TERRIFIC
Enhancing Interoperability

SEVENTH FRAMEWORK PROGRAMME

Deliverable D6.2 of Task 6.1

Detailed plan for tool development and synergies across work packages

Circulation: PU[1]

Partners: SINTEF

Authors: Vibeke Skytt

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Executive Summary

This document contains deliverable D6.2 of the TERRIFIC FoF STREP Project.

This deliverable describes identified synergies between the TERRIFIC work packages and also summarizes the expected tool contributions from the work packages 1 to 4 and the need for tools in the same work packages. Further, the document contains a plan for the tool development within WP6.

Contents

1 Introduction

Isogeometric analysis attempts to bridge the gap between CAD and analysis and harmonize the technologies used. Hughes et al., see [5], introduced in 2005 an analysis framework which is based on NURBS where they propose to describe both geometry and simulation results by NURBS surfaces and volumes, i.e. to use spline elements.

An isogeometric toolkit is intended to provide software tools for isogeometric analysis. In some applications, for instance shape optimization or non-linear simulation problems, an isogeometric solver may be such a tool, but in most cases isogeometric software tools will rather concern the area of spline spaces, geometry and tools for isogeometric analysis. Tools for common operations occurring both in traditional FEA and isogeometric analysis, such as linear equation solvers, should probably not be included in such a toolkit. An isogeometric toolkit will thus have many tools in common with a geometry toolkit, but must provide a more direct access to the function space and must be able to handle trivariate entities.

Both isogeometric analysis and CAD use NURBS, but their ways of using them differ. In isogeometric analysis the use is restricted to non-trimmed entities, while CAD also uses other surfaces types and surfaces must be expected to be trimmed. Boundary represented CAD models represent solids implicitly by describing their boundary, trivariate entities are not used. An analysis suitable model intended for isogeometric analysis contains 2- or 3-variate non-trimmed NURBS entities. These differences imply that a conversion from a CAD type solid to a model fit for isogeometric analysis is non-trivial. Section 6.3 will focus on this issue.

Section 4 gives an overview over the tools that the application work packages, WP1 to WP4, plan to deliver and over the tools these work packages need to support their work. We can see that the relevant tools differ drastically in size and complexity. Many useful tools are very specific with regard to their purpose.

When the construction or assembly of a toolkit is part of an ongoing project, like in TERRIFIC, one must be aware of the following: *Not all the tools assembled during the project will be available early enough to be used in the project itself.* Tools finished late in the project are in reality not usable for other project activities unless this is planned up front and there is a close collaboration between the tool developer and the application developer.

2 State of the art

The concept of an isogeometric toolkit was first developed in the EU project Exciting in the FP7 transport program, see [4]. There an isogeometric toolkit was assembled with contributions of background software from SINTEF (SISL and GoTools) and INRIA (Axel). The toolkit was extended in the project period 2008-2012, through work both within the project and in parallel (national) projects. No other isogeometric toolkit is available. The Exciting toolkit is available for the TERRIFIC project, and thus TERRIFIC has a good basis for its toolkit work. More information about the initial version of the TERRIFIC toolkit can be found in the report provided in deliverable D6.1.

As stated in the introduction, there is a fundamental difference between a Brep CAD model and an isogeometric model. How is this modeling problem handled in current isogeometric analysis? To answer this question we must distinguish between the 2-variate and 3-variate case.

2.1 2-variate isogeometric modeling for analysis

An isogeometric model must be watertight and this is usually not the case for a CAD model. Furthermore, an isogeometric model should preferably possess the property of being locally refinable. These conditions are met by T-splines as introduced by Sederberg et. al. 2003, see [7]. A T-spline surface is watertight and smooth, and isogeometric analysis has been successfully applied to this type of geometry. Furthermore, combining T-splines with Bézier extraction provides the ability to run isogeometric analysis within established FEA software, although extraordinary points require special attention, see [6].

LR B-splines as an alternative to T-splines are currently being developed at SINTEF, see [2]. This concept is believed to solve the same type of problems and is more flexible, but less mature.

Block structuring is yet another alternative approach to create a model fit for isogeometric analysis. It is used a lot in flow simulations, see for instance [1], and already has some support in the current version of the TERRIFIC toolkit, which as mentioned above corresponds to the toolkit assembled in the Exciting project. The blocks meet with exact C^0 continuity, but since a model is divided into blocks mainly due to extraordinary points, higher order parametric continuity is in general impossible to achieve. A block structured model can be built one block at the time or by making use of information from an initial CAD type surface model.

2.2 3-variate isogeometric modeling for analysis

There is currently no efficient pipeline to construct a trivariate isogeometric model from a CAD model and it is tedious to construct a complex trivariate model directly. There are, however, some approaches to tackle this problem:

- A T-spline surface combined with the method of boundary elements avoids the problem of creating a trivariate model. This is, however, not applicable for all problems.
- A model represented by its T-spline boundary is immersed in an axes-parallel hierarchical B-spline grid. This approach is used by Düster et. al., see [3].
- A number of trivariate models may be created by sweep operations applied to one or more NURBS surfaces or a T-spline surface.
- Block structured trivariate models. This is the approach taken in the TERRIFIC toolkit, but currently only very simple models are handled. There is also a tendency to get a larger number of blocks even for simple models.

3 Long term vision

A boundary represented CAD solid is far from being analysis suitable. It is, however, not obvious that a corresponding trivariate, block structured isogeometric model is analysis suitable either. A CAD model typically contains a lot of details that are not required in all types of simulations. Ideally, details should be represented in a way that makes it easy to remove them in a model simplification process.

An ideal isogeometric modeling and analysis process is illustrated in figure 1. An initial CAD model is analyzed and transformed to a trivariate model where features are represented by trimming, but the trimming is required to be much more controlled than what is frequently the case in CAD. This allows features to be removed if one wants to analyze a simplified model while they can be kept if a more detailed analysis is performed. Then either the isogeometric analysis must be extended to handle trimmed elements or

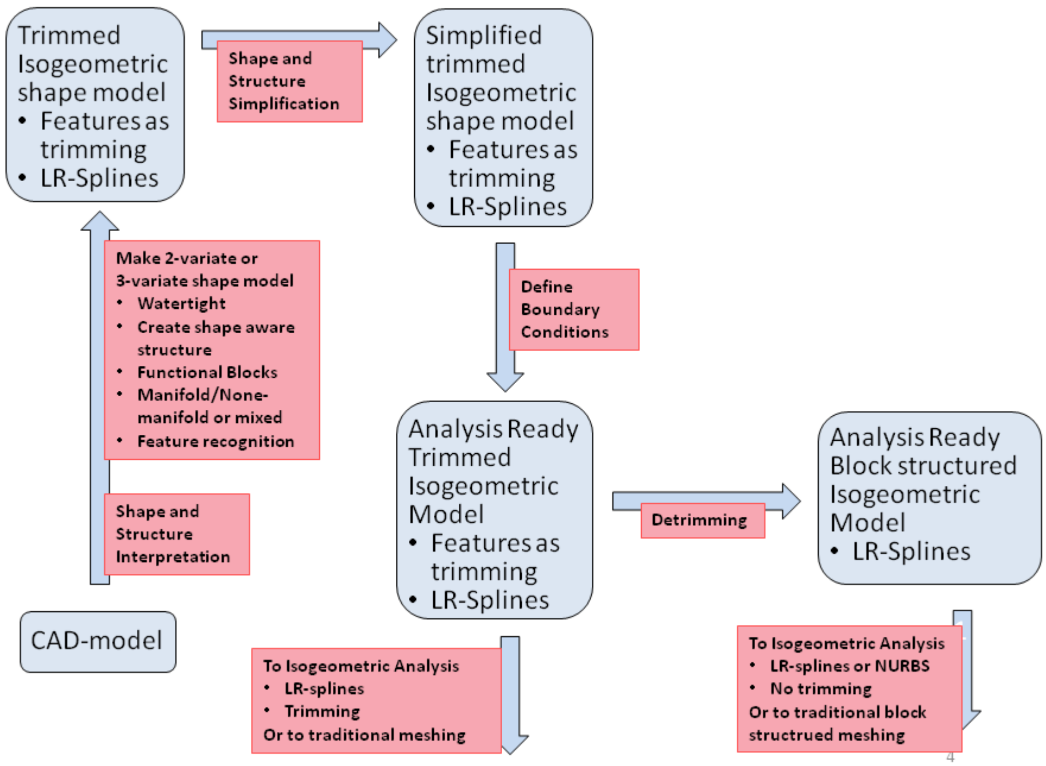

Figure 1: An envisioned pipeline for the isogeometric analysis process

block structuring is performed at a late stage. Such a process demands a lot of advances:

- Shape and structure interpretation of a CAD model to grasp design intent.
- Distinguishing between features and function to produce a preliminary block structuring of a model.
- Developing a concept of controlled, exact trimming to be applied to a trivariate block. Low order algebraic surfaces are envisioned to be used in this context.
- Automatic translation from a boundary represented model to a trivariate, block structure model with or without trimming.
- Isogeometric analysis handling non-conformal elements and trimming.
- LR B-splines also becoming a part of the concept.

The process outlined above will improve the flexibility within isogeometric modeling and analysis, but is not applicable in the short to medium term. In TERRIFIC we aim at improving the current block structured representation and especially the methods for creating these models.

4 Coordination of tool development across work packages

All work packages of TERRIFIC are obliged to contribute to the toolkit, although WP5 will not create any toolkit software. WP6 is the main responsible for the toolkit coordination, but is supported by the *Synergy and Toolkit Working Group* with representatives from all work packages. The application work packages, WP1 to WP4, provided in their first deliverables lists of their planned contributions to the toolkit and of their needs for tools. This section summarizes the information from D1.1 to D4.1 and the ongoing discussions in the Toolkit Working Group. Note that no transfer of ownership is performed when submitting code to the TERRIFIC isogeometric toolkit.

Work package	Tool provided	Date	Domain
WP1 (task 2)	Flow volume segmentation	M 18	isogeometric modeling
WP1 (task 2), WP2	Surface segmentation	M 6	isogeometric modeling
WP1 (task 2)	Volume segmentation	M 33	isogeometric modeling
WP1 (task 2)	Basic functionality for triangular meshes	M6/12	geometry, triangulations
WP2	Solver for linear elasticity	M 12	isogeometric analysis
WP2	Solver for nonlinear elasticity	M 24	isogeometric analysis
WP2	Solver for harmonic balance method	M 33	isogeometric analysis
WP2 (task 2)	Sensitivity computations	M 24	isogeometric analysis
WP3	Solver for 3D linear elasticity	M 24	isogeometric analysis
WP3	Solver for 3D Navier Stokes	M 24	isogeometric analysis
WP4	Transform a collection of trimmed patches to one non-trimmed one, 2D	M 24	CAD to isogeometry
WP4	Compute self intersection points of offset curves and surfaces	M 24	geometry interrogation
WP4	Compute silhouette curves	M 24	geometry interrogation
WP4	Regions defined by silhouette curves	M 24	geometry interrogation
WP4	Communication with TopSolid data base		conversion

Table 1: Tools to be provided by the application work packages

Work package	Tool needed	Domain	Tool/ provider	Date available	Effort
WP1	Spline surface from triangulation	geometry modeling	GoTools	M 6	tuning, small
WP1, WP3	Volume from boundary surfaces	geometry modeling	GoTools	M 6	exists for non-rational
WP2	STEP and IGES import	conversion	GoTools	M 6/12	small-medium
WP2, WP3	Create isogeometric model from CAD input	CAD to isogeometry	GoTools	M 12 and on	huge
WP2	Change parameterization of trivariate NURBS models	geometry modification	GoTools and INRIA	M 6	exists, tuning
WP2	Visualization tools	simulation results	Axel	M 6 and on	exists, extensions?
WP3	Isogeometric linear elasticity solver	isogeometric analysis	TUM/ UNIKL Exciting result	M 6	exists
WP3	Evaluate B-spline basis functions, 2D and 3D	geometry interrogation	GoTools	M 6	exists
WP3	Read untrimmed NURBS surfaces from IGES	conversion	GoTools	M 6	exists
WP4	Self intersection computations	geometry interrogation	INRIA, possibly GoTools		basics exists
WP4	Compute silhouette curves	geometry interrogation	SISL	M 6	exists
WP4	Handle surface sets with trimmed surfaces	topology	GoTools	M 6	exists
WP4	Represent and evaluate B-spline curves and surfaces	geometry interrogation	GoTools	M 6	exists

Table 2: Tools requested by the application work packages

Table 1 gives a summary of the tools which the application work packages plan to provide, while table 2 presents the tools these work packages need in order to perform their work. Note that tools on computations of silhouettes and self intersections appear in both tables. These tools are planned to be produced in WP4, but some background functionality already exists in the current toolkit. WP6 will not be involved in this activity.

Both WP2 and WP3 will perform work on linear elasticity and the two work packages will cooperate to exploit the synergy. Furthermore, the linear elasticity solver developed in the Exciting project will be used in this context.

WP1 and WP2 will cooperate to develop the tool *surface segmentation* and provide it to the toolkit. This work will involve a diploma thesis.

Most of the tools requested from WP6 are already a part of GoTools or Axel and consequently already available, yet some effort may still be required to adapt the methods to the exact needs. One request, however, sticks out as requiring a huge effort and posing a large risk, namely the need to convert boundary represented CAD solids to a trivariate isogeometric model. This tool is the main topic of section 6.3 and will be discussed there. WP6 will focus on this tool, but it is clear that a general solution will not be reached during the TERRIFIC project.

WP5 is addressing the long term archiving of data. This requires:

- Data to be archived from the application work packages;
- Conversion software between STEP and GoTools from WP6;
- Ensuring in cooperation with WP6 that the STEP standard facilitates the archiving of isogeometric models and simulation results.

Tools that are to be used by other work packages within the TERRIFIC project need to be available at an early stage. Tools added late in the project, which will be the case for many tools from the application work packages, will have limited use in the project, but be very useful for follow-up work in the isogeometry field after TERRIFIC.

5 Toolkit development

Task 6.2 is concerned with all the development of the initial toolkit inherited from the Exciting project except the conversion between a boundary represented CAD model and an isogeometric model, and the communication with STEP. These items are handled within task 6.3. The content of Task 6.2 is

- Toolkit contributions from other work packages. While the realization of the promised tools listed in table 1 belongs to this task, the responsibility for the contribution remains with the application work package.
- Necessary improvements to the visualization tools. This is handled by INRIA.
- Extensions to the functionality regarding evaluation and manipulation of NURBS curves, surfaces and volumes. As this functionality is currently part of GoTools, SINTEF will be responsible for this class of tools.
- Necessary upgrade of tools to handle rational curves, surfaces and volumes where this is not the case today. SINTEF is responsible, but note that not all functionality can be upgraded to rationals.
- Change of the parameterization of surfaces and volumes. Both SINTEF and INRIA have software to perform reparameterization and are responsible for their own tools.

6 Relation to STEP-type CAD

Task 6.3 is concerned with the development of a prototype component allowing CAD-models represented in the STEP-format to be easily accessible through the toolkit. This will allow the integration of the TERRIFIC results into real industrial information flows, and has the following components:

- Communication with the STEP file
- Conversion from an isogeometric model to a CAD type model
- Conversion from a boundary represented CAD model to an isogeometric model

6.1 Communication with the STEP file

GoTools already has a STEP reader using the STEP tools of JOTNE, but this reader can be seen as an early prototype and needs some improvements before it is applicable in TERRIFIC:

- Adapt to a new interface of JOTNE's tool
- Add some entities which are missing at this stage
- Handle assemblies
- Improve the stability especially with regard to elementary surfaces

To complete the STEP tools in GoTools and to facilitate long term archiving of data, which is a part of WP5, a STEP writer must be implemented. In order to be able to archive both the isogeometric model and the corresponding simulation results, the appropriate STEP format, AP209, must be extended. This extension will mainly be handled by JOTNE. The time frame for the WP6 activity in this subtask is:

M12 Complete STEP reader

M18 STEP writer

M33 STEP writer including new AP209 entities

Transfer of geometry data within TERRIFIC will either use STEP or IGES files. Since the STEP standard allows for much more transfer of information related to the model than IGES does, the STEP solution is preferable.

6.2 Harvesting a Brep CAD model from an isogeometric model

The outer boundary of a trivariate block structured isogeometric model is itself a boundary represented CAD solid. This boundary shell will contain only NURBS surfaces, no analytic surfaces will be included in the shell and no trimming is performed. However, the surface set will be watertight. The boundary shell of a 3D isogeometric model can be fetched using functionality existing in the toolkit today.

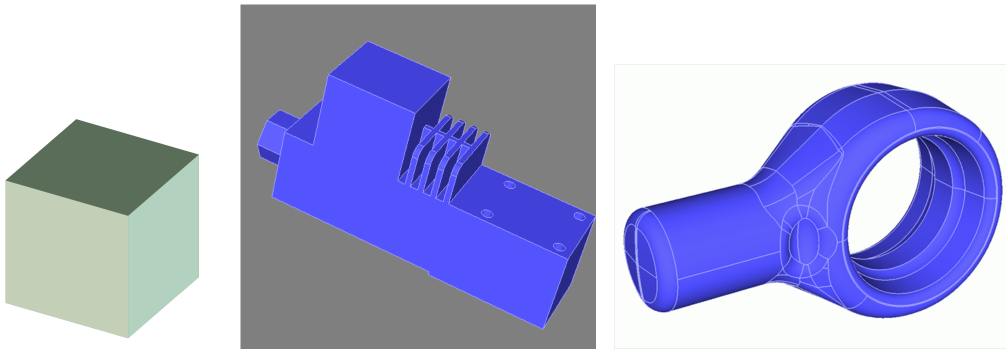

Figure 2: Boundary represented CAD solids of varying complexity

6.3 The creation of an isogeometric model from a Brep CAD model

This subtask will be the main activity for WP6 and SINTEF in the TERRIFIC project. The work will be performed within the GoTools framework. Some functionality supporting this task already exists in GoTools and the initial toolkit; this will be explained in section 6.3.1.

CAD models have varying degrees of complexity; this even applies to models consisting of only one solid. There is a huge difference between the simple cube in the left picture of figure 2, the complex part in the middle picture and the model with a relatively simple shape, but a very complex representation in the right picture. One common translation strategy will not be able to handle these very different models. A number of different strategies or tools are required. The translation process must:

1. Analyse the model
2. Select an appropriate tool and apply this tool
3. Check the result and try a different tool if required

This process should be as automatic as possible. User input may still be required and not all kinds of models will be handled, yet the class of allowed models will be extended throughout the project.

It will be important to preserve as much information as possible from the initial CAD file, but it is a fact that some specific models and some types of models carry more relevant information than others. This will influence the kinds of models we are able to handle.

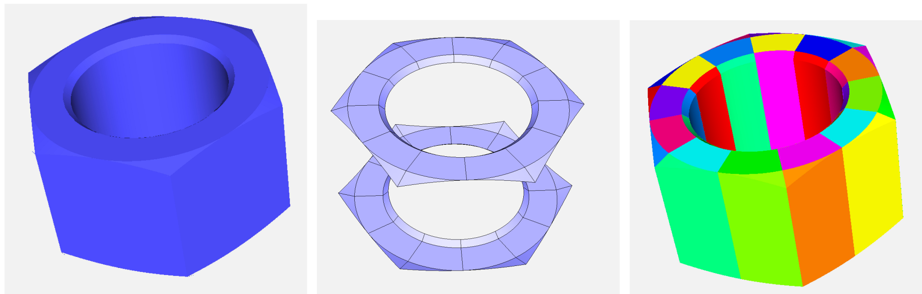

Figure 3: An isogeometric model constructed from a CAD model

6.3.1 The current situation

Boundary represented solids can be read from a STEP or IGES file, but assemblies are not handled. In the IGES case, only the surfaces belonging to the solid are read, the topology structures are created within GoTools.

GoTools contains some tools for the direct creation of models, and these can be combined with a selection of surfaces from the boundary shell of a CAD solid. In figure 3 a number of surfaces at the top side of a given CAD model were used as a starting point for the volume construction. Combining existing GoTools functionality with some manual work, these surfaces are translated to a surface set containing only non-trimmed B-spline surfaces. The B-spline surfaces are mirrored around a specified plane and the volume model is created by loft.

It is also possible to perform an automatic translation for some very simple models. The focus so far has been on mechanical parts. They typically have large surfaces, possibly with holes. The most important aspect of these models in the isogeometric modeling context is that the patch division is mostly related to shape and the features tend to occur only in one direction of the model. The translation possibilities are currently very limited and the toolkit must be extended in this field.

6.3.2 Envisioned tools

There is not one single method suitable to handle all translations. We envision a number of new or extended tools. During TERRIFIC, we will implement a number of tools starting with the simplest ones. The more complex tools may be simplified or postponed until after the end of the project if the list turns out to be too ambitious:

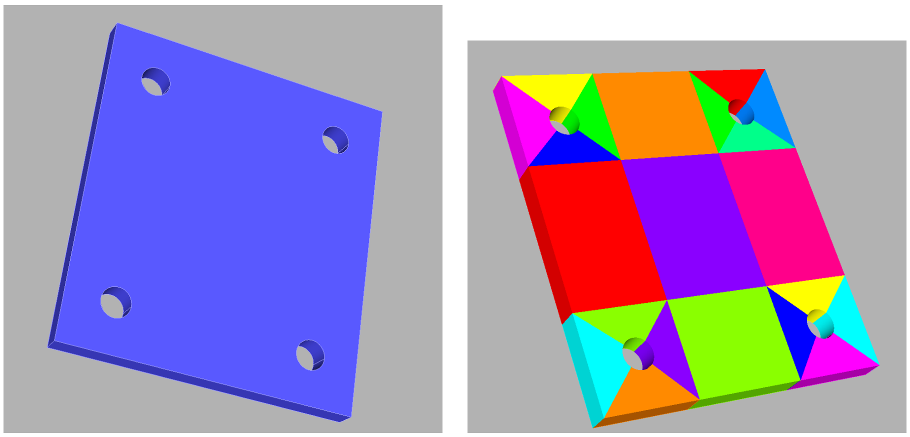

Figure 4: A simple boundary represented CAD model and the corresponding isogeometric block structured model

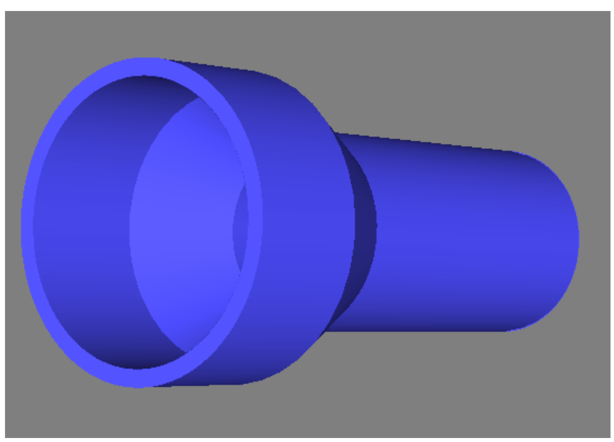

Figure 5: A rotational model

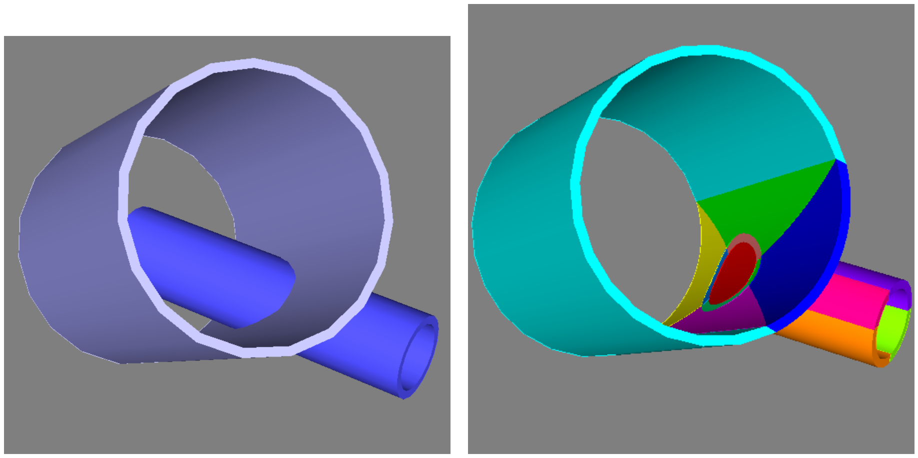

Figure 6: A union between two pipes where one piece is removed

- Recognize linear sweep in a simple model.
- Extract sweep information and recreate the model by linear sweep. The model in figure 4 was translated directly, but could also be handled by creating a block structured surface model and generating the volume model by sweep.
- Recognize a rotational model. Such a model is shown in figure 5.
- Extract rotational information and recreate the model by rotation.
- Transform a surface model with trimmed surfaces and holes to a block structured surface model with non-trimmed NURBS surfaces.
- Identify symmetries in a Brep model.
- Identify one direction in a Brep model where there is some sort of topological symmetry.
- The Boolean operations union, intersection and difference applied to volumes. We may for instance want to remove material from one entity in a volume model. Then we can start by modifying the boundary shell of this entity according to the actual operation. The modified boundary shell is a boundary represented solid and can be handled as such. However, as we modify this solid, we must be aware of it

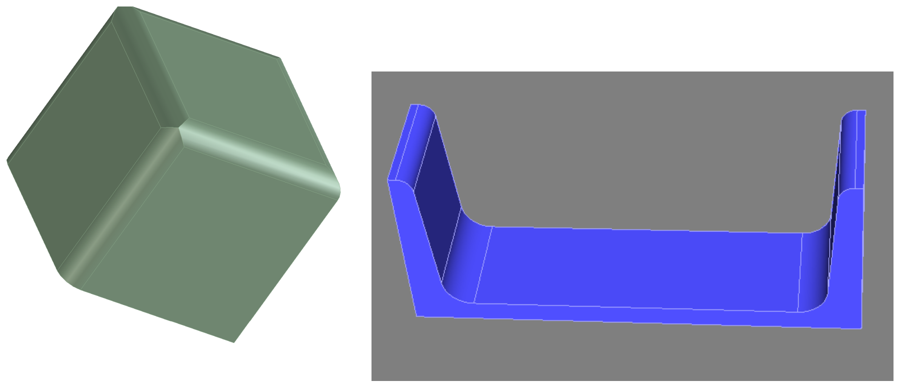

Figure 7: Two simple, but very different models with blends

being one solid in an assembly, and some modifications may influence adjacent solids. Figure 6 shows a union operation applied to two pipes represented as spline volumes. One of the resulting pieces is removed during the process.

- Reparametrize features, for instance corner curves, to ensure that they lie on a constant parameter surface in an associated volume.
- Translate simple Brep models that possess the requested topological symmetry to block structured, trivariate isogeometric models.
- Snap a suitable block structured, trivariate isogeometric model to a given boundary shell. The topological properties of the two models must be the same.

NURBS create problems for some operations as already mentioned in section 5. Boolean sum operations, for instance, are not easily applicable for NURBS input. Not all methods may be extended to NURBS at all, and some may be extended only for certain input conditions. In some cases alternative modeling techniques may be applied. This is particularly relevant for isogeometric modeling. Internal boundaries in a surface or volume model can normally be moved within the model as long as the model shape does not change. This freedom can be utilized to create surfaces or volumes by loft instead of using a Coons patch approach.

Blending is important in solid modeling and figure 7 shows two models with blends. Though each is simple, already these two models are very

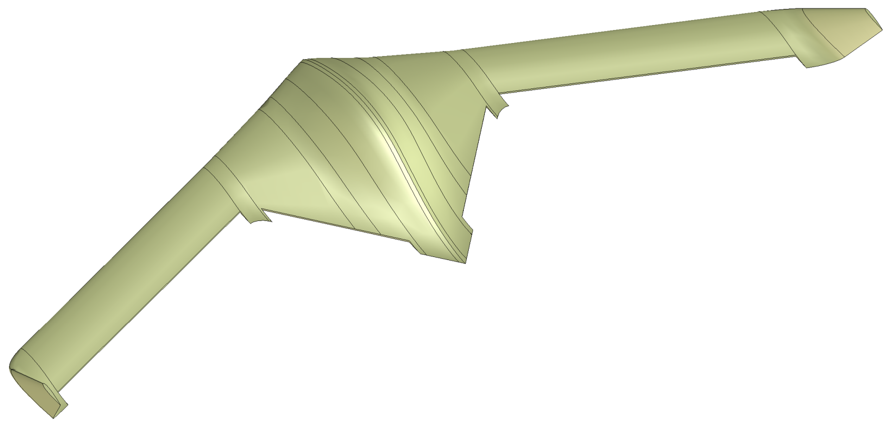

Figure 8: A model with free form surfaces

different, and it is obvious that one strategy cannot be applied to all blended models. In some cases, models with blends must be split to separate the blends. This is the case for the first model in the figure. Moreover, the blending is not smooth all over. The corners caused by the blend will lead to additional splitting. Also in the second case, the blends will lead to splits, but not to separate the blends. The model will be split in the middle of the blend or at one blend boundary. In both cases, the remaining part of the blend needs to be integrated with the adjacent surface. Thus the issue of merging of surfaces arises. This situation needs to be identified and handled. What is the appropriate continuity along the merging curve? How much modification of the adjacent surfaces do we allow when merging surfaces?

In general, approximation is required to translate a CAD model into an isogeometric model. Thus, the tradeoff between approximation accuracy and data size must be emphasized. Data structures that allow us to keep information, for instance about analytic surfaces and surfaces intersecting in some intersection curve, are important throughout the remodeling phase to avoid multiple approximations of the same entities.

Figure 8 shows a nice model with a number of free form surfaces. It should be possible to remodel this model as a block structured, trivariate isogeometric model, although with degenerate volumes. However, the isogeometric model should contain a smaller number of blocks than suggested by the patch structure of the CAD model. Some CAD surfaces need to be merged into larger entities to improve the structure of the isogeometric model. In general, one should be careful when considering the CAD structure while designing the structure of the isogeometric model. Still, the current toolkit version depends heavily on the CAD structure, and that will still be the case during most of the TERRIFIC project.

6.4 Plan for tool development

This section presents a plan for the tool development within Task 6.3. While a very large quantity of CAD models exist with different shape configurations and different complexities in the representation, only a fraction of these models will be handled during the TERRIFIC project. The plan is designed to make it possible to handle simple configurations at an early stage and then extend the class of possible models throughout the project.

6.4.1 Plans for month 12

The focus at this stage is to be able to handle simple models of one solid. Some user interaction must be expected, but the aim is an automatic process. The goals will be to:

- Automatically convert simple boundary represented models to block structured isogeometric models. The relevant types of models are similar to the models handled at the current stage, but the stability of the process will be improved.
- Integrate and make use of information coming from analytic curves and surfaces.
- Use plane normal and cylinder axis information to define parts of a local coordinate system of a volume model.
- Recognize models that may be created by linear or rotational sweep provided that the necessary information can be found in analytic surfaces in the CAD model. The wheel from WP2, see figure 9, is a candidate for this functionality, but a relatively complex one. Perform sweeping.

Figure 9: The train wheel from WP2

- Convert surface sets including trimmed surfaces to surface sets with only non-trimmed NURBS. This is an extension to the current functionality and we expect many configurations to be handled, but not all. Degenerate configurations will not be prioritized. This functionality is important for 2D models, but is also a part of the conversion of Brep solids into trivariate block structured models, and it can be combined with loft or sweep to create an isogeometric volume model.

- An updated STEP reader will be included in GoTools. This reader depends on the JOTNE tool EDM.

- The outer boundary of an isogeometric model may be fetched. This produces a boundary represented CAD model that may be stored in the internal GoTools format or in an IGES format.

One class of models that is expected to be handled by this toolkit version consists of plates with holes. The assumption is that the model is represented by large surfaces where the holes are given by trimming. There will also be a restriction on the complexity of the configuration of holes.

In general there are a number of restrictions related to the Month 12 deliverable:

- The models must have “one coordinate system”. This means that it must be possible at each point to identify one direction that can be treated as the thickness direction of the model, and this direction must be consistent for the entire model. The direction needs not to be constant, but must vary gradually. In figure 5, this direction rotates around the model axis.

- Features (holes, removal of material or added material) exist only in the thickness direction.

- Only one category of features exist for each model.

- The patch division in the model is entirely related to shape. Thus, the edges in the CAD model will become edges also in the isogeometric model.

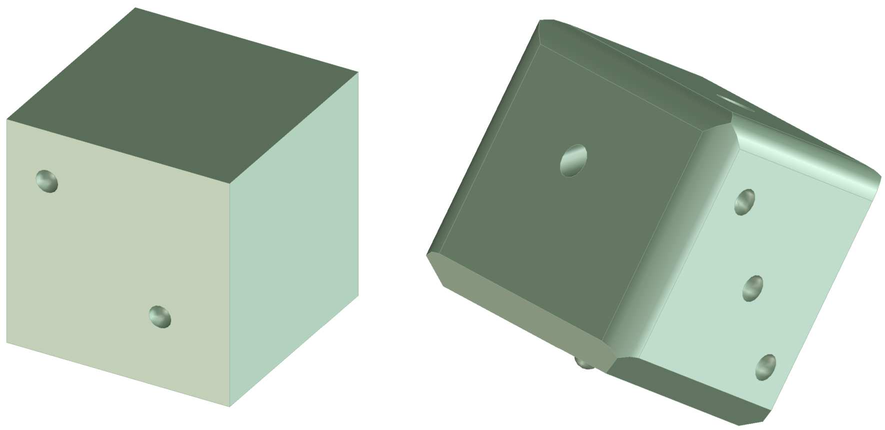

Figure 10: One model with features only in one direction, and one with features in several directions and of different kinds

6.4.2 Plans for month 18

This deliverable is the last one where we can expect that it is possible to use the results in the application work packages. Thus, we emphasize the implementation of functionality that will extend the class of models to be handled. However, we must expect some limitations with regard to the model complexity handled by these new tools. This implies that there will be models of the same type where we will be able to convert one model but not the other.

The goals will be:

- A strategy for handling blends, see figure 7 for examples. There are many unresolved questions regarding models with blends and many configurations that must be treated differently. Thus, it is unlikely that all kinds of blends will be handled at this stage. Still, blending is important in modeling and this feature must be prioritized. Blending will therefore be one focus in this deliverable, but not all configurations will be covered.

- Features in more than one parameter direction. Figure 10 shows two boxes with additional features. The first one has features only in one direction and should be handled by month 12. The second has features in several directions and blends, added material and removed material. This last type is scheduled for month 33, but a version without blends may be a topic for month 18 as well as the model in figure 11.

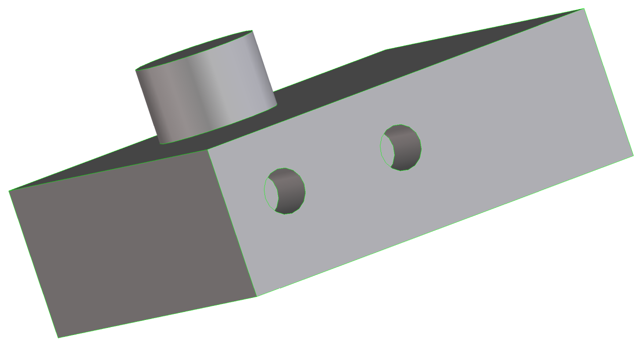

Figure 11: Features in more than one direction

- Boolean operations. There will be certain restrictions to the possible input configurations.
- More complex models belonging to the category of solids handled in M12.
- Some models with several solids (assemblies). Only simple cases will be handled.
- A STEP writer will be included in GoTools. This writer will depend on the JOTNE tool EDM.
- The outer boundary of an isogeometric model may be fetched as a boundary represented CAD model and exported as a STEP file.

6.4.3 Plans for month 33

This deliverable is due almost at the end of the project. Thus, the extensions to the toolkit in this deliverable will mainly be of use beyond TERRIFIC. The main aim is to stabilize the toolkit and extend existing functionality to handle larger classes of models. If possible, further extensions will cover the following areas:

- Several types of features in the same model. Figure 12 shows a rotational model with holes. The approach in this case would be to

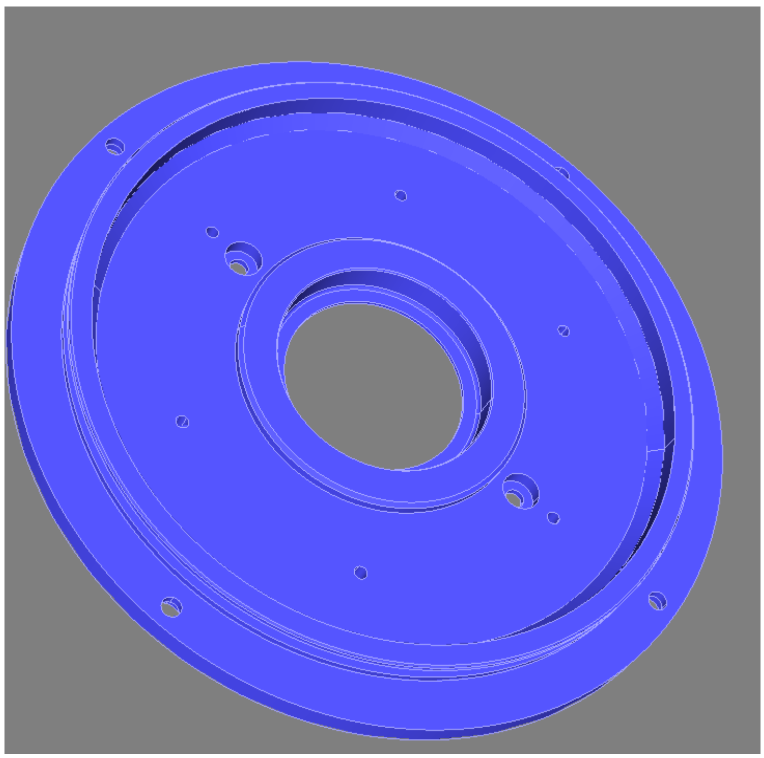

Figure 12: A rotational model with additional holes

create the rotational solid without holes and remove material using the Boolean operation difference.

- Creating an initial volume model of suitable topology and snapping it to a given boundary shell.
- Joining initial surfaces to get a more appropriate initial patch structure. Work from WP4 can provide methodology in this context.
- Analyzing whether a model can be produced by linear or rotational sweep from free form surfaces
- More complex models belonging to the category of solids handled in M18.
- Improved stability.
- Functionality to export an isogeometric mesh with associated solution fields to a STEP file.

7 CAD models suitable for automatic conversion to isogeometric models

We have already seen in figure 2 that the complexity of CAD solids varies a lot. Moreover, assemblies may consist of a large number of solids. The full diversity of models will not be considered during the TERRIFIC project. However, one aim in the project is to create a complete pipeline from CAD to isogeometric analysis for some real life test cases, one of which is the wheel from WP2, see figure 9. This is a rotational model with a lot of surfaces. It is not monotone along the rotational axis, a feature that adds some complexity to the process. Characteristic for this model and for other models where we see translation as a realistic option is: *The CAD representation of the model corresponds to the shape of the model.* Furthermore, the shape is not overly complex.

During the TERRIFIC project we will focus on:

- Models where the patch division corresponds to shape features
- The shape is modelled with large surfaces, holes are rather represented by trimming than by division into many small patches

- Features and symmetry information are easily extracted from the model, for instance by using elementary surfaces like planes and cylinders

8 Summary

WP6 consists of three major parts:

- Coordination of toolkit work amongst the partners
- Maintenance of the initial toolkit and small to medium size extensions to the existing functionality
- The relation between a boundary represented CAD model and a model fit for isogeometric analysis

The last part is by far the largest and most challenging. It is not realistic to cover all aspects of this problem during the TERRIFIC project, but the strategy is to look for classes of problems that may be handled and also focus on the particular models used in the application work packages.

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