then used for mesh generation, which serves as the basis for all further simulation steps. After all simulation steps have been completed in the solver environment, the so-called post-processing procedure is performed. Evaluation of simulation results as well as suggestions for improvement of the 3D CAD model takes place in this stage.

6 APPLICATION OF THE APPROACH

The application of the new approach of optimized data exchange is explained based on the three types of projects those are presented above. Each of these project types is assigned to a real project from the automotive industry. The data exchange between the internal or customer-specific CAD environment and the internally placed CAE environment is considered for all three application cases.

6.1 Application in a Type I Project

Figure 4 shows the optimized data exchange process for Type I projects, where geometry and joining technology data are created in the customer-specific CAD environment. Usually, access to the customer environment takes place via remote machines. This means that the supplier-internal engineers are creating data directly in the customer-specific CAD environment. The generated data are then exchanged between the customer-specific and supplier internal environment by using two PDM systems.

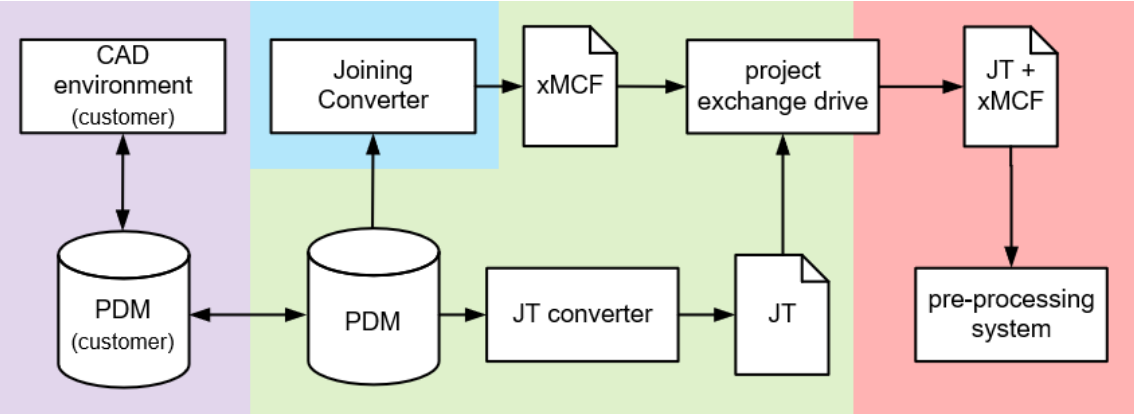

Figure 4: Application of the approach in Type I projects.

In this case, the customer transmits both geometry data and joining technology data as native "CATIA" file. This requires that geometry data must be converted to the neutral file format JT using a standard JT converter.

Since the JT converter is installed in the internal PDM environment, the JT generation may take place with each export of geometry data. Subsequently also joining technology data are transmitted as "CATIA" native file, the use of the tool "Joining Converter" is necessary. This tool has the task to create the xMCF file out of the native CAD-based joining technology data. Once both data file formats (JT and xMCF) have been created, they can be forwarded into the project exchange drive. From there, data are transferred to the CAE environment to be processed in the desired simulation tasks.

6.2 Application in a Type II Project

In comparison to the above shown Type I project, CAD data are created partly in the customer-specific environment (so called COP – Carry Over Parts, COM – Carry Over Module) and partly in the supplier internally installed CAD environment. This means that already existing customer-specific CAD data have to be imported into the internally used CAD environment (e.g. "CATIA") and after the import, the 3D CAD model is processed in the internally installed CAD environment. For the creation of the residual data in the internal CAD environment, the two tools "CATIA" and "JoiningTec" are used.

After merging of both data sets (data set of the customer and data set of the automotive supplier) and the completion of the 3D CAD model in the supplier-internal CAD environment, the two tools "Joining Converter" and "JT converter" are used for export purposes. Therefore, the tools generate the two internally used neutral file formats xMCF and JT, which are then transferred to the project exchange drive. From there, CAE engineers can directly access the data and import them into the CAE environment. The completed 3D CAD model as well as all simulation results are then exchanged with the customer-specific environment.

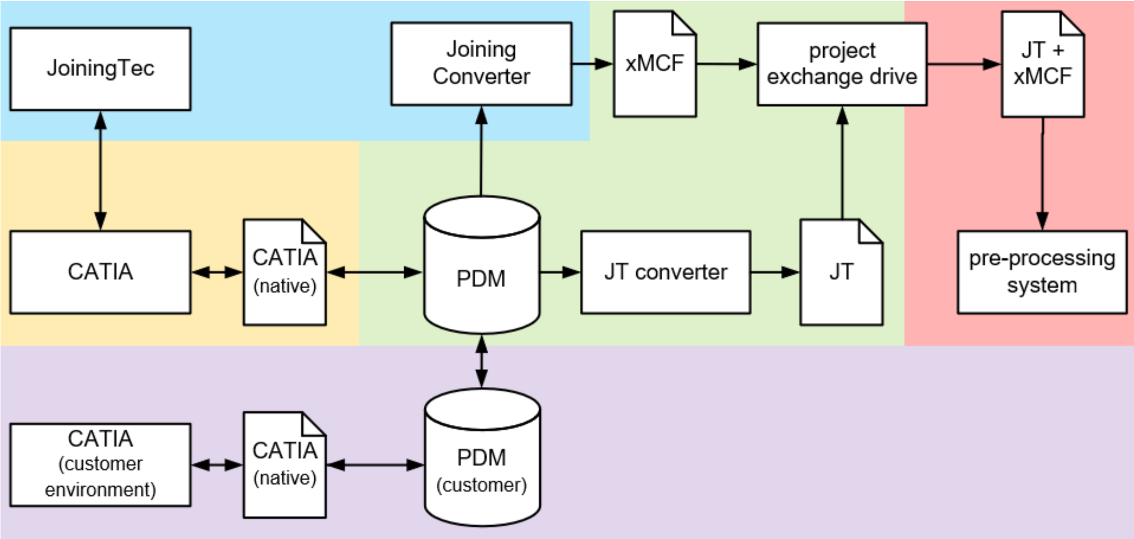

Figure 5: Application of the approach in Type II projects.

6.3 Application in a Type III Project

Since this type of project is a supplier-internal project, all internal methods, tools and processes can be used. Data are created in the internal CAD environment by using the CAD tool (e.g. "CATIA") for creating geometry data, while the creation of joining technology data takes place in the tool "JoiningTec". The generated geometry and joining technology data are forwarded into the PDM environment where they are stored. While it is possible to export joining technology data directly as xMCF file by using the tool "JoiningTec", the JT creation takes place in the internally installed JT converter. All necessary data can be exchanged via the project exchange drive.

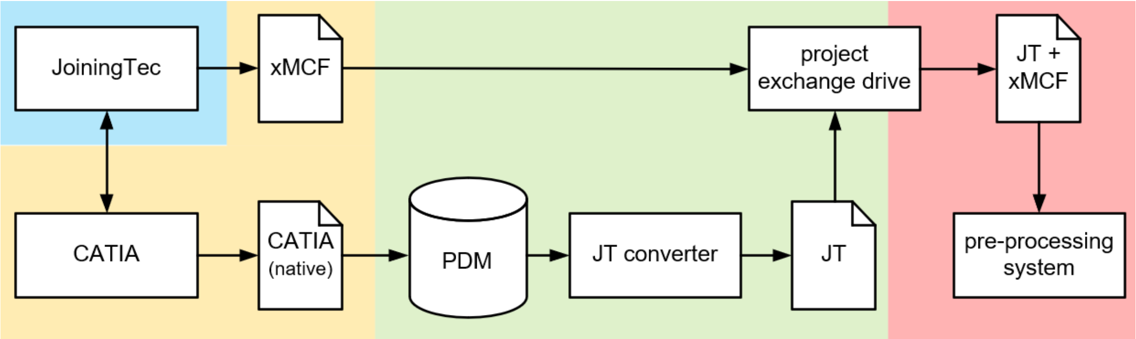

Figure 6: Application of the approach in Type III projects.

Since there are (almost) no customer requirements for data exchange in Type III projects, data exchange between customer and supplier is not necessary during the development process. The procedure of data exchange between both internally installed environments, CAD and CAE follows always the same path. At the end of the project, the customer receives all CAD and CAE generated results. The exchange of the results, which can also contain the complete 3D CAD data set, depends on contractual conditions and may vary between different projects.

7 CONCLUSIONS

From the viewpoint of an automotive supplier, the development data exchange process between customer (OEM) and supplier environment as well as the internal supplier data exchange process varies in a broad range. Furthermore, these exchange processes have not been defined by standards, which leads to an existing gap in the field of data management. The present paper delivers an approach to close the gap in data exchange between customers and automotive engineering service providers, exemplary focusing on body-in-white joining technology data. Furthermore, it delivers an approach of supplier-internal data exchange between the used CAD and CAE environments, considering different types of projects (Type I, II and III) and boundary conditions (e.g. data exchange formats for internal data transmission, data formats transmitted by the customer, data structures, etc.)

In summary, it can be mentioned that the introduced optimized data exchange process can be applied for all automotive joining technology development project types. This allows using either customer-specific or internal processes, methods and tools. Furthermore, the approach is designed flexible in a way that occurring changes (such as new exchange formats or new joining technology types) can be quickly reacted to. Due to the implementation of a uniform data exchange process in the field of geometry and joining technology data, the amount of necessary information to be transferred can be minimized and the data transfer efficiency increases. This also includes process-optimization, so that data losses are minimized. Therefore, the introduced data model provides a good leverage point for an intelligent integration of knowledge-based design methods and design automation into automotive body development.

In practical application studies carried out in the automotive industry, it has been shown that by applying the optimized data exchange process, including the above-mentioned tools and methods, the required time for an exemplary CAD-CAE data exchange procedure has been reduced by about

25% for one simulation loop. Considering that in typical body-in-white development four to six loops are performed, significant time and cost savings can be achieved. In addition, this time saving means that the exchange of CAD data to the various manufacturing departments can be started earlier, which results in an earlier market launch of newly developed vehicles and derivatives.

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