SAF - STRUCTURAL ANALYSIS FORMAT

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ABSTRAKT

V tomto článku je představen open source formát SAF (Strucutral Analysis Format) sloužící k výměně výpočetních modelů stavebních konstrukcí. SAF je založený na formátu Microsoft excel a jako takový byl vytvořen a uveden do praxe v posledních letech s důrazem na praktickou použitelnost a možnost plnohodnotného zapojení statiků do pracovních procesů v rámci BIM. Vývoj formátu SAF spadá pod iniciativu v rámci Nemetschek Group, řízenou námi ve společností Scia Engineer. V článku je poskytnut základní popis principu fungování open source formátu SAF, webová stránka a veřejné úložiště na GitHubu včetně diskuse. Poskytnut je přehled všech objektů nyní dostupných v SAFu včetně popisu, jakým jsou jednotlivé objekty definovány. Uplatnění SAFu v rámci BIM problematiky je uvedeno na dvou příkladech, kde jsou vyhodnoceny klady a zápory uvedených postupů. Na konci článku je nastíněn jak další možný vývoj v rámci formátu SAF, tak i jeho rozšířená aplikace v praxi.

KLÍČOVÁ SLOVA

Analýza konstrukcí • Výměna dat • SAF • BIM • Open source

ABSTRACT

This article introduces in last recent years developed data exchange excel based file format called SAF (Structural Analysis Format) with focus on structural engineering discipline and possibilities of BIM workflows for structural engineers. SAF is an open source project and it is being developed under Nemetschek Group, driven by us in Scia Engineer company. SAF format basic description is provided with the links to GitHub repository and SAF documentation web page. Review of all SAF supported objects is shown and data structure is explained within the SAF objects represented by the single excel sheet. Types of used attributes are described in general with option to refer between objects within the one SAF file, which is representing the analysis model. Usage of SAF is described by two examples of BIM workflows where pros and cons are evaluated. Possibilities for future development in SAF and extended usage in practice are discussed at the end of this article.

KEYWORDS

Structural Analysis • Data Exchange • SAF • BIM • Open Source

1. INTRODUCTION

The construction industry is moving towards digitisation step by step. There is already variety of BIM (Building Information Modeling) collaboration online platforms offering complete solutions for project management and whole live cycle management of buildings - from pre-design phase to demolition. As a one of inputs for these BIM collaboration platforms are often used models in IFC format. IFC (Industry Foundation Classes) format was introduced in 1994, continuously developed and maintained by buildingSMART is now widely adopted by all stakeholders in constructions processes and by tools (CAD software etc.) that engineers are using in their daily practice. IFC offers an unrestricted data exchange and together with capabilities of collaborating platforms offers options for cooperation between almost all professions participating in construction process - MEP engineers, architects, drawsmans, electrical engineers, investors, contractors and others. All of them can cooperate and profit from the BIM processes. Main advantages are common data storage, data distribution, clear rights structure, clash detection, comparison of model's revisions, issue tracking and more. It is clear that this trend is going to continue even leveraged now with the recent experience with Covid-19 pandemic. (BuildingSmart n.d.) (Hong et al. 2022) (Adrian Michalski 2022)

Structural engineers unfortunately stay aside these offered solutions at the moment. Structural analysis model in not usually stored on BIM collaborating platform and structural analysis is being done outside of the BIM processes, without direct connection to structural model (IFC) and information flow to other stakeholders. There is the existing IFC Structural Analysis View (IFC SAV) dedicated to structural engineering but the format has not met the same level of adoption as standard IFC and is not used widely at all. IFC SAV is not being further developed and maintained now. Therefore comes SAF (Structural Analysis Format) on the scene. With the aim to improve workflow of structural engineers, providing them with the opportunity for being part of the complete BIM workflow and ability to easily transfer data between various software. SAF initiative started in SCIA, the company of the Nemetschek Group. First SAF version was released in the year 2019 and since then is being constantly developed. SAF is basically excel based format with sheets dedicated to structural analysis objects (materials, nodes, beams, slabs, loads, supports and hinges etc.). Properties are stored in excel cells, in rows are defined objects and columns represent specific attributes. Every excel sheet represents set of similar analysis elements. Format is readable even in the excel itself and can be easily adjusted also outside of the structural analysis application, that is capable of reading and interpreting the SAF file. SAF can be also inspected in free SAF viewer web application, which is part of the Scia AutoConverter (Figure 1). SAF is an open source format that everyone can adopt and contribute to the development. SAF is designed to open doors of cooperation for structural engineers with ambition to become widely adopted standard for structural analysis mod-

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els. SAF adoption of companies such as Dlubal, Frilo, Graphisoft, Scia Engineer, IDEA StatiCa and others shows that the ambition is justifiable. (BuildingSmart n.d.) (Nemetschek & Scia n.d.*c*)

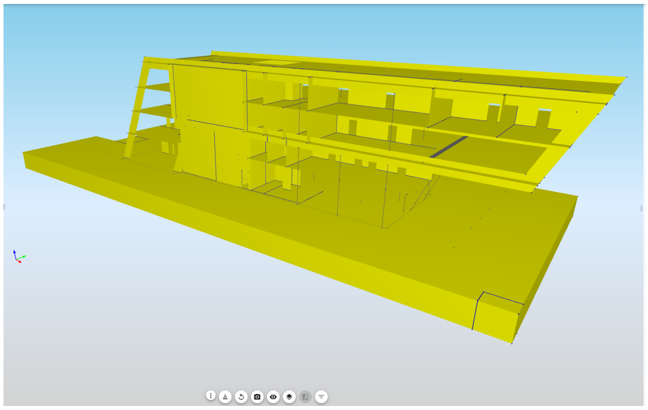

Figure 1: *SAF 3D render in free SAF viewer (.jpg file).*

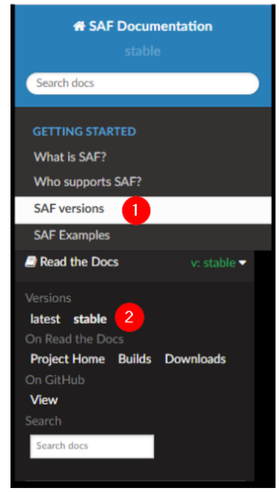

Figure 2: *Navigation on SAF webpage through the version (.jpg file).*

2. WHAT IS SAF

SAF is a new format defined based on excel file with a purpose to easily transfer data between applications and people incorporated in construction process. SAF main domain is the structural analysis design part of the construction process. SAF is open to contribution of the structural analysis community, repository of documentation itself can be found on GitHub where issues and discussion are being raised, solved and implemented into the SAF format. (Nemetschek & Scia n.d.*c*), (Nemetschek & Scia n.d.*b*)

2.1. SAF definition

The structure is clearly defined by the freely accessible SAF web page *www.saf.guide* . Where everyone can find definition of all objects supported in SAF, everyone can browse in previously released version (1) (Figure 2) and also check out the newly defined objects and changes in pre-release preview of next version of SAF documentation (2) (Figure 2). On the left side of the page there is a tree object structure where everyone can inspect the all defined objects. Short feedback loop for objects in the design state is key for avoiding issues in the state of adoption and implementation by other parties. The SAF documentation is now following semantic versioning rules (version 2.0.0 and latest) which define clear rules for the versioning and backward compatibility of versions. All versions are described with a version number MAJOR.MINOR.PATCH. For more about semantic versioning see *https://semver.org/*. Important for adoption is also the fact that there is SAF SDK (Software Development Kit) available upon request - it makes implementation for every party easier since there is a lot of done in advance (validation rules for the input file etc.). (Nemetschek & Scia n.d.*c*) (Preston Werner n.d.) (Dlubal 2021)

2.2. SAF objects

There is 40 objects available in SAF and they can be divided in 5 main categories: General Information, Analysis Elements,Supports and Hinges, Loads and Results. All objects and their classification can be found in Table 1. Object names are self-explanatory designed regarding to its purpose. General Information and Results are presented in first column together (both categories contains only two objects). (Nemetschek & Scia n.d.*c*)

In the **General Info** objects are stored general information about projects. Typically name, time and place data, level of detail, source application, SAF version, information about GCS (Global Coordinate System) definition, national code used and other general information.

In the **Analysis Elements** objects are stored data about the structure itself. Data related to materials definition, nodes, cross-sections, beams, slabs, walls, internal edges, storeys etc. These data define the structure in 3D space.

The **Supports and Hinges** objects allows users to place additional data on already defined objects belonging to Analysis Elements. These additional data are constrains type objects, typically support in node, line supports, surface supports with various type of other constrains objects available in SAF.

The **Loads** are group of objects which are providing another type of additional data. Examples of load objects are point loads, thermal load,dedicated surface loads, free surface load etc.

In the **Results** group are so far two objects defined. Internal forces on beams (1D members) and internal forces on 2D element edges. (Nemetschek & Scia n.d.*c*)

2.3. SAF objects structure

SAF objects structure is coherent among all objects. Every sheet (except of Project and Model sheet where structure is slightly different) follow same rules. Each sheet in SAF file represents the specific type of object. In the Figure 3 there is an example presented of sheet StructuralCurveMember. It defines 1D analysis object, usually column, brace, beam or girder. Every row represents one member (analysis object). Attributes of that member (analysis object) are stored in columns. Every column represents value for specific attribute which name is presented in a column header. For example we can see here that member (analysis object) in row 4 has attribute "Name" equals to value "B278", attribute "Cross section" equals to "CS2" and attribute "Type" equals to "beam" etc. Attribute values could be different for every object (row) as is clear in the excel example. In general there could be three types of values stored as attributes: A general string type value ("Name" = "B278"), string used as a reference to another SAF object ("Cross section" = "CS2", where "CS2" is the name of valid cross section defined in StructuralCrossSection sheet) and an enum, where value

Table 1: *SAF objects review and classification*

General Info and Results	Analysis Elements	Supports and Hinges	Loads
Project	StructuralMaterial	StructuralPointSupport	StructuralLoadGroup
Model	StructuralCrossSection	StructuralSurfaceConnection	StructuralLoadCase
	CompositeShapeDef	StructuralCurveConnection	StructuralLoadCombination
ResultInternalForce1D	StructuralPointConnection	StructuralEdgeConnection	StructuralPointAction
ResultInternalForce2DEdge*	StructuralCurveEdge	RelConnectsStructuralMember	StructuralPointMoment
	StructuralCurveMember	RelConnectsSurfaceEdge	StructuralCurveAction
	StructuralCurveMemberVarying	RelConnectsRigidCross	StructuralCurveMoment
	StructuralCurveMemberRib	RelConnectsRigidLink	StructuralSurfaceAction
	StructuralSurfaceMember	RelConnectsRigidMember	StructuralSurfaceActionThermal
	StructuralSurfaceMemberOpening		StructuralCurveActionThermal
	StructuralSurfaceMemberRegion		StructuralPoinActionFree
	StructuralStorey		StructuralCurveActionFree
	StructuralProxyElement		StructuralSurfaceActionFree
			StructuralSurfaceActionDistri

can be set to one of the pre-defined values, for example "National code" in the Model sheet. (Nemetschek & Scia n.d.*c*)

Not all data are required to be filled in excel. There are three types of data from the perspective of importance. First group is always required - attributes like unique names, coordinates defining nodes, nodes defining the 1D and 2D elements, value for force load, reference on which 2D structural analysis element the load should be applied etc. Second group are required values triggered by a condition "required if" attributes. For example in case of StructuralSurfaceAction object (Surface Load) when it should be applied to the sub-region of the specific slab. The specific reference to a sub-region is required only if "Force Action" (load is applied to) equals to "On 2D member Region". Third option are not required values, these can be filled and then they provide more precise information about an object but they are not spatial for the data transfer. For example "Type" equals to "beam" in the Figure 3 is not required values and cell could be left empty. (Nemetschek & Scia n.d.*c*)

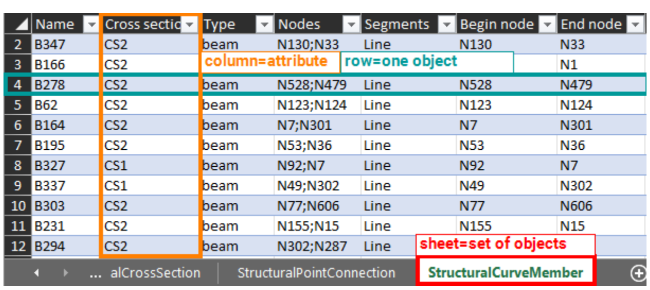

Figure 3: *SAF object structure explained (.jpg file).*

3. STRUCTURAL ENGINEERS IN BIM PROCESSES

Let us take a look on first examples of integration SAF and structural engineers into the BIM workflows. First example is with embedded analysis model directly in BIM authoring aplication. Second example provides more flexibility of BIM workflows using the SAF format and web application called Scia AutoConverter in connection to BIM collaboration environment.

3.1. Example Workflow: Embedded Analysis Model

Structural model is created and as part of that model an analysis model could be automatically or on demand created. Analysis model is in this case created actually by an architect or drawsman and then issued to the structural engineer. It could be done with files exchange using a SAF file, dedicated file XML export or other proprietary direct link between CAD application and structural analysis application. In this workflow SAF offers a standardized solution for creation of analysis model in BIM authoring application that could be handed to various analysis software and therefore provides option to save development capacities that are needed to maintain variety of file exports and direct between app connections designed for every software exclusively. These types of connections are usually two-way with the ability to update models. Examples: ArchiCAD SAF export, Scia Engineer and Autodesk Revit connection. (Figure 4) (Graphisoft n.d.) (CADS & company n.d.) (Autodesk n.d.)

Pros of this approach are:

- All-in-one model provides simple solution, especially for well established partnership between stakeholders and well developed connections.

Cons of this approach:

- The analysis model together with constrains and loads is being created in CAD application which is not mainly focused on structural analysis.
- The modeller has additional responsibilities outside of scope of his field of his/her domain.
- Analysis model definition is as flexible as authoring BIM application allows. Additional changes are usually necessary in final structural analysis application.

3.2. Example Workflow: BIM Collaboration Environment

Structural model is created in BIM authoring application (Allplan, ArchiCAD, Revit etc.). IFC model is exported to BIM collaboration environment with using file export/import or with API call when available. Model is being converted from structural model to analysis model using the web application Scia AutoConverter and can be saved on BIM collaboration platform or exported directly to SAF format. Scia AutoConverter is a web application

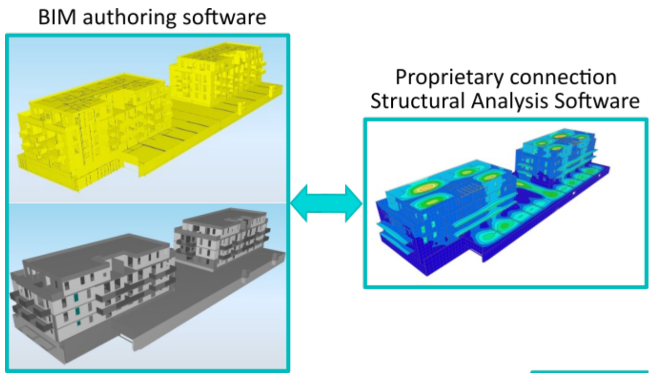

Figure 4: *SAF in BIM workflow - embbeded model (.jpg file).*

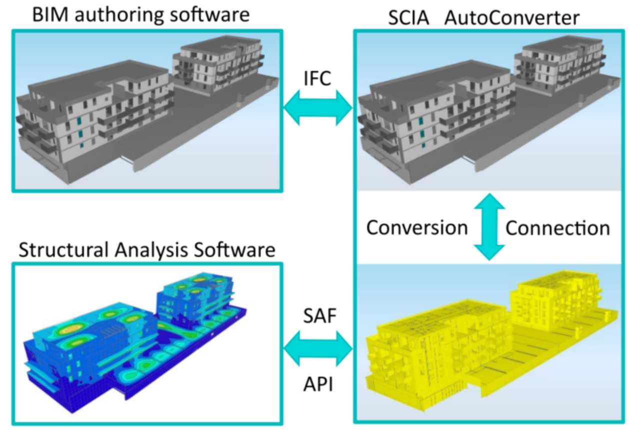

Figure 5: *SAF in BIM collaboration platform workflow (.jpg file).*

design for conversion of the structural models (IFC models) to analysis ones and allows export to SAF format. Successful conversion puts quality requirements for IFC models created in BIM authoring software, because they are used by structural engineers afterwards. Certain level of attribute export settings and precision in modeling is required. Scia AutoConverter brings automation to the process of model creation in structural analysis application - process that was usually doubled in workflow of structural engineers and brought additional time cost with the remodeling of the structure based on 2D drawings or based on IFC file obtained from architect or modeller. There are also other benefits brought by the collaboration platform like both way revision comparison and issue tracking for structural engineers and other stakeholders in the process. Structural analysis model can be imported via SAF or API when available to desired structural analysis software that structural engineers are using (Scia Engineer, Dlubal, Sofistik etc.). (Figure 5) SciaEngineer (n.d.) Allplan & Bimplus (n.d.)

Pros of this approach are:

- Structural analysis discipline is fully in hands of structural engineer.
- Modeller can fully focus in his discipline. He is not confronted with analysis model creation, only handover the data in BIM environment.
- High level of flexibility in creation of analysis models for structural engineer.
- Structural analysis model creation is an automated process that brings the time and costs reduction.

Cons of this approach:

- Process might be too complex for smaller projects.

4. FUTURE OF SAF

We are going to work on extensions of the SAF format in the coming months and years. At the current state we are able to transfer geometry on very high level, complex shaped double curved surfaces and spline 1D members can be written down to SAF and exchanged smoothly. The extension will be necessary in the part of defining supports and constrains. For example non-linear behaviour described with non-linear curves is not possible at the moment in SAF and now could cause a data loss in the transfer process. Loads sorting objects like StructuralLoadGroup and StructuralLoadCase requires review and improvements. Also new enums and referencing between SAF objects is on the table which will improve SAF capabilities. Recently approved proposals from GitHub discussion will be implemented soon in development preview documentation. GitHub discussion and participation of the community is highly appreciated. (Nemetschek & Scia n.d.*a*)

Also, it is great to see that other companies are more and more using SAF format. It means that communication between multiple applications and software is being standardized, easier to develop and maintain. It brings more reliable and advance tools for structural engineers into their daily practice. (IDEA n.d.)

What we are looking for also at the moment is an extension and usage SAF towards automated workflows in structural engineering. With usage tools of parametric modeling and visual scripting like Grasshopper, Rhino. Imagine that you define a parametric structure in Grasshopper, with ease you will export it in SAF or even directly import the structure into the structural analysis software with SAF file in background. Then API will automatically run the calculation with all desired checks and based on results you can steer (manually or automatically) the geometry definition in Grasshopper and optimize the structure in pre-defined boundaries with structural analysis application providing you the final valid structural engineering report. This is not actually so far away.

5. CONCLUSION

The SAF (Strucutral Analysis Format) is presented in broader view of BIM processes including the structural engineering discipline into BIM workflows. SAF is an easy to use excel based structural analysis model data exchange format with focus on structural engineering discipline. This format is and open source project held under Nemetschek Group driven by us in Scia Engineer company. SAF format is generally introduced and important information about documentation location, principles of releasing versions are described. SAF is an open format with repository located on GitHub where everyone can contribute and discuss new development based on needs of the structural engineers on the market. Provided is also brief review of all objects supported in SAF format. Rules and principles on which data are stored in the excel sheet on object level are introduced. Also basic rules of SAF attributes types and references are described. Examples of two main BIM workflow with focus on structural engineering and usage of SAF are described and evaluated. First workflow is more straightforward with higher demand on modeler where structural analysis model in being created together with structural model in BIM authoring application. Second workflow is more general, using the BIM collaboration platform and Scia AutoConverter tool providing more flexibility to structural engineer and saving dramatic amount of time and costs. The future options for usage and extension of SAF discussed at the end of the article.

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