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# Integration of document- and model-based building information for project management support

Frank Opitz[a]*, Ronny Windisch[a], Raimar J. Scherer[a]

[a]*Institute of Construction Informatics, Technische Universität Dresden, 01062 Dresden, Germany*

**Abstract**

In spite of the upcoming BIM based work paradigm and related technologies in the AEC sector traditional semi- and unstructured documents, like formwork or reinforcement drawings, will remain an essential part of the overall project information resources. Such kind of documents are still the basis of the daily work in construction projects and are, in contrast to a BIM, valid as mandatory objects of agreement and integral parts of contracts. Therefore document management will remain a crucial part of the overall project management. Based on the fact that in the frames of practical projects traditional documents will coexist together with model-based building information the existing technological separation between those different worlds of information is counterproductive and out-of-time since it may cause information losses, inconsistent information resources and hinders an adequate and project wide adoption of BIM technologies. The aim of this work is to develop a practical method that allows for the use of IFC building information models within a database-driven project management environment to make model-based building information available for project and document management purposes. The proposed method will establish an integrated overall project information resource constituted by a persistent linkage between elements of the building model and the associated documents.



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*Keywords:* Building information modeling; document management; project management; IFC; data integration; document-object-links

## 1. Introduction

Building information is been represented traditionally by semi- or not formalized documents like construction drawings, specifications for building systems and material lists. Due to the upcoming method of Building

* Corresponding author. Tel.: +49-351-463-35741; fax: +49-351-463-33975.
*E-mail address:* frank.opitz@tu-dresden.de



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Information Modeling (BIM) the traditional way of building information representation is shifted to a model-oriented approach where the overall building information is stored in a commonly shared comprehensive building information model that allows for on demand retrieval of information subsets needed by downstream tasks and business processes [14]. Whereas the model based approach is widely adopted in the early project phases, e.g. for design, clash detection and coordination of disciplines, traditional documents are still the dominant information resource in the later project phases. In terms of practical projects this mostly results in a complementary but technological separated use of document and model based project information. Accordingly, existing BIM software applications and tools already used in practical projects are mostly focused on design phase offering functionality e.g. for building design, modeling and (3D) visualization. Downstream building life cycle phases like construction, operation and maintenance as well as general project management are still weakly supported by appropriate BIM tools. This might be one of the reasons for the slow implementation of the BIM work paradigm in the AEC industry [5] [8], in spite of the well documented benefits especially with regard to the later building life cycle phases [1]. This leads to a technological gap within the overall process chain and a setback from new model based working to traditional document based processes. Based on the fact that in the frames of practical projects traditional documents will coexist together with model-based building information the technological separation between those different information resources is counterproductive and out-of-time since it may cause information losses, inconsistent information resources and hinders an adequate and project wide adoption of BIM technologies. From this point of view a complementary linkage between model and document based building information on data level is supposed to re-connect the interrupted overall information process chain by establishing an integrated project information resource [7].

In practical project environments the use of document management systems (DMS) is common practice in order to cope with the large sets of documents generated during the project lifecycle. Modern DMS provide at least for archival storage of various types of documents, document lifecycle management and document retrieval ensuring reliable access to the set of stored documents. In most practical applications a DMS is integrated into a project management information system (PMS). A PMS allows for assignment between a set of documents and related (pre-defined) business processes in order to specify and control the workflow and information delivery with respect to the project requirements. However, in almost all cases the inclusion of a document into the DMS database is based on an alphanumerical document key stored in the document file name. The document key is created manually by the document owner (according to a given project specific document key schema, i.e. a given list of attributes and predefined sets of attribute values) and decrypted by the DMS based on predefined rules. This approach has several drawbacks since it is error-prone and restricted to a very small set of building and document information, consequently limiting the document retrieval and management capabilities offered by the DMS.

An alternative approach to this would be the application of embedded, descriptive document metadata which may serve as a bridge between unstructured/semi-structured and structured project information resources [10]. Document metadata represents structured information which can be used to describe the document content, its structure or administrative information to support resource management [11]. In combination with BIM-CAD authoring tools a significant part of the descriptive document metadata required for document management and information integration could be derived directly from the internal building model without the need for manually rework. Such kind of metadata enables a computer interpretable connection between a document and the related content of the corresponding building information model based on automated workflows for document validation, inclusion and integration. Furthermore, the capabilities and functions of new BIM data management tools and methods (e.g. model querying, 4D/5D model analysis and simulation, change management and model comparison) will become available for practical document and project management business processes if a reliable connection between the document and the model based information resources exists.

## 2. Link methodology

The suggested methodology aims to integrate document and model based information resources based on the application of explicit document-object-links which can be generated automatically and stored in a DMS data base.

This approach is dedicated to the application in the frames of practical project environments with strong focus on its efficient implementation based on existing PMS infrastructures consequently utilizing the capabilities offered by (open) standard and commonly used technologies like SQL, PDF and Industry Foundation Classes (IFC, ISO 16739). The Extensible Metadata Platform (XMP) standard [6] [18] is used for creation, processing and interchange of embedded and customized metadata. XMP is based on the W3C Resource Description Framework (RDF) [17] and provides an open but proprietary metadata methodology applicable for portable document files (PDF) [3] as well as various other kinds of resources. The XMP standard encompasses an extensible data model (including a set of defined core metadata element sets) and an RDF/XML syntax based serialization format [16] for concrete representation of metadata stored in a particular document.

### *2.1. Link types and semantics*

A document-object-link generally implies an explicit relation between a set of documents stored in a DMS and a set of objects contained in the corresponding building model. A link is defined by its type and additional link attributes specifying the link semantics. The type of the link indicates the cardinality of the relation and is basically determined by the documents type and contents. The cardinality specifies the valid number of elements contained in the document and object sets related by a particular link (Fig. 1). For example, a single link with cardinality 2:n (subtype of m:n link type), that indicates a relationship between exactly two documents and multiple model objects, is been described formally as a tuple $\{(d_i, d_j)\ (o_1, o_2, \ldots, o_n)\}$ containing two arrays with $d_i$, $d_j \in D$ (set of documents) and $o_1, o_2, \ldots, o_n \in O$ (set of objects contained in the corresponding building model). The elements of the document and model object sets are represented by the according element IDs.

Additional link attributes can be used to attach semantics to a link describing the indicated relation in more detail. Potential information to be attached to a link may be information about link creation (e.g. link creator, date of creation, parameters used for link creation), technical link specification (e.g. valid document and model object types, document format) or workflow management parameters (e.g. assigned work domain, task, actor or document status). The interpretable link semantics enable extensive link processing in terms of link validation as well as analysis of the integrated model data, e.g. by applying predefined link integrity constraints determining restrictions on the values of link attributes which are valid for a particular link. An example constraint may be the statement “For any building model object of type column, slab or beam with assigned material reinforced concrete a link to two documents, one of type formwork drawing and one of type reinforcement drawing, must exist (at a certain time)”.

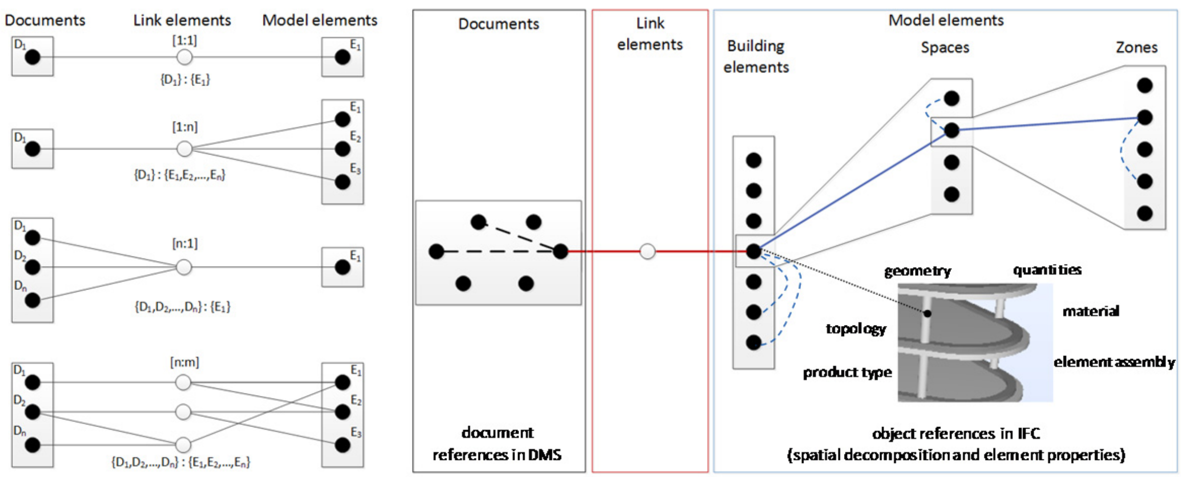


Fig. 1. Basic link types (left), transitive relations and additional object properties accessible by document-object-links (right)

Since the links provide for access to the BIM data the link semantics can be derived also by evaluating the object references of the linked model objects. For example, in IFC an object of type wall is related to a space object and each space object is related to the building storey object it belongs to (i.e. spatial zone object) by explicit object references. Due to the transitivity of the document-object-links the IFC object references can be used to represent the relations between documents and model objects in different levels of detail without the need for creating additional links (Fig. 1). Furthermore, the document-object-links enable access to a wide range of information stored in the building model like element geometry, quantities, material or topological information.

### *2.2. Link representation and storage*

In principle there are four different approaches to formally represent and store the information about the document-object-links which differ mainly regarding the amount of storable link information, information access capabilities, effort required for link creation, management and implementation in practical project environments:

1. Within the building model (i.e. using IFC): IFC provides for referencing external resources via accordant object type definitions (Fig. 2), i.e. instantiated references are part of the particular building model [2].
2. Using an external link model according to the multi-model approach (Fig. 2): The multi-model concept [4] [12] is specifically dedicated to the integration of non BIM data provided on the basis of standard or quasi-standard data models with no further expansion of the BIM. Thereby the involved models are linked by the application of a separated link model and kept separately manageable [9].
3. As a genuine part of an ontological model specification: This approach is based on an ontological representation of the integrated data model which explicitly defines the relations between the elements of the involved data models in a more holistic context [13].
4. Within the document meta model respectively within the schema of the DMS data base: This approach is similar to the approach using IFC as link container but in contrast to the IFC based approach the links are defined by the DMS data base schema and are stored in the DMS data base accordingly. Thus the document metadata schema represents a subset of the DMS database schema. However, the DMS oriented approach can be extended by the model-oriented approach if the derived link information is propagated to the IFC model data.

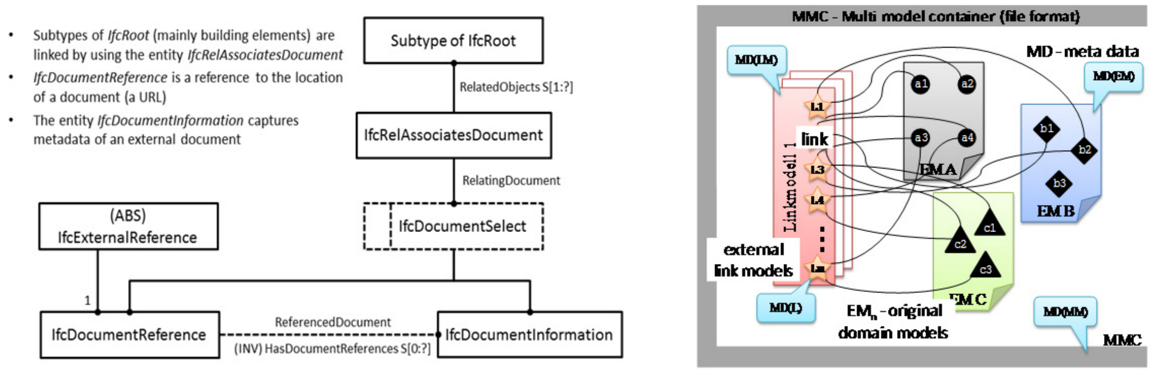


Fig. 2. Link representation and storage: part of IFC schema defining external document references (left) and Multi-model Container (right)

The methodology proposed here applies the latter approach for link representation and storage using embedded descriptive document metadata based on the XMP standard. The designed metadata schema is shown in Fig. 3.

Section A encompasses information about the building model containing the elements which are linked to a certain set of documents and the linked objects itself. This section is optional part of the document metadata but mandatory for the DMS data base schema. Section B specifies information about the spatial zone related to the contents of the linked document. It allows for document linkage on different levels of detail with respect to the spatial structure of the building and is used to support automated link creation process. It is mandatory for the document metadata schema but is optionally be used since spatial zone is not known in any case. Section C specifies information about the building elements contained in a document. This information is used for automated link creation process and is therefore mandatory for the document metadata schema as well as DMS data base schema. This information has to be exported by the BIM-CAD authoring tool or derived from the building model respectively and stored into the documents metadata. The information content of this section represents the minimum data set needed for consistent assignment between a set of documents and a set of model elements. The actual link is defined by the transitive relationship between *Document* and *ModelObject*. The remaining part of the presented schema specifies further information describing the document itself rather than its content or the document-object-links.

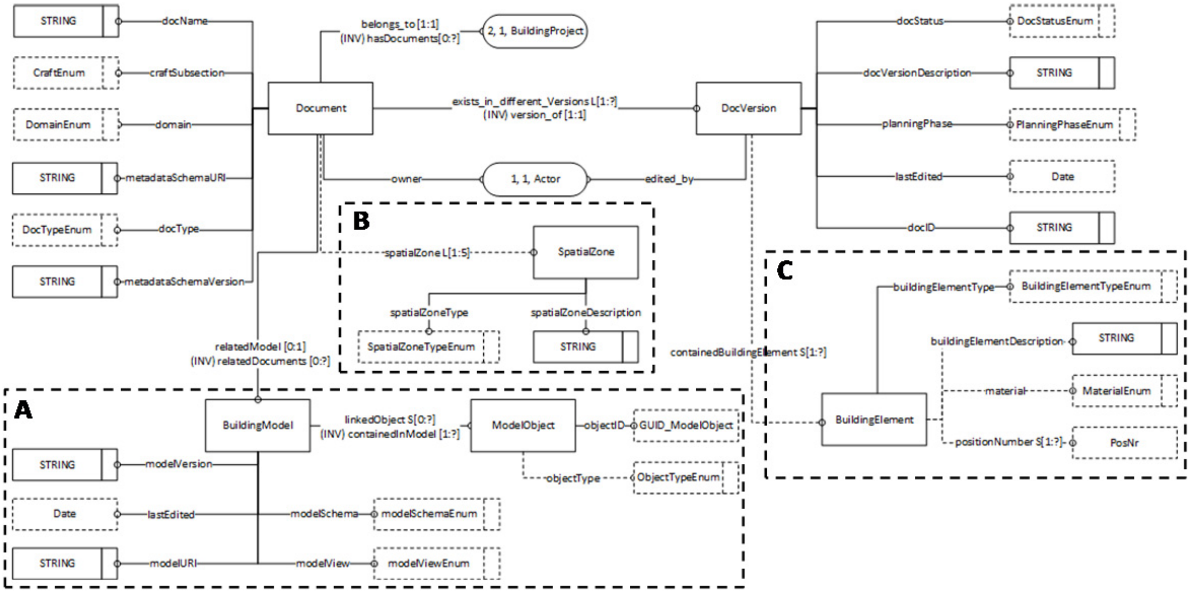


Fig. 3. Document metadata schema as part of the DMS data base schema

### 2.3. Link generation

It is obvious that due to the huge amount of elements contained in a building model as well as the large set of related documents the resulting set of links may become of enormous size. In most cases manual link creation will therefore not be appropriate for practical applications and has to be supported by automated link creation. The automated link creation process is based on a set of mapping rules which can be also configured on demand depending on the particular project requirements. The mapping rules specify the corresponding information subsets of both the document metadata and the IFC model data used for link creation. The information subsets specify a type of checksum which is used to identify a valid document-model object pair if the checksum derived from each the document metadata and the building model data is identical. The minimum information subset would be the Globally Unique ID (GUID) assigned to IFC model objects. A more complex information subset may be the aggregation of building element type, element material and spatial zone containment. The link creation process may also involve the evaluation of existing links, e.g. if the actual document to be linked is a revised version of an existing document.

### *2.4. Link utilization*

Once the links are created and stored in the DMS data base they can be used to analyze and query the resulting integrated model data. Model querying enables evaluation, analysis and assessment of the stored documents with respect to the particular information (or information subsets) described by the building model, e.g. for grouping and sorting of documents regarding different user perspectives on the building model or to support project coordination by identifying all relevant documents or drawings which are affected as a result of building model analysis (e.g. clash detection, construction simulation or cost estimation) and have to be re-worked according to the found issues and the involved building elements or zones. On the other side the building model may be analyzed or evaluated based on the information stored in the DMS data base, e.g. to trace and visualize the project progress or to support automated quantity take-off dedicated to particular contractors and the related set of documents.

However, querying the integrated model data requires link evaluation by starting either on the building model or on the document metadata side (i.e. the DMS data base), e.g. search for building model elements which are linked to a given document or vice versa. The query execution process evaluates the stored link information based on a mapping between the elements resulting either from a model or a DMS data base query and the related elements contained in the building model or the DMS data base respectively. A query can be also extended by various search conditions utilizing the link semantics, the available document metadata or additional information contained in the building model as well. For example, the user wants to search for all concrete building elements which have no reinforcement plan assigned.

### *2.5. Link Management*

The link management has to ensure integrity and consistency of the link information stored in the DMS database with respect to the linked building model. Since the building model as well as the document metadata is stored separately the set of link elements must be synchronized and dynamically adjusted following different rules for link management. Existing links may be updated (exchange of linked objects), modified (update of link attributes) or deleted by the DMS according to the link management rules or on demand by the user. For example, possible rules for link management are as follows:

- if a (linked) document is deleted the related link element is deleted too,
- if a document is deleted (archived or substituted) the related link element is retained,
- if a document ID is changed the related link attribute is updated,
- if the (relevant part of the) document metadata is changed the link creation process has to be repeated.

The most of these rules may be realized by standard database integrity constraints or stored procedures. In case the building model is changed (or a new model version was created) the stored link information has to be reviewed and the affected link elements have to be updated. This includes the creation of new link elements according to the applied model changes. Substituted or unused link elements should be retained in the DMS database in order to enable retracing of the link element lifecycle and restoring of older link element versions.

## 3. Implementation and use case example

### *3.1. BIMdox prototype*

The outlined methodology has been implemented in a prototypical software application called BIMdox. The Java-based prototype BIMdox is a tool to generate, modify and validate PDF documents with embedded metadata in Extensible Metadata Platform (XMP) standard based on a predefined metadata schema (see section 2.2). The created documents can be added to a connected DMS composed of a relational database and a document repository. BIMdox integrates the filter toolbox BIMfit [15]. BIMfit provides several filter functions for querying an IFC-based building model and is used to retrieve the IFC model data needed for link creation by the multi parameter matching process and for link processing as well. BIMdox allows for mapping between the relevant parts of the IFC schema, accessed via BIMfit, and the context dependent matching parameters of the link creation and link processing operations represented by the document metadata schema, queried by standard SQL. The BIMdox graphical user interface integrates a model viewer (http://www.ifctoolsproject.com) for 3D visualization of the IFC building model and enables user access to the interlinked information resources (Fig. 4).

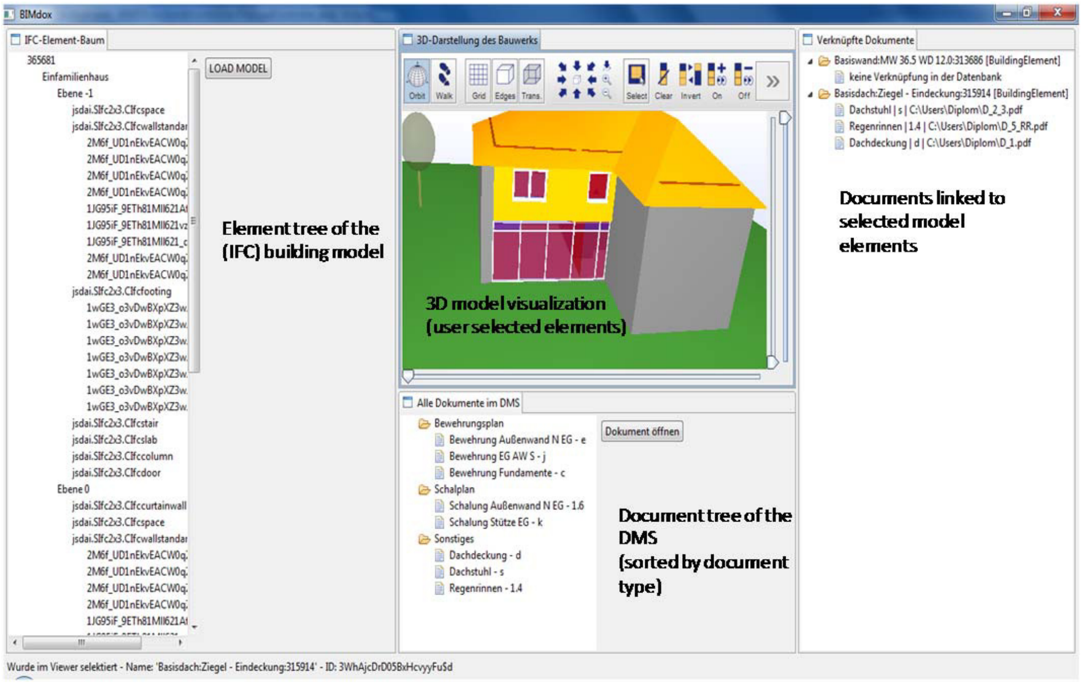


Fig. 4. GUI of the BIMdox prototype – document search based on user selected building elements enhanced by 3D model visualization

### *3.2. Creating the linked document-building-model*

The starting point of a particular use case scenario may be the export of a reinforcement plan (e.g. for a concrete slab of a residential building) in PDF format by using export interface of the used BIM-CAD authoring tool. Simultaneously all relevant metadata which can be derived from the internal data model of the CAD tool is serialized in XML and embedded into the document file according to XMP metadata standard and the predefined BIMdox metadata schema. In a second step the stored metadata is validated by the user and the program (BIMdox) checks if the metadata schema is implemented correctly. After successful validation the document is indexed (document ID is assigned, e.g. Doc_3g45) and stored in the DMS by integrating the document into the document repository and inserting the contained metadata into the DMS database (including the reference URI referring to the storage location of the document). Step three includes the selection and validation of the IFC BIM model by the user. Afterwards the document can be linked to the related model objects according to its contents described by the document metadata. For the automated link creation process at first the element type and the optional parameter *positionNumber* might be chosen if available since it allows for unique assignment of related building elements (in case GUID is maintained it should be used preferably). Depending on the number of building elements of type slab with the particular position number contained in the building model the resulting link will be of type 1:1 or 1:n. Since the element type and the position number are stored in the DMS database they can be queried by SQL. Accordingly, the IFC building model will be filtered by the related BIMfit functions applying object type and the value of the position number as selection criteria (selection of all objects of type *IfcSlab* and retrieval of the value of the *positionNumber* property for the set of building element objects selected prior). The returned set of values is matched against the SQL result set. If it evaluates to true the GUIDs of the related model objects are requested and inserted into the connected DMS data base (attribute *GUID_ModelObject* in *ModelObject*) by SQL data manipulation operation. The principle sequence of the link creation process (after the document is created and included into the DMS data base) is shown in Fig. 5.

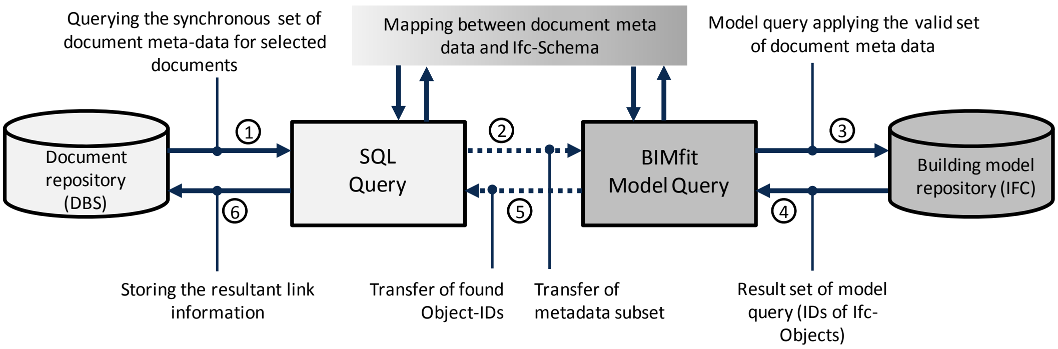


Fig. 5. General BIMdox link creation process

If the position number is not stored in the building model, or if no match is found, additional link parameters need to be applied. This might be the spatial zone where the given building element is located (e.g. building storey or space) and/or the assigned material. If the link creation process fails even after the application of all available parameters it must be assumed that the document is invalid (e.g. the metadata creation was defective). In this case the document is marked as "unlinkable" in the DMS data base and the user is notified.

### *3.3. Querying the integrated model data*

If the document-object-links are created they can be used to query the integrated model data using the BIMdox prototype (Fig. 4). A typical query may be the search of documents belonging to a particular building element. This type of query can be done easily by direct user selection of a building element either in the building element tree or the 3D model viewer integrated in BIMdox. If a building element is selected, e.g. a wall element of the 2nd floor, it will be highlighted in the model viewer and the GUID of the element will be sent to a SQL query filtering the corresponding documents by evaluating the available link data stored in the connected DMS data base. The resultant set of documents is displayed to the user as a list of document (file) names. The opposite type of query supported by the current version of BIMdox is the search of building elements which are related to a given document. Based on a user selected document the application identifies the IDs of the linked objects by querying the DMS data base. The returned IDs are assigned to a BIMfit model query to filter the related elements by the matching IFC object GUIDs. The search result is displayed to the user by highlighting the filtered building elements in the 3D model viewer.

A more complex query may be the search for all concrete building elements which have no reinforcement plan assigned. For this, all building elements with the value 'ReinforcedConcrete' in the attribute *name* of the referenced *IfcMaterial* objects are filtered first by executing an accordant BIMfit model query. The returned object GUIDs are stored and subsequently matched with the data sets of the attribute *GUID_ModelObject* listed in the DMS data base table *ModelObject* by using SQL query. This query involves also the *Document* relation checking whether the value of the *DocType* attribute is 'ReinforcementDrawing' or not. The difference of both result sets (result of BIMfit query and result of the SQL query) returns the set of reinforced concrete building elements which have no linked document of type reinforcement plan stored in the database. The retrieved object GUIDs are used to highlight the related building elements in the 3D model viewer.

## 4. Conclusions

It must be assumed that in the frames of practical projects traditional documents will coexist together with model-based building information. The existing technological separation between those different but strongly related information resources is counterproductive and out-of-time since it may cause information losses, inconsistent information resources and hinders an adequate and project wide adoption of BIM technologies. The presented work aims to develop a practical method that allows for the use of IFC-based building information models within a database-driven project management environment to make model-based building information available for project and document management purposes. The proposed approach is based on the application of embedded descriptive document metadata and explicit document-object-links which are stored in a common DMS data base system. Open standards (SQL, PDF, IFC, XMP) and common practice technologies are used for implementation in order to enable efficient integration into existing PMS infrastructures.

The integration of document and model-based information opens up numerous applications and benefits regarding document and project management. For example, visual support of the document search and retrieval can be enhanced by a 3D representation of the building model including the filtering of the building model according to different user perspectives and various multi-model criteria, e.g. for target-performance comparison in project management. The developed method is also suitable for the use on mobile devices (e.g. construction progress documentation, in situ recording of defects) as well as for integration of other document types (e.g. invoices, specifications) and media (photos, videos).

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