Proceedings of TMCE 2012, May 7–11, 2012, Karlsruhe, Germany, Edited by I. Horváth, A. Albers, M. Behrendt and Z. Rusák

MODELING ASPECTS OF HYPER-COMPLEX PRODUCTS IN NUCLEAR ENGINEERING PROJECTS

Alexander Sharmazanashvili
ATLAS Collaboration
European Organization for Nuclear Research
Switzerland
Lasha.Sharmazanashvili@cern.ch

ABSTRACT

Nowadays High-Energy Physics research with it ambitious goals intensify pressure on engineering activity for designing and construction of unique scientific devices. Facilities for the physics experiments become more and more complex and it sets new engineering challenges for their design and construction. These trends to be founded in nowadays several high-energy physics projects - Large Hadron Collider, Geneva, Switzerland; International Thermonuclear Experimental Reactor, Cadarache, France; Facility for Antiproton and Ion Research, Darmstadt, Germany. One of the most complex among of them is the ATLAS experiment, part of Large Hadron Collider project. Science and engineers from several countries are collaborated in ATLAS experiment in order to build world largest and most complex scientific facility – ATLAS detector. ATLAS detector is 46 meter long and 25 meter diameter device situated on 100 meter underground Geneva, Switzerland and weighted 7'000 tones. ATLAS collaboration unifies 169 partners from 37 countries with 2'500 scientists and engineers.

Thus from one side we have special tasks for designing and construction and from other side distributed tasks between big amount of collaborative partners. Paper describes unique methodologies and approaches for creation of geometry model of full detector for the construction life cycle developed by groups of IT and mechanical engineers of ATLAS collaboration. Results of case studies are represented concerning to construction of ATLAS detector at European Organization for Nuclear Research, Geneva, Switzerland.

KEYWORDS

Large Hadron Collider, ATLAS collaboration, Models migration, CATIA Integration, STEP

1. INTRODUCTION

Nuclear Engineering is special field of engineering activity for designing and construction of scientific devices of High Energy Physics (HEP) research and experiments. Nowadays HEP research is going more and more deeper in investigation of principles of the universe - what was happened after the big bang, how matter was created, are there any extra dimensions and microscopic black holes, etc. As a result, facilities for experiments are becoming more and more complex which brings new engineering challenges for their design and construction. There is no similarity with traditional designing and construction approaches and methodologies implementing in auto-motto, aerospace or ship building fields.

Several HEP international projects are going on nowadays in Europe: LHC – Large Hadron Collider, CERN, Geneva, Switzerland; ITER – International Thermonuclear Experimental Reactor, Cadarache, France; FAIR – Facility for Antiproton and Ion Research, Darmstadt, Germany. Largest among of them is LHC. LHC consists of several projects and collaborations for development of 27 km length accelerator machine and associated detectors. ATLAS collaboration is the part of LHC project. The aim of collaboration is to construct, build and maintain most complex scientific facility ATLAS detector. Main peculiarities of design and detector construction life cycles are as follow:

1) *Design Product is Unique*, developing one time for one, very specific purpose. So engineering solutions and methodologies has no inheritance. For instance, all detectors in LHC have magnet system for generation and control of magnetic fields. However, there are no similarities between them from the point of view of assembly structure, part configuration, size or mass properties.

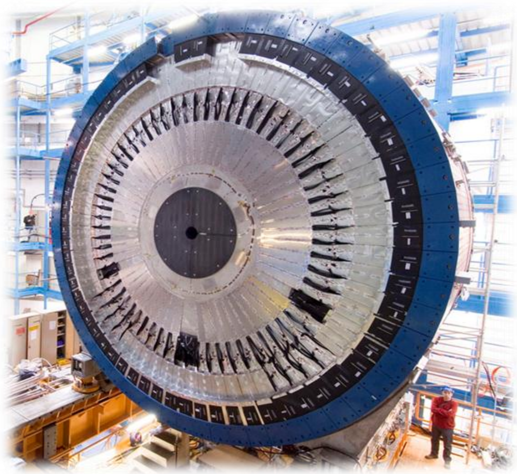


Figure 1 Tile Calorimeter, ATLAS Detector

2) *Large Sizes and Unique Mass Properties of Designs* constrained with strict requirements to maintain high accuracy of machining and assembly. ATLAS detector is 46 meter long and 25 meter diameter device weighted 7'000 tones. One of the sub products of detector is Tile Calorimeter (fig.1) which is 8 meter diameter cylindrical construction consists of 64 separate segments. Each 6 m length and 350 kg weight segment was assembled with 50 micron accuracy.

3) *Complexity of Product.* ATLAS detector model contains more than 3'700 CAD assemblies and ~10Mln parts (fig 2, a). They are integrated in high dense environment. Clearance of integration is 50 mm. All detector components are "wrapped" around with huge amount of services – cables and pipes (fig 2, b). Total length of cables is 3'500 km.

4) *Large scale of Collaborative Partners*. ATLAS collaboration unifies 169 partner institutions from 37 countries with 2'500 scientists and engineers.

Thus, we have unique design with large size and mass properties, complexity and large scale of collaborative partners. So, main difficultness of such kind of design environment is in development of entire geometry model of full detector for the construction life cycle. This stipulates necessity for development of methods and tools for the migration of CAD models and their integration in entire logical structure. Research targets in this case are as follow:

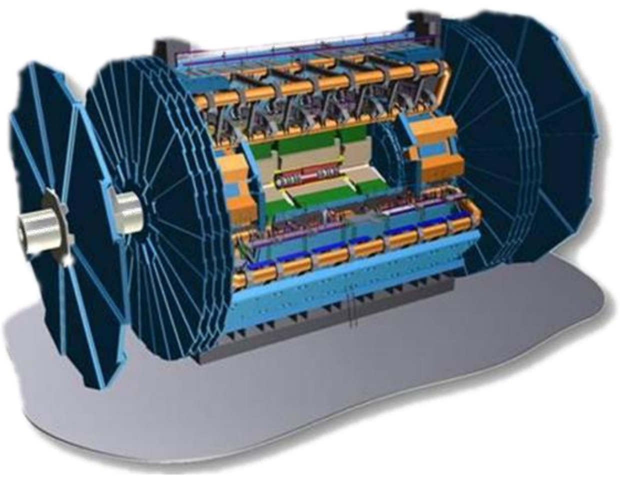
1) Models Transformation – foresee development of methods and tools for the transformation of models from heterogeneous design environment into main platform

2) Validation – foresee development of methods and tools for checking of migrated models on consistency and conformity with source models

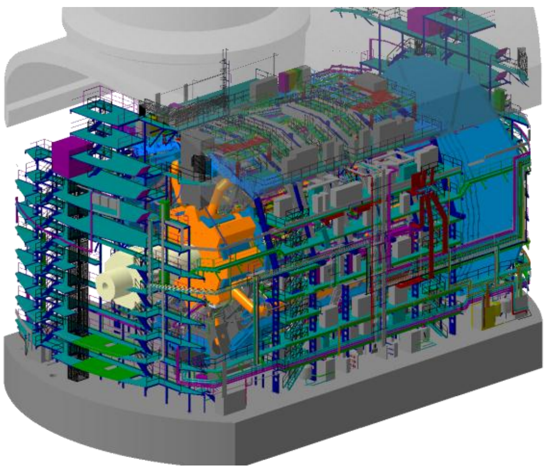
3) Integration – foresee development of methods for the integration conflict checking and models insertion in entire logical structure of detector

Three main groups were collaborated in order to reach the goals of given research topics:

- ATLAS TCn – Technical Coordination team including staff of designers, analysts and integration engineers



a) Detector Components

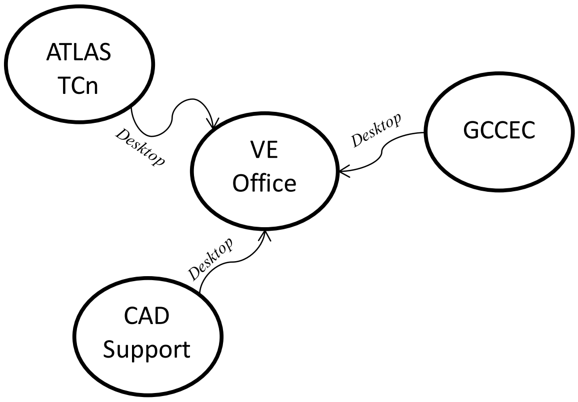


b) Detector Components with Services

Figure 2 ATLAS Detector CAD Models

- CERN CAD Support – providing workability of CAD platforms, databases and developing special utilities for data visualisation, documentation and model migration
- GCCEC – Georgian CADCAM Engineering Center, responsible for the development of entire geometry model of ATLAS detector, integration conflict checking and installation process dynamical modelling.

Special virtual engineering environment has been built. Groups were situated in different sites of CERN, Geneva, Switzerland and Tbilisi, Georgia and collaborated activity in virtual engineering office by sharing of design desktops using Dassault's CATIA V5 platform.



2. MODELS TRANSFORMATION

ATLAS Detector has comparatively simple profiles, mostly lines and arc's but assemblies have enormous complexity. Development of entire geometry model of detector is caring out by large number of partners. So, main issue for the models transformation is ensuring of data centralization and control. For data centralization special PDM systems and servers were implemented built especially at CERN:

- EDMS – Engineering & Equipment Data Management Service based on Oracle database and ensures that engineering and equipment data as well as documentation for projects and installations are safeguarded, organized, verified and remain retrievable on a long-term basis [1]
- CDD – CERN Drawing Directory provides uploading CAD models and related drawings from design office of partner institutions to CERN and creation of references for future retrieval and proceeding [2]. Access into this data provided via a graphical interface based upon Oracle forms and the Web
- DFS – CERN Distributed File System provides the possibility to offer a reliable, redundant and replicated file system that is logically accessible and that is spanning over a large number of independent servers [3].

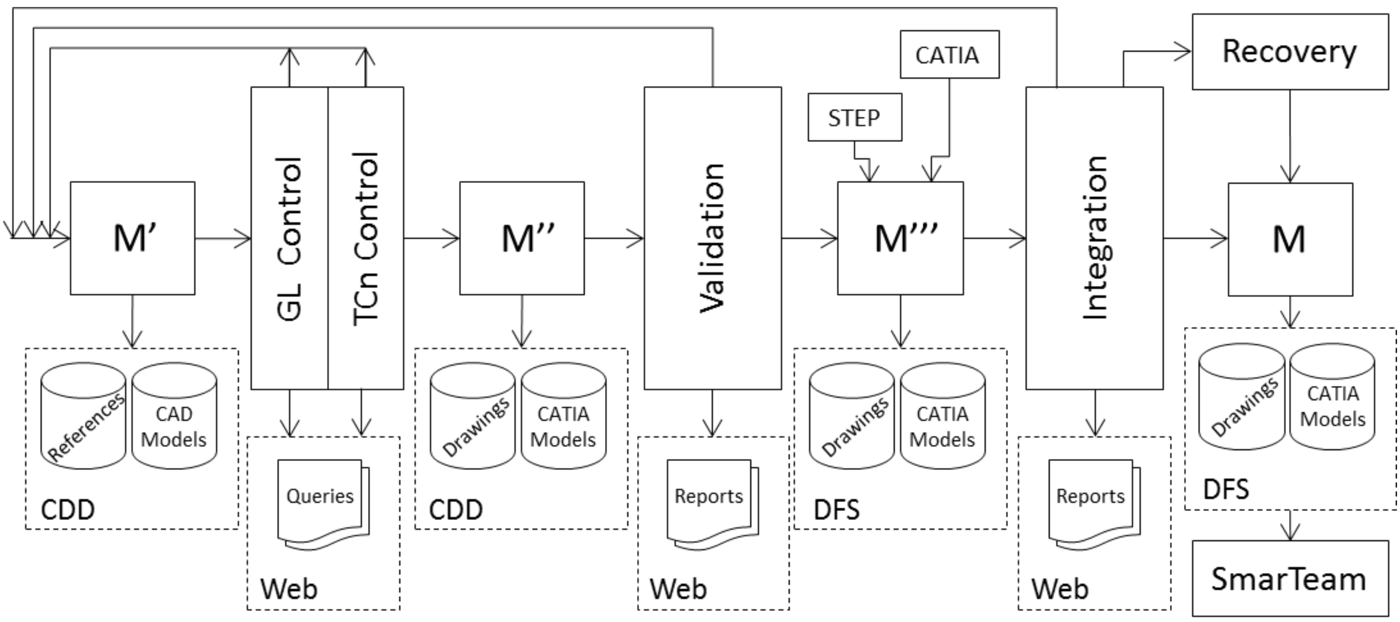


Figure 3 Models migration life-cycle

CAD models migration life cycle [4] developed by GCCEC is presented on fig.3. Globally it is one transaction **Γ:M'→M** with 3 intermediate steps:

$$\Gamma_1\text{:M'}\rightarrow\text{M''}$$
$$\Gamma_2\text{:M''}\rightarrow\text{M'''}$$
$$\Gamma_3\text{:M'''}\rightarrow\text{M} \qquad (1)$$

Where,

M'– Generic heterogeneous model

M'' – Pre-candidate CATIA model

M'''– Candidate CATIA model

M – Final CATIA model

Γ_1 - Migration transaction

Γ_2 - Validation transaction

Γ_3 - Integration transaction

On the *first* stage designers are creating models using one of the available CAD platform. Then via CDD models are uploading on CERN database and corresponding references are creating. Once the model exists in the database it can be modified, controlled, approved, classified and consulted, according to the rules defined for each model using CDD applications.

On the *second* stage designer from home institution sign electronically the last version of model, or a whole set of models and submit it for archiving. Execution of archiving process was responsibility of CAD support team. Once the archival process is over, the model can be visualised but no more modified.

The *last* step of execution of Γ_1 transaction is model approval. Several approvers indicate via CDD Web if they accept or reject submitted model. 1st approvement comes from ATLAS TCn group leader, responsible for the development of corresponding detector component. 2nd approvement is doing by TCn integration team. After checking integrity of model and according to the received comments coming from the 1st step control, TCn integration deciding at the end to accept or to reject the model. After passing the above mentioned 2 control steps, CAD support team was created CATIA pre-candidate models on DFS (M'' on fig.3) containing document types as follow:

M'' =
- 2D drawings
- Facet based models
- Native *without* history
- Native$^+$ *with* history

3. VALIDATION

Purpose of Γ_2 - Validation transaction is checking of M'' set of models by comparison with initial M' set of models and identification of failed models with detailed investigation of geometry faults.

M'' set contains data, converting into CATIA with different methods and tools.

M''/Native are .CATParts built on the base of encapsulated solids. This is partly editable model allows replacement or delete of whole solid in the tree. However, solids itself cannot be modified while never contain sketches and profile descriptions. M''/Native models were generated by standard STEP based tools.

M''/Native$^+$ are .CATParts containing sketch based solids. So, solids are editable and their generation is possible by the convertor software by execution of special feature recognition tasks and interpretation of geometry description tree. Corresponding tool was developed by CERN CAD support team. However, formalization of above mentioned task is very difficult. As a result majority of M''/Native$^+$ models are failed.

M''/Facet are facet based representation of component geometry in CGR format. Generation of

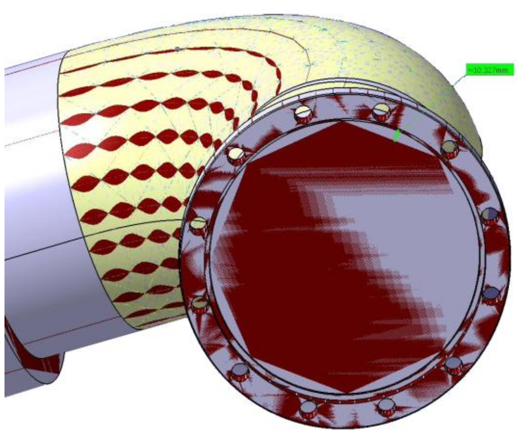


Figure 4 Approximation faults of CGR

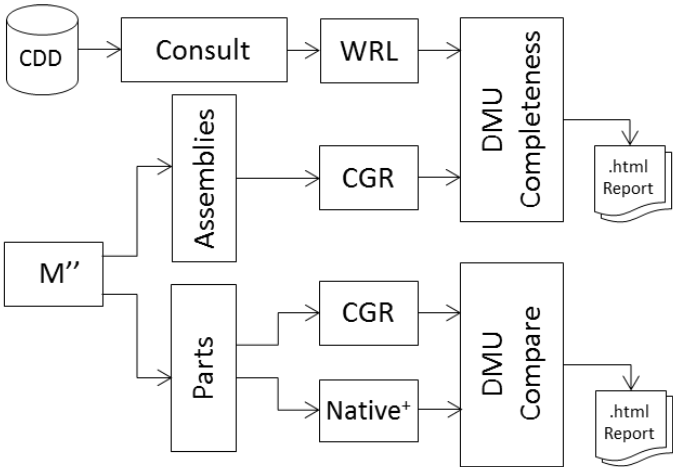


Figure 5 Models Validation Flow

facets never related with feature recognition tasks. Facet model is hard copy of the screen representation. Thus, CGR convertation is most reliable and error-free. However it has also disadvantage while copying as well all inaccurateness relating with screen resolution, approximation, etc. It is normal practice when designers putting less accuracy for visualisation while it decrease number of nodes for modelling and saves performance. However as a result it brings considerable inaccurateness of approximation of arc's and cylinders with large dimensions. Fig.4 illustrates example of solenoid service pipe of ATLAS detector which has 10mm value of approximation of CGR in comparison with solid.

According to above mentioned specifics of M" set of models and existing tools of models convertation, GCCEC developed models validation methodology. *Two* separate procedures of models checking have been formed - compare checking and completeness checking. Compare checking foresees validation of parts converting into CATIA. Parts are relatively simple and contain limited number of solids. This limitation is coming from convertor software ensuring fewer faults for the models with fewer amounts of geometry features inside. For instance connector software developed by CERN CAD support team for Γ_1 transaction sets 32'000 nodes limitation as a max size of submitted parts on CDD.

While CGR is screen copy of initial CAD model, it was decided to make comparison of CGR and M"/Native$^+$ .CATPart models for the validation of parts received after Γ_1 transaction (Fig. 5). CATIA V5 DMU Analyse module has been chosen for the calculations. Analyse study includes investigation of clouds of received differences, separation computational inaccuracies from real geometry and identification of missing or damaged volumes. Another study during the DMU analyse is comparison of mass properties and calculation of differences in volume, square and center of gravity. Last analyse study is calculation of CGR models approximation. GCCEC engineers in Georgia were running above described analyses sessions in CATIA DMU and taking decision about the weather, considering M" models received from Γ_1 transaction failed or not. Results were documented in .html reports of compare checking and uploaded on the web servers at CERN.

Completeness checking foresees validation of CATIA assemblies to be sure that all associated parts are presented in .CATParts. GCCEC engineers in Tbilisi office were constructed CATIA assemblies in V5 DMU Analyse module from the M"/CGR's of associated parts (Fig. 5). Than WRL facet based model of full assembly were downloaded from initial CAD assembly. Special web application *Consult* developed by CERN CAD support and permitting extraction of models from CDD, has been implemented. Thus, for each .CATPart from M" set it was learning the weather, considering part is consistence, missing some parts or miss positioned. Results of DMU calculations were documented in *.html* completeness report and uploaded on CERN web servers.

4. INTEGRATION

Purpose of Γ_3 - integration transaction is checking of M" set of CATIA models on compatibility with full model of ATLAS detector by identification of possible clashes and clearances. Γ_3 foresee as well integration of valid M"' candidate CATIA models into final M model of ATLAS detector and recovering of CATIA Native$^+$ of those valid models who are failed during the Γ_2 compare analysis.

Integration conflicts checking were processing on the base of M"'/CGR models. They were placed together with existing M model of ATLAS in CATIA V5 DMU analyse module for calculation of clashes and clearances.

1st step in this direction is identification of all overlaps and clearances for considering assemblies and generation of technical reports. This step was executed by GCCEC engineers in Tbilisi using

CATIA DMU modules. Results in *.html* reports were uploaded for further consideration on CERN web servers. On the 2nd step responsible designer together with ATLAS TCn integrator were analysed all conflict cases and assigned status relevant/not_relevant to each of them. Models with relevant conflicts were sent back with integration reports to responsible designers in home institution for correction and re-submission on CDD. On the 3rd step, corrected models again passed through all Γ_1, Γ_2, Γ_3 transactions. 4th step of Γ_3 - transaction is insertion of fine models (which are successfully passed through the conflict checking procedures) into logical structure of entire M model of full detector.

3 hierarchical levels of detalization have been formed for the description of ATLAS logical structure. 1st level corresponds to detector components:

B - Beam Vacuum

I - Inner Detector

A - LArg Calorimeter

L - Tile Calorimeter

T - Toroid Magnets

M - Muon Spectrometer

J - Shielding

S - Services

H - Support Structure

F - Infrastructure

2nd level contains 26 units of detalization of A, L, T, M, S, H and F; 3rd level have 14 sub-units of T, M, H and F. In total there are 50 separate units in logical structure of ATLAS detector. Each unit is associated with corresponding .CATProduct in M final CATIA model. CATProduct's itself contains facet based descriptions of geometry on the base of CGR models.

More than 700 relevant conflicts have been found by GCCEC during the development of M final CATIA model of ATLAS detector.

Another part of Γ_3 transaction is recovering of failed CATIA Native+ models (fig.3). Recovery is valid for those models which are failed in Γ_2 compare checking and are fine in Γ_2 completeness and Γ_3 integration conflict checking. GCCEC has produced

		M' /Assy's	M' /Parts	M'' /CDD	Failed CATIA Native+	
I	GOI1	29	830	414	144	34.8%
A	GOA1	2	4	2	1	50.0%
L	GOL1	8	20	10	3	30.0%
T	GOTB	32	376	188	61	32.4%
	GOTE	33	692	346	111	32.1%
M	GOMB	17	334	167	63	37.7%
	GOMC	220	2798	1399	484	34.6%
	GOMA	23	266	133	50	37.6%
S	GOSB	98	398	199	79	39.7%
	GOSE	30	148	74	45	60.8%
	GOSM	14	42	21	12	57.1%
	GOSR	41	168	84	35	41.7%
	GOSG	27	76	38	29	76.3%
	GOSO	12	26	13	6	46.2%
H	GOHX	133	334	167	119	71.3%
	GOHB	24	234	117	95	81.2%
	GOHT	5	20	10	5	50.0%
	GOHM	2	2	2	1	50.0%
F	GOF1	71	536	268	149	55.6%
J	GOJ1	10	104	52	14	26.9%
	Total:	831	7408	3704	1506	40.7%

Figure 6 Models failure statistic

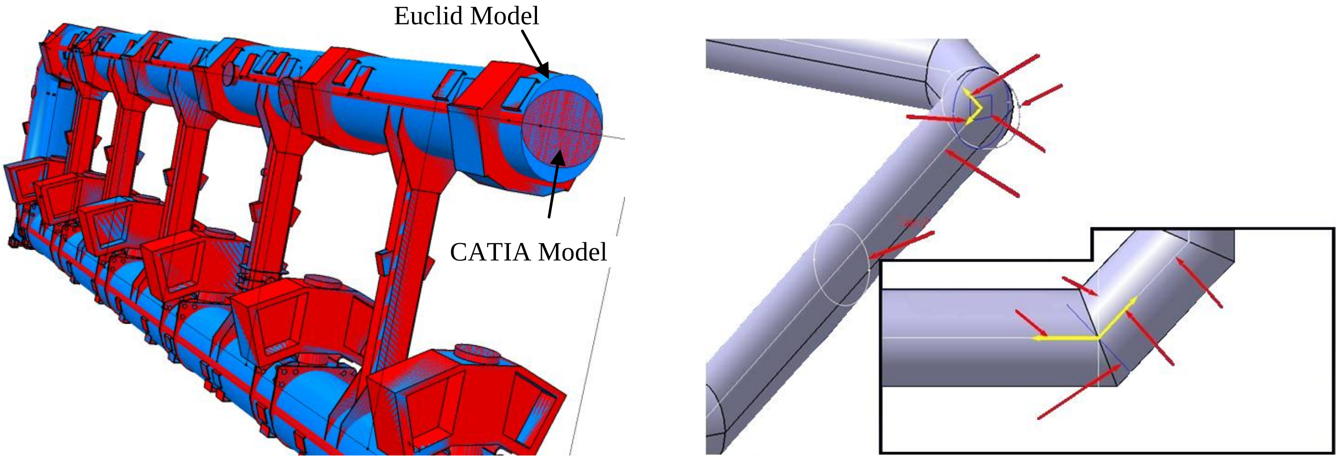
3’704 compare and 792 completeness reports [5]. Models failure statistic presented on Figure 6.

40.7% of M”/Native+ has been failed. Majority of failures detected for Muon system having a biggest amount of models. Poor quality of Γ_1 transaction detected for GOSG (76.3%), which is subpart of S Services of gas and pipes; GOHX (71.3%) - subpart of H - support structure of access platforms and GOHB (81.2%) – subpart of H - support structure of Feet’s and Rails.

Reasons why transformed models are failed in geometry can be grouped in *two* categories [6]:

1) Incompatible description of geometry in source model which brings faults of transformation
2) Faults of transformation software during the feature recognition and interpretation of geometry tree inside the model

1st category of faults is mostly related with fatal errors of designers during the identification of global parameters of design. For instance often designers forgetting to fill all the necessary fields in drawing stamp submitted on CDD. As a result in M”/CGR’s were generated without no M”/Natives. Also wrong values of some parameters like scale factor, axis



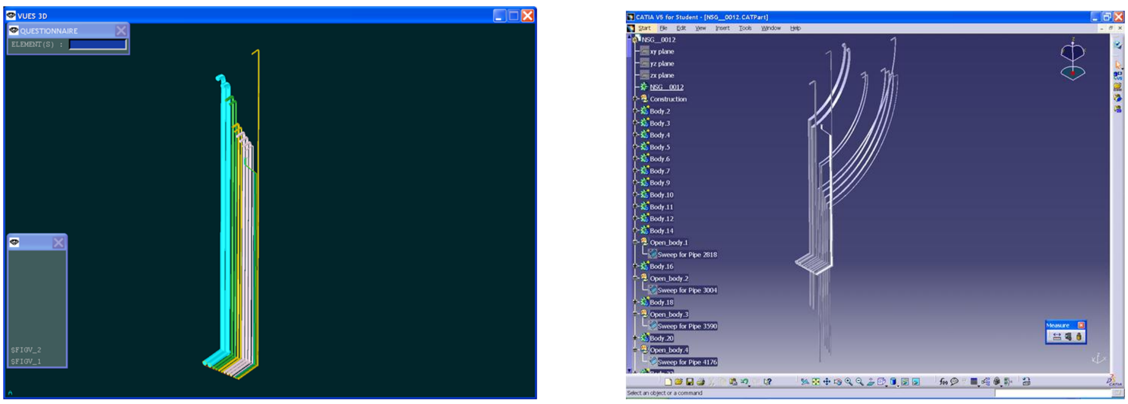
a) **b)**

Figure 7 Difference of interpretation of model tree

system, variable precision, etc., due wrong sizes and position of M" set of models. All that faults can be repaired relatively easy by putting correct values and redone of Γ_1 transaction.

2nd category of faults require deep analyse of model tree and correction of geometry description mostly on sketch level. Figure 7 illustrates case of different interpretation of same sketch profile of ATLAS magnetic coil in CATIA and Euclid. Coil cylinders in Euclid (Fig.7, a) built on the base of *arc* (Fig.7, b) which is the same along the all the length of guide *line*. However, CATIA interpret tree in different way. On the first vertex of roundcorner CATIA builds cylinder while forming *arc* is in perpendicular plane with guide *line*. But for the 2nd vertex of roundcorner it is in non-perpendicular plane (Fig.7, b). So, for that vertex CATIA consider ellipse instead of *arc* along the guide *line*. As a result CATIA model contains deformed cylinder (Fig.7, a). Solution for this case is to reposition in CATIA forming a*rc* in order to be perpendicular to guide line along the full length. This fault of model transformation is typical for the all other models of pipes and services. Figure 8 illustrates another fault of interpretation of model tree in Euclid and CATIA [7] of service pipes. All corrections in model tree for the ATLAS have been done by GCCEC.

In addition M''' integrates models coming from STEP and CATIA. CATIA models are passing through the integration flow like all models coming from Γ_2 transaction. However, STEP files first have to be converted into sketch based editable CATIA format. STEP files contain encapsulated solids (or facets) without sketches. To convert them into editable format, sketches should be built and assign to all encapsulated solids or facet based surfaces.



a) Euclid model **b)** CATIA model

Figure 8 Faults of interpretation of model tree

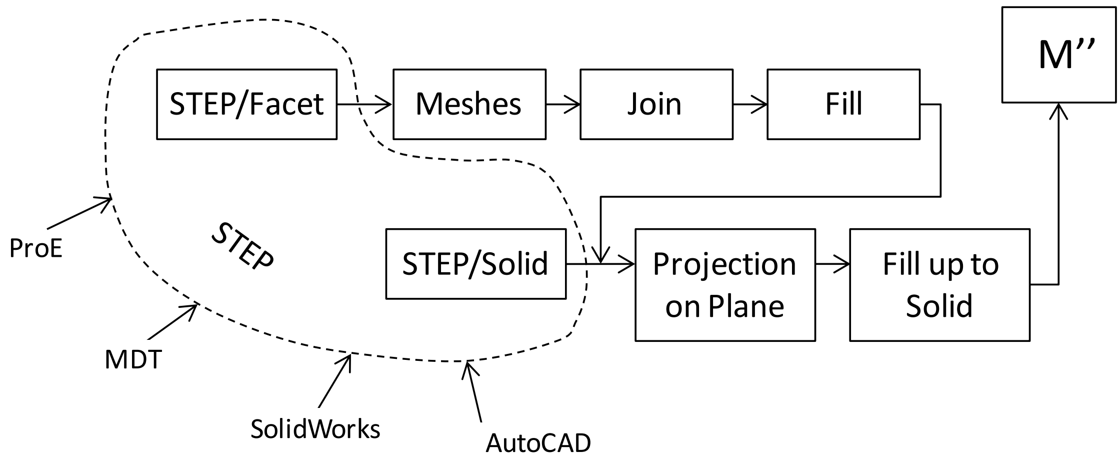


Figure 9 STEP integration flow

GCCEC developed methodology [8] for the reprocessing of new editable solids in CATIA (Fig. 9).

There are 2 ways to make editable solids in CATIA from STEP:

1) Using encapsulated STEP/solids - in CATIA/Part_Design module new plane is defining in existing partbody item. Then STEP solid projecting on it. As a result new sketch is constructing on the plane. After it is possible to reproduce new solid from the sketch using dimensions from the existing STEP solid as a constraints

2) Using STEP/facet based surfaces. Initially, existing shapes are reprocessing as a set of multiple lightway meshes by standard Open/Save_as procedures of WRL->DXF->STEP. Then set of meshes join into one entire surface using CATIA/Generative_Shape_Design module and fill up with solid body using CATIA/Part_Design module (Fig. 10). Further steps are the same like in case of STEP/solid models.

Once, CATIA native models are generating from STEP, then they passing through the same steps of Γ_3 - integration transaction as other migrated models.

Finally, all proposed methods and tools have been developed and implemented for the models migration and their integration into entire geometry description of full detector. Full set of M CATIA models have been uploaded on DFS and later was moved on

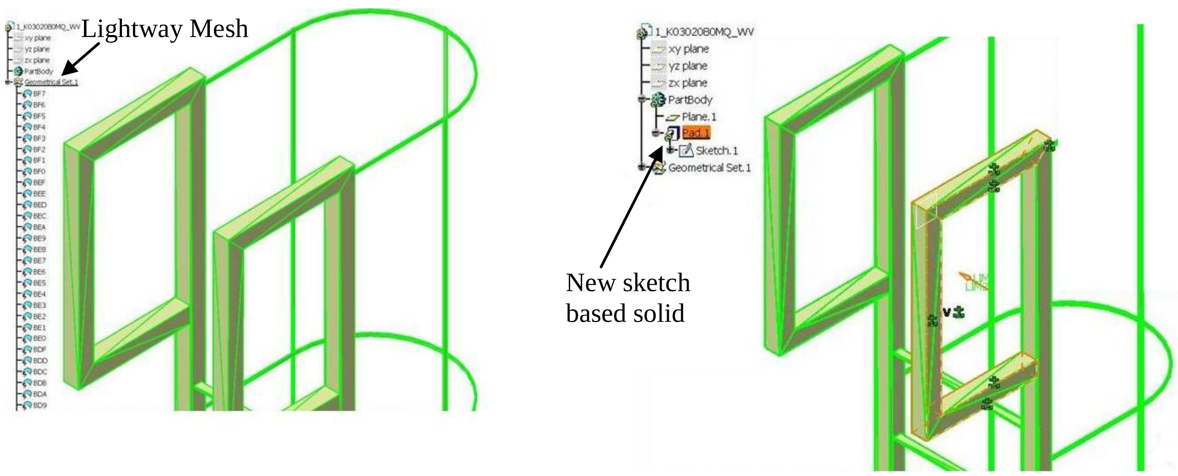


Figure 10 Generation of sketch-based solids

CERN/SmarTeam database as a first official geometry description of ATLAS detector. It consists of 3'705 assemblies, 10'000'000 mechanical features and takes 31Gb disk space. GCCEC spent 31 months and ~13'000man/hour [5] for this development. M final set of CATIA models was the base source which was implemented in the ATLAS detector construction life cycle.

5. CONCLUSIONS

1) Main task for the creation of geometry descriptions of HEP facilities is development of CAD models migration life cycle
2) CAD models migration life cycle contains 3 main stages of models transformation, validation and integration
3) It is impossible to migrate the initial model directly into the final one. Intermediate prototypes should be generated to ensure step-by-step approximation of initial description into final
4) Development of tools and organizational methods for data centralization is important issue for models migration
5) Good results of investigation of models transformation quality can be reached by comparison of solid based and facet based representations of the same model, while they are followed different paths of transformation. Special attention should be paid to approximation of facet models
6) Entire geometry description of full HEP facility should be done on the facet based models. It makes possible modelling of hyper-complex assemblies and provides all necessary calculations for integration conflicts checking
7) Migration life cycle foresee to establish many simultaneous considerations and feedbacks between the collaborative groups. Existence of virtual engineering offices are necessary
8) CATIA V5 platform fully responds to all requirements of models migration and development of entire geometry description of full HEP facilities

ACKNOWLEDGMENTS

This work would not have been possible without the continuous support of the managements of the ATLAS, ATLAS Technical Coordination and CERN CAD Support Team. Special thanks to ATLAS technical coordinator Marzio Nessi, ATLAS integrators Mark Hatch and Tatiana Kliutchnikova and head of CAD support team Eric van Uytvinck.

REFERENCES

[1] The CERN Engineering and Equipment Data Management Service / CERN Publishing EDMS Service, Geneva, Switzerland, https://espace.cern.ch/edms-services/default.aspx

[2] CERN Drawing Directory: CDD General Information Page / CERN Publishing EDMS Service Geneva, Switzerland http://edms-servic.web.cern.ch/edms-service/CDD/#ANCH01

[3] DFS Distributed File System: DFS WebDAV Portal by IT-OIS / CERN Publishing EDMS Service, Geneva, Switzerland https://dfs.cern.ch

[4] Methodology of CATIA Implementation in ATLAS Technical coordination Project / CERN Publishing EDMS Service, Geneva, Switzerland: 2004/1163614 v.1, https://edms.cern.ch/document/1163614/1

[5] General Acknowledgement of Acceptance issued by ATLAS collaboration and Georgian CADCAM engineering Center / CERN Publishing EDMS Service, Geneva, Switzerland: 2008/1163609 v.1, https://edms.cern.ch/document/1163609/1

[6] Sharmazanashvili A., 2004, "Development of ATLAS-CAVERN CATIA model for ATLAS TCn", Annual report of activity / CERN Publishing EDMS Service, Geneva, Switzerland: 2004/1163617 v.1, https://edms.cern.ch/document/1163617/1

[7] Boncompagni Y., 2007 "Migration des données Euclid3 vers Catia V5", Stratégie / Etat des lieux / Recommandations, Technical Support Department, / CERN Publishing EDMS Service, Geneva, Switzerland: 2007/1163618 v.1, https://edms.cern.ch/document/1163618/1

[8] Tusishvili D., 2009 "How to Convert CGR files to CATPart", Georgian CADCAM Engineering Center, / CERN Publishing EDMS Service, Geneva, Switzerland: 2009/1163619 v.1, https://edms.cern.ch/document/1163619/1