IFC BASED MODEL VIEW DEFINITION FOR HYBRID ENERGY SYSTEMS

Kamil Umut Gökçe, Assist. Professor, umut.gokce@eos-ses.de
Hasan Ufuk Gökçe, Assist. Professor, ufuk.gokce@eos-ses.de
EOS Sustainable Energy Solutions GmbH, Vahrenwalder Str. 7 30165, Hannover, Germany

ABSTRACT

The Industry Foundation Classes (IFC) object model as a standard data model which has a quite large scope is proposed as a standard approach (ISO-PAS 16730) to identify the specifications and enables interoperability between the AEC (Architecture Engineering and Construction) applications. Currently the majority of AEC software and system developers use IFC APIs (Application Protocols) that are capable of importing and exporting IFC/STEP files, however the IFC based applications in the energy efficiency domain has not yet well articulated. At the moment sophisticated building energy management systems (BEMS) are available worldwide. However, they consist of ad-hoc combination of off-the-shelf building energy management and off-the-grid energy generation systems. This ad-hoc combination presents many difficulties as the BEMS consist of number of tools utilizing various information exchange protocols that have to be integrated within the M&T software packages. The optimization of these systems for efficient energy management adds another layer of complexity to the design and management procedures of these systems. However, even though various solutions have been proposed in the last years, a general approach based on an acknowledged standard is still missing. In this paper, a new building information model complying with the data schema of the industry foundation classes (IFC) standard is addressed. It allows for coherent integration of different information, helping to achieve the interoperability of the involved tools and services. The buildingSMART initiative's Model View Definition Format is used to develop the formal specification for this new model. The Generalized Model Subset Definition Schema (GMSD) is applied for the subset content's formal specification. The essence of the developed approach is in the consistent definition of a partial IFC model for hybrid energy systems. The developed concept has been tested on two sample buildings in Hannover Germany.

Keywords: building information modeling, industry foundation classes, energy management systems, off-the-grid energy generation systems, model views

1. INTRODUCTION

Interoperability of the heterogeneous applications in the domain of energy management can be best achieved by using generalized and standardized representations of the needed product data from various systems and services, thereby enabling optimized and energy efficient building operations (Gökçe 2012). Therefore, in the last years several IT systems integrating various application domains have been developed to obtain networked-based environments. Such systems typically combine energy management and off-the-grid energy generation systems thereby allowing reducing operation costs, and increasing system efficiency. However, developed solutions largely lack generality in terms of data interoperability. Integration of product and process information is based on the specific internal data models of the used component systems, and not on generally applicable and hence standardized data models (Gökçe 2012). All this significantly decreases flexibility, multi-dimensional data analysis, and last but not least hybrid system design. In spite of its promising potential, a standardized Building Information Model (BIM) based on the IFC product model of the buildingSMART initiative is still practically unused for energy management purposes, even though "the majority of AEC software developers already provide IFC APIs that are capable of importing and exporting IFC/STEP files" (Nour 2007).

Furthermore the engineering and deployment aspects of current systems require extensive manual work with much trial-and-error in programming devices, composing applications from devices, deploying devices in buildings with complex radio propagation characteristics, developing data structures for data acquisition, and analyzing tasks (Gökçe et al. 2011). Integrated IT tool support for these activities does not exist; available tools are stand-alone products, often tied to specific standards. These existing tools neither support the exchange of information between different application stages, nor do they consider the extension of an existing wired or wireless monitoring, control and off-the-grid energy generation systems during operation (Gökçe 2010). This lack of appropriate tools currently outweighs the benefit of software interoperability.

In this regard, a single combined information and communication platform would not adequately predict the consequences of the building performance behavior and the needs of the building occupant/operator to manage energy consumption efficiently (Gökçe et al. 2011). To avoid these shortcomings, a promising approach is the implementation of a dynamic modular infrastructure based on the acknowledged standard models.

2. RESERCH OBJECTIVES

In this paper, we address the existing gap between the data provided in the application domains and services used for energy management and off-the-grid energy generation systems on the one side and their association to the BIM data contained in the IFC model on the other side. In this regard, we propose a new methodology that provides coherent integration of product and process information based on the IFC data model standard. This methodology supports the interoperability of the involved tools and services. The essence of this newly developed approach is in the consistent definition and use of newly developed IFC Partial Models for hybrid energy systems that pulls together the needed product and process data to provide seamless information flow through standardized product and process information.

By developing the IFC Partial Models, the management of large-scale complex networks, services and mobile applications complying with the new network and management protocols which supports seamless end-to-end network composition and service operation through sensor hardware can be facilitated (Gökçe 2012). Thereby a model-driven approach integrating application domains and intelligent services based on the IFC model which provides monitoring, analysis and control of performance, and energy generation from off-the-grid energy systems, at all stages of the buildings' lifecycle can be developed. In order to address this aim, a project namely "HESEBO – Hybrid Energy System for Energy Efficient Building Operations" has been granted in 2013 and the initial concept has been tested on two sample buildings in Hannover Germany.

3. BACKGROUND

In the last decades, various research and development initiatives have examined heterogeneous integration of software and hardware systems to create user-sensitive, networked-based environments for inter organizational collaborations which complement context-based managerial views coupled with the IFC model data standard (Gökçe 2012). This research initiatives include Process Matrix approach, based on an extended application of Generic Process Protocol coupled with the dedicated use of the Unified Modeling Language (Katranuschkov et al. 2004), IFC-compliant integrated AEC systems using smart objects (Halwafy et al. 2005), process oriented information modeling methodology for IFC model development (Chen 2006) and the development of product model based processes and data exchange procedures in the ProIT project, compiling design guidelines necessary for product modeling and establishing model structures for the re-use of product libraries (cf. ProIT 2004).

Moreover, IFC has already used and in use in different building development projects. Among the first examples for using IFCs in such a way are "The Headquarters for the Danish Broadcasting Corporation" (Karlshoj 2002), "The LBNL E-Lab Building" (Bazjanac 2002) and "The Helsinki University of Technology Auditorium Hall HUT 600"project (Kam et al. 2002). In these projects IFC-based data exchange took place among architects, mechanical engineers, construction managers and 4D research collaborators using IFC release 1.5.1, whereby the necessity of partial IFC model exchange was altogether strongly emphasized (Gökçe 2012).

However, the goal of lossless, incremental data flow through different application systems which would allow seamless system integration is still not fully articulated. This can be changed by switching to a more structured way of defining partial models, as suggested in the BLIS project (Heitanen 2002).
BLIS developed concepts allowing to start with the high level IFC classes, such as IfcWall, IfcBeam etc., which are then detailed step by step to reach the low level classes related to geometry, material, and various systemic properties.

Accordingly, in this approach a partial model can be defined in two ways: (1) generally, by using an engineering ontology representing the content of the targeted product data model, and (2) specifically, by mapping the general view to an existing release of the product data model e.g. IFC2x3 (Gökçe 2008). A set of diagrams and form sheets are used to improve comprehensibility and maintenance. However, the definitions developed in such a way are not directly applicable as data queries (Gökçe 2012).

4. INTEGRATION METHODOLOGY

In order to realize software interoperability for hybrid energy systems in this research, a principal methodology for creating IFC Partial Models and their binding to requirements through functional parts have been developed as part of the Information Delivery Manual (IDM) (Wix 2005).

Furthermore a comprehensive study of the current IFC model has been conducted to reveal entities, attributes and relations covered by IFC with regard to identified information resources. This study identifies gaps and suggests the associated modifications and re-structuring needs. The relevancies of the information resources in relation to IFC objects are examined according to IFC model requirements. This examination provides a mapping between the information resources and the IFC classes. An information resource defines one to several partial IFC classes. Usually product model classes cannot be used as single entities, but they are embedded in a network of classes defined as IFC Concepts (Gökçe 2012).

Overall, the grouping of IFC Concepts enables the implementation of adaptable IFC Partial Models (Views) that are required for standardized system integration. The aim in forming a concept is to obtain a clear definition and reuse ideas and software code (Gökçe et al. 2011).

In our approach, IFC Partial Models and IFC Concepts are defined by using the General Model Subset Definition schema, GMSD (Weise et al. 2003, Weise and Katranuschkov 2005). GMSD is a schema which allows a neutral definition format for different types of data exchange as well as client/server implementations. It has the ability to define generic views as well as specifically needed model subsets.

5. DEVELOPING AN IFC PARTIAL MODEL FOR HYBRID ENERGY SYSTEMS

In order to identify the basic content of the IFC Partial Models (IFC Views) for hybrid energy solutions based on IFC 2x3 version (IFC 2x3 ISO/PAS 16739), all required attribute values and objects' possible relationships have to be modeled to support the identified requirements. High level requirements' mapping to IFC views are illustrated in Figure 1.

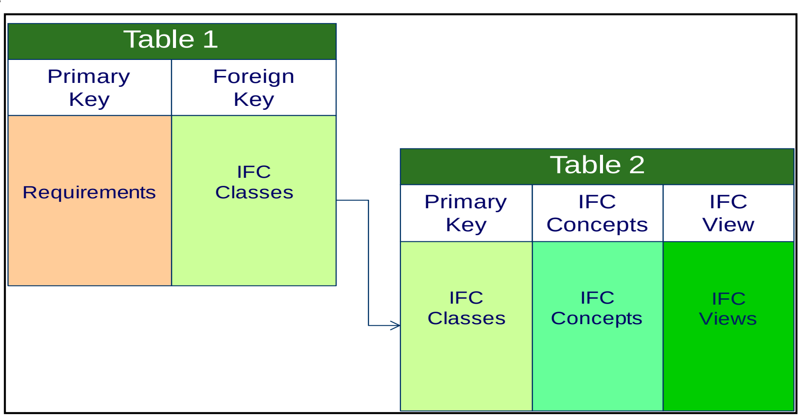

Figure1: Table formalization from Requirements to IFC View Formalizations

In this regard, each requirement related with the application domains and services has been considered. These requirements (as primary keys) lead to a respective structuring of related IFC classes (as foreign keys).The primary key of the given relational table uniquely identifies each requirement. It is an attribute that is guaranteed to be unique or it can be generated as a globally unique identifier. Primary keys consist of a single attribute or multiple attributes in combination. The foreign key identifies a column or a set of columns in one (referencing) table that refers to a set of columns in another (referenced) table. The columns in the referencing table must be the primary key in the referenced table. The values in one row of the referencing columns must occur in a single row in the referenced table.

In our case, the formulated IFC classes (as primary keys) are brought together under IFC Concepts. These concepts are gathered to provide the related IFC Partial Model definitions for energy efficient building operations. Different parts of the IFC product data model are provided as IFC Concepts. An IFC Concept is a grouping of an IFC model subset so that one IFC Concept describes an object, such as a building element's objects, certain specific characteristics or bundled properties (cf. ProIT 2004).

In this context, IFC Concepts are developed based on the proposed IFC Model View Definition Format (Hietanen 2006) of the BuildingSMART initiative. Based on the collected IFC classes referenced by the requirements the concepts which are needed for the realization of the IFC Partial Models for energy efficient building operations can be provided (Gökçe 2012). Each IFC Concept uses one (1:1) or many (1:n) IFC classes in its composition. On the other hand, IFC classes can be represented in one (1:1) or many (1:m) concepts to support different demands. For example in IfcClassification, arrangement of objects into classes and assignment of classification notation to objects have to be represented separately (Gökçe 2012).

6. REQUIREMENT ANALYSIS

The requirements needed for the IFC Partial Models for Hybrid Energy Systems are examined based on four scenarios: (1) Data Aggregation and Representation, (2) Building Performance Analysis, (3) Off-the-Grid Energy Generation, and (4) Artificial Intelligent based Predictive Control for Energy Efficient Management and Intelligent Energy Generation. These scenarios are proposed based an integrated platform suggested by Gökçe (2012), as depicted in Figure 2.

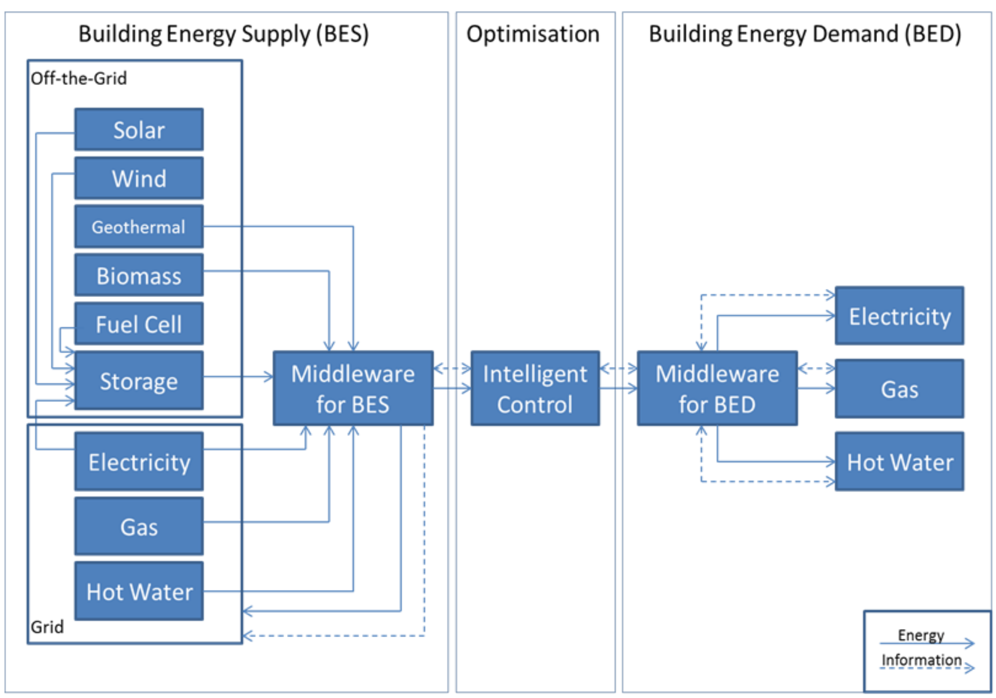

Figure 2: Integrated Platform for Hybrid Energy Systems

The developed system with regard to building energy demand side covers a modular platform as depicted in Figure 3 addressing intelligent energy management, that integrates multiple dimensions of building information such as performance data (e.g. energy consumption, temperature, light), system data (e.g. status, switch settings) and process data (e.g. inspection, maintenance, repair) which supports integration concepts, holistic monitoring and analysis methodologies, life cycle oriented decision support and information and communication technologies (Gökçe, 2010). This is implemented as an extension to international standards (e.g. IFC 2x3 ISO/PAS 16739).

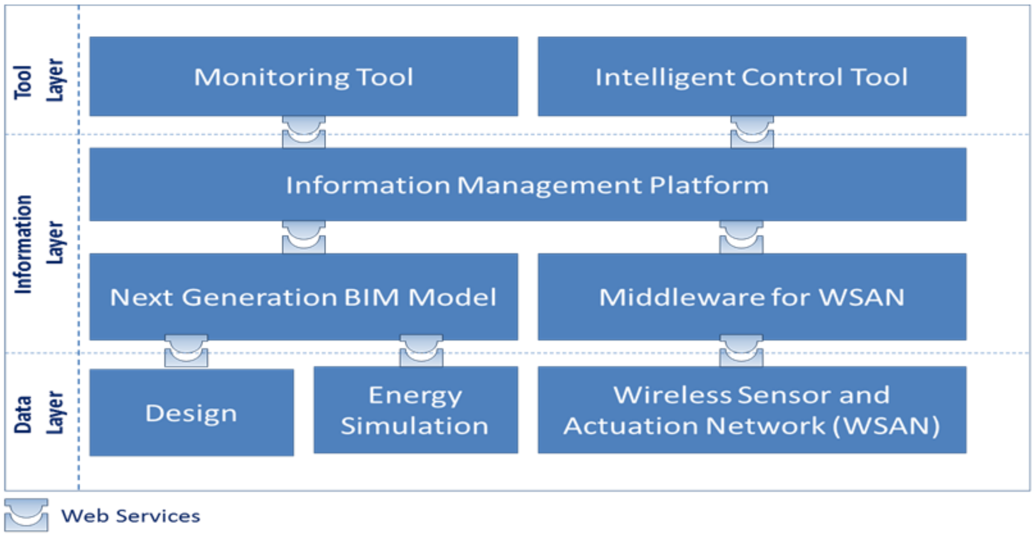

Figure 3: Application Layers for Intelligent Energy Management

In this paper, the requirements associated with the first scenario Data Representation and Aggregation, and their mapping to IFC classes will be partially presented. In this context, the dynamic data collected from the network embedded systems (sensor & actuation network) and the persistent data extracted from the BIM tools (design and energy simulation tools) are stored, aggregated and represented to the stakeholders for performing multi-dimensional analysis of the building performance. The system extracts sensor data from wireless sensor/meter network via a developed middleware for WSAN. The proposed Information Management Platform is composed of: (1) Operational data store, (2) Extraction Transformation and Loading (ETL) tool, and (3) Data Warehouse core. Collected sensor/meter data is stored in the operational data store for data cleansing and redundancy check processes. This pre-processed data is loaded to the fact data section of the data warehouse system via an Extraction, Transformation, and Loading (ETL) tool. The ETL tool is also used to populate the dimensional tables by extracting data from the BIM tools as depicted in Figure 4. Loaded fact data and dimensional data is aggregated with regards to different stakeholder requirements in the data warehouse core and presented through specific Graphical User Interfaces.

In this case, the IFC Partial Models can be developed based on the requirements of the dimensions such as location dimension, organization dimension, HVAC dimension and time dimension developed for complex data queries.

In order to formalize the transition from exchange requirements to an IFC Partial Model definition, the information defined in these dimensions is examined with regard to the IFC data model. An established requirement can define one or several IFC Classes as given in Table 1.

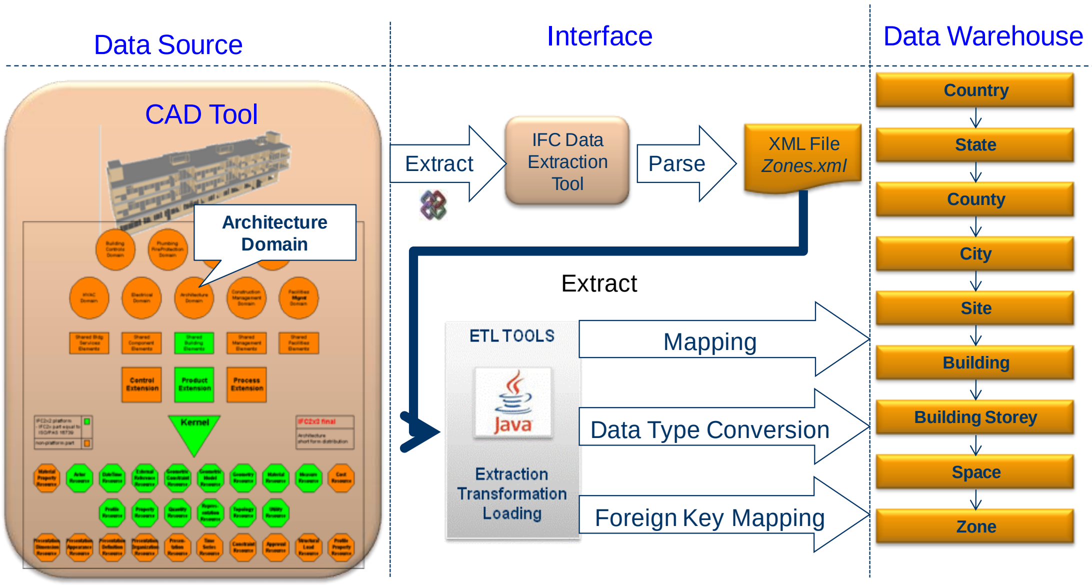

Figure 4: The ETL Process for Populating the Location Dimension Table

Table 1: Requirements Mapping - Location Dimension to IFC Classes (partial representation)

Requirements for Location Dimension	**IFC Classes Referenced by the Requirements for Location Dimension**
IDs	**** IfcRoot***
Building	**** IfcBuilding, IfcBuildingStorey***
Building Zones	**** IfcZone***
Building Spaces	**** IfcSpace, IfcSpaceType***

An IFC Partial Model contains one to several IFC Classes. These classes are represented in a network of mutual inter-dependencies that collectively define IFC Concepts, specified as standard one page description of the new IFC Model View Definition Format (Gökçe 2012). An IFC Partial Model View comprises several IFC Concepts which define the complete set of needed IFC Classes as depicted in Table 2. GMSD is used to formalize the proposed views and to explicate the respective IFC Subset Content.

Table 2: Mapping of IFC Classes to IFC Concepts for IFC partial model development (partial representation)

IFC Classes Referenced by the Requirements for Location Dimension	**IFC Concept for Location Dimension**	**IFC Partial Model for Hybrid Energy Systems**
**** IfcRoot***	*** Location Concept**	**The integration of Concepts provides the IFC Partial Model for Energy Efficient Building Operations**
**** IfcBuilding, IfcBuildingStorey***		
**** IfcZone***		
**** IfcSpace, IfcSpaceType***		

7. CASE STUDY

This new methodology has been applied in two buildings in Hannover - Germany. The sample buildings are office and residential buildings.

The following steps were undertaken to apply this scenario: (1) Building and Building systems have been modeled using building information modeling editor (Autodesk Revit), (2) Building energy performance has been simulated using the energy simulation tool (IES), (3) Wireless systems have been deployed, and (4) Data Warehouse services have been implemented based on the developed IFC Partial Models.

In this context, newly developed IFC Data Extraction Tool as depicted in Figure 4 extracts the data from a source application (e.g. CAD and Simulation Tools) and loads the extracted data to the Target Application (in XML file) based on the developed partial models.

The processes of the tool involve: (1) Information instances (based on developed dimensions) in the source application (e.g. CAD and Energy Simulation Tools) are extracted by the translator, (2) Extracted data is assigned to appropriate IFC classes, (3) the entity instance data are then mapped from IFC classes into a text file format defined by the ISO-STEP Part 21 (based on developed IFC Concepts), (4) this file is then received by the other application and interpreted by the receiving application's translator in terms of the IFC object instances it represents, (5) the translator in the target application (e.g. XML File) writes the relevant IFC objects into its native data structure based on the proposed IFC partial models.

The IFC data exchange scenario depicted in Figure 5 is used to provide exchange of IFC based standard data between Design, Energy Simulation tools and Data Warehouse Core.

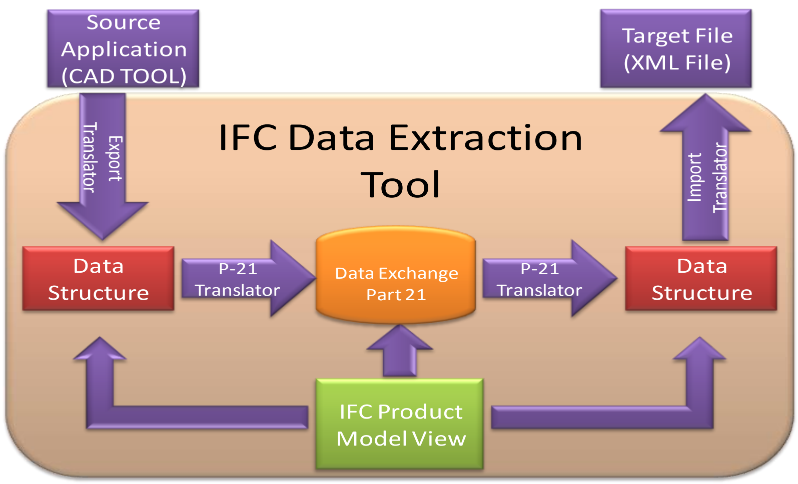

Figure 5: IFC Data Extraction Tool

8. CONCLUSIONS

In order to provide exchange of energy related data, based on the IFC data model standard in this work, a new methodology is proposed to develop IFC Partial Models for energy efficient building operations, which include minimal set of new IFC classes, data types and object relations. These IFC Partial Models support the exchange of energy related information based on defined requirements associated with dimensions structured in the data warehouse core. The mapping between dimensions' requirements and IFC classes is provided. These classes are brought together in a network of classes using so called IFC Concepts. The grouping of IFC Concepts enables the implementation of IFC Partial Models. This approach leads to the development of an integration methodology for existing domain applications and intelligent services. In order to formalize IFC Partial Models, IFC Concepts are developed based on the IFC View Definition Format of the BuildingSMART initiative. However, due to the specific requirements of our model, such as the representation of classes in EXPRESS-G, appropriate modifications are made in the formalizations. Realization of the IFC Partial Models based on the IFC Concepts is accomplished using the General Model Subset Definition Schema (GMSD) method. Validation of the developed concepts is provided with the help of the GMSD support tools. For applications on the field, two sample buildings in Hanover is used. In this context, a new IFC Data Extraction Tool is developed to extract the data from source applications (e.g. CAD and Simulation Tools) and loads the extracted data to the Target Application.

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