
Towards Registration of Construction Drawings to Building Information Models

Maciej Trzeciak

Technische Universität München · Arcisstrasse 21 · 80333 München · Germany ·
E-Mail: maciej.trzeciak@tum.de

The construction industry is on its way towards adapting Building Information Modeling. On one hand, this planning method based on digital models brings a number of benefits ranging from improved clash detection to further automation and development of the industry. On the other hand, however, the industry is still heavily dependent on construction drawings. To face this challenge, BIM design applications allow to derive drawings consistent with BIM models. However, due to a high level of fragmentation of the industry, construction drawings and BIM models are often exported to vendor-neutral formats and stay disjointed from each other. This fact leads to the situation that any discrepancy between them can easily arise in case of any modification of disjointed BIM models or construction drawings. In this paper, a closer look is taken at a general model-to-image registration process, and its applicability to the problem of positioning construction drawings against BIM models which is the first step towards the consistency verification between these two objects. Additionally, the author proposes the framework of a system which can be potentially used in the drawing-to-model registration process.

Keywords: BIM, construction drawings, drawing-to-model registration, 2D-3D matching

1 Introduction

The construction industry is in the process of adapting Building Information Modeling (BIM). BIM allows to generate a three dimensional digital model of a structure with a high level of associated information. On one hand, this planning technique brings a number of benefits, such as improved planning quality, clash detection, and precise calculations of quantity take-off for cost estimation. On the other hand, however, the industry is still heavily dependent on construction drawings, not least because they continue to be the obligatory and legally binding documents among contractual partners (designers, contractors, clients) and they remain to be the preferred medium of the design information delivery to the engineers and employees on construction sites. Additionally, it is common sense in the industry today, that BIM models should not be over-detailed as this would get the effort-benefit ratio out of balance. Instead, BIM practitioners agree that details should continue to be defined and delivered using conventional drawing-based approaches.

These facts imply the coexistence of construction drawings and BIM models in the industry for a significant time in the future. To face this challenge, professional BIM design applications provide deep geometric and semantic integration between 3D geometric representations of building elements and the respective 2D shapes in digital drawings and thus, allow to derive drawings consistent with 3D models. However, this consistency exists only in the proprietary formats of the respective software providers. Since the data exchange in the construction industry is of paramount importance due to its high level of fragmentation,

vendor-neutral formats have proved to be the most suitable approach. As disjointed drawings and BIM models representing the same built facility in vendor-neutral formats might be edited irrespectively of each other, inconsistencies may easily arise. It is often the case that disjointed construction drawings are further edited by modifying them and adding additional information using third party applications, which usually brings many discrepancies which currently cannot be automatically detected and must be coordinated manually. One of the steps towards the consistency verification between drawings and BIM models is the automated positioning of construction drawings against BIM models, further named the drawing-to-model registration.

2 Drawing-to-model registration

In a broader sense, the positioning of a 3D model against an image is known as the model-to-image registration (JUNG ET AL., 2016) or 3D-to-2D registration (WUNSCH AND HIRZINGER, 1996). The problem approached in this paper is actually the opposite since the idea is to register a drawing to a 3D model. Shape registration is a task of aligning two shapes in a shared coordinate system (SHAO ET AL., 2014), conceptually shown in Figure 1. The figure presents a drawing manually aligned to a BIM model. The aim of this paper is to introduce the possible automation of this process.

The shape registration process has been utilized across many various research domains, for example in sketch-based 3D shape retrieval (SHAO ET AL., 2014), or in matching aerial images to 3D building models (JUNG ET AL., 2016). The latter conclude, that the general approach to all 3D-to-2D registration problems has not been possible so far due to an individual nature of each problem. However, the following three steps have been common across most of the approaches: (1) feature extraction; (2) similarity measure and matching; (3) transformation.

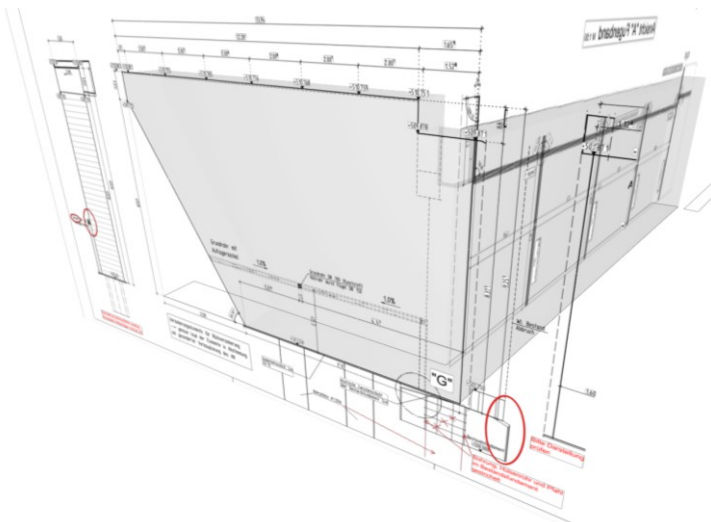


Figure 1: Solibri: a manually aligned construction drawing to a BIM model.

2.1 Properties of extracted features

Two different shapes are not directly compared. Instead, they are usually translated into feature vectors, also called shape descriptors, which are further used for matching in order to determine how similar two descriptors are (the similarity problem is under consideration in the next section). Shape descriptors, in turn, are instantiations of a certain shape representation as defined in (IYER ET AL., 2005). This section does not address the problem of how to extract features, but what properties should be considered so that a shape representation and thus the extracted features are applicable for the drawing-to-model matching.

Shape has been the subject of fundamental research in computer vision and robotics, and many methods proposed in these fields, have been also applied to solving a vast array of other problems in various domains of science. As (PU AND RAMANI, 2006) say, there is a popular belief that the contour of an object, understood here as the outer lines of the object, is a medium used for matching two objects with each other. Therefore, most of the proposed methods concentrate on the contour matching. However, contour-based methods do not seem applicable in the registration of construction drawings to BIM models, since the drawings, for example cross-sections, usually have complex internal structure (see Figure 2). Therefore, the shape-based methods applied for the registration here, should be discriminative enough to consider the differences in internal structure.

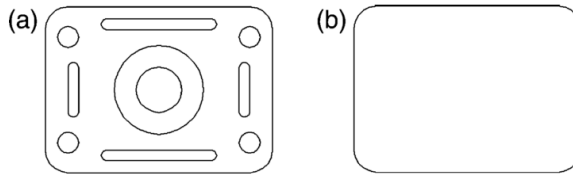


Figure 2: The difference between a drawing (a) and its contour (b). The contour is not enough for a meaningful description of the drawing (PU AND RAMANI, 2006).

Since engineering drawings are scaled and their shape in vendor-neutral formats remains disjointed from a 3D model, their shape representation must be invariant to transformation (here understood as translation-, rotation-, and scaling-invariance) in the 2D-to-3D matching process.

(TANGELDER AND VELTKAMP, 2008) consider a few other aspects related to the 3D shape retrieval domain, a few of which seem applicable to the problem raised here. One of them is already mentioned discriminative power of a shape representation. It seems to play a role in model-to-drawing matching because the point is to capture these properties which discriminate model and drawings well enough so that they can be properly matched. However, the issue of similarity of two objects can be subjective. For example, shapes of certain building elements in construction drawings in most cases are the direct orthographic or isometric projections of their 3D shapes in BIM models. However, the exceptions are such elements as doors, which are not the direct projection of its real 3D shape, but certain icons conforming to some engineering design standards. In addition, cross-sections of walls, for example, are filled in with certain hashing. There are dimensional lines describing shapes of building elements which do not exist in 3D models in the form of shape. Instead, this information is encoded in semantic attributes of information models. These elements cannot take part in the matching process based on shape. The question may arise if the remaining shapes are

enough to unambiguously match such a drawing to a model and how the matching process is affected.

2.2 Similarity measure and matching

According to (TANGELDER AND VELTKAMP, 2008) matching is the process of determining how similar two shapes are. It seems reasonable that the term “similar” must be defined in the context of measuring the similarity between a construction drawing and a BIM model. (WEN, TANG, AND SU, 2016) claim that the focus of the model-to-image matching concentrates mainly on the shape feature similarity measurement. This means that shapes are translated into feature vectors which are further used for matching in order to determine how similar two descriptors are. It is often called a correspondences or a matching problem. As mentioned in (IYER ET AL., 2005), similarity can be measured by a similarity metric, which, for shape feature vectors, is basically a distance function between pairs of these vectors. Feature vectors can be understood as points in feature space, between which the distance is measured. (TANGELDER AND VELTKAMP, 2008) add that the term dissimilarity better corresponds to the notion of distance because small distance stands for small dissimilarity, and large distance – large dissimilarity. The similarity measure described in this section do not work for relational data structures such as graphs or trees where other methods such as exact or in-exact graph matchings are used.

Depending on application, a metric should have desired and undesired properties. Let S be a collection of shapes. Then, a distance function d on a collection S is defined as $d : S \times S \rightarrow \mathbb{R}$, with the following possible properties for all shapes x, y, z in S (TANGELDER AND VELTKAMP, 2008). Remark: not all the possible properties are listed here.

1. Identity: $d(x, x) = 0$
2. Positivity: $d(x, y) > 0$
3. Symmetry: $d(x, y) = d(y, x)$
4. Triangle inequality: $d(x, y) + d(y, z) \geq d(x, z)$

As long as most of these properties seem self-explanatory, the interesting one might be the triangle inequality. If the partial matching is desired, property 4 should not hold. Given a small distance $d(x, y)$ if a part of x matches a part of y , Figure 3 returns: (a) a small distance between a man and a centaur; (b) a small distance between the centaur and a horse; (c) a large distance between the man and the horse (large dissimilarity). Since the sum of the first two components is less than the third component, the metric with property 4 will not work for partial matching. Therefore, (FAGIN AND STOCKMEYER, 1998) proposed to formulate a weaker form of this axiom, named a relaxed triangle inequality: $c(d(x, y) + d(y, z)) \geq d(x, z)$, for a constant $c \geq 1$, if the point of a metric is to partially match objects.

Partial shape matching (as opposed to global shape matching) finds a part of a shape similar in a part of another shape. This aspect seems particularly interesting while matching detailed drawings presenting only a part of the whole model. Additionally, it is often the case that the burden of detailing is shifted from models to drawings and thus the drawings contain more details than the models. A typical example can be a detailed drawing of a steel connection which contains additionally drawn screws and thin plates usually not existing in

a BIM model. Since these screws and other additional parts partially occlude the main building elements, the need for partial shape matching arises.

A very common distance function between two shapes $x, y \in \mathbb{R}^N$ is named L_p distance (also known as Minkowski distance) and is defined as follows:

$$L_p(x, y) = \left[\sum_{i=0}^N |x_i - y_i|^p \right]^{1/p}$$

For $p = 2$, the metric is basically the Euclidean Distance, which is commonly used for similarity measurement.



Figure 3: Original triangle inequality (4) does not hold under partial matching because $d(\text{man}, \text{centaur}) + d(\text{centaur}, \text{horse}) < d(\text{man}, \text{horse})$ (VELTKAMP, 2001).

2.3 Transformation

Once a drawing and a BIM model are matched well enough and the correspondences between them is established, there remains a matter of the actual alignment of these two in a shared coordinate system. The alignment process is done by the transformation i.e. translation, rotation, and scaling in a shared three dimensional space so that a drawing visually fits to a 3D model as conceptually shown in Figure 1.

According to (JUNG ET AL., 2016), the function responsible for the transformation should take into account such factors as geometric discrepancies between two data sets, the mechanism of data acquisition, and the required accuracy of the registration. The state-of-the-art solution is to compute the initial alignment based on the corresponding features and then, to apply a refine algorithm such as Iterative Closest Point – ICP algorithm (BESL AND MCKAY, 1992) for rigid transformations between two shapes (SHAO ET AL., 2014).

3 Proposed drawing-to-model registration framework

This section presents a conceptual framework for the drawing-to-model registration problem described in this paper. The idea is similar to the one used in view-based 3D Model Retrieval, in which two 3D models are similar if they look similar from different views based on the shape of these views. Accordingly, the 2D-3D matching problem is translated into the 2D-2D one. In this framework, a drawing is supposed to be registered in a specific place of the three dimensional space of a BIM model if the projection derived from that place is the most similar to the query drawing. Therefore, two major things are fundamental

in this approach: (1) The derivation system which builds a set of isometric projections based on a BIM model; (2) Shape representation and the related similarity measure method based on which a query drawing is compared to the projections derived from a BIM model.

The derivation system is supposed to work in a way that decreases a number of projections to be compared with the query drawing so that the solution space is not infinite. For example, uniformly distributed projections are supposed to be derived from a BIM model in a dynamic and construction-knowledge-oriented way following certain rules stipulated by the algorithm (for example, cross-sections are usually perpendicular/parallel to the main directions of a model and not at a certain angle).

Shape representation should fit the purpose of comparing a query drawing with projections. It can be based on the techniques used in the domain of engineering drawing retrieval. Therefore, such properties as invariance to translation, rotation, scaling and partial matching must be considered in finding the desired shape descriptor and its dissimilarity measure method. Figure 4 presents a scheme of the proposed system.

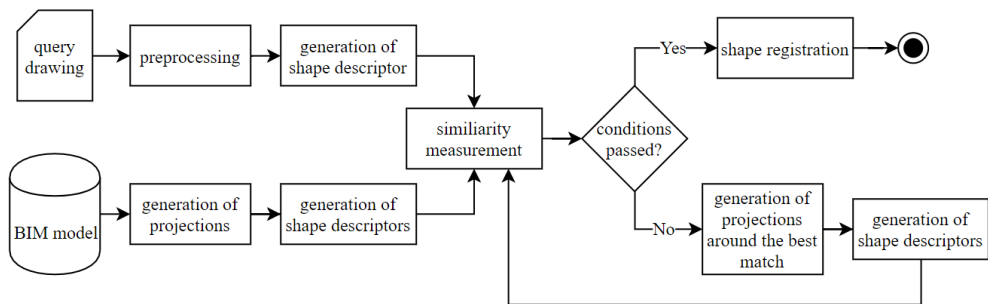


Figure 4: Proposed system for the drawing-to-model registration.

Since the shape of building elements in construction drawings in most cases is the direct orthographic/isometric projection of their 3D shapes in BIM models this approach can be applied after certain preprocessing of a query drawing and projections. In addition, the thickness of line segments must be considered so that only the elements which are cut by a cross-section (represented by a thick line) can be compared to a projection. In this way, the problem of a depth shown in the drawing can be eliminated. Besides, thin line segments, text and annotations must be excluded from the matching process.

4 Summary

In this paper, a problem of drawing-to-model registration in the construction industry is introduced. The author presents a general approach to the 3D-to-2D registration problem and renders it to the specific nature of positioning construction drawings against a BIM model. Properties of extracted features, the matching process, and the transformation of two shapes are considered in terms of their applicability to the raised problem. Eventually, the author proposes a conceptual framework for the drawing-to-model registration.

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