Deliverable D6.4 of Task 6.1

First Report on synergies and isogeometric Toolkit

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Executive Summary

This document contains deliverable D6.4 of the TERRIFIC FoF STREP Project, and describes the cooperation between the partners, the partner contributions to the toolkits and the synergies achieved in the project by the end of the first project year.

Contents

1. Introduction

The deployment of Isogeometric Analysis (IGA) in industry depends on IGA software modules becoming available that cover a wide range of necessary functionalities. In TERRIFIC such software is assembled in the Isogeometric Toolkit.

Some TERRIFIC partners have a long tradition of disseminating research results in Open Source Libraries:

- INRIA with axel - algebraic geometric modeling - http://axel.inria.fr/
- SINTEF with GOTools http://www.sintef.no/Projectweb/Geometry-Toolkits/GoTools/ and SISL - http://www.sintef.no/Projectweb/Geometry-Toolkits/SISL/.

The first Isogeometric Toolkit was assembled in the EU-funded EXCITING project (October 2008 - March 2012) http://exciting-project.eu/. This tool started out from the above-listed tools of INRIA and SINTEF, which were extended both in EXCITING and through contributions from national French and Norwegian research projects addressing different aspects of isogeometric analysis and representation. In EXCITING a completely new model tool emerged from the group of TU Munich, namely the isogeometric linear elasticity solver. The work on this module is now continued by TERRIFIC partner UNIKL, made up of the TU Munich group that has moved in the meantime. In TERRIFIC also the commercial code Express Data Manager is included as a profession tool for interfacing to ISO 10303 files.

The above tools constitute the starting point of the TERRIFIC Isogeometric Toolkit, where a first version was described in *D6.1 Initial version of the TERRIFIC Isogeometric Toolkit*, which was ready in March 2012. This early assembly of modules made available to all partners in TERRIFIC has been essential in creating a platform for synergies and cooperation between the partners and work packages in TERRIFIC. The deliverable *D6.2 Detailed plan for tool development and synergies across work packages* was also submitted in March 2012, coordinating the toolkit development across TERRIFIC, and providing plans for the toolkit for months 12, 18 and 33.

As cooperation between partners is essential for establishing the envisaged extensive toolkit, this report now addresses at month 12

- The cooperation between the partners and between the work packages
- The status of the Toolkit development.

2. Cooperation in TERRIFIC

TERRIFIC is organized in five clusters, each pairing an industrial company with a research institute or university, where four of the five clusters target a specific work package.

- Austrian Cluster(WP1) ECS and JKU, with some contributions from SIEMENS
- German Cluster (WP2) SIEMENS and UNIKL, with some contributions from JKU
- Italian Cluster (WP3) ALENIA and UNIPV
- French Cluster (WP4) MISSLER and INRIA
- Norwegian Cluster (WP5, WP6) JOTNE and SINTEF

The closest cooperation happens of course within the different work packages.

Cooperation within work packages

Work package	**Description**
WP1 ECS/JKU	There are regular contacts by meeting, e-mail, phone and joint master students, at least bi-weekly. Algorithms are developed by JKU and then transferred to ECS for industrial use and testing.
WP2 SIEMENS/UNIKL	Identification of industrial benchmark, discussion about properties and specification of specific test cases (see D2.2) Discussions about general solver development, Algorithm and Software development, solver interface specifications (e.g. TRILINOS).
WP3 ALENIA/UNIPV	There are regular contacts by meeting, e-mail, and phone, at least bi-weekly. ALENIA have provided CAD-models for agreed tests, UNIPV have modified the data into a suitable isogeometric format, in an iterative loop and cooperation.
WP4 MISSLER/INRIA	There are regular contacts by meeting , web-meeting, e-mail, and phone, when necessary. Algorithms are under development by INRIA from specifications and CAD-models provided by MISSLER for initial tests. The very good contacts between the parties are a key issue towards the success of WP4 in a very demanding production environment. The partners expect to see good results during the second part of Year 2 when extensive testing will take place from industrial cases.
WP5 JOTNE/SINTEF	There are regular contacts by meeting, e-mail and phone, with joint participation in the ISO-meetings concerning standardization and STEP-translator to GoTools. Cooperation with industrial partners to define validation plan.
WP6 SINTEF	SINTEF has made available to TERRIFIC the pre-existing software libraries GoTools and SISL as background information. The GoTools version for TERRIFIC will be updated at regular intervals, and we expect also future GoTools developments from other projects to be added to the Toolkit.
WP7 SINTEF, MISSLER, INRIA, JOTNE	The project web site has been set up by INRIA in cooperation with SINTEF, and the contents filled in mostly by SINTEF. A press release and a one-page flyer were developed in cooperation between MISSLER, JOTNE and SINTEF. The relations to IMS[2] are coordinated by SINTEF and JOTNE, with SINTEF participating in the IMS meeting in September 2011 in Barcelona, and JOTNE participating in IMS and ISO-meetings.

[2] Intelligent Manufacturing Systems, http://www.ims.org/

An overview of the cooperation between the different work packages is provided by Figure 1. There is established cooperation between three of the four application-oriented work packages, namely WPs 1, 2 & 3. WP4 is positioned somewhat aside, however, it is closer to manufacturing and immediate industrial use than the other WPs. Anyway, WP4 is also a heavy contributor to the isogeometric toolkit, so that their results are easily accessible for the other partners.

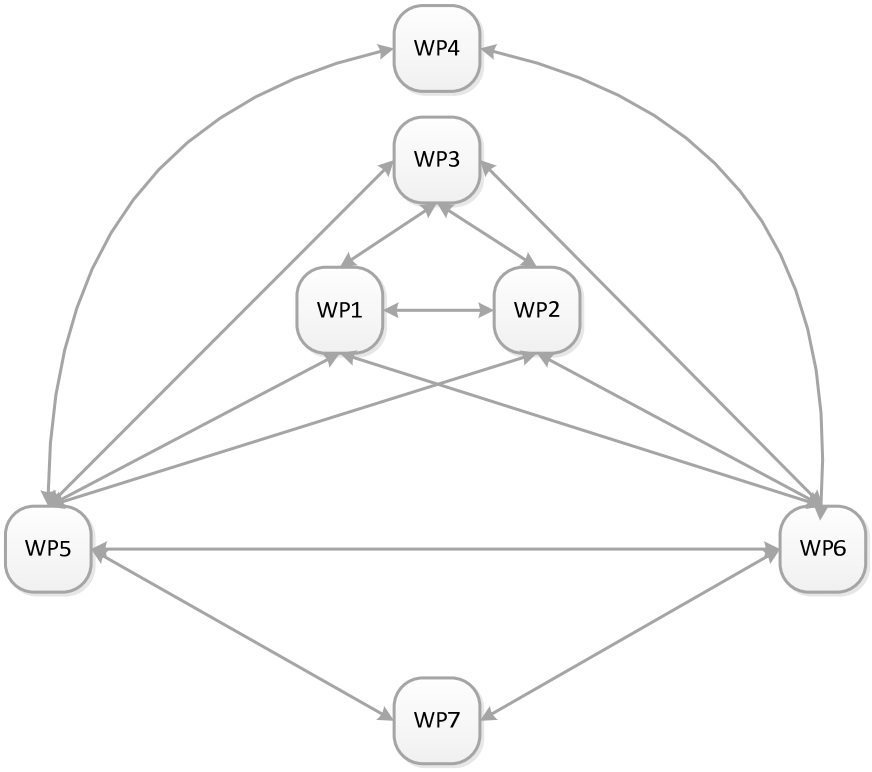

Figure 1. Cooperation between work packages. Note that most work packages cooperate with the other work packages. Among the four application-oriented work packages only WP4 is not integrated in a closer cooperation.

Cooperation as seen from WP1

Cooperation with	Title	Description of Cooperation
WP2	Integrating design optimization results	JKU cooperates with SIEMENS on issues related to the integration of design optimization results (which were obtained by traditional FEM-based numerical simulation techniques) into existing CAD data, using capabilities provided by the Isogeometric Toolbox (WP6).
WP2	Hierarchial spline methods in IGA	JKU cooperates with UNIKL on the use of hierarchical splines and adaptive methods in isogeometric analysis.
WP6	Contribution of modules for toolbox	WP1 contributed modules for feature detection and edge graph creation to the isogeometric toolbox.

Cooperation as seen from WP2

Cooperation with	Title	Description of Cooperation
WP3	Information and experience exchange	Exchanges about experiences with isogeometric simulation and the usage of GoTools in this context
WP6	Contributions to GoTools	Feedback on GoTools "Isogeometric Model", feature suggestions, testing and bug reports. The "Isogeometric Model" is incorporated into the structural solver to support multipatch models.

Cooperation as seen from WP3

Cooperation with	Title	Description of Cooperation
WP2	Implementation of GoTools in Scientific Computing	During the first weeks of the project, Dr. Anh-Vu Vuong from work package 2 was invited for a visit to the Department of Mathematics of the University of Pavia and to the CNR-IMATI E. Magenes center. During this period of interaction we exchanged information on how to implement scientific computing issues using GoTools. In particular focusing on Galerkin projection methods, we discussed how to use GoTools to evaluate isogeometric basis functions for a chosen solution space. There are regular contacts related to issues described above.
WP6	Cooperation with GoTools	We contributed with bug reports to the development of GoTools.

Cooperation as seen from WP4

Cooperation with	Title	Description of Cooperation
WP6	Contribution to Isogeometric Toolkit	Contribution to Isogeometric Toolkit: The "parametrization" package developed by INRIA provides a set of tools for the parametrization of computational domains that can be used in isogeometric applications and for the control of machining tools. It is depending on GoTools for the computation of B-splines. A plugin for INRIA's Axel has been developed.

Cooperation as seen from WP5

Cooperation with	Title	Description of Cooperation
WP6	Initiate extensions to ISO 10303	Several meetings have been held by WP5 and WP6 representatives, both project internal and with the ISO committee TC 184/SC 4 to identify the need for isogeometry-related extensions to existing standards. It has been concluded that both ISO 10303-42 and ISO 10303-209 need to be extended to support isogeometric content, such as LR-splines and non-manifold aggregations of volumes.

WP4 - WP6	Workshop on Industry Challenges in Geometric Modeling, CAD and Simulation	Members from WP4, WP5 and WP6 took part in and gave presentations at the annual industry workshop co-organized by SINTEF, Technische Universität Darmstadt, and Fraunhofer IGD Darmstadt, held on March 22&23, 2012 in Darmstadt, with an audience of about 25 people.
All WPs	Preparation of D5.1	WP5 interacted with all four industry case work packages and project management in preparation of D5.1, "Definition of the industrial use cases and scenarios". Descriptions of the industry cases in D1.1 through D4.1 were jointly tailored and harmonized for use in the public presentation contained in D5.1.
All WPs	Preparation of D5.2	WP5 interacted with the four industry case work packages and with project management on preparation of D5.2, "Detailed plan of the validation process". In cooperation with WP2 and WP7, a questionnaire on product usefulness was designed. Subsequently WP1 through WP4 filled in this questionnaire, thus describing their expectations concerning the usefulness of the industry case innovations. Based on these replies, an innovation validation scheme was derived. 15 key performance indicators have been identified.

Cooperation as seen from WP6

Cooperation with	Title	Description of Cooperation
WP1	Modules for feature detection	WP1 contributed modules for feature detection and edge graph creation to the isogeometric toolbox.
WP2	The GoTools module isogeometric_model	This module offers an interface between a block structured geometry model fit for isogeometric analysis and the analysis itself. A 2D version of this interface was implemented prior to TERRIFIC, but not taken into use or tested within an application. WP2 has tested this interface and suggested some improvement, which is now implemented. A 3D version of the interface is currently under implementation.
WP2	Models for isogeometric analysis	SIEMENS has constructed a number of CAD models that can serve as test cases for the translation into trivariate, block structured models fit for isogeometric analysis. This model translation is a main activity within WP6. A couple of versions of the model to be simulated in WP2 have also been delivered to WP6 for an initial assessment.
WP3	Model for isogeometric analysis	An initial model and information about the preferred isogeometric model have been sent from WP2 to WP6. This input will serve as a specification for a modelling tool in the isogeometric toolkit.

WP5	STEP relations	The STEP reader in GoTools relates to Part 42 of STEP and some of its extensions. It uses JOTNE's tool EDM as an interface to the STEP file. JOTNE has recently developed a new interface to EDM (prerelease), and GoTools is being updated to use this new interface. The STEP reader is currently being updated to take advantage of that. Simultaneously, the GoTools data structures and data types for curves and surfaces are extended to be able to make use of more of the information in the STEP file. In particular this implies that information related to elementary curves and surfaces is being used in the construction of models suitable for isogeometric analysis. The STEP reader should currently be used for models with one solid only. The geometry will be read even if a file contains several solids, but the topology information will not necessarily be transferred to GoTools. This restriction will be removed during TERRIFIC.
WP5	Extensions to STEP Part 42	Part 42 is currently not able to store a multi block trivariate model with adjacency information. This issue has been brought up at an ISO/TC meeting in Stockholm and various extensions to the standard have been discussed. The feedback so far is positive.
Contribution to Isogeometric Toolkit	GoTools and SISL	SINTEF has made available to TERRIFIC the pre-existing software libraries GoTools and SISL as background information. The GoTools versions will be updated at regular intervals, and we expect also future GoTools developments from other projects to be added to the Toolkit.
Contribution to Isogeometric Toolkit	Visualization, modeling and computation with Axel	INRIA’s Axel is a geometric modeler which embeds dedicated representations and computational tools through a mechanism of plugins. Plugins based on GoTools, the parametrization package and the subdivision solvers package have been developed.

3. Status of the Toolkit development at Month 12

A toolkit server has been established at partner INRIA and all partners have access to it for downloading tools or uploading contributions. From early on in TERRIFIC, the tools AXEL, GoTools and SISL were available on this server.

It is still too early to expect modules from WP1-WP4 to be integrated into the Toolkit. However, a module from WP1 addressing feature detection and edge graph creation was uploaded to the server in Month 6 (March 2012), and a solver for linear elasticity is planned from WP2 August 2012, and will soon be uploaded.

Consequently, in the first project year, the toolkit work has been focused on helping other partners to use the existing Toolkit and on planning developments for the Toolkit adjusted to the actual needs in the application work packages. A table addressing the cooperation in these aspects has been added at the end of this section.

The following seven actions were identified for WP6 in month 12 in the initial specification document D6.2. Action 3 has not been pursued as a higher prioritized Action 8 has been introduced.

Action 1: Convert simple boundary represented models

Goal: 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.

Status: A prototype exists. It is rule based and handles many configurations. However, in some cases the rules do not fit well to the configuration and the functionality must be improved to handle these cases. The functionality will be continuously extended and improved throughout the project.

Action 2: Augmented analytic representation

Goal: Integrate and make use of information coming from analytic curves and surfaces.

Status: This task depends on Action 6. Information coming from analytic curves and surfaces is integrated and made use of in Action 4. An extended use of this information is possible and should be pursued.

Action 3: Local coordinate system

Goal: Use plane normal and cylinder axis information to define parts of a local coordinate system of a volume model.

Status: This action has not been pursued as other actions have had higher priority.

Action 4: Recognize rotational sweeps

Goal: 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. Perform sweeping.

Status: Prototype implementations for recognition of linear and rotational cases and subsequent sweep exist. The functionality depends on Action 6 and may change due to changes in the STEP converter. The functionality from Action 1 is used, thus changes here will influence the sweep result. Information from analytic curves and surfaces is used to recognize a sweep situation. Tori and surfaces of revolution are not yet included in the framework, but

this requires only a small extension. The treatment of rotational models where the rotation is less than 2π is not yet complete.

Action 5: Convert to non-trimmed NURBS

Goal: 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.

Status: A prototype implementation exists handling a number of configurations, but many configurations are still not handled. The status is approximately as expected when the goal was formulated.

Action 6: Update STEP reader

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

Status: A prototype implementation exists and is used in the context of other actions, in particular Action 4. The effort will now be directed towards stabilization and handling of data sets from different sources as they can possess different characteristics.

Action 7: Outer boundary

Goal: 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.

Status: Once a volume model is created, for instance by Action 4 or 5, the boundary surfaces can be fetched and represented as a surface model. This surface model corresponds to a boundary represented solid.

Action 8: Additional functionality – Isogeometric surface and volume model

The GoTools module isogeometric_model is intended as an interface between a multi block model intended for isogeometric analysis and the analysis itself. The surface case was implemented prior to TERRIFIC and has been tested by WP2 in this period. Some extensions to the isogeometric surface model have been implemented to meet requests from WP2. Furthermore, a somewhat restricted volumetric version of this interface has been implemented and local testing has been performed. The volumetric interface is not yet tested within an application.

Work package	**Contribution to Isogeometric Toolkit WP6**
WP1 ECS/JKU	Modules for feature detection and edge graph creation created
WP2 SIEMENS/UNIKL	Feedback on GoTools "Isogeometric Model", feature suggestions, testing and bug reports The "Isogeometric Model" is incorporated into the structural solver to support multi-patch models
WP3 ALENIA/UNIPV	Contributed to the development of GoTools with bug reports
WP4 MISSLER/INRIA	Package for parametrization of computational domains in isogeometry that provides a set of tools for the parametrization of computational domains, which can be used in isogeometric applications and for the control of machining tools. It is dependent on GoTools for the computation on B-splines. A plugin for INRIA's Axel software has been developed.
WP5 JOTNE	Assistance to WP6 on the use of the STEP interface for the Isogeometric Toolkit
WP6 SINTEF	GoTools and SISL SINTEF has made available to TERRIFIC the pre-existing software libraries GoTools and SISL as background information. The GoTools versions will be updated at regular intervals, and we expect also future GoTools developments from other projects to be added to the Toolkit.