An approach for the extension of openBIM MEP models with metadata focusing on different use cases

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Abstract
Building Information Modeling (BIM) is one of the key technologies in the building and real estate industry and will have a great impact on the value chain of all stakeholders along the building sector. BIM methodology supports the overall building life cycle in which mechanical, electrical and plumbing (MEP) plays a central role. Properties such as the energy consumption and operating costs of a building are fundamentally determined by the quality of MEP planning and implementation. Studies have shown that open data interfaces such as industry foundation classes (IFC) and the interoperability between different software environments are particularly important for MEP planning. Several research studies show that openBIM data models for MEP are not yet fully applicable in real world projects. This paper explores which metadata is needed - and when - for BIM to deliver its benefits in the building life cycle. Furthermore, the use case building energy performance (BEP) simulation is investigated to identify the gap between the current capability to use IFC for MEP planning and BEP simulation, based on a typical hydronic heating system.

Introduction
The use of Building Information Modeling (BIM) represents a fundamental technological leap in the construction and real estate industries and has medium- to long-term implications for all stakeholders in the value chain of the construction sector. Mechanical, electrical, and plumbing (MEP) has a major part in this field. The quality of MEP planning and coordination is one of the central and most resource-intensive tasks in the construction process and it is crucial for energy consumption and human comfort within the building (Boktor et al., 2014; Wang and Leite, 2016). Studies show that open data interfaces such as Industry Foundation Classes (IFC) and interoperability between software environments are of great importance, especially in the area of MEP (Both et al., 2013; Kovacic et al., 2013). Uniform data models and modeling standards are important pre-requisites for open data exchange via openBIM. openBIM is a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows (buildingSMART-International, 2014). Current developments like, national standards such as the Austrian BIM standard ÖNORM A 6241-2 and the associated “ASI-Property Server”, as well as international standardization groups such as CEN/TC 442 are important activities in this context. Nevertheless, the current development stage of MEP BIM models shows that a comprehensive and consistent usage in different applications is currently limited. Because of information losses within MEP models using the openBIM approach, re-modeling is often part of reality. One of the reasons is, that the current standards for openBIM MEP models are not sufficient in terms of available information and parameters, to meet the requirements of a powerful continuous BIM planning (Castell-Codesal, Javier and Frantzen, Jürgen, 2015). Based on stakeholder feedback from the building domain, Hauer et al. (2018a) confirms, that missing parameters in IFC especially in MEP represent one of the biggest obstacles for a continuous use of the openBIM approach. Thus, this paper explores, which metadata is needed - and when - for BIM to deliver its benefits in the building life cycle. An approach to increase the quality of openBIM MEP models in terms of metadata in different phases of the building life cycle will be presented. This paper deals with the above questions focusing on the use case of MEP building energy performance (BEP) simulation.

State-of-the-art
MEP plays an important role in the BIM methodology. To enable a smooth and improved cooperation between different actors in the construction industry and interoperability between software environments (i.e. a data exchange in machine-readable form), different standardization activities and initiatives take place at different levels.

Standardization activities
Figure 1 shows a collection of important MEP BIM standards at national and international level: on the Austrian national level, two main standards ÖNORM A 6241 Part 1 and Part 2, focus on the use of digital building documentation. Part 1 specifies the digital data exchange, and data storage for information on building construction and related spatial civil engineering constructions, which are required for the management of real estate property over the life cycle (“ÖNORM A 6241-1,” 2015). Part 2 specifies the technical implementation of a unified,
structured 3D data model for building construction and related spatial civil engineering constructions based on BIM. It provides the bases for a comprehensive, unified, product-neutral, systematized exchange of graphical and metadata. Furthermore, it regulates the BIM workflow in an openBIM project over the entire life cycle of a building (“ONORM A 6241-2,” 2015). Based on Part 2 and the existing IFC data structure, an initiative called “ASI-Property Server” was developed. It is a freely accessible database which provides specifications for valid model contents (components), the associated responsibility (author), the delivery time (project phase) and the specification (value range).

Figure 1: Simplified overview, BIM standardization activities with focus on MEP (adapted according to Alvermann, 2016; Gamperling, 2017; Hauer et al., 2018b)

The German VDI department for building services (BS) deals with the development of the guideline VDI 3805 - Product Data Exchange in the Building Services\(^2\). The aim of this guideline is to create standardized data descriptions that allow to produce uniform product specifications in machine-readable form for different product groups. This standardization makes it possible for different CAD and simulation programs to use product data catalogs from different manufacturers without additional "interface programs" (Treek et al., 2016; VDI, 2018).

The international standard ISO 16757 (based on VDI 3805) deals with data exchange between MEP objects and software providers and aims to internationalize the national standard. The aim is to support the integration of manufacturer product data in uniform digital product data for the use in calculation, simulation and planning programs as well as in BIM models in general. ISO 16757 uses existing standards such as IFC and International Framework for Dictionaries (IFD) (Gamperling, 2017).

The international standard ISO 16739 deals with data exchange in the construction industry and in plant management and is continuously further developed by the internationally active organization buildingSMART\(^3\). This standard is the basis for a manufacturer-independent and cross-software data transfer of digital models. It is based on the specification of the Industry Foundation Classes (IFC) - a description of data structure and file format. The IFC specification is used for the universal representation of a real-world building as digital model (Hauer et al., 2018b). Despite several extensions, the current granularity of IFC attributes remains insufficient for applications such as thermal HVAC simulations (Treek et al., 2016).

At the European level, the CEN Technical Committee 442-Building Information Modeling is currently working on the topic BIM in 7 different working groups. The scopes of these working groups are standards, specifications and reports which specify methodologies to define, describe, exchange, monitor, record and securely handle asset data, semantics and processes with links to geospatial and other external data (Alvermann, 2016; CEN, 2018). The integration or interaction from international level to national level is shown with arrows in Figure 1.

**Stakeholder feedback from the building industry**

In the running research project metaTGA\(^4\), stakeholder feedback from the building industry was collected to investigate the following question: What is the applicability of current MEP BIM models from a practical point of view. The following challenges have been identified (Hauer et al., 2018b) among others:

- the reusability of IFC models or an error-free transfer between different software environments is often not possible, due to missing attributes in the IFC structure or the insufficient export capability.
- BIM models from manufacturers are often too detailed in terms of geometrical information. On the other hand, required metadata is often missing. The provided models should be made more manageable and have an adequate storage size by e.g., simplifying the geometry.

**IFC and BEP interfaces**

In the research community, different approaches and software prototypes have been developed to close the gap between BIM and various simulation environment for energy simulation. Currently there are different tools to extract geometrical and building property information from BIM models in order to transfer it to BEP simulation software, e.g., EnergyPlus, IDA ICE, etc. see for example: Bazjanac et al., 2011; Jeong and Son, 2016; O’Donnell et al., 2013. The problem of a correct space boundary representation is of particular relevance in this context.

Investigations were made to translate IFC to BEP simulation tools, e.g., EveBIM tool see Robert et al., 2014. This research was based on the standards IFC 2x3 and IFC 2x4. This stage of IFC was simply not able to deal with HVAC information. Liu et al., 2013 shows that the information content in IFC, green building XML\(^5\) (gbXML) and EnergyPlus schemas partially overlap, but it is not rich enough to meet the requirements of HVAC performance analysis in operation, even when combined.

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\(^2\) https://www.vdi.eu/engineering/vdi-standards/

\(^3\) http://www.buildingsmart-tech.org

\(^4\) www.metatga.org

\(^5\) http://www.gbxml.org
A solution is the extension or the definition of own property sets, containing necessary information of MEP/HVAC systems. For this reason, HVAC systems definition is left to a third-party tool relying on the targeted simulation tool’s data model (Robert et al., 2014). Even with the new IFC4 Add2TC1’s specification (extension of the domain HVAC), a detailed MEP/HVAC definition is often not possible without defining own property sets, as it is done in several software suites, e.g., CYPE7.

Current state-of-the-art research shows that IFC4 Add2TC1 is currently not able to provide a data structure and necessary attributes to deal with third-party simulation tools for MEP design. This research should support the standardization process and increase the quality of MEP components. The research results will be published in the standardization community.

General methodology

The following investigations are based on a standard heating system (see Figure 2), consisting of three main components: an air/water heat pump, a buffer tank (two inlet/outlet ports, no additional heating system or heat exchanger) and a floor heating system, which is a typical, HVAC combination in the D-A-CH region for newly built buildings. The system was chosen as an example to investigate following benefits: the introduced processes can be seen as general guide lines to be able to create more detailed MEP openBIM models used for BEP simulation and the BIM planning process, regardless if the component exists in the IFC4 structure.

This system will be analysed in terms of which attributes are needed for BEP simulation and of the capability of IFC4 Add2TC1 to handle (represent) these attributes in the current data structure. It should help to gain feedback of the usability of IFC and increase the usage in the building industry. In this practical example, the heat pump representation in IFC differs from other components. In this case, IFC is currently designed to store such systems as unitary equipment (IfcUnitaryEquipment) which is a set of components combined in a single product, e.g., air handlers, heat pumps, and split systems etc. The following analysis concerning IFC attributes was done on an overall heat pump product view, not of each single component like condenser, compressor, etc.

The following sections describe the overall approach of how to create the databases for a high-quality openBIM model including a basis for process modeling for different use cases, e.g., sizing of HVAC components, BEP simulation, etc. Furthermore, these results are used to identify the gap between the current capability to use IFC for MEP planning and BEP simulation.

7 www.buildingsmart-tech.org/ifc/IFC4/Add2TC1/html/
8 www.cype.com

![Figure 2: Standard heating system to be analysed consisting of an air/water heat pump, buffer tank and a floor heating system.](image)

**Process of data generation**

The first step in the analysis of MEP models was to generate a high-quality metadata basis for each component. Further requests from the metaTGA stakeholder feedback for MEP models were, e.g.:

- the developed models, in particular the specified attributes and metadata, should have a strong practical relevance and should consider the entire life cycle of a building, especially planning and operation.
- the developed models should be validated by experts to guarantee a strong practical use.

To meet these requirements a universal concept for metadata harvesting, defining of pre-requirements for process models and the usage of the metadata sets was developed as shown in Figure 3 - step 1. For each component, various sources of information (e.g., VDI 3805, Austrian standardized specification for building services (in German language: Standardleistungsbuch Haustechnik7), manufacturing data sheets, IFC4 Add2TC1, experience from experts) were analysed, resulting in a detailed parameter screening of the available metadata. The available parameters were examined for their practical relevance and reduced to the essential ones. Finally, parameters were grouped into categories with the same content, e.g., planning, sound emission, ports etc. Value ranges with corresponding SI-Units were defined for numeric parameters, if possible.

![Figure 3: Concept of a simplified process model for data harvesting, the definition of a basis for process modeling and the usage of the metadata sets.](image)

An essential question associated with this set of metadata is which data is needed - and when - for BIM to deliver its benefits over the entire building life cycle. These questions can be answered by the development of a process model for BIM use cases, e.g., sizing of HVAC components, quantitative determination, etc. using standardized languages like integration definition (IDEF) or business process model and notation (BPMN). As one development step, the metadata must be associated with different stakeholders and building life cycle stages according to the Austrian Standard ÖNORM A 6241 Part 2 - Appendix B10 and the Austrian scale of fee structures for architects and engineers (in German language: Leistungsmodell-Technische Ausrüstung LM.TA-201411) (see Figure 3- step 2). To ensure practical relevance of the developed results, a cross-check by experts is performed on a regular basis (see Figure 3- step 3). Finally, the set of metadata can be used for further developments of BIM process models or for high-quality openBIM MEP models supporting BEP or the BIM planning process by using a suitable data management platform like BIMQ12 (see Figure 3- step 4).

It should be mentioned, that these processes (step 1 to step 3 in Figure 3) ideally only need to be done once, e.g., in the course of standardization activities, or if companies want to establish their own BIM MEP/HVAC standards. As soon as this process is done or the results are publicly available, as it is planned in the metaTGA project, the time-consuming processes is reduced to a minimum, provided that the company already has BIM experience. Using this high-quality BIM models can save time during the BIM planning process of a building, because all relevant data is specified and assigned to the responsible stakeholder. This will make the BIM processes more effective and will save time and money.

First results and findings

The described workflow is the basis for the subsequent investigations of the introduced HVAC system. Each component was analyzed individually focusing on required metadata and their allocation to building project phases, with the main purpose to investigate the capability of IFC to support BEP simulation. The analysis focuses on three different BEP simulation tools: IDA ICE 4.8, EnergyPlus 8.6, and TRNSYS 17 including the TESS libraries Version 17.1.

As shown in Figure 2, three main components for detailed analysis were chosen: an air/water heat pump, a buffer tank and a floor heating system (pumps, pipes, valves and expansion storage were neglected). For each of these components, one component class (or “type”) is considered for each of the three simulation tools. This sometimes makes it necessary to choose a class among several alternatives. For instance, TRNSYS and the TESS libraries offer more than ten different types for the modeling of vertical stratified storage tanks, differing for instance in terms of integrated heat exchangers, fixed or variable inlets, uniform or non-uniform losses. In each case, the simplest type applicable to the modelled system was selected. For the buffer tank, a type without integrated heat exchangers, with fixed inlets and uniform losses was selected. Table 1 gives a summary of simulation components to be analyzed which fits best to the investigated components of considered heating system.

Table 1: Mapping between components to be analysed to the corresponding simulation components of each simulation environment

<table>
<thead>
<tr>
<th>Component</th>
<th>EnergyPlus</th>
<th>TRNSYS</th>
<th>IDA ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air/water heat pump</td>
<td>Col:Heating:WaterToAirHeatPump:EquationFit</td>
<td>Type 941 ([TESS library]</td>
<td>Air to water heat pump</td>
</tr>
<tr>
<td>Buffer tank</td>
<td>WaterHeater:Stratified</td>
<td>Type 534</td>
<td>water tank (with stratification)</td>
</tr>
<tr>
<td>Floor heating</td>
<td>Zone:HVAC:LowTemperatureRadiant:VariableFlow</td>
<td>Type 653</td>
<td>Floor heating/cooling layer + macro model floor heat</td>
</tr>
</tbody>
</table>

Table 2 gives an overview of the identified and chosen attributes for the individual components. It shows the total number of attributes for modeling for each component divided into categories (Nb. of attributes required for modeling) and an overview of how many parameters of each category are specified in IFC4 (white section):

- direct (this means the parameters could be identified directly in a corresponding property set of the component)
- indirect (this means the parameters could be identified in IFC only by its physical properties, but not directly associated to a property set of the component. It would be possible to extend the property set by its own metadata set, using existing IFC types of physical properties)
- missing (this means that it was not possible to identify these parameters in current IFC4 Add2TC1 standard).

Furthermore, it gives an overview which information sources have been taken into account in order to obtain a complete list of attributes as possible (blue section). Finally, Table 2 shows for each category and simulation environment (section green, red, dark grey), how many parameters are at least necessary for BEP simulation (column total min required) and how many could not be found in IFC and assigned directly or indirectly to the simulation environments (column missing in IFC).

A critical view on Table 2 shows, that none of the information sources is able to provide all necessary metadata, which has been identified as important for MEP BIM models. Furthermore, in the current IFC standard, only ~50% of the metadata can be stored in the existing...

11 https://www.ingenieurburo.at/media/Kwc_Basic_DownloadTag_Co
12 https://www.bim-q.de/index.php?id=8
IFC data structure. In all different categories, a lack of metadata could be identified.

Table 2: Overview of attributes (summarized in categories) for the components heat pump, buffer tank and floor heating system: where does the information come from (blue section), which data are at least needed for the use case BEP simulation in various simulation tools (total min required in section green, red dark grey) and how many attributes are missing in IFC from the point of view of MEP BIM modeling (light grey) or BEP simulation environment (green, red, dark grey section).

- Focusing on BEP simulation, the attributes required for HVAC performance simulation represent only a small share of attributes identified as necessary for planning, construction and facility management. Some categories of attributes, such as those related to weight, labeling, maintenance and guarantee, are generally not relevant for simulation. Geometry information is also mostly dispensable for simulation. Dimensioning and operation parameters as well as efficiency properties tend to be more relevant for simulation, which can be easily seen in Table 2. Generally, it seems that the intersection of the set of attributes necessary for simulation and of the set of attributes identified for the general planning, construction and operation processes is small. It appears that the data required for BEP simulation represents only a rather small share of the general data requirements identified in the stakeholder process.

Still, the parameters required for simulation of the example system components can for most part be found in the obtained data set or at least derived from it, with some limitations:

- a few parameters representing simulation options rather than component information, such as the number of nodes for tank simulation, are not present in the obtained data set.

- some parameters require a transformation from the BIM model to simulation parameters. For instance, heat pump performance (thermal output and compressor power) coefficients in EnergyPlus can be derived by curve fitting from performance at different operating points, which represent more sensible values to store in BIM. Another example are the locations of tank inlets and outlets, which may have to be translated from a height information into a node number, or thermal loss coefficients, which may be calculated based on material properties.

- in case of the buffer tank and the heat pump, IDA ICE seems to use a higher number of detailed physical parameters which one cannot assume to be represented in a general BIM model, such as an empirical parameter for temperature inversion. For such detailed parameters, the use of default values seems more plausible than translation from BIM.

Table 3: Overview of missing attributes needed for BEP simulation not represented in the current IFC4 Add2TC1 standard for the components heat pump, buffer tank and floor heating system

A deeper look into missing attributes needed for HVAC simulation but not represented in the current IFC4 Add2TC1 standard is provided in Table 3. It appears that some necessary attributes for BEP simulation are missing for all three simulation environments in general, e.g., heating source, nominal operation points for heating/cooling, total thermal power of heating circuit distributor, whereas other parameters, e.g., Required Energy Efficiency Ratio (EER) at specified operating conditions, etc. are depending on the individual model of the component of the various tools. For example, IDA...
ICE offers more flexibility in defining a heat pump, which results in the high number of missing parameters compared to IFC, than EnergyPlus and TRNSYS.

Table 4 shows the findings of the basis for further developments for process modeling for the example of heat pump. On the one hand, it gives an overview of the assignment of metadata to the life cycle phases of a building according to LM.TA. On the other hand, it shows which stakeholder is involved in a particular phase and is responsible for the various parameters. It seems that more than 50% of the parameters are necessary for the planning phase, since they need to be processed in planning-related phases (LPH1-LPH5) and due to the stakeholder involvement (e.g., HVAC planers, electricity planers, architects, etc.). The rest of the parameters is assigned for facility management and operation. Furthermore, Table 4 provides a summary of the total number of parameters for the other components buffer tank and floor heating system assigned to the different phases, which indicates a similar situation. Critically spoken, based on this case study, BIM - especially in the building and HVAC domain - seems to have its focus currently on the planning side, whereas its benefits for maintenance and operation have not been discovered yet.

Table 4: Information basis for process model development. Assignment of metadata to the life cycle phases of a building according to LM.TA and the involved stakeholders

<table>
<thead>
<tr>
<th>Phase</th>
<th>LPH1</th>
<th>LPH2</th>
<th>LPH3</th>
<th>LPH4</th>
<th>LPH5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting and dimensions</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Operation parameters</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ports (electrical, hydronic)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry information</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Label information</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material properties</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound properties</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance/repair</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Total attributes</td>
<td>100</td>
<td>54</td>
<td>42</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

The results imply that these models will have their advantage in all phases (planning and operation) during the building life cycle, since operation-relevant parameters are taken into account from the very beginning, e.g.: plant number, maintenance interval and activity, type of refrigerant, temperature ranges (supply, return), mass flow rates, pressure losses etc. In fact, it is a challenging task to keep track of these parameters during the entire life of a building. However, with the presented results, process models focusing on use cases for building operation or facility management can be easily designed and reduce the risk to forget necessary or relevant parameters for building operation.

Next Steps

The presented results from data harvesting and the assignment of metadata to the life cycle phases as well as the definition of responsible stakeholders is, according to Figure 3, the basis for further developments of openBIM MEP- and process models. This section gives an overview of necessary development steps to be able to use the models for daily business.

Current investigations of the capability of IFC supporting BEP simulations show, that there is a gap between available data in IFC and mandatory data within the simulation tools. To benefit from BIM in the current state of development - using BIM planning data of MEP models for BEP simulation - one possible approach is shown in Figure 4. Using a BIM information management platform like BIMQ, it is possible to create one’s own MEP models including metadata with a corresponding data structure. This platform serves as data server providing each involved stakeholder, the necessary information for the corresponding BIM process, e.g., sizing of HVAC components using BEP simulation. For native software tools like Autodesk Revit or ArchiCAD, it is already possible to create config files which map the customized MEP model of, for example, a heat pump with the corresponding family in Revit. Each single parameter from the BIMQ model is mapped to corresponding parameter in Revit or ArchiCAD. Furthermore, this platform allows to export model view definition (mvdXML) files. An mvdXML file provides the possibility to define a subset of models including implementation guidance or implementation agreements for all IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) used within this subset. It thus represents the software requirement specification for the implementation of an IFC interface to satisfy the Exchange Requirements (buildingSMART-International, 2015). In the author’s opinion, this functionality can be used for BEP simulation environment as well. Using this export function to create an mvdXML file like “Pset_BEP_HpsimParameters.mvdXML”; in combination with a software parser to map the parameters from mvdXML to the corresponding BEP simulation parameters, would make it possible to couple BIM with BEP simulation environments, as illustrated in Figure 4.

Figure 4: Approach of mapping detailed IFC openBIM MEP models into BEP simulation tools

Although the described approach needs to be further developed, implemented and tested, it shows one promising solution to couple BIM modeling processes
with BEP simulation. Looking at the market, some software tools try to offer this functionality using similar approaches. For example, the software simplebim\textsuperscript{13}, is one of the already existing software tools in the market, which tries to couple BIM models (using a plugin for IDA ICE to generate a customized IFC file, but focusing on geometry, spaces and material properties of the building only) with IDA ICE. Another tool is provided by the company CYPE\textsuperscript{14}, which creates own property set to be able to transfer parameters between their own software tools to be able to perform BEP simulation. 

**Conclusion**

This paper explores which metadata is needed - and when - for BIM to deliver its benefits over the building life cycle. It presents processes that need to be done once (e.g., in the course of standardization activities or to create one’s own company standard) to create the data basis for advanced openBIM MEP models, in order to increase the usability of BIM models in the field of MEP over the building life cycle. Therefore, the purpose of the created BIM model, needs to be discussed from the very beginning. The analysis shows, that current BIM models mainly serve the planning process which also includes BEP simulation. While the currently available ways to define components such as heat pumps in IFC are practically unusable for simulation, the models developed in the research project metaTGA presented in this paper would provide most of the input required for simulation, even though this input represents a small part of the entire range of proposed attributes. Still, differences in views between planning and construction processes on the one hand and simulation on the other hand mean that a one-to-one mapping between attributes defined in BIM and simulation inputs will not always be possible. For that reason, some mapping procedures, involving several attributes for one-to-many or many-to-one, have to be defined, in addition to a prototype to prove the concept of parsing IFC parameters to MEP parameters, as it is presented in this paper.

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\textsuperscript{13} http://www.datacubist.com

\textsuperscript{14} http://www.cype.com/en/