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FDMU – Functional Spatial Experience beyond DMU?

Shuichi Fukuda[b] , Zoran Lulić [c] , Josip Stjepandić[a,1]
[a]PROSTEP AG, Darmstadt, Germany
[b]Stanford University, USA
[c]University of Zagreb, Croatia

Abstract. To stay competitive, the companies have to respond quickly to the changing demands of customers. At the same time, the products become more and more complex, including more complex functionalities, and enterprises now have to deal with concurrent multi-disciplinary environments if they want to optimize their products globally. This would come with the development of in-process simulations, but new methods and new tools are needed in order to enable a bridge between the development domains. An important approach is Digital Mock-up (DMU), which provides a robust development method to enable the spatial integration in concurrent environment. In the past decade the DMU has been implemented as a mandatory development method ensuring good project progress within distributed collaborative development. Nevertheless, there is a strong need to pursue the product development by additional methods, which progress beyond DMU. The development of mechatronic systems involves many disciplines, which utilize their own specific methods, processes as well as software tools in order to create partial models of an overall system. A very tight collaboration of the disciplines is essential, since all the partial models are interdependent. However, information between these engineering domains is exchanged only periodically. Progressing rapidly in short steps, the developers need an assisting tool to vividly obtain the first impression on functional behavior of their products ("physicalisation of data") in each stage of product development. This paper describes a new approach of cross-skill engineering cooperation between various engineering domains (mechanical, electrical, software etc) called Functional DMU which provides a first, quick insight (functional spatial experience) in the recent progress of singular development tasks and corresponding results in the context of the whole product.

Keywords. Concurrent Engineering, Digital Mock-up, Functional DMU, Functional spatial experience

Introduction

Digital mock-up (DMU) has become a key method in product development for many industries (automotive, aerospace, transportation, etc). DMU is a virtual representation of the entire product model (e.g. with all variants, options and versions) throughout the product life cycle and serves as visualization, validation, communication and decision platform [1]. The DMU is reduced from CAD data and is generated directly from the

[1] Corresponding Author, E-mail: josip.stjepandic@opendesc.com

CAx tools through the use of data reduction methods such as tessellation. The creation of DMUs for variants and versions is not a special overhead (depending on the size of the data and the hardware used, the process usually runs overnight and is started by the system automatically). In addition, the archiving goes smoothly directly from the PLM systems, because the mock-ups are already available in digital form [2]. The data can come from different CAD systems.

The visualization and validation can be carried out in the context of the whole product and in each phase in the product development because DMU is based on a geometric product structure with full structural integrity. DMU provides different views of the future product, e.g. from the design, manufacturing planning and validation point of view. Depending on the perspective, the relevant information is displayed. This facilitates early frontloading and a framework for the methodological support of concurrent engineering. Regardless of the level of development and the location (with the additional support of multi-site communication and collaboration tools), the development teams review compatibility of their developments, detect early errors and conflicts and consider alternative solutions. Suppliers can be entirely integrated into this process with respect to the confidentiality rules (they have access only to the data they need).

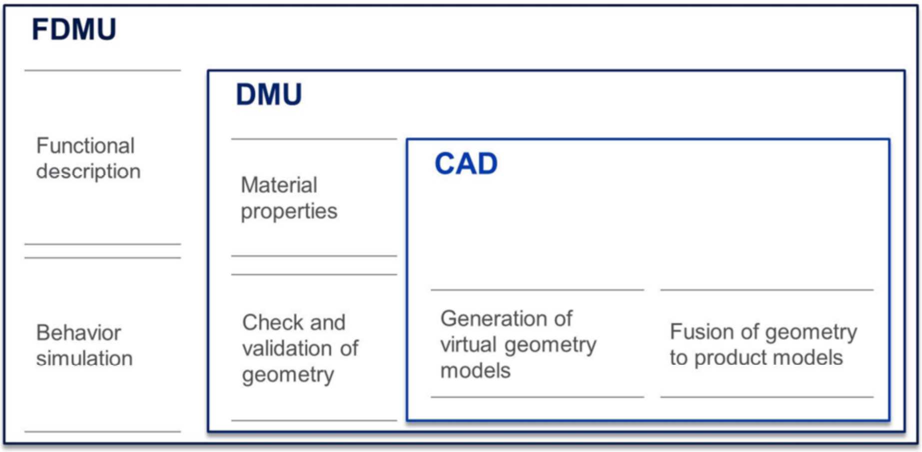

Figure 1. Functional DMU versus DMU.

The expansion of the digital mock-up to functional aspects (Functional Digital Mock-up, FDMU), is an attempt to create more powerful tools for product development. The virtual products stored in DMU should be enriched by the information which describes the functionality with respect to environment (Fig. 1). Based on DMU, FDMU comprises the results of all simulations needed for full presentation of the behavioral system description. Literally spoken, FDMU extracts the data from all virtual models of a product and gives them a physical meaning. It makes the product function experienceable. With this in mind FDMU facilitates the “physicalisation of data” by setting the physical effects in context of a product. As a prerequisite, one has to ensure a deep interaction between visualization and numerical simulation with respect to product life-cycle management. FDMU application requires three basic components: a description of the geometry, a description of the behavior and a visualization of the results.

1. Related Work

In many scientific works, the questions of reducing or preventing inconsistencies between partial models have been analysed [3]. However, there is still an optimisation potential regarding the prevention of inconsistencies between models, especially between CAD and correspondent behaviour models. An approach for a continuous information exchange between both types of models is needed. The approaches can be basically divided into four groups.

One of the main approaches currently used consists of extracting information from geometrical data including its constraints and inserting it into the simulation model. According to this approach, Modelica models have been associated to CAD models (CATIA). Thereby, an interface extracts the properties of CATIA models in order to integrate them into a Modelica model. The involved CAD program “CATIA” does not play any role during simulation of Modelica model. The main weakness of this approach is the size limitation of most of the simulation software packages, to visualise the whole product.

A further approach has been presented in order to exchange data between the CAD and the simulation software. The principle consists also of extracting information from CAD to put it in Modelica via a database. However, model parameters that have been stored into database may be modified arbitrarily. Therefore, there is an existing risk of running simulation on the base of wrong parameters. To avoid this risk, a parametric link between both models can be used. Component objects are created, containing information related to a CAD model and its corresponding behavioural model. Therefore, the data related to behavioural model may be extracted from CAD model. This approach has a significant complexity and performance limitations.

Additionally, there are some integrative approaches. All those approaches have the characteristic in common that the functionality of one system (often the CAD system) and therefore its advantages may not be accessed during the simulation. Simulation tools are not focused on managing geometric information and its visualization in 3D environments. Moreover, modifications of the CAD models, from which information has been extracted for input into the simulation environment, can lead to inconsistencies.

Last but not least, there is the CAx System CATIA V6 from DassaultSystemes with a comprehensive new approach (Requirements – Functional – Logical - Physical) to support the product development in all phases with high level of interaction between singular modules. It comprises the design and various types of simulation in a unique platform as well. The problem of CATIA V6 is the low acceptance based on the fear to drop many applications at once and replace those at the same time by a new, not really mature software.

A significant support for all those FDMU approaches is given by Modelica Association with the Functional Mock-up Interface (FMI) [4]. In this approach, many tools for modeling the geometry and product behavior are equipped with a common interface (Fig. 2), listed in [5]. This interface exports the model output containing both the behavior and the input parameters of a simulation: those are practically the calculation method and the initial values of equations. A simulation tool with the FMI interface can then read these models to simulate a particular behavior. This approach is therefore particularly interesting in that several models and several simulations can be run in parallel, and thus the overall behavior of a complex system can be represented [6].

Nevertheless, all described approaches have significant weaknesses in representing the performance in the entire product context (e.g. a passenger car) with a short lead time (quasi online). Therefore, there is a need for further research and development work to calculate or to extract the minimal subset of data needed for a sufficient visualization of physical effect in such a context. While by zooming is possible to online visualize each relevant detail within the DMU, the similar way is needed for physical effects within FDMU.

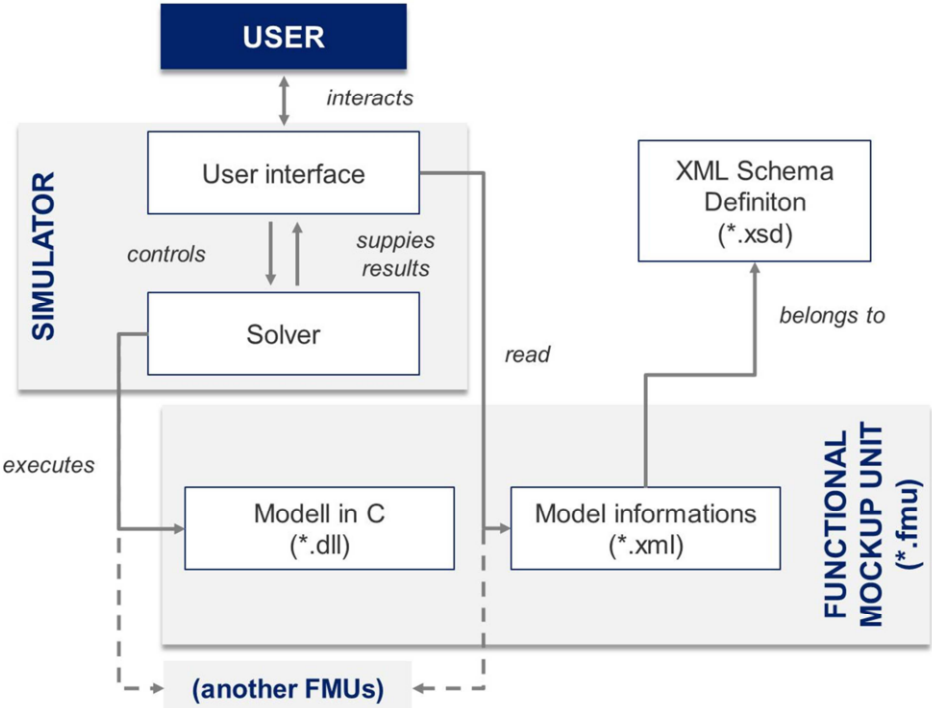

Figure 2. Functional mockup interface.

2. Use Case

Typical use cases for FDMU always arise when several different physical effects appear on the tight space of a product. One such example is the passenger car, wherein the comfort of a living room is anticipated, which is affected by many vehicle-related as well as environmental influences. Therefore, the design of the vehicle interior becomes correspondingly difficult. A central component of comfort optimization concerns the vehicle acoustics, which is considered in the complex NVH (noise, vibrations, harshness).While noise and vibration can be determined by appropriate experimental methods, harshness is a subjective property, and reflects human subjective impressions [7] [8]. The scientific analysis of sound perception is subject of psychoacoustics.

The psychoacoustic characteristics of a vehicle are a decisive factor for almost every buyer of premium cars [9]. Therefore, appropriate experimental and simulation methods have been developed that help to control, to mitigate or to combat the noise [10] [11] [12] [13].

No less important is to make the properties of the sound system in the vehicle so that an optimal subjective perception is achieved for every passenger at every interior variant. Here, both the position (driver seat, passenger seat, rear seat) and the fine adjustment of the seat position have great importance.

This is an area for Functional DMU that the acoustics of the interior of the vehicle is depicted for each vehicle variant for each passenger in each seat position (fig. 3) to ensure that decisions on the design of the overall system can be represented. The scenario describes a system for automatic volume control of (at least) two active sound sources. In this scenario, a person is in the vicinity of the two sound sources. His position, and therefore the distances from the sound sources can be changed. Both sound sources emit varying signals, e.g. music from a stereo system. In the area noise is present too, compromising the clarity of the music. Another part of the system is a microphone which detects the total sound pressure in the interior of the vehicle. Total sound pressure is composed of both the music and from the noise. Figure 3 illustrates this scenario from a bird's perspective.

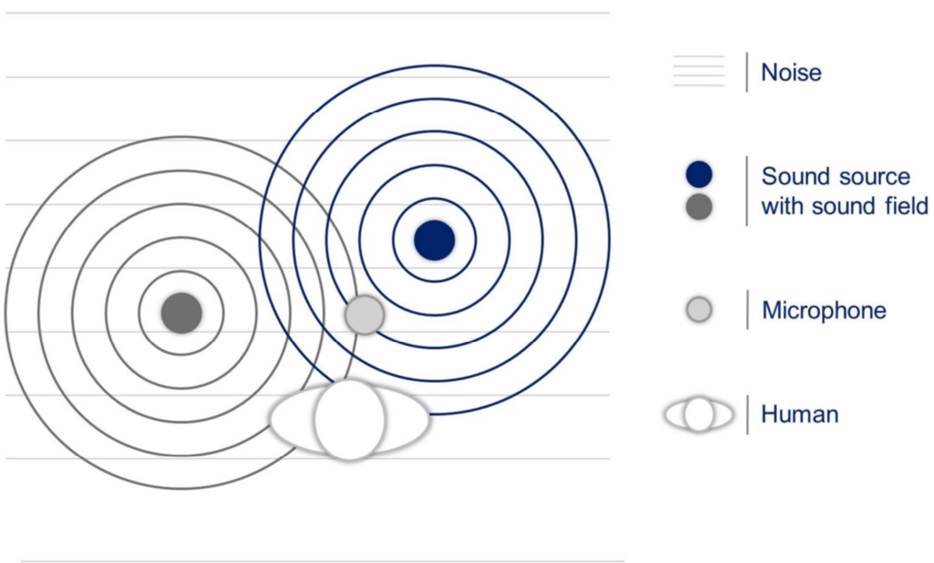

Figure 3. Use case Acoustics setup in a passenger car.

Depending on how a human is changing his position in space, he receives the sound from the speakers with different true stereo loudness. At the same time the sound sources play the music differently. This is the stereo sound that is not created from exactly the same signal on both channels.

The input parameters of the scenario are therefore the positions of the human, the speaker and the microphone, the sound power of the two speakers and the overall sound pressure that is detected by the microphone. The total sound pressure arises from the sound of the speakers, as well as from the rest of the (interfering) noise in the environment.

In addition, the knowledge on the position of the microphone is required to calculate the sound pressure share of the speakers in the total sound pressure. A sound pressure level limit is introduced to the system, with the ability to perform the adjustment in order to prevent human health.

From these parameters, it is determined which sound power change is needed in each of the speakers to prepare a balanced listening experience to passengers. This means that it takes both speakers to equalize the loudness and the volume of the music adapts to the disturbing ambient noise. A control system has the task to control the speakers so that a balanced listening experience (balance) is created for the passenger, no matter what position he is in the room. Moreover, the system reacts to changes in the noise, so that the combined sound pressure of the speaker is always in a fixed ratio to the sound pressure of the noise. Thus, the clarity of the music and the listening experience for the passengers remain constant. The acoustic performance of the speaker is known to the system, or it is calculated by the system in real time. Along with the overall sound pressure measured by the microphone in the area and later determination of the position of the passenger, the sound pressure level of the noise can be determined.

3. Concept

To achieve the goal, the architecture was defined according to Figure 4 [14]. Geometry definition and visualization can be accomplished either by the CAD system CATIA V5 or the JT format by using with an appropriate viewer. The processing of the acoustic models is carried out with a specially developed solver based on theoretical fundamentals described in [8]. Microsoft Excel supplies the Input/Output and low level standard calculations.

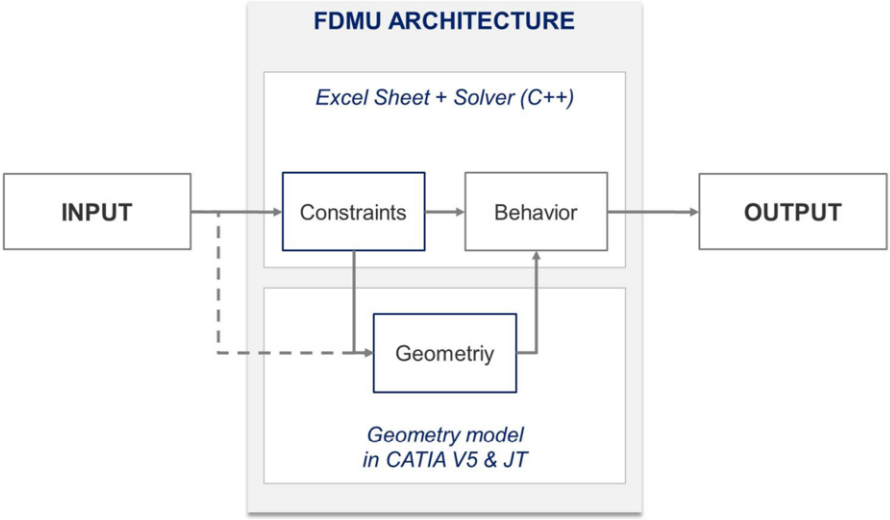

Figure 4.FDMU architecture.

The Excel file consists of two sheets. The first sheet is used as design table, which is accessed by CATIA V5 and JT viewer. In summary, this sheet comprises the important geometric information that is visualized in CATIA V5 and JT viewer. Thus this sheet calculates the mid-position of the ear. CATIA V5 can use the parameters in this sheet to externally control the parametric models. The input of parameters doesn't run in CATIA V5 but in Excel. By update function the parameter values in CATIA V5 are imported again and the entire model updated. This approach facilitates the use of many geometric variants within only one CATIA V5 model.

The user inputs data in the design table with the position and kinematics of seats. These data affect the behavior as well as the geometry in the selected use case. The user can change the CAD model if necessary, without influencing the behavior. One sheet contains the result for behavior with the required changes in the noise power of the speakers. The body height of the human as well as his seat position (driver, passenger, rear seat) are the parameters too. The list of parameters is closed by the position of the loud speakers and the microphone.

A second sheet contains the description of the behavior in the use case. First, the user must enter the distributed architecture of several frequency ranges with amplitude values measured by the microphone. These measurements represent the total sound pressure of all sounds in the application scenario. Secondly, the sound power levels of both speakers must be registered across multiple frequency ranges.

The need to record the sound performance and the overall sound pressure is the main weakness of this architecture. If the sound system would really exist, this would not be necessary and it would happen automatically. This enhancement should be implemented in the next project phase.

For this, the visualization of the behavior is limited by the limitations of Excel. Data series in Excel sheets can be represented in a variety of charts or graphs. Excel also allows sorting of information by freely selectable criteria. For example, values are marked when they exceed certain limits, can be placed in a hierarchy, as in the evaluation matrix of the use cases in this work. It is desirable that the behavior of the system can also be shown directly on the geometry model, such as an application scenario for heat distribution on surfaces.

Such representations of the model are actually not intended for CATIA V5 and JT. However, workarounds through various visualization software packages are possible. This can be used to illustrate a specific behavior on such geometric elements. In the use case for this work it could be visualized, for example, at what distance to the speakers, there is a certain level of sound pressure. The typical color schema can be used to mark and distinguish the singular parameter values. JT facilitates the similar visualization options.

In Figure 5 two spheres are modeled, with their centers are the mid-points of the speakers from the use case. The radius of the ball is dependent on the acoustic performance of the speaker and transmitted by the design table in CATIA V5. In addition, these spheres will be transparent in order to improve the clarity of presentation. This image is created only for clarity. In a real system, the sound pressure distribution has a substantially different shape, since the speakers are aligned in a certain direction. It would also significantly affect the distribution if the structure of the car interior were taken into account.

All means needed for visualization of such fields are available in the proposed concept. The implementation is necessary only by refining of the simulation algorithms.

Similar procedure can be used in the demonstration of further interior equipment (e.g. sensors, heating, air conditioning, environmental affects, etc).

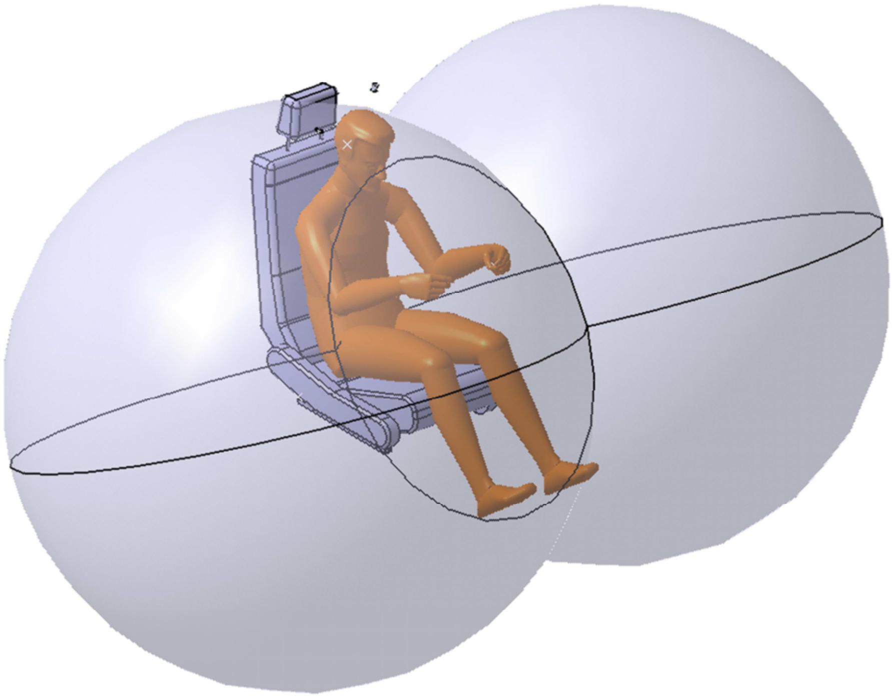

Figure 5. Illustration of spaces with equal noise pressure level.

4. Further Development

The FDMU solution described here demonstrates all the advantages (lowcost, rapid implementation and deployment, user-friendly interface and application) and disadvantages (difficult coordination, functional overlap, costly maintenance, data exchange losses) of the bottom-up principle in the development of complex IT applications. As an integrated standard FDMU system in the market offering of a software vendor seems unlikely at the present time, the further development must obviously run in two main directions.

First, the candidate applications must get better interoperability capabilities. For this purpose, the consistent implementation of FMI for each simulation tool would be very helpful und shall become one of the purchasing criteria.

Second, the loose coupling of individual components must be hierarchically controlled. FDMU is therefore distributed on four levels (Figure 6): CAD / PDM system, HIL / SIL system, DMU / VR system and, finally, the FDMU environment. To achieve a higher performance of the overall system, it is necessary to strengthen the component "FDMU environment" so that it assumes the user interface and the control of residual components. A similar application is described in [15]. This component shall also provide a template by which individual applications are inserted into FDMU system.

Finally, the open question remains of how the FDMU can be integrated into an enterprise-wide PLM concept to ensure the quick access, the data consistency and the broad data availability [16].

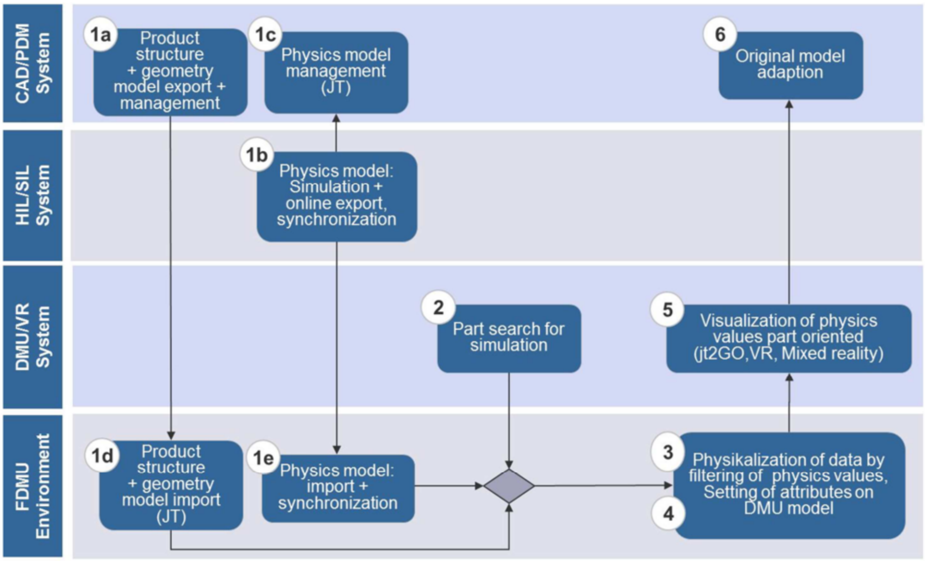

Figure6. Information flow within an integral interactive FDMU application.

5. Conclusions and Outlook

FDMU is an attempt to breathe life in the 3D geometric models customary in the modern product development: With the addition of models describing the behavior of a product to purely geometric models, it is not only the appearance but also the function of a product which is shown virtually. A product becomes a virtual experience and does not have to actually exist.

FDMU allows the product developer to make much more precise predictions about the future product than before, and facilitates the search of failure sources during development. This work represents a contribution to the implementation of FDMU and shows how a FDMU architecture can be realized relatively simply and with means widely used in an enterprise. In addition, various approaches are possible for the implementation and dissemination of FDMU in the product development.

During this work an architecture has been developed, which fulfills the main requirement of FDMU: coupling of digital geometry and behavior models. By using a CAD system the creation and manipulation of geometric model structure is possible. All variable parameters that will impact both on the geometry and on the behavior of the system are stored into Excel. One can define many behavior scenarios in Excel, as long as they can be represented by mathematical or logical operations.

The possibilities for the visualization of the behavior are limited in this architecture, but it can be extended through workarounds. For a larger-scale deployment of the architecture, one can also consider simplifying workarounds by using macros. In addition to this architecture, another approach is presented, in which the advantages of neutral 3D interface formats such as JT [17] are used. In this alternative architecture the modeling of the geometry is limited. However, monetary benefits are very promising in this case. The implementation of this architecture can provide points of contact for further scientific work.

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