Title:
Towards an Extended Model based Definition for the Digital Twin

Authors:
Alexander McDermott Miller, mille649@purdue.edu, Purdue University
Ramon Alvarez, ralvarez@purdue.edu, Purdue University
Nathan W. Hartman, nhartman@purdue.edu, Purdue University

Keywords:
CAD, Digital Twin, Behavior, MBD

DOI: 10.14733/cadconfP.2017.342-346

Introduction:
Model-based definition is an emerging paradigm which utilizes 3D-CAD models to carry engineering information. The introduction of CAD tools led to the realization that drawings may no longer be the best method for communicating information. The 3D format offers significant advantages over its 2D counterpart. Adoption of MBD offers significant cost and time savings, "a savings of more than $3M annually at a single naval facility will be generated by implementing MBD" along with "a 33 percent reduction in the development schedule of new items is expected" and "MBD shall also create a significant reduction in manufacturing errors, which should result in a decrease in the amount of rework, providing significant cost savings." [2]. As industry completes MBD adoption, the next step will be moving beyond MBD's roots.

The original focus of MBD was on the communication channel between design and manufacturing, but now it is spreading across the entire organization. MBD no longer refers solely to manufacturing. It is not purely a geometric activity. The MBD theory encompasses all aspects of a product. This concept was formalized in the digital twin "A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" [1]. In essence, the digital twin is a perfect replica of a physical object that is digital. Although the goal for MBD was set by the digital twin concept, the steps to be taken in achieving have not yet been determined. This research explored the extension of the 3D-CAD model to move towards a Digital Twin.

Main Idea:
Companies have seen significant cost savings by adopting the MBD methodology, and continued research supports further MBD adoption. MBD methodologies which originated in the 80's and 90's has now begun to be realized by leading adopters. Models have assumed fully the position which drawings had previously had. Considering this, new research is needed to move past the theoretical barrier which exists in the MBD field. The digital twin is a concept which was developed by an Air Force research group, and this would be the next logical step of MBD adoption. However, the digital twin was purely conceptualized in this research group, and no steps or methods for creating the environment was not documented.

The digital twin is composed of all aspects of the real-world product. One of these aspects is behavior. Behavior does not refer to the performance of a product, but instead refers to physical manifestations in parts in response to external stimuli. The external stimuli are hypothetically anything, but will most often be restricted to other parts in the system, and the operating environment. The behavior of the product is manipulated by the design to support a function. Behaviors are not under human control, but are utilized to deliver functions. This is why shape historically has been used to define products. A specific shape would be prototyped and tested for its behavior. The producers would know that specific shapes would capture the desired behaviors. Technological improvements are now reversing that process. Behavior can also be used to change the shape. This can be seen in 3D printing experiments that improve structural characteristics. The goal of the digital twin will be that these two aspects work in tandem to deliver a better product.

When objects are designed, they incorporate a validation method, or validation specification. Validation specifications are the method by which a product is determined to meet the functional

Fig. 1: Model of the acceptable variation of a product. (a) Shape specifications and (b) functional specifications.

requirements. The validation specifications are typically geometric in nature. An object is manufactured, and checked against its validation specification. Humans constrain an object down to a specific and tested shape, because our methods for analysis have historically been too expensive for

Fig. 2: Shape specifications as a subset of functional specifications, and the expansion of shape specifications utilizing behavior. (a) Shape specifications within functional, and (b) expansion of shape specifications using behavior.

any other method. This created shape specifications, a highly constrained and understood shape and material that could deliver the desirable behavior. Shape specifications, Fig. 1(a), are the possible variations of a product within a specific geometric definition which meet the prerequisite performance parameters. This is the current level of validation specification. In reality however, there is a vast array of variation which can still meet the necessary functional objectives of the product. These variations have simply not been evaluated. All possible variations of a product definition that accomplish all performance parameters, even the geometry configurations that are not used, are functional specifications. An image of this can be seen in Fig. 1(b). This image represents that the possible ways to achieve a function are highly variable, and the specific constraints that are set on a product are not the only shape that could work. By incorporating behavioral information into the validation specification, it expands, as can be seen in Fig. 2. What constitutes a functional part, is not a shape, and therefore, how a product needs to be defined should evolve. This research sought to expand the tools for definition in order to leverage this understanding of a product.

Integrating shape and behavior into a usable form is the focus of this research. Current PLM tools are capable of storing information in separate forms in a database location, but this does not build the relationship between them. They exist as separate entities categorized together instead of creating a more complete definition. The goal of this research was to build an understanding between behavior and shape through the 3D-CAD model, but in order to do this the CAD model needed to be extended. A focus of this research was the storage of behavioral information in the 3D-CAD model. This leads to a second important question, what behavioral information can and should be stored in the CAD model. This question is best answered by those implementing an MBD implementation, as the needs and information varies between industry. This research did select a specific type of information with which to use in storage.

The research focused on spatially indexed information. This refers to characteristics of the object which will vary across the surface or throughout the volume of the object. An example of this would be how the surface of an object will never be perfectly flat using today's manufacturing methods. This difference between nominal topology and actual topology affects the behavior of the part. It is not only geometric information, but in fact could be physical characteristics such as hardness or residual stress. This is how this research effort sought to integrate behavior and the CAD model.

This research sought to integrate geometry and behavior which has a relationship with the geometry by storing the behavioral information in the CAD model. The CAD model will act as an index for the behavioral datasets. This could provide a significant advantage to those exploring the CAD model and better demonstrating digital twin, because normally disparate work efforts would be registered together. However, defining a function based on the behavior is challenging, because we understand relatively poorly the link —behavior— between structure and function [3]. Therefore, identifying the relationship of Fig. 1(a) to Fig. 1(b) is a significant challenge. Future research which contributes to the understanding of Fig 1 will improve our ability to improve our products from a behavioral approach, and further support implementation of technologies such as the one developed here.

This work represents an effort to bring MBD to a more refined state, and close the gap between current MBD and the digital twin goal. This research set forth to explore possible methods for storing and retrieving information from within the CAD model. This research led to the development of a software which is capable of storage and retrieval of information in the 3D-CAD model.

Implementation

The developed software solution as seen in Fig. 3(a), to expand the MBD framework, contained the ability to take in external datasets, such as data located in excel or text files, and bring in that information into the CAD package. The imported data is embedder into the CAD model at a vertex level defined by the user or by the users' data set. A User could also use the CAD model itself as a 3d index to embed additional information manually if desired. The software solution would then allow a User to embed the data into the CAD model. This model with the embedded information could be saved in the brand specific CAD package native format for later use or the model and embedded data could be saved out to neutral file format (NFF), such as a STEP file for use in other CAD packages or for archival. Testing of the embedded data in the NFF is of course compared to the data in the native format to verify data accuracy viability of the methodologies used, to embed the data and to verify if the data has been corrupted in anyway. The software solution also contains the ability to search throughout all of the embedded data sets found within the CAD model and retrieve desired information as can be seen in Fig. 3(b) via the automated keyword search utility.

The user also has the ability to decide what kind of visualization or reporting method is best suited to display the embedded data as seen in Fig. 3(c). The desired information could be displayed directly onto the model in several preprogrammed methods, such as colored locations or have the data displayed as text right on the model much like PMI information would be displayed. Also the information can be retrieved and displayed as text in a reporting window if no visualization method is desired.

As an example, if a user has several datasets such as performance and manufacturing data concerning a wing. Those datasets could be embedded into a wing model and the user can bring up all the information concerning the wing stress or the wing wear and display the locations of where that data is located on the CAD model as well as obtain the information in text format. This would be done all within the CAD package that the user already has experience with. The user could also embed additional data sets which include attributes about that model, such as wear rate and residual stress from manufacturing, and be able to save and share that file with colleagues. The user's colleague could then use the software solution to see what is already embedded in the model with simple exploration tools, such as a drop-down box which shows data from attributes embedded into that model, and use the software solution to automatically create a visualization to better see the desired data.

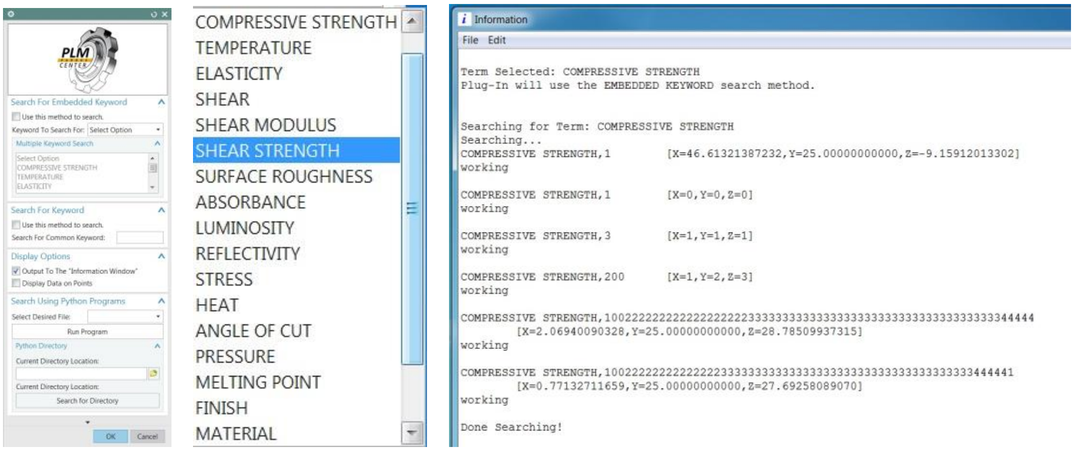

Fig. 3: Data Exploration options available in the plug-in. (a) The main search engine with multiple data exploration methods as well as data manipulation and visualization options, (b) A close up of the plug-in's automated keyword search tool, (c) One of the basic data visualization methods.

In order to expand on the MBD framework a major consideration went into laying out a software architecture that could be programmed to function independently of what CAD software it would be developed for. This consideration is an attempt into creating a system whose results could be safe for archival and future retrieval without the concern that future CAD program upgrades or the use of different CAD programs would not cause a loss of the data in expanded MBD.

The research explored multiple software architecture ideas and implementation methods in order to weigh the benefits and determinants that could affect the results of the expanded MBD CAD data. In this research methodologies were selected for the software architecture which would minimize the dependencies of brand specific CAD software. While this would create more programming overhead in order to implement a solution it would in the long run allow the developed software, which implements the expanded MBD solution, to be more resilient and less prone to failures from future brand specific CAD software upgrades or changes. This chosen methodology would also allow future version of the software architecture to be ported over to other CAD software brands or to be developed to run independently of a CAD environment, such as allowing PLM software or other independent software packages to interact with the data.

Since a concern in the philosophy of MBD is the ability to archive and retrieve data our research solution needed to incorporate the concepts of long term achievability for future use. Our research explored additions to the software architecture such that it would incorporated methodologies of current CAD file standards which can currently support the expanded MBD as well as experience the least amount of data degradation, or ideally no data degradation, if the CAD file standards change in future iterations of those formats.

Summary

This research extended the Model Based Definition (MBD) to incorporate behavior and product characteristics. The objective is to demonstrate that behavioral information could be incorporated into MBD. The implementation section outlines the solution that was created to extend the MBD framework, and demonstrates that behavioral information can augment any CAD package. This research also extends the theory behind MBD in that shape alone should not constitute the definition of a product rather that the product is a multifaceted concept composed of many domains of knowledge that should be brought together to work in tandem. The digital twin should not simply be a replica of the physical object, but also augment the definition of the physical product.

Conclusion:

The objective of this research was to extend the 3D-CAD model through behavioral information. The solution developed achieved this, and provided insight into the benefits of such a solution. Through interaction with experts, the researchers were able to identify the potential value of an extended CAD model. The value was being able to search between and among datasets, visualization of the data sets, and downstream human or machine consumption of extended information. An extended 3D-CAD model will continue to be developed, and this research represents foundational work in the utilization of behavior in the CAD model to create a digital twin.

References:

[1] Glaessgen, E.; and Stargel D.: The Digital Twin paradigm for future NASA and US Air Force vehicles, 53rd Struct. Dyn. Mater. Conf. Special Session: Digital Twin, Honolulu, HI, *US*. 2012.

[2] ITI (2013). US Navy Model Based Definition Initiative Identifies Significant Savings. ITI. Retrieved from http://www.iti-global.com/us-navy-model-based-definition-initiative-identifies-significant-savings.

[3] Mocko G.; Malak R.; Paredis C.; Peak R; A knowledge repository for behavioral models in engineering design. ASME 2004 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Jan. 1, 2004, 943-952. https://doi.org/10.1115/detc2004-57746