TERRIFIC
Enhancing Interoperability

SEVENTH FRAMEWORK PROGRAMME

Deliverable D6.6

First extension of the TERRIFIC Isogeometric Toolkit

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Partners: SINTEF, UNIKL

Authors: Vibeke Skytt (SINTEF), Anh-Vu Vuong (UNIKL)

Quality Controller: Jochen Haenish (Jotne)

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[1] RE= Restricted to a group specified by the Consortium (including the Commission Services).

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Executive Summary

This document contains deliverable D6.6 of the TERRIFIC FoF STREP Project.

This deliverable describes the further development of the TERRIFIC isogeometric toolkit since delivery D6.3 in Project Month 12. The main contributor to the deliverable is SINTEF, but other partners have also been involved in the toolkit extension. The SINTEF contribution is partly deviating from the plan presented in D6.2. The main reason for that is the experience gained with the joint CAD model designed to meet the request of the reviewers to demonstrate close cooperation between work packages.

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1 Introduction

Delivery D6.6 is a toolkit delivery. It consists of an update of the isogeometric toolkit and an associated report. The purpose of the toolkit in TERRIFIC is to provide relevant and well tested tools for use within the project, but also beyond TERRIFIC. The toolkit consists of a collection of tools organized in subsets. The division into subsets is related to the provider and to the purpose of the tools. The tools are implemented in C++ and the different parts of the toolkit share a common structure. The ambition is that this toolkit shall be the preferred source of software tools for isogeometric modelling and analysis.

All partners participate in WP6. SINTEF provides general tools, mostly on the geometry side, and functionality to create models fit for isogeometric analysis. This functionality is integrated in GoTools, which is SINTEF's main geometry toolkit. Other partners create tools related to the work packages WP1 to WP4 and adapt these tools to the toolkit. The resource distribution is as follows: SINTEF has 33 months, WP1 partners (JKU and ECS) have 18 months, WP2 partners (Siemens and UNIKL) have 14 months, WP3 partners (Alenia and UNIPV) have 16 months, WP4 partners (INRIA and Missler) have 16 months and Jotne has 6 months to support STEP related work. INRIA hosts the server for the TERRIFIC toolkit.

The toolkit already provides a rich set of support tools for analysis if a block structured isogeometric model already exists, where each block is a NURBS surface or volume. Thus, the main emphasis for SINTEF in TERRIFIC is to extend the set of tools for the creation of such models and the path from a CAD model to an isogeometric model is particularly emphasized. In addition, the tools for communication with other systems through the STEP format are important.

2 Plans and toolkit contributions

Table 1 relates the current toolkit delivery to the plans made at month 3 and 6 of the TERRIFIC project as described in the deliverables 6.1 and 6.2. In the remainder of this section, we will explain the content in some detail.

2.1 Surface segmentation

The following is a prelimenary description of the toolkit module Surface segmentation based on information from WP1. It will be updated. The module contains tools for detection of sharp edges in a triangulated surface. The topology of a triangulation is created from file input, and the edge detection is based on triangle normals.

2.2 Elasticity solver

The toolkit contribution related to WP2 for the isogeometric toolkit in TERRIFIC consists of an isogeometric structural solver. For the first year the focus

Partner, related work package	Contribution	Type (planned/new)	Status
JKU, ECS (WP1)	Surface segmentation	Planned	Delivered at month 6
JKU, ECS (WP1)	Flow volume segmentation	Planned	To be discussed
JKU, ECS (WP1)	Basic functionality for triangular meshes	Planned	Started
UNIKL, Siemens (WP2)	Linear elasticity solver	Planned	Completed
SINTEF (WP6)	Blends in the conversion of CAD models to isogeometric models	Planned	Started
SINTEF (WP6)	Features in more than one direction in CAD file	Planned	Started
SINTEF (WP6)	Boolean operations on volumes	Planned	Not prioritized
SINTEF (WP6)	Simple assemblies	Planned	Not prioritized
SINTEF (WP6)	STEP writer	Planned	Prototype
SINTEF (WP6)	Export the outer boundary of an isogeometric model as a CAD solid using STEP	Planned	Prototype
SINTEF (WP6)	Quality testing of CAD models	Not initially planned	Delivered
SINTEF (WP6)	LR B-spline surface	Not initially planned	Prototype implemented

Table 1: Planned toolkit contributions

was mainly set on problems from linear elasticity. UNIKL adopted and improved the displacement and stress computation from the EXCITING isogeometric toolkit based on our previous work and have added additional features like eigenvalue computations. Furthermore, we contributed to the GoTools "Isogeometric Model" by testing it in our simulation enviroment, providing bug reports and suggesting additional useful features. The "Isogeometric Model" in GoTools was incorporated into the structural solver to support multipatch models. Therefore, we were able to set up more complex multi-patch geometries, which turned out to work well with the elasticity solver. To be able to compute even more complex problems we also connected the solver with powerful numerical software libraries. These achievements have been discussed, among others, in detail in D2.2.

Thus, we are very confident that we are on the right track as the points discussed above were achieved as scheduled at project month 12. The topics we focus on at the moment are nonlinear problems and sensitivities in full accordance with our work package goals and timetable. The results will be adapted to become a part of the toolkit. The related toolkit deliverable is in month 24.

2.3 GoTools extensions

The planned GoTools related contributions to the toolkit for this delivery were mainly related to an improvement in the methods and tools for creating a block structured, volume model from a CAD solid. This concerns functionality already existing in the toolkit, but the class of CAD models for which an acceptable result is expected, is relatively small. This class of relevant CAD models needs to be extended and the main emphasis for this delivery was to proceed towards more complex models and in particular models with blends and model features that cannot easily be identified with one parameter direction in the volumetric model. Some work has been done in this direction and the results are put into the toolbox, but we have not reached the stage that we had originally hoped for.

Some developments towards Boolean operations were planned for the current delivery. The purpose was to create more complex models by a direct use of the toolkit. The core of this functionality coincides with the remodelling of isogeometric models from CAD models, but new interfaces were required. Model creation through Boolean operations will, however, as an intermediate step lead to more than one boundary represented solid (typically two), which have to be processed simultaneously. This is similar to creating isogeometric block structured models from simple assemblies. These two planned activities have not been adressed due to changes in the priorities, but we will come back to them at a later stage.

A module for quality testing of CAD models, see section 5, has been added to the toolkit.

2.4 STEP converter

A prototype STEP writer for writing single solids and related entities to a STEP file has been implemented. The STEP converter in GoTools uses EDM_cpp10_SDK from Jotne. EDM_cpp10_SDK is a C++ early binding interface to the EDM Express database. By this interface one can generate the C++ header and implementation files for any Express schema compiled into the EDM database. By using the generated C++ files together with the cpp10.lib and edmikit500.lib it is possible to build C++ applications that operate on Express objects in an EDM database. The EDM_cpp10_SDK comes with both a 32 bits and a 64 bits version and is built for Microsoft Visual Studio 2008. The EDM_cpp10_SDK is an extension to the standard interface to EDM described in EDMassist found at
http://edmserver.epmtech.jotne.com/EDMAssist/WebHelp/EDMAssist.htm.

The outer boundary of an isogeometric model is in itself a CAD solid although the surface types allowed are limited compared to a standard CAD model. We can then combine the possibility to fetch the surface set representing this boundary with the ability to create STEP files.

2.5 New priorities

Clearly, the SINTEF contribution to this toolkit delivery has not been according to plan. Some issues have been delayed or only partly been adressed while others have been introduced. During the work with the extension of the tools for creating an isogeometric model from a CAD model, two issues have arisen which have changed the focus of the development in the short run:

- During the review meeting in October 2012, the reviewers suggested a demonstration case for cooperation between the work packages, see section 3. The first step in such a demonstration path is to create an isogeometric model from a CAD model. The suggested model seemed initially to fit well into the topic for the current deliverable, but also demonstrated the need for a renewed strategy in this remodelling approach.

- The LR splines format, see section 4, for representing spline surfaces and volumes with the property of local refinement seems to be a promising tool in the creation of isogeometric models. The demonstration case, in particular, illustrated the need for such a tool. An extension of the toolkit with this data format is also of interest for the University of Pavia (UNIPV), which wants to use it for adaptive refinement during isogeometric analysis.

3 The demonstration model

Figure 1 shows the proposed demonstration case. It is one CAD solid created by Siemens using a commercial CAD system. It has a certain complexity with two holes and two indentations and a relatively skewed shape. Furthermore, it

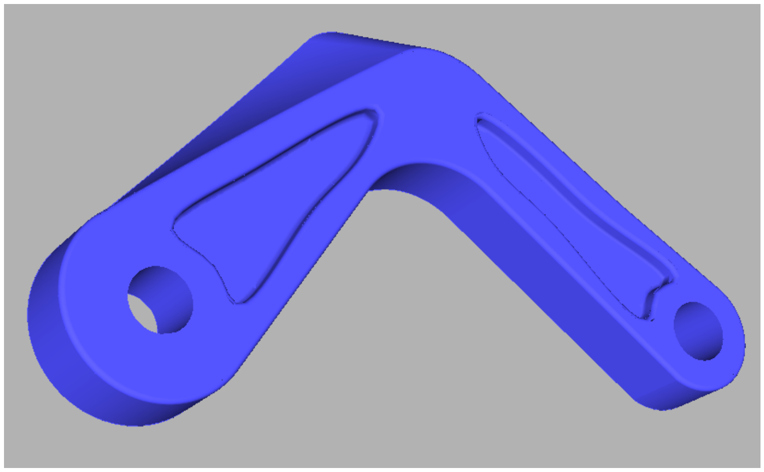

Figure 1: The proposed demonstration model represented as a CAD solid

is equipped with blends both between the top face and the side of the model and in the indentation areas. The model contains both elementary surfaces and free form surfaces, i.e., B-spline surfaces. Still, the model has an unambiguous "thickness direction" and only one level of blocks is required for an isogeometric model in this thickness direction. The blends provide a complexity factor, but fit well into the current plans for extensions of the toolkit.

3.1 Model structure

Looking at the model in more detail, see figure 2, we observe that it is divided into a number of small patches, in particular in the blend areas. This is a well known feature of many CAD models, see for instance figure 3, where a relatively simple shape is divided into more than 100 surfaces. In that model many of the surfaces are B-spline surfaces. All of them are represented as trimmed, but many could just as well be represented without trimming.

The surface structure of the demonstration model is of little use as a guidance to how an isogeometric representation of the model should be structured. In fact, it may prevent a good structure. In general, the structure of a CAD model must be considered with scepticism. The modelling is not performed with the purpose of analysis in mind, neither isogeometric nor standard FEA. The modelling tools of the CAD system influence the result to a large degree, and the designer may be an occasional user that does not have the knowledge how the system can be tweaked to give a particular result.

In the current toolkit, we have chosen to ignore the fact that the structure of the CAD model cannot be trusted. This is done deliberately. Even for models with a good structure, an automatic remodelling to an isogeometric model is a demanding task, and we have focused on the remodelling of selected models

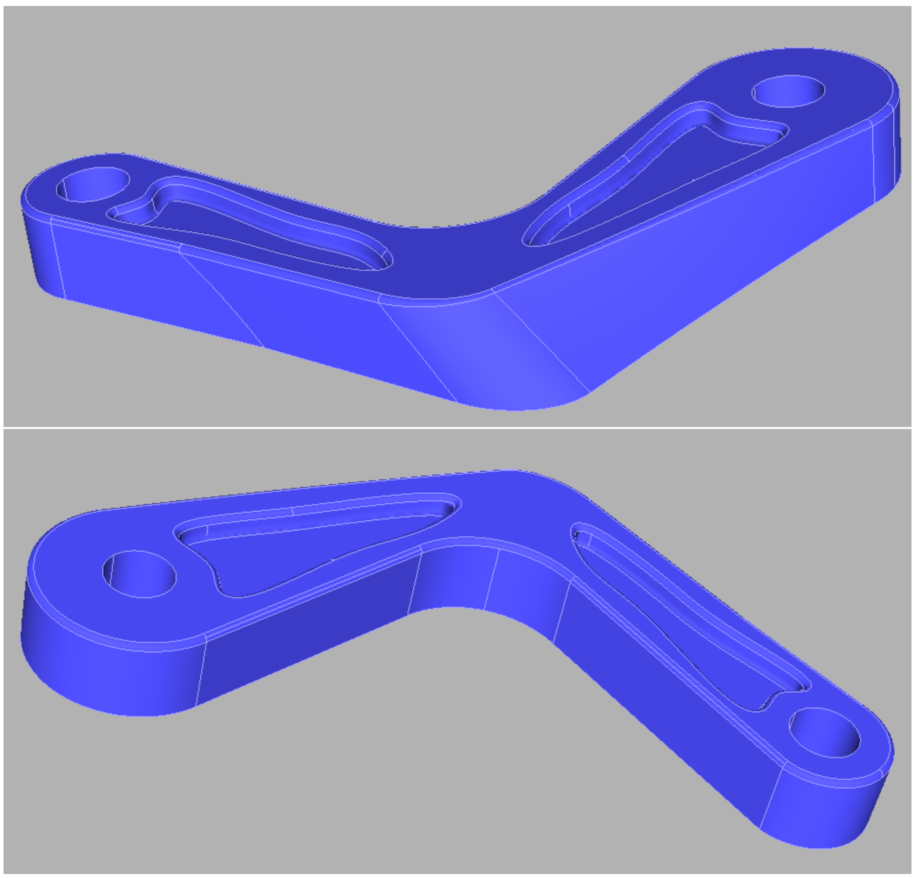

Figure 2: The patch structure of the demonstration model

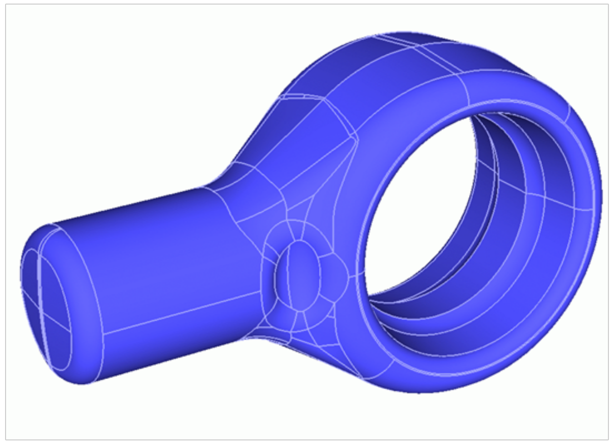

Figure 3: A model of an object with a relatively simple shape, but a complex patch structure

where the surface structure does not create additional problems. Considering the demonstration model, this strategy may be ready for rethinking.

The simplest holes in a model, see for instance the first picture in figure 4, are represented with cylinder surfaces and typically a hole is represented by two such surfaces forming a complete cylindrical piece. The cylinder in the picture is also split symmetrically to the shown split. Most probably, this cylinder split does not fit the needs of an isogeometric model, see the second picture in figure 4. Here the face boundaries of the CAD model are superimposed on the block structured model. Thus, the remodelling algorithm needs to recognize the situation and move the split. This is, to some extent, being done, but the launching of this modification functionality requires smoothness between the initial surfaces and a consistent configuration of the surfaces when all trimming information is removed. Can this functionality be extended to be used in the remodelling of the demonstration model?

3.2 The planned structure of the isogeometric model

Figure 5 illustrates the planned block structured volume model. The blue curves are the boundary curves of the planar surfaces on the top and the bottom of the model and the boundary curves of the faces representing the bottom of the indentations. The various features must be isolated from each other. This is illustrated by the black lines bounding surfaces in the interior of the model representing block boundaries. Note that in the true model, these curves will not be linear. The model has blends around the top planar surface. They will lead to curved curves, but are removed in the current abstraction.

The inner trimming loops in the two planar surfaces connected to the cylinder surfaces are split in order to create 4-sided surfaces close to these holes.

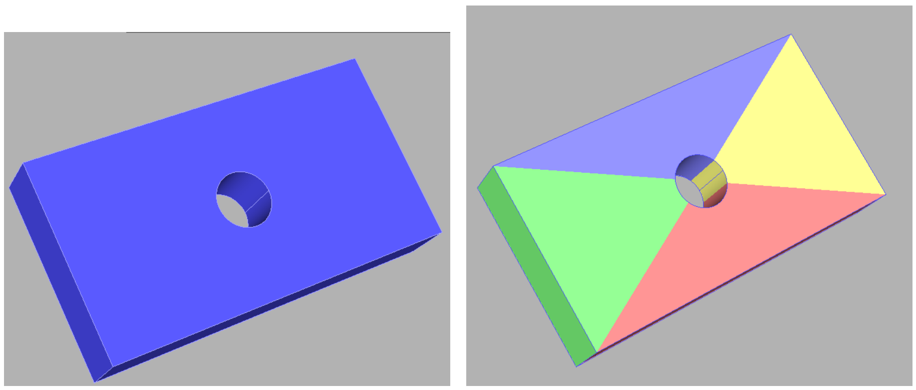

Figure 4: Block structuring around a hole

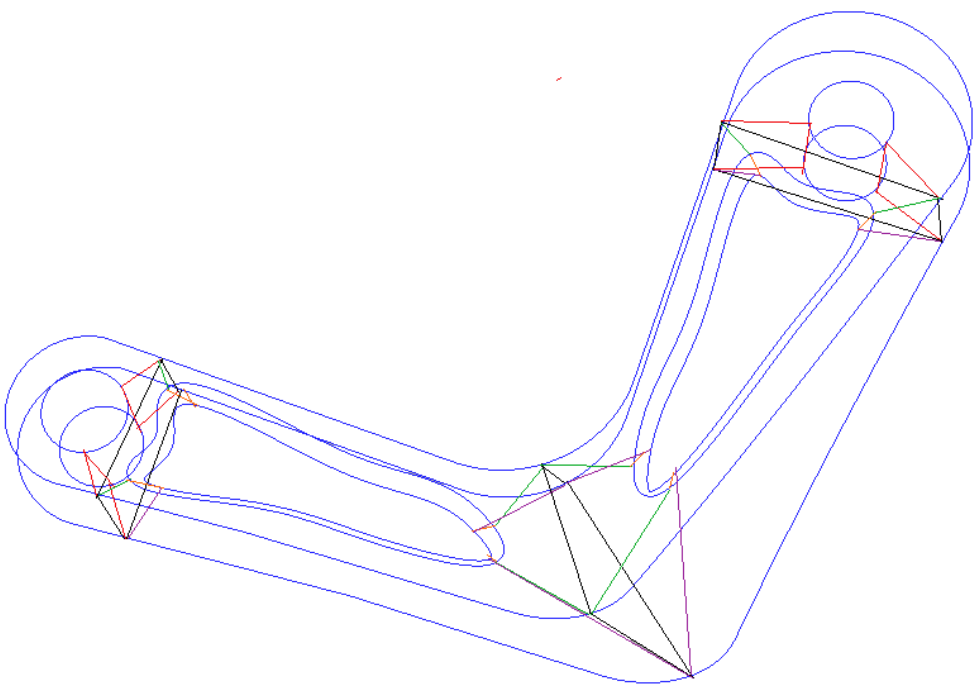

Figure 5: Sketch of wire frame of block structured volume model

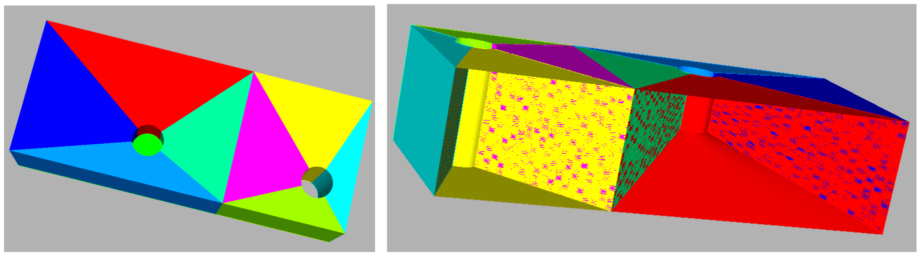

Figure 6: Model with one hole and one indentation. Block structure.

This is illustrated by red lines and these lines are connected along the cylinder surfaces in the hole. Combining red and black boundary curves, we can imagine inner splitting surfaces in the volume resolving the situation around the holes and defining volume blocks in these areas.

Similarly, a splitting of the top surface is performed towards the holes representing the indentation (green lines) and these splitting curves are continued in the side surfaces of the indentation (orange lines). The bottom surfaces of the indentation which have smooth boundaries are by this split equipped with 4 boundary curves, and can be side surfaces in volume blocks.

Finally, we can add wires (violet) going from the vertices of the bottom surfaces in the indentation to vertices in the bottom plane where the first splitting surfaces (black) are intersecting the boundaries of the initial planar surface. New splitting surfaces are now made up of the blue boundary curves of the bottom surfaces in the indentation and the black and violet wires. The imagined block structure is similar to the one that can be found in figure 6 where the model is opened up on one side in the second picture. In the demonstration case, the geometry of the blocks is more complex.

Will we be able to create an isogeometric model with the prescribed structure? We computed a block structured version of the upper planar surface to resolve inner trimming related to holes and indentations. The result is shown in figure 7. The positions of the attachment points of the split curves to the trimming curves related to the indentation could be improved. Otherwise, the result is quite close to the goal except for an extra split from the outer boundary towards one of the circular holes. It is indicated by a cross in the figure. Such a split will not mess up the structure, it will only lead to an additional block, but why does it appear?

3.3 Model quality

We applied a number of tools for testing CAD model quality to the demonstration model. These tools are described in section 5. The intention was to identify eventual gaps and kinks in the model, both between faces and between edges in the model. Figure 8 shows tangential discontinuities in the model where the tolerance is set to 3 degrees, i.e., smaller discontinuities will not be visible. We

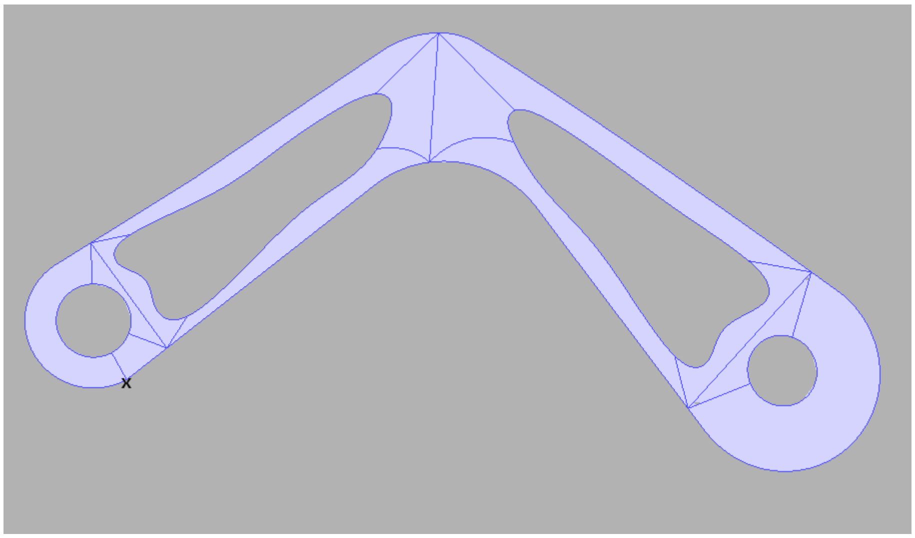

Figure 7: Block structure corresponding to the top planar surface

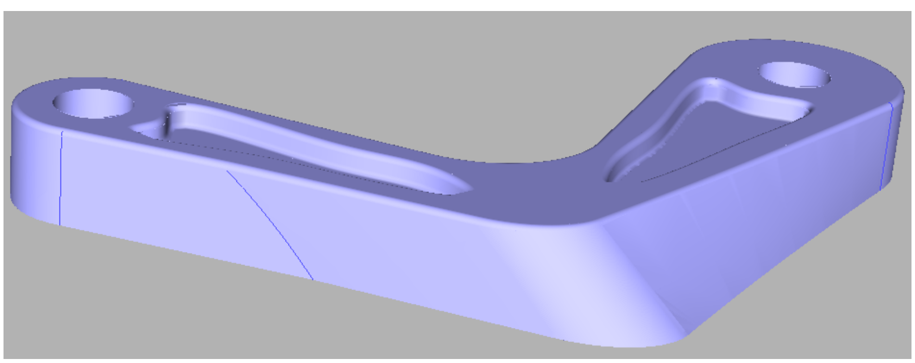

Figure 8: Tangential discontinuities in the model

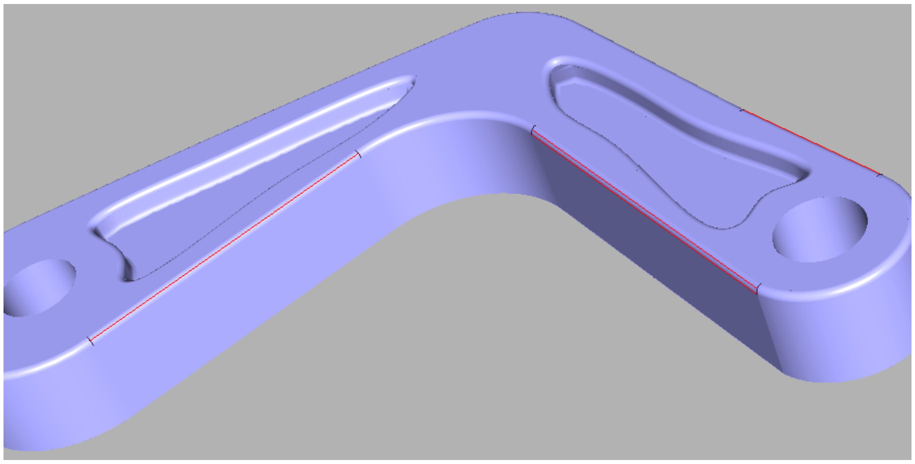

Figure 9: Positional discontinuities in the model

can see that there is a kink in the model meeting the top surface at the unexpected split. Further investigations reveal that the size of the discontinuity is about 10 degrees. This may be intentional and will, as already mentioned, lead to another block in the model. More questionable is the skewed edge in the middle of the picture. It represents the common edge between a planar surface and a trimmed B-spline surface. The tangential discontinuity here is about 4 degrees and a split according to this edge will lead to several new blocks and the structure of the model must be reconsidered. Using a smaller tolerance for tangential discontinuity reveals issues in the blend areas, in particular related to the indentations.

Figure 9 shows gaps related to the outer blend area in the model. The red curves illustrates gaps that are computed with a small tolerance which is still a larger tolerance than the model tolerance given in the STEP file. The size of the gaps indicates, however, that they should not create any problems for the computation. Worse, however, are the black curves close to the red ones. These gaps are larger than 0.005 while the total model size is less than 1.

Figure 10 shows gaps between adjacent trimming curves. They appear in the same area as a tangential discontinuity between faces and also positional discontinuities of various magnitudes, see figure 11. The analysis of one particular trimming curve in this area reveals a situation where a cylinder surface is trimmed by a circle, but the axes of the cylinder and the circle are not parallel. The angle between them is about 4 degrees. Clearly, the circle can still approximate the cylinder within a given tolerance if the tolerance is large enough, but the state of the model still provides a difficult ground for subsequent operations. Figure 12 zooms in on a detail in the same area. 4 surface patches meet in a fuzzy corner. This configuration also creates problems for the processing of the model.

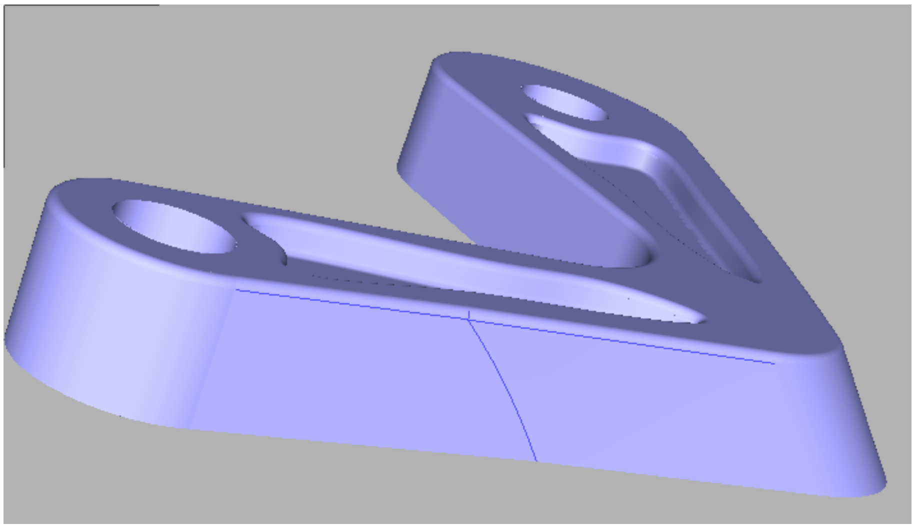

Figure 10: Gaps between edges in the model

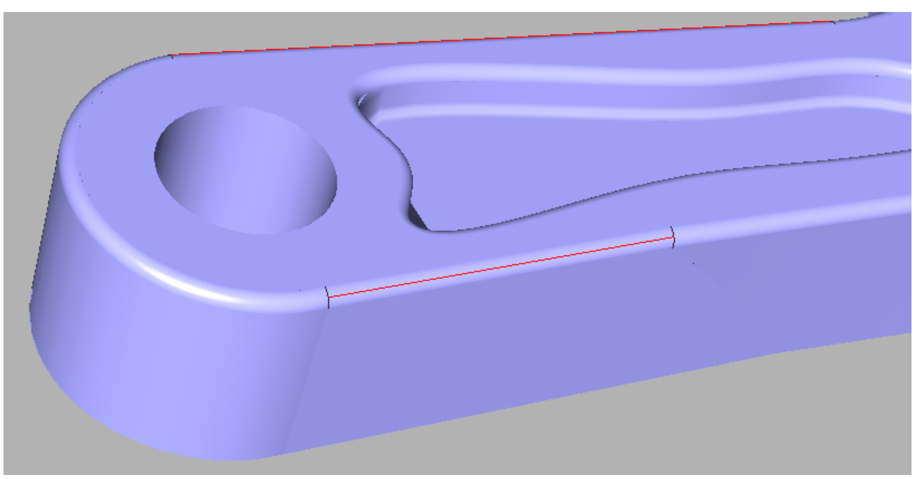

Figure 11: More positional discontinuities

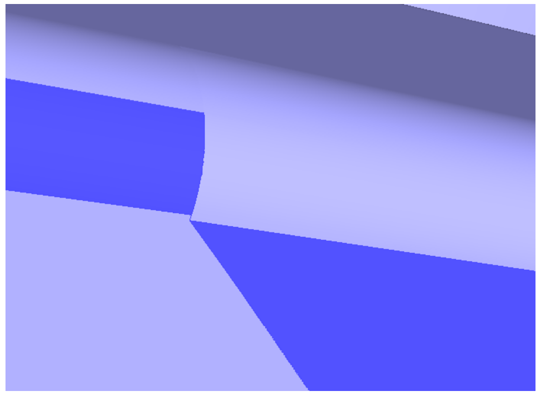

Figure 12: Joint between faces in the area of the outer blend

3.4 Strategy for continued remodelling

The analysis of the proposed demonstration case shows a model with poor accuracy, inappropriate surface structure and some complex features that are not needed for the purpose of the demonstration. The strategy for dealing with this case and similar cases needs to be divided according to the time frame:

Short run. Simplify the model and try to improve it in problem areas. Reintroduce complexities when possible.

Medium run. Introduce LR splines and use this concept to merge small surface patches into larger entities and at the same time improve the continuity of the model. The format is described in section 4. One open issue here is the level of automation for selecting surfaces for merging.

Long run. Improve the robustness of the algorithm considering the intention of the model more than the actual realization. A solid, also a boundary represented one, is by definition continuous. An edge bounding two faces is defined to lie on both faces even if the accuracy is poor. An edge loop is intended to be continuous. Model repair is also a relevant issue in the long run.

The short run strategy will be applied for the demonstration case. This suggestion has already led to the creation of simpler representations of the model by Siemens. In addition, the initial model will also serve as a test case for the use of LR B-spline surfaces for model improvement. The long run strategy is not expected to be addressed during the TERRIFIC project.

4 LR splines

B-spline surfaces are well suited to compactly represent large smooth areas. However, if the shape is mainly smooth, but with localized areas of higher

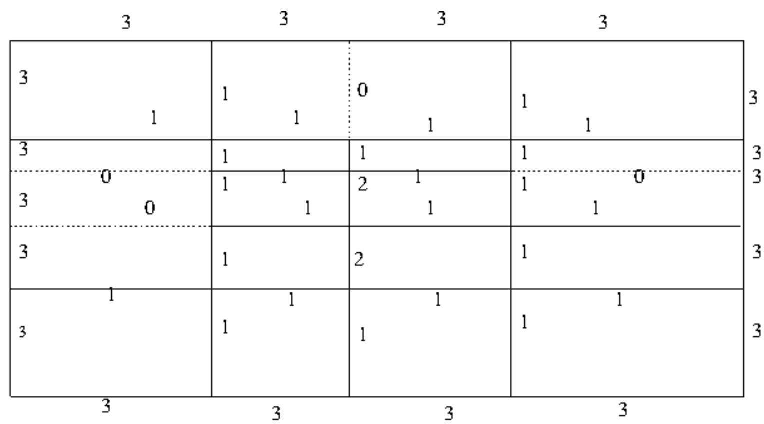

Figure 13: The parameter domain of an LR B-spline surface is represented as a regular mesh where the knot lines can have varying multiplicity. The numbers shows the multiplicity of each knot. This mesh corresponds to a quadratic surface.

complexity, the data size of a B-spline surface tends to be high. It is not possible to insert data locally into a B-spline surface and the same applies to B-spline volumes. Knot lines are global for a surface or volume and in an isogeometric block structured context where we demand corresponding spline spaces at the interface between blocks, the knot lines become global for the entire model.

LR B-splines, or locally refined splines, are B-spline surfaces and volumes with the ability of local refinement, both with respect to local knot insertion and local degree elevation. The concept is defined in [1]. LR B-splines are well adapted to model shapes where the level of complexity varies throughout the object. The format also provides the possibility of keeping local the additional knot lines introduced to get corresponding spline spaces at block boundaries. So far, the emphasis has been on local knot insertion. Degree elevation has not been prioritized.

An LR B-spline surface is typically created from a B-spline surface by inserting new knot lines. The knot lines can be defined in order to represent details in the model, to refine the surface close to boundaries to enable exact continuity of some degree towards adjacent surfaces, or to allow for adaptive refinement in isogeometric analysis. A new knot line is required to split the domain of at least one basis function and all basis functions with a domain being split by this knot line will be split and represented by two new basis functions defined on a reduced domain.

The parameter domain of an LR B-spline surface can be seen as a mesh, and we define knot insertions in this mesh. Figure 13 illustrates the mesh of an LR B-spline surface. It has many similarities to the mesh of a B-spline surface, but the multiplicity of a knot may vary throughout the domain and zero multiplicity is allowed. A knot line that has multiplicity zero for some part of its interval is local.

A basis function of an LR B-spline surface is composed of two univariate B-spline basis functions. It is minimal meaning that no basis function with a smaller domain can be defined on the given knot vectors. However, the domain of the basis function may contain knots only partly defined in this domain. Contrary to B-spline surfaces, the size of the domains over which the basis functions are defined, will vary, and the number of basis functions defined over each element varies. An element is defined as the area between two consecutive non-zero knot lines in each parameter direction. One new knot insertion may give rise to the split of several LR B-splines due to partial knot lines in the LR B-spline domains.

LR B-splines have the following properties:

- The have their domains in R^d where $d \geq 2$
- New B-splines are created by refining existing B-splines
- Nested spline spaces are guaranteed
- Partition of unity is ensured by scaling the basis functions
- An LR B-spline surface or volume is contained in the convex hull defined by its coefficients
- Linear independence of the B-splines is not guaranteed by default. It is ensured by
  - Restricted freedom in how to choose new knot lines
  - If there is no possibility for linear dependent B-splines in an element or along a knot interval. This check is made by the so called peeling algorithm which counts the number of basis functions that can possibly be included in a linear dependency relationship.
  - If the dimension of the spline space is equal to the number of basis functions

  Thus, in general it is required to test for linear independence of basis functions and take action if this is not the case. The action can be to remove the last knot insertion or extend it appropriately to resolve the situation.

Figure 14 shows one LR B-spline surface with details that can be represented due to the ability of local refinement and one surface with a feature that is diagonal to the parameter directions of the surface. The representation of this hill requires a high degree of knot insertion along the diagonal.

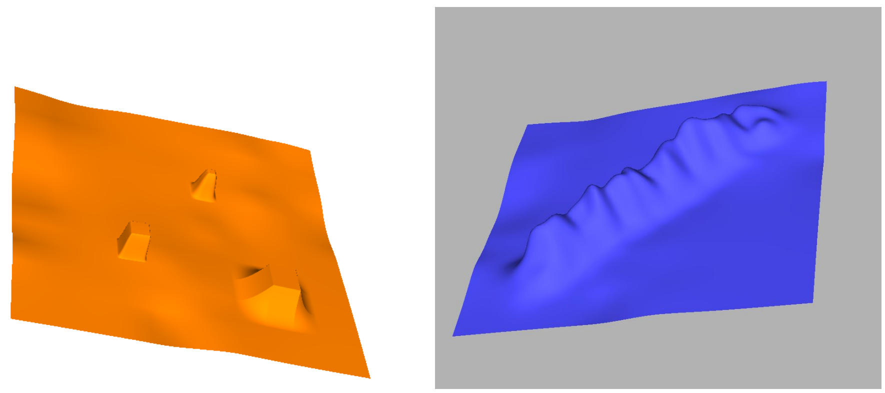

Figure 14: LR B-spline surfaces

4.1 LR B-splines in GoTools

LR B-spline surfaces are integrated in GoTools as a sub class of the entity parametric surface. This choice makes a number of operations defined for parametric surfaces, for instance closest point iterations, available automatically.

Defining LR B-spline surfaces as parametric surfaces requires a number of defined interface functions to be implemented. Then, the surfaces can be included in a surface set and be used in combination with other surfaces. This is, for instance, useful if one wants to automatically create an isogeometric model from a boundary represented solid initially defined by a CAD model. By replacing some of the initial surfaces by LR B-spline surfaces and merging small surface patches into larger ones, we get a superior start point for the remodelling task. Note, however, that some functionality requires spline surfaces. This is, in particular, the case for SISL intersections.

Among the functionality provided by GoTools LR spline surfaces are included:

- Refinement. Insert one new knot line or a number of knot lines simultaneously
- Evaluation
- Iterate through all elements or basis functions
- Pick boundary curves and boundary loops
- Fetch a sub surface
- Expand the LR B-spline surface to a full tensor product spline surface
- Visualization
- Compute bounding box

- Closest point

Tests for linear independence of the spline set will be added within a short time frame. Plans exist to extend the format with LR B-spline volumes.

5 Tools for quality testing of CAD models

The analysis performed on the demonstration model made use of a GoTools module with a set of tools to check the quality of CAD models. The tests make use of the tolerances associated with a surface model, i.e.,

gap CAD models are seen as continuous if they are continuous within this tolerance. If the distance between two points is less than this tolerance, they are viewed as identical. A reasonable tolerance lies in the interval $[1.0e^{-6}, 1.0e^{-2}]$, but should depend on the expected quality of a model.

neighbour This tolerance is used in adjacency analysis and it represents the maximum distance between neighbouring surfaces or curves. If two curves or surfaces lie more distant than this tolerance, the entities are found not to be adjacent. The neighbour tolerance should be larger than the gap tolerance. If nothing specific is known, a factor of 10 makes sense, but if the gap tolerance is really small, a larger factor should be used. Surfaces that lie closer to each other than the neighbouring tolerance are found to be adjacent, but if the distance between the surfaces somewhere is larger than the gap tolerance, the surface set contains gaps. This is an error in the model.

bend If two surfaces meet along a common boundary and corresponding surface normals form an angle which is larger than this tolerance, it is assumed that there is an intended sharp edge between the surfaces.

kink If two adjacent curves or surfaces meet with an angle less than this tolerance, they are seen as G^1 continuous. It the angle is larger than this tolerance, but less than the bend tolerance, the intended G^1 continuity is broken and this is an error in the model. The tolerance depends on the continuity requirements of the application. One suggestion is $1.0e^{-2}$. The bend tolerance must be larger than the kink tolerance, for instance by a factor of 10. Both angular tolerances are given in radians.

The available quality tests can be classified as follows:

Face continuity Checks for continuity between faces in a surface model. Positional and tangential discontinuities with respect to the gap and the kink tolerance, respectively, are returned. Discontinuities larger than the neighbour tolerance or bend tolerance are assumed to be intentional, and thus no error is reported.

Edge continuity Checks for positional and tangential discontinuity between edges in the model. The same tolerances are used as for face continuity.

Accuracy of bounding entities Whether or not the distance between an edge and its associated face, a vertex and its associated edges and a vertex and its associated faces is less than the gap tolerance.

Acute angles Check for acute angles between adjacent faces or edges. The kink tolerance is applied.

Degeneracies Identify surfaces with boundary curves degenerating to a point and surfaces with degenerate corners. Identify vanishing surface normals and curve tangents, intersections between boundary loops belonging to a trimmed surface and self intersections of boundary loops. The gap tolerance is used in the intersection and self intersection tests while the neighbour and kink tolerance is used in degeneracy tests. The gap tolerance is used in tests for vanishing tangents and normals.

Small entities Identify small edges, small faces, sliver surfaces, and narrow regions in faces. The narrow region test relates to the neighbour tolerance while the other tests use specific tolerances.

Consistency of orientation Check for consistency in loops, i.e., the curves defining the loop are head to tail oriented, or in surface models. For closed face sets, all surface normals should point out of the model or into it, preferably out. Also open face sets should have consistent surface normal directions at face boundaries. However, the face orientation test is currently not up to date and the result can unfortunately not be trusted.

Identical entities Check for identity of vertices, and identical or embedded faces or edges. The neighbourhood tolerance is used.

Spline entity testing Check spline curves and surfaces for G^1 and C^1 discontinuities. The test is localized to knots of high multiplicity. The gap and the kink tolerances are used for these tests. Check also for spline entities with close, but not identical knots. Such entities can create problems for certain operations. A specific tolerance is used in this test.

Curvature information The minimum curvature radius and curvature radii less than a given threshold can be obtained. The test is applied to all curve or surface entities in a model.

The tests described above are localized in the class FaceSetQuality in the GoTools module qualitymodule. The test suite is not implemented during the TERRIFIC project, but the module is now equipped with documentation and some example programs and will become a part of the TERRIFIC tool kit.

6 Conclusion

The current deliverable differs somewhat from the plans made in Month 6. There has been development in the directions indicated by the plan, but we have not

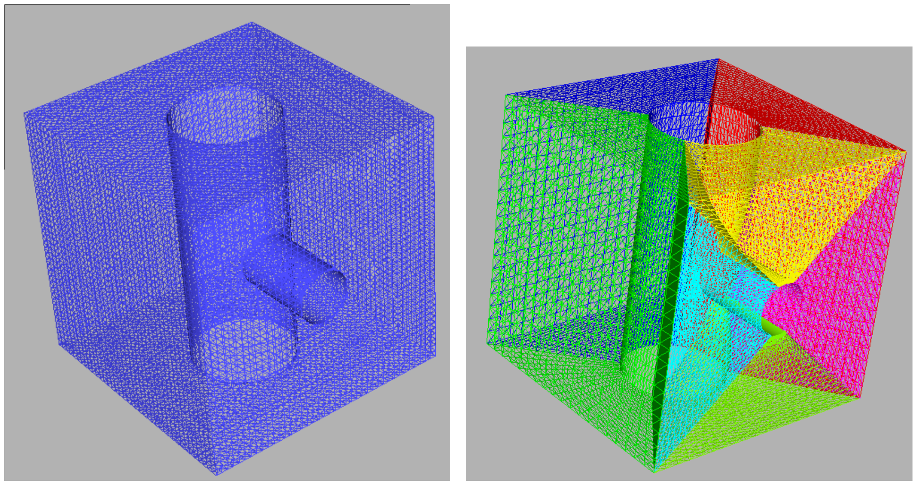

Figure 15: A tube joint internal to a box

reached as far as we had hoped for. However, we will continue the work towards converting gradually more and more complex boundary represented solids into models fit for isogeometric analysis. Figure 15 shows a boundary represented tube joint inside a box and the corresponding isogeometric block structured model. This case has features in more than one direction, but if we imagine an axis in the large cylinder and the use of cylinder coordinates, the structure of the model becomes much simpler.

A prototype STEP writer is implemented, but the plans for Boolean operations on volumes and simple assemblies are currently not pursued.

A module for quality testing of CAD models is added to the toolkit.

The linear elasticity solver from WP2 is a part of the toolkit. WP3 and WP4 have not yet had any planned toolkit deliveries.

7 Plans until Month 24

Work package 6 does not have a toolkit delivery planned for this point in time, but the current work will proceed. The major activity will be the demonstration case. We will start simple and gradually include more complexities. Siemens and WP2 are highly involved in the creation of various versions of the demonstration model. In order to be able to handle non-academic test cases, a good treatment of blends is crucial. Thus, we aim at an automatic translation from a CAD model of the demonstration part to an isogeometric model where blends are included. On the other hand, a simpler patch structure and better model quality are preferable. It is not realistic to expect to be able to convert all CAD models to isogeometric block structured models regardless of the properties of the initial CAD model. We will continue to focus on analysis friendly models, but need to put some effort into the definition of that term. We have to face that models are created in CAD systems, but it is also clear that these systems possess some flexibility with regard to the structure of the model created. These considerations touch the work the University of Pavia and Alenia have done in WP3 and we will seek to exploit this synergy.

The work with LR B-splines will be continued. The aim is to make this format an integral part of the creation of isogeometric models. We want to merge small surface patches in the CAD model into larger LR spline surfaces. This relates well to subject 1 in WP4 and the similarity of these two activities calls for a collaboration. We will also extend the set of analysis tools using the LR B-spline format.

WP5 will continue the work on extending the STEP format to provide formats for transfer of isogeometric models and analysis results, and LR spline surfaces and volumes. Results from this work will trigger work on a STEP writer for isogeometric models in WP6.

The work packages WP1 to WP4 have planned the following toolkit contributions in this period:

WP2 Solver for nonlinear elasticity

WP2 Sensitivity computations

WP3 Solver for 3D linear elasticity

WP3 Solver for 3D Navier Stokes

WP4 Transform a collection of trimmed patches to one non-trimmed patch, 2D version

WP4 Compute silhouette curves

WP4 Define regions from silhouette curves

References

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