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A single solution method for converting 2D assembly drawings to 3D part drawings

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Abstract

Although solid models play a central role in modern CAD systems, 2D CAD systems are still commonly used for designing products without complex curved faces. Therefore, an important task is to convert 2D drawings to solid models, and this is usually carried out manually even in present CAD systems. Many methods have been proposed to automatically convert orthographic part drawings of solid objects to solid models. Unfortunately, products are usually drawn as 2D assembly drawings, and therefore, these methods cannot be applied. A further problem is the difficult and time-consuming task of decomposing 2D assembly drawings into 2D part drawings. In previous work, the authors proposed a method to automatically decompose 2D assembly drawings into 3D part drawings, from which 2D part drawings can be easily generated. However, one problem with the proposed method was that the number of solutions could easily explode if the 2D assembly drawings became complex. Building on this work, here we describe a new method to automatically convert 2D assembly drawings to 3D part drawings, generating a unique solution for designers regardless of the complexity of the original 2D assembly drawings. The only requirement for the approach is that the assembly drawings consist of standard parts such as bars and plates. In 2D assembly drawings, the dimensions, part numbers and parts lists are usually drawn, and the proposed method utilizes these to obtain a unique solution.

Keywords: Assembly drawing; Part drawing; Orthographic view; Solid model

1. Introduction

In recent years, solid modelers have become popular mechanical CAD systems. On the other hand, 2D CAD systems are usually used in the design of products that do not need complex curved faces. If products consist of a great many parts, 2D drawings are often more effective than solid models, because it is difficult and time consuming to create the solid models of the products. Despite this, solid models are still required for catalogs, manuals, etc. and so it is necessary to convert 2D drawings to solid models. In present CAD systems, this conversion is usually carried out manually, which can be troublesome when the 2D drawings become complex.

Though several automatic conversion systems have been developed, they cannot be applied in many situations because they can only deal with a single solid. Many actual products, on the other hand, are drawn as 2D assembly drawings consisting of several parts. In previous work, we attempted to solve this problem by proposing a method to automatically decompose 2D assembly drawings into 3D part drawings [1], from which 2D part drawings could be easily generated. However, one drawback to the method was that the number of solutions could easily explode when the 2D assembly drawings became complex.

In this paper, we propose a new method to automatically convert 2D assembly drawings to 3D part drawings, which overcomes the limitations of our previous method. To achieve this, the only requirement is that the original assembly drawing consists of standard parts such as bars and plates.

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When standard parts are used in 2D assembly drawings, the dimensions, part numbers and parts lists are usually listed. Utilizing this information, the method here is able to generate a unique solution, regardless of the complexity of the original 2D assembly drawing. This method has been partially implemented to verify the algorithm.

2. Related works

Many researchers have investigated ways to automatically convert orthographic views to solid models [2–7]. An early example is that of Idesawa [8], who proposed a method to automatically generate wireframe models and surface models from orthographic views. The wireframe models were generated by projecting orthographic views onto a 3D environment, and then a closed loop of wires was recognized as a face. In these models, a number of false wires and faces could be generated. Therefore, it was necessary to search for true wires and faces before the solid model solutions could be obtained. Idesawa proposed a search process to obtain the solutions from the surface models. However, it was found that the search process would become increasingly complex and the number of solutions would increase in proportion to the complexity of orthographic views. When the number of faces is n in the surface model, there are 2^n decisions to make concerning the existence of the faces before solutions can be found. Therefore, a more efficient search procedure has been required to obtain the solutions easily and quickly.

Wesley and Markowsky [9] proposed a method that obtained the solutions by blocks. Each of the blocks was recognized as a closed region of faces in the surface model. There could be some false blocks, and so true blocks were searched to obtain solid models as the solutions. Since the number of blocks is much fewer than the number of faces in each orthographic view, blocks are more effective than faces in the search process to obtain the solutions. However, Wesley and Markowsky did not indicate an efficient algorithm to obtain solutions from blocks. Therefore, when the number of blocks made from an orthographic view was n, their method searched 2^n combinations of the blocks to obtain the solutions. As a result, it was difficult to apply their method to complex orthographic views.

In Wesley and Markowsky's method [9], the faces of blocks were limited to planes. Sakurai and Gossard [10], on the other hand, applied cylindrical, conical, spherical and toroidal faces to the blocks, and Dutta and Srinivas [11] proposed a method to convert two polygonal orthographic views to solid models. In previous work, we proposed a method that effectively reduced the search process for true blocks [12,13] and extended this method to 2D assembly drawings [1]. However, there was still an issue that the number of solutions easily exploded when the 2D assembly drawings became complex. In this paper, we propose a method that solves this problem for 2D assembly drawings.

In Section 3, we review the authors' previous method to convert 2D assembly drawings to 3D part drawings. In Section 4, we show how this approach can be modified to generate unique solutions even for complex 2D assembly drawings. In Section 5, we offer a number of examples that demonstrate the effectiveness of the proposed method. In Section 6, we discuss some of the limitations of the method, and in Section 7, we make our conclusions.

3. Overview of original method

3.1. 2D vertices and edges

When 2D assembly drawings are input into a CAD system, the outlines are divided into straight and curved lines. These lines are called 2D edges. The end points of the 2D edges are called 2D vertices. 2D edges and vertices correspond to edges and vertices of 3D assemblies, although some 2D vertices and edges appear as silhouettes if the 3D assemblies include curved faces. Since these silhouettes are needed to make the wireframe models of the 3D assemblies, all 2D vertices and edges that can exist as silhouettes are drawn in the 2D drawings. These are called silhouette 2D vertices and edges.

Fig. 1 illustrates a product (Example 1) that consists of two parts. The coordinate systems on the front view and top view of Example 1 are $x-z$ and $x-y$, respectively. The 2D vertices and edges of Example 1 are recognized as in Fig. 2. In this figure, a dash-dot 2D edge on the front view is a silhouette 2D edge.

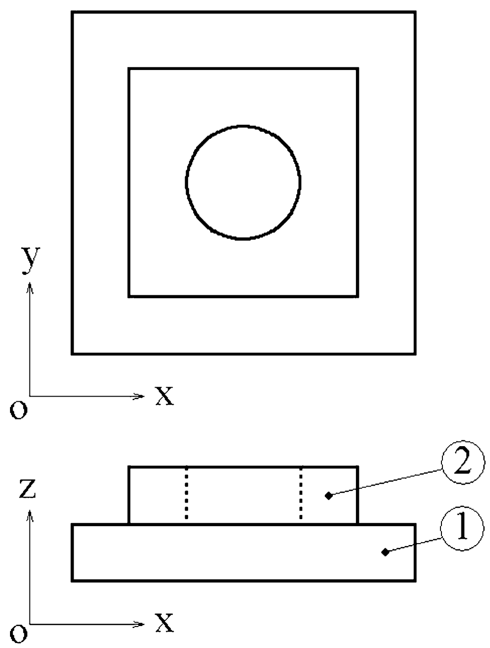


Fig. 1. Example 1.

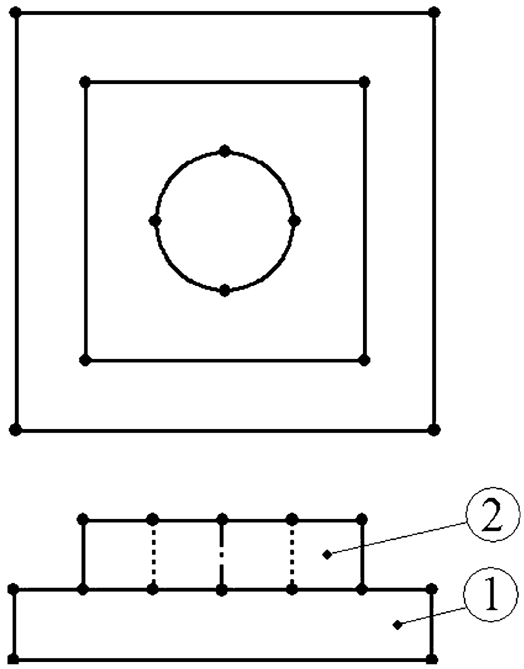


Fig. 2. The 2D vertices and 2D edges of Example 1.

3.2. 3D vertices and edges

The combinations of 2D vertices of front views and top views can be used to make vertices of solid models of assemblies. Each 3D edge that can correspond to 2D vertices and/or 2D edges are drawn between two 3D vertices. If two or more edges cross each other at a point other than one of the 3D vertices, these edges are erased in this method because they can easily generate redundant solutions [11]. Fig. 3 illustrates all the 3D vertices and edges that form the wireframe model of Example 1.

3.3. 3D faces, blocks and 2D faces

A face is recognized as a closed loop of edges. Fig. 4 illustrates each face of Example 1, which combine to form the surface model of Example 1. Note that the method can also use curved faces as in Sakurai and Gossard's method [10]. A block is recognized as a closed region of faces. For Example 1, three blocks ($B1, B2, B3$) are recognized as in Fig. 5. A 2D face is recognized as a closed loop of 2D edges,

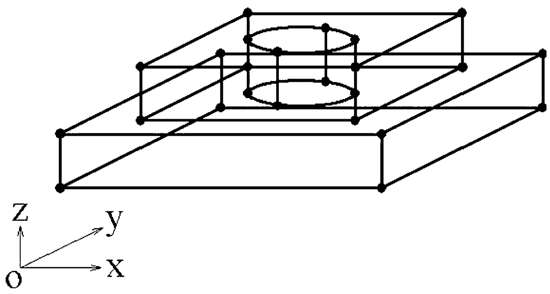


Fig. 3. The wireframe model of Example 1.

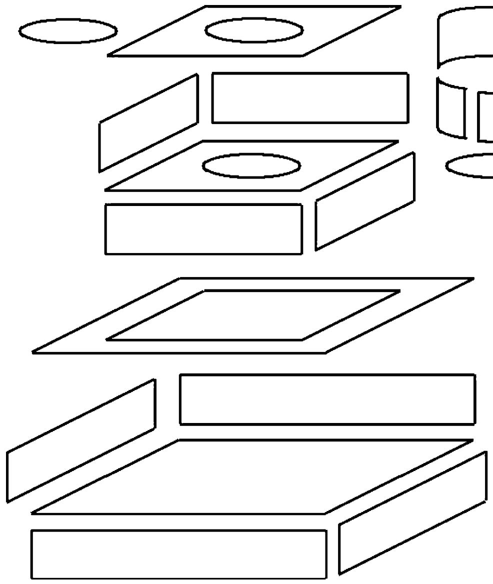


Fig. 4. Each face of Example 1.

with the exception of silhouette 2D edges. 2D faces are used to find false blocks. Fig. 6 illustrates each 2D face and part number for Example 1.

3.4. Search for solutions

The solutions are obtained by combining true blocks for each part. Fig. 7 illustrates the relationships between 2D faces and blocks for Example 1. In this figure, suppose both $B1$ and $B2$ belong to the same part. Then, four 2D edges forming a circle on the top view of Example 1 would be erased. This contradicts with the actual 2D assembly drawing of Example 1, and therefore, it is found that neither $B1$ nor $B2$ belong to the same part. Similarly, suppose $B2$ is false. Then, four 2D edges would be erased on the top view, which contradicts with the actual Example 1. Therefore, it is found that $B2$ is true, and belongs to part 2, because its part number points to a 2D face of $B2$. In the same way, it is found that $B3$ belongs to part 1, and $B1$ is false or belongs to part 1. Therefore, two solutions are obtained as in Fig. 8.

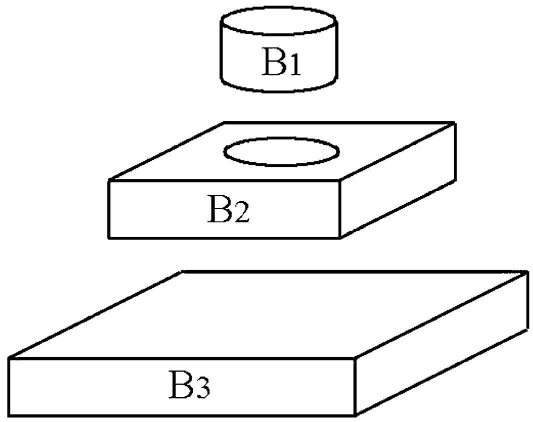


Fig. 5. Each block of Example 1.

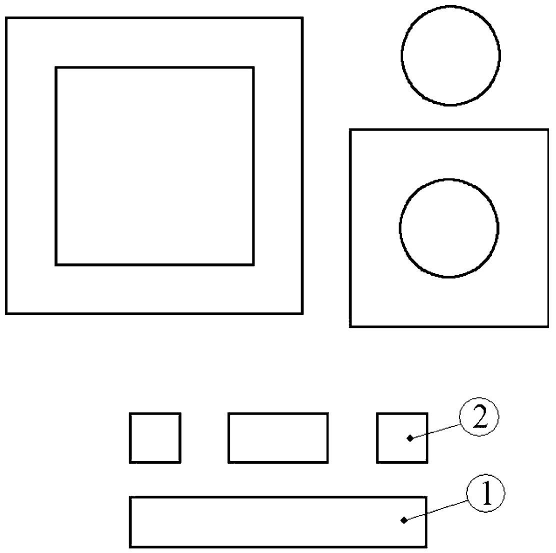


Fig. 6. Each 2D face of Example 1.

3.5. Complex drawings

Since Example 1 is a simple 2D assembly drawing, only two solutions are obtained. However, when 2D assembly drawings become complex, the number of solutions increases rapidly. Fig. 9 shows a complex drawing of a table consisting of six parts (Example 2), and Fig. 10 illustrates the wireframe model of Example 2. Fifteen blocks are made from the model as in Fig. 11. To obtain solutions for Example 2, 2^{15} combinations of the blocks are possible. Using our original method, 107 solutions were generated, two of which are illustrated in Fig. 12. In Section 4, we show that if Example 2 is recognized as an assembly that consists of only bars and plates, the strange solutions such as those in Fig. 12 will never be output.

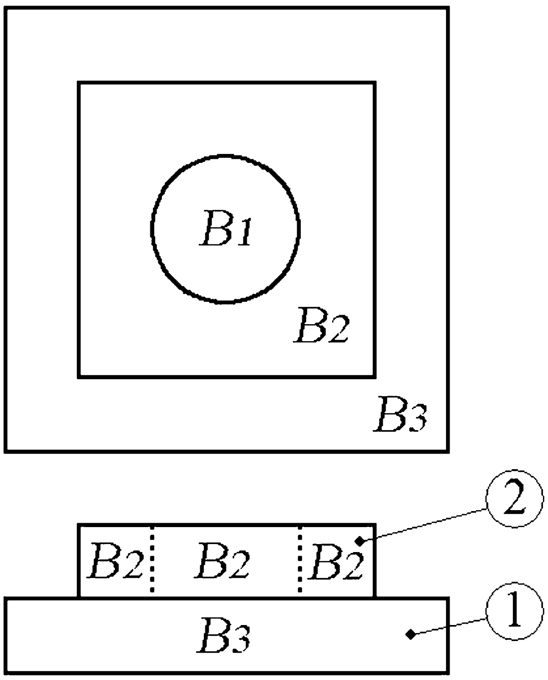


Fig. 7. The 2D faces and blocks of Example 1.

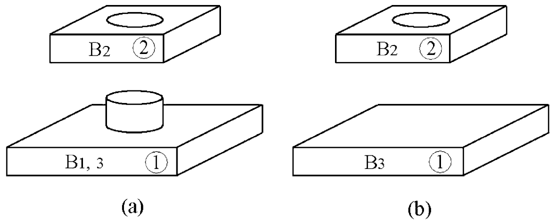


Fig. 8. Two solutions for Example 1.

4. A novel method to convert 2D assembly drawings to 3D part drawings

Standard parts, such as bars and plates, are often used to design products, and the dimensions, part numbers and parts list are usually indicated in the 2D assembly drawing.

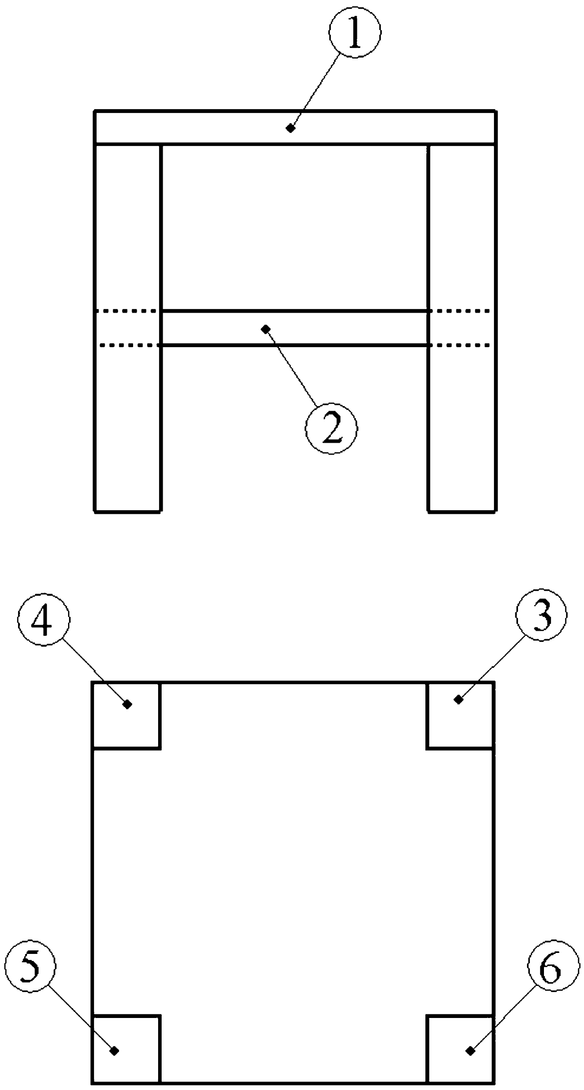


Fig. 9. Example 2.

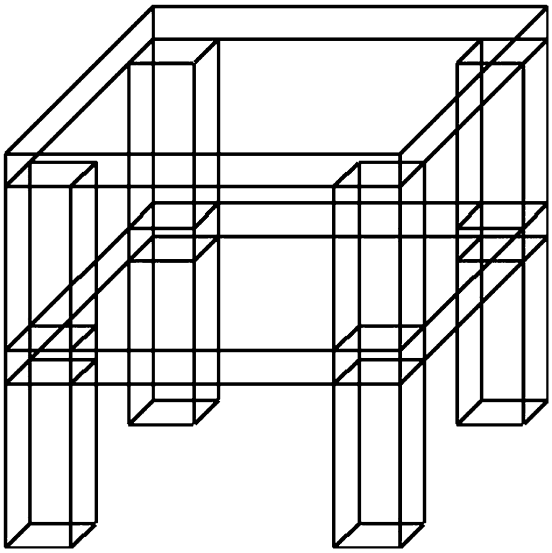


Fig. 10. The wireframe model of Example 2.

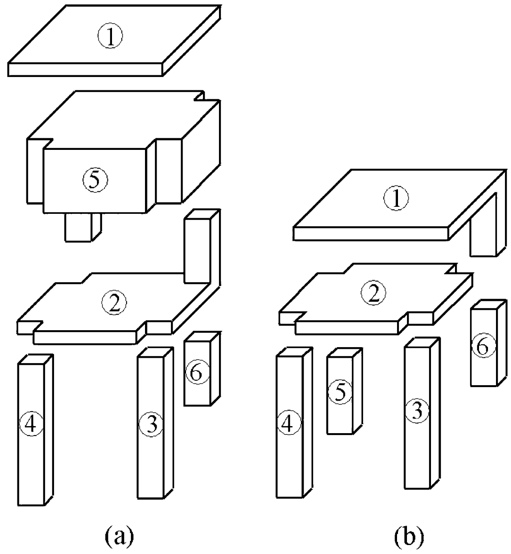


Fig. 12. Two examples of the solutions for Example 2.

The proposed method utilizes the dimensions and parts list to convert 2D drawings to solid models. If the dimensions and parts list are added to the assembly drawing for Example 2, the resulting drawing is that given in Fig. 13 (Example 3). This figure will be used as a test 2D assembly drawing for the method proposed here.

The basic algorithm to convert the 2D assembly drawing to a 3D assembly model is as follows

1. Input 2D assembly drawing.
2. Separate 2D assembly drawing into virtual 2D part drawings.
3. Recognize blocks from virtual 2D part drawings.
4. Search for true blocks for each part.
5. Output 3D assembly drawing.

Each step of the algorithm will now be explained in detail.

4.1. Virtual 2D part drawings

When a 2D assembly drawing is input, the 2D vertices, 2D edges, 2D faces, part numbers and parts list are first

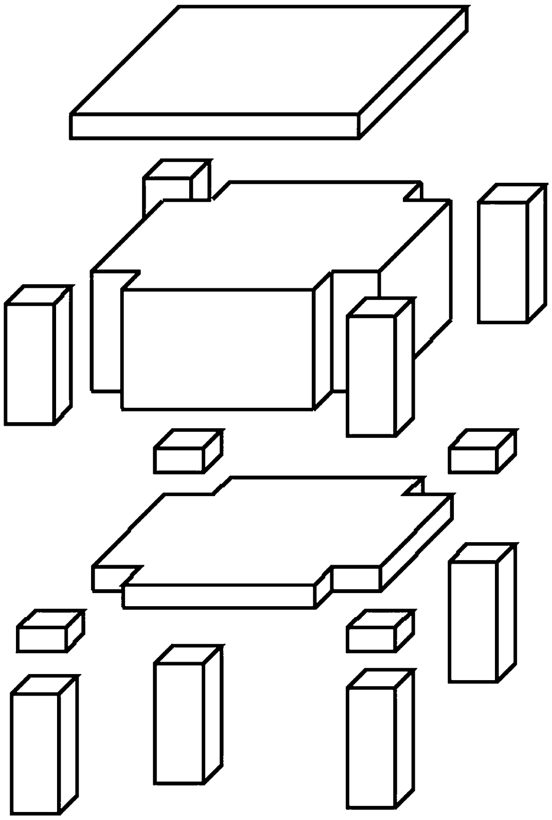
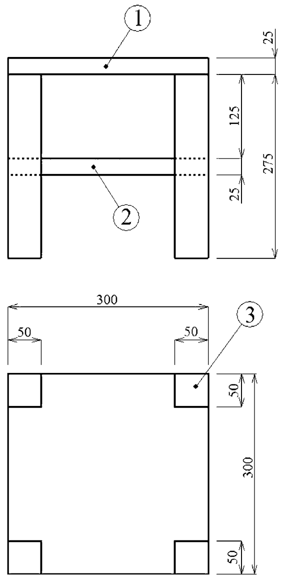


Fig. 11. The blocks of Example 2.



NO.	SIZE	QTY
1	25×300×300	1
2	25×300×300	1
3	50×50×275	4

Fig. 13. Example 3.

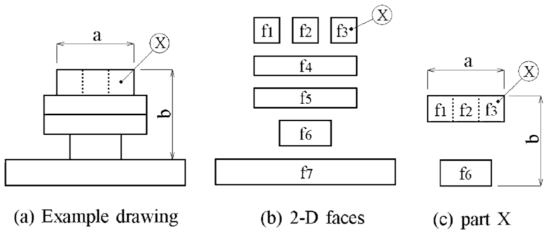


Fig. 14. An example to make virtual 2D part drawings.

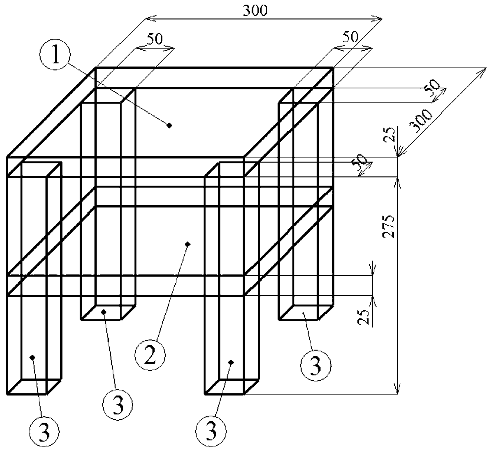


Fig. 15. The solid models of parts defined in the parts list of Example 3.

recognized. The experimental system for the proposed method uses Drawing Interchange File (DXF) files as CAD files. Using DXF files enables lines, texts and dimensions to be distinguished as different entities from each other. For example, each dimension is expressed as a block of text and lines in DXF files. The parts list is recognized as a table consisting of straight lines and characters. Each part number can be recognized as a circle containing a number and a leader line attached to the circle. If a part forms a cylinder, its size is expressed as $\phi a \times b$ in the parts list, and if a part forms a cuboid, its size is expressed as $a \times b \times c$ in the parts list. When the size of a cylinder or cuboid is recognized from the parts list of the 2D drawing, a rectangular or circular region corresponding to this part is recognized in the 2D drawing and separated from the drawing as a whole. We refer to these separated regions as virtual 2D part drawings.

Fig. 14 illustrates an example to make virtual 2D part drawings. Fig. 14(a) is an example 2D drawing. There is a part X with size $a \times b$ in this figure. Fig. 14(b) illustrates each 2D face ($f1, f2, \ldots, f7$) recognized from Fig. 14(a). It is recognized that part number X points to $f3$. Each virtual 2D part drawing must consist of 2D faces recognized from its original 2D assembly drawing and must form one closed region in each view. Therefore, 2D faces are not cut when virtual 2D part drawings are made from their original drawings. Also, 2D edges that do not form any 2D faces are excluded from virtual 2D part drawings in this process. The separation of virtual 2D part drawings from their original drawings is performed by extending the leader lines of dimensions automatically. If some dimensions lack leader lines, the required leader lines are added to the dimensions. As a result, the virtual 2D part drawing of part X consists of $f1, f2, f3, f6$ as in Fig. 14(c). In this figure, since part X consists of two separated regions, it is found that Fig. 14(a) is not a correct drawing.

In the parts list for Example 3 (Fig. 13), it is recognized that there is one part 1 with a size of $25 \times 300 \times 300$, one part 2 with a size of $25 \times 300 \times 300$, and four part 3, with a size of $50 \times 50 \times 275$. Dimensions that correspond to the six parts in the list are searched in the 2D assembly drawing. Fig. 15 shows an overview of the solid model solutions of all parts of Example 3. Fig. 15 is different to the wireframe model in Fig. 10, as it includes both the part numbers and dimensions obtained from the dimensions, part numbers and parts list in Fig. 13. Fig. 16 illustrates three virtual 2D part drawings for Example 3, where the four part 3 are represented by the same front and top drawings. The virtual

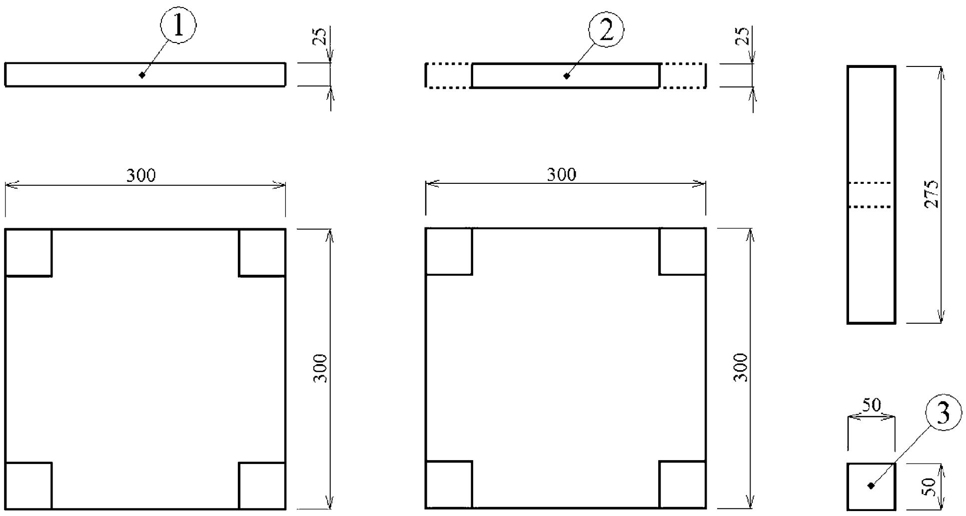


Fig. 16. Three virtual 2D part drawing for Example 3.

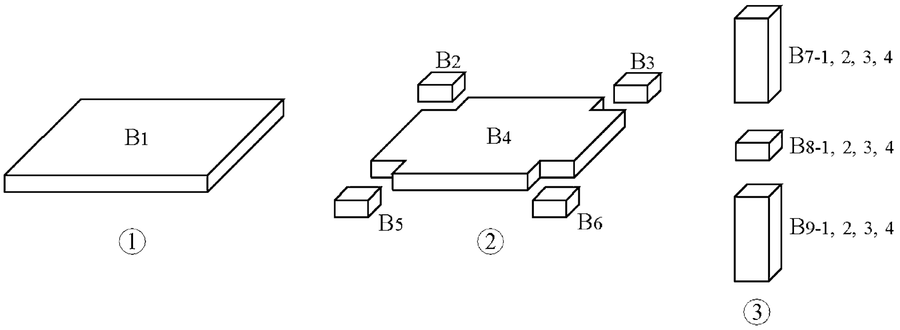


Fig. 17. The blocks recognized from Fig. 14.

2D part drawings in Fig. 16 contain the information needed to generate exact solid models of each part as the solution.

4.2. Four conditions to determine existence of blocks

In the proposed method, blocks are recognized in each virtual 2D part drawing by constructing wireframe models and surface models as described in our earlier paper [1]. The existence of each block is decided for each part to obtain the solutions. If the truth of a block cannot be decided, it is called an undecided block. Fig. 17 illustrates the blocks recognized from Fig. 16. Since there are four part 3, there are four blocks called $B7$-$1,2,3,4$, four blocks called $B8$-$1,2,3,4$ and four blocks called $B9$-$1,2,3,4$ recognized for the parts as shown in Fig. 17. Fig. 18 illustrates the overview of the 3D relationships among the blocks in Fig. 17. In this figure, it is found that $B2$, $B3$, $B5$, $B6$ are the same blocks as $B8$-$1,2,3,4$. To obtain the solution, these overlaps of blocks must be excluded.

When true blocks are searched for in each part, the following four conditions are applied. Let us consider a part A in the 2D assembly drawing, and a block B that is recognized from the virtual 2D drawing of part A.

4.2.1. Existence_condition

If, without block B, the dimensions and/or part number in the virtual 2D part drawing cannot be generated when the solid of part A is projected, or part A does not form a solid, block B must be a portion of part A. For example, the candidates of blocks consisting of part 3 are $B7$-$1,2,3,4$, $B8$-$1,2,3,4$ and $B9$-$1,2,3,4$ in Example 3 and if one of them is false, one of part 3 cannot be projected to its virtual 2D part drawing or it does not form a solid. Therefore, all of the blocks must be true.

4.2.2. Overlap_condition

If block B overlaps part A and one or more other parts (part $A,'$ part A'', …), block B is true in only one part and is false in the other parts. For example, since $B7$-$1,2,3,4$, $B8$-$1,2,3,4$ and $B9$-$1,2,3,4$ are true in part 3 because of the *Existence_condition* described above, $B2$, $B3$, $B5$, $B6$ become false in part 2.

4.2.3. 2D edge_condition

If the types of 2D edge projected from block B change or disappear for block B to be true for part A, block B must be false for part A. For example, for $B5$ and $B6$ to be true in part 2, all of the dotted 2D edges must be changed into solid 2D edges on the top view in Example 3. Therefore, $B5$ and $B6$ are false in part 2.

4.2.4. Identity_condition

Suppose that there are two part A called part $A1$ and part $A2$. When the existence of all blocks in part $A1$ are decided and the existence is undecided for blocks in part $A2$, the undecided blocks can be decided as the shape of part $A1$ is the same as part $A2$. For example, if $B7$-1 is false, $B7$-$2,3,4$ become false, or if $B7$-1 is true, $B7$-$2,3,4$ become true in Example 3.

4.3. Search for solutions

The existence of almost all blocks can be determined by the *Existence_condition* and *Overlap_condition*. Subsequently, the *2D edge_condition* and *Identity_condition*

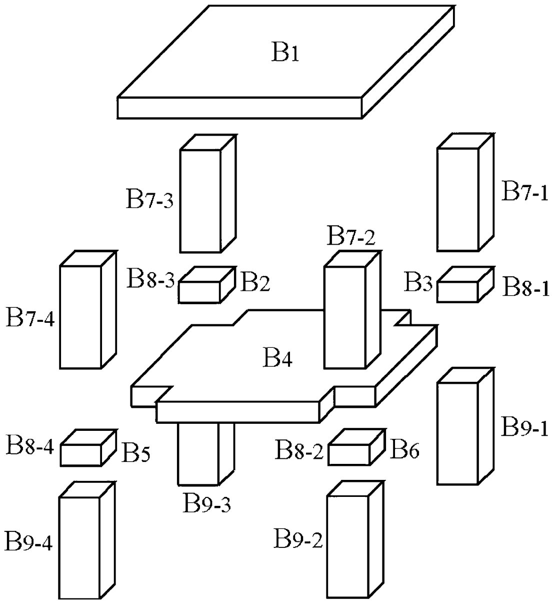


Fig. 18. The 3D relationships among blocks in Fig. 17.

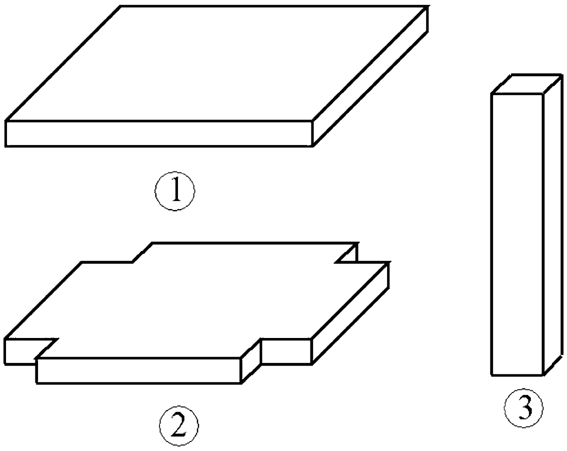


Fig. 19. The solution for Example 3.

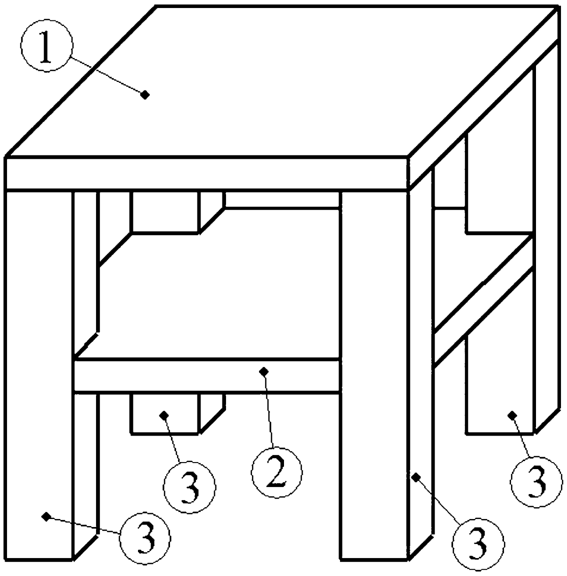


Fig. 20. The 3D assembly model of Example 3.

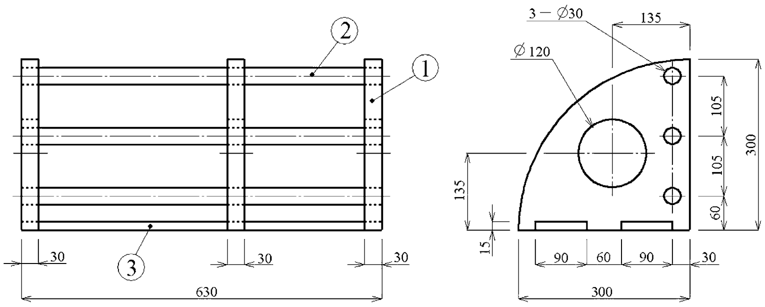
can be used to perform a detailed search for solutions. For Example 3, the existence of each block is decided in the following steps. (1) $B1$ in part 1, $B4$ in part 2 and $B7$-1, 2, 3, 4, $B8$-1, 2, 3, 4, and $B9$-1, 2, 3, 4 in part 3 are shown to be true by the *Existence_condition*. (2) $B2$, $B3$, $B5$, and $B6$ are shown to be false in part 2 by the *Overlap_condition*. As a result, only one solution is obtained as in Fig. 19. Fig. 20 illustrates the 3D assembly model obtained from the solution in Example 3. In the same way, if Example 1 consists of two plates and the dimensions, and so on, are drawn in Fig. 1, only one solution is obtained by the proposed method, corresponding to the drawing given in Fig. 8(a).

5. Examples

Fig. 21 shows a 2D assembly drawing of a book shelf (Example 4). Example 4 consists of eight parts that are classified into three types as given in the parts list. Fig. 22 illustrates each virtual 2D part drawing for Example 4. In the dimensions of part 2, three circular regions whose diameter is 30 are recognized by searching for a leader line with '3-ϕ30' written nearby. Fig. 23 illustrates the blocks recognized from Fig. 22.

The existence of the blocks is determined as in the following steps. (1) $B1$ in part 1, $B8 \sim B12$ in part 2 and $B13 \sim B17$ in part 3 are true according to the *Existence_condition*. (2) $B2$, $B3$, $B4$, $B6$, and $B7$ in part 1 are false by the *Overlap_condition*. As a result, $B5$ in part 1 is undecided. When the *2D Edge_condition* is applied to $B5$, it is found that $B5$ is false and only one solution is obtained as in Fig. 24. Fig. 25 illustrates the 3D assembly model obtained from the solution for Example 4. In contrast, using our original method without applying the parts list, dimensions, etc. Example 4 would generate approximately 70,000 solutions.

Fig. 26 shows a 2D assembly drawing of small container (Example 5). Example 5 consists of seven parts that are classified into four types as given in the parts list. Fig. 27 illustrates the wireframe model of Example 5. Our original method recognizes 17 blocks from the wireframe model as shown in Fig. 28, and generates approximately 6×10^6 solutions. Using the proposed method, virtual 2D part drawings are recognized for Example 5 using the 2D assembly drawing as in Fig. 26. Fig. 29 illustrates the virtual 2D part drawings of parts 1



NO.	SIZE	QTY
1	30×300×300	3
2	∅30×630	3
3	15×90×630	2

Fig. 21. Example 4.

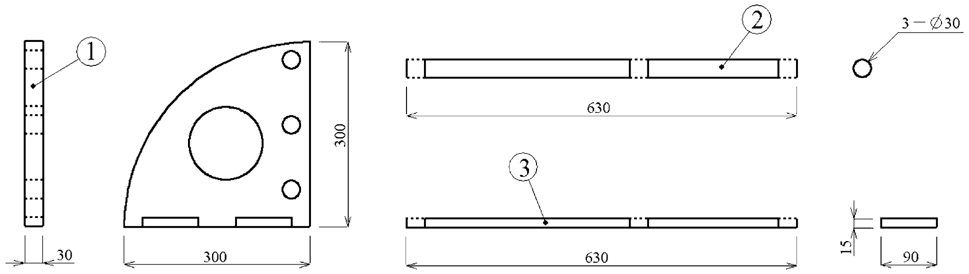


Fig. 22. Each virtual 2D part drawing for Example 4.

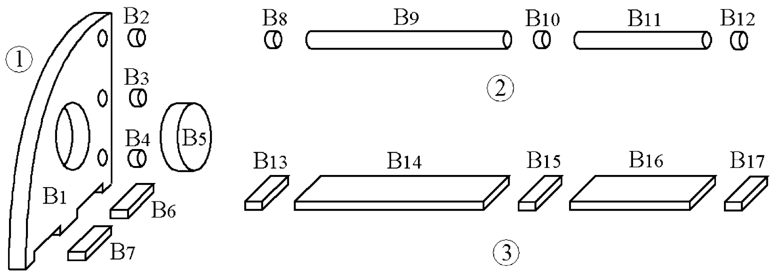


Fig. 23. The blocks recognized from Fig.19.

and 4 for Example 5. In this figure, since each part generates only one block, the two generated blocks become parts 1 and 4. For parts 2 and 3, four possible virtual 2D part drawings are recognized as in Fig. 30. In this figure, it is obvious that (a) and (b) correspond to parts 2 and 3 because of their part numbers. Fig. 31 illustrates the blocks recognized from Fig. 30.

Since $B3$ and $B6$ overlap with $B9$ and $B10$, not all of them can be true. It is obvious that $B1$ is part 2. Suppose that (c) corresponds to part 2 and (d) corresponds to part 3. Then, $B12$ becomes part 3. However, all of the overlapping blocks must become true by the *Identity_condition*. Therefore, it is found that (c) corresponds to part 3 and (d) corresponds to part 2. When the *2D Edge_condition* is applied to the blocks of (b) and (c), it is found that $B5$, $B6$, $B7$, $B8$, and $B11$ are true and $B10$ is false. Then, $B9$ becomes true and $B3$ becomes false by the *Existence_condition* and *Overlap_condition*. When the *Identity_condition* is applied to $B2$ and $B4$, it is found that they are true. As a result, only one solution is obtained for Example 5, as shown in Fig. 32. Fig. 33 illustrates the 3D assembly model obtained from the solution.

6. Discussion

When 2D assembly drawings become complex, multiple combinations of dimensions could be recognized for each part, as in Example 5. In this case, the following two conditions are effective to recognize only one virtual 2D part drawing for each part

1. If some outlines remain in the 2D assembly drawing after all virtual 2D part drawings have been separated, we know that the separation is not correct.

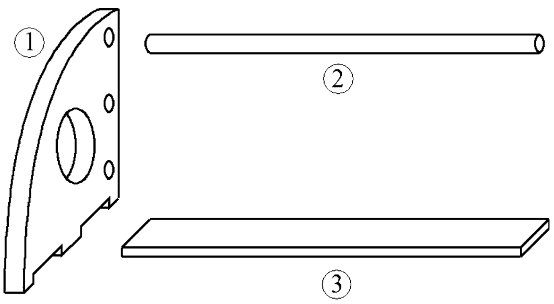


Fig. 24. The solution for Example 4.

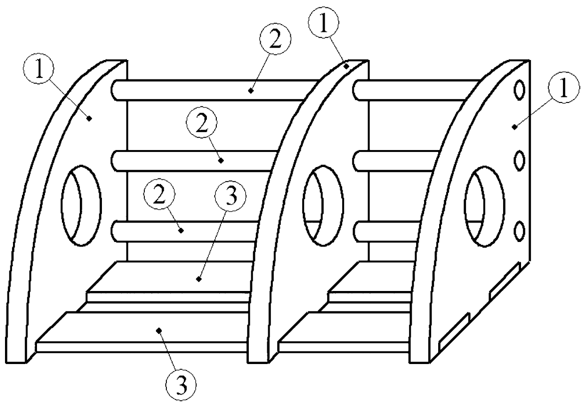
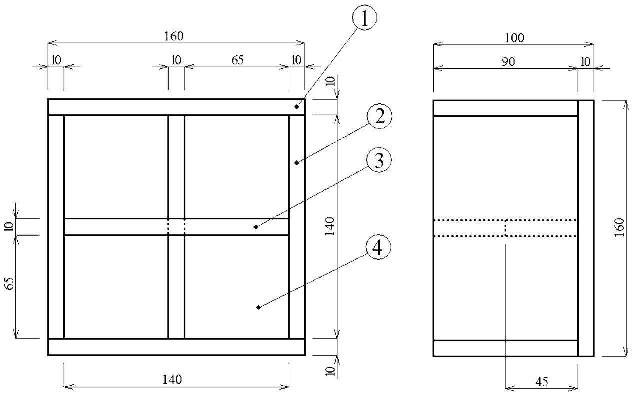


Fig. 25. The 3D assembly model of Example 4.



NO.	SIZE	QTY
1	10×90×160	2
2	10×90×140	2
3	10×90×140	2
4	10×160×160	1

Fig. 26. Example 5.

2. Blocks made from virtual 2D part drawings do not intersect each other at their edges and/or faces.

Moreover, if some dimensions are lacking in the 2D assembly drawing, the distances between 2D vertices can be searched instead of the dimensions. In this case, many combinations of distances could be recognized as dimensions in the 2D drawings, and the two conditions described above become more effective.

Using the proposed method, it is shown that undecided blocks seldom exist after all the search conditions have been applied. However, in some cases there are blocks that ignore all of the conditions, and this results in more than one solution for the 2D assembly drawing. On the other hand, false blocks generally result in solutions with removed regions in the bars and plates. It is difficult to think that removed regions are knowingly designed in the bars and plates because of the strength loss and cost of machining. Therefore, undecided blocks can usually be considered to be true, and so the number of solutions always becomes one.

In addition to bars and plates, this method can be applied to the other standard parts such as bolts, nuts, bearings and so on by recognizing their standardized expressions in 2D drawings. If unspecified parts that are not standard parts are included in the 2D assembly drawings, this method can be synthesized with our original method [1] to generate 3D assembly models. In this case, the numbers of solutions would be increased in proportion to the shapes of the unspecified parts. However, the numbers of unspecified parts

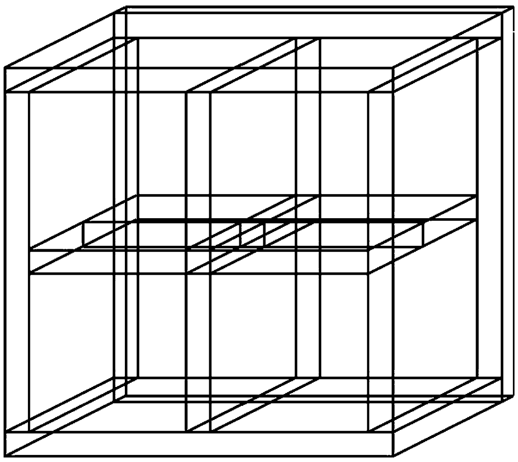


Fig. 27. The wireframe model of Example 5.

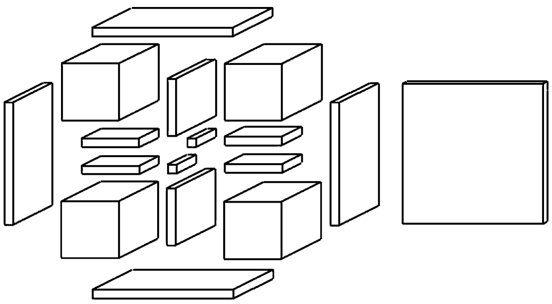


Fig. 28. The blocks generated from Fig. 24.

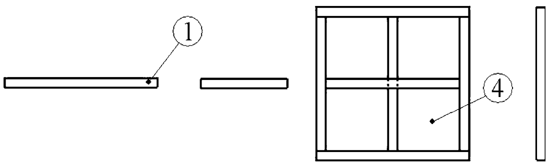


Fig. 29. The virtual 2D part drawings of parts 1 and 4 for Example 5.

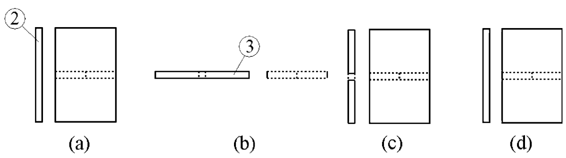


Fig. 30. Four possible virtual 2D part drawings of parts 2 and 3 for Example 5.

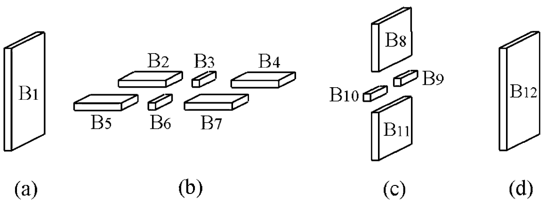


Fig. 31. The blocks recognized from Fig. 25.

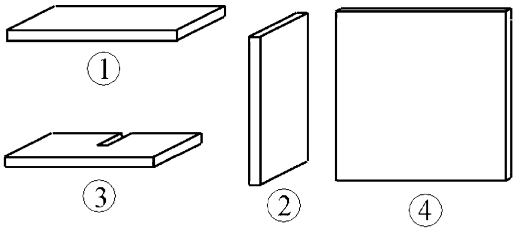


Fig. 32. The solution for Example 5.

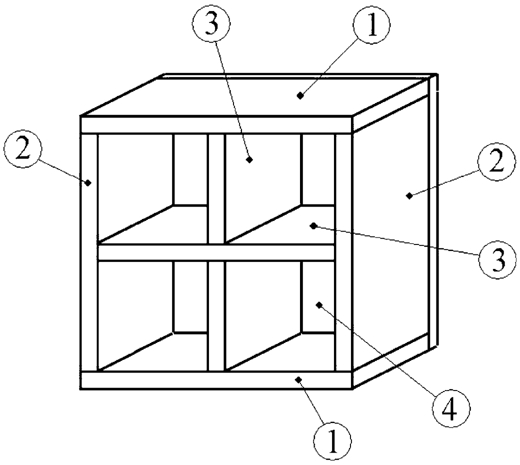


Fig. 33. The 3D assembly model of Example 5.

are much fewer than standard parts in almost all mechanical products. Therefore, the search process to obtain correct solutions would not become overly difficult.

In general, 2D assembly drawings must be drawn correctly for this method to be successful. However, typical 2D drawings often incorporate many simplified expressions such as partial views, local views and sectional views. In these cases, the overview of the solid models as solutions can be obtained by using the dimensions and parts lists, and then the exact solid models as the solutions can be obtained by adding or erasing some lines in the virtual 2D part drawings. This may introduce many solutions, and so new conditions to reduce the solutions would be needed. Also, the application to hierarchical 2D assembly drawings consisting of a great many parts is an important issue for this method.

Practical conversion systems of 2D drawings and 3D models have been developed for low and mid-range commercial CAD systems. For example, SOLIDWORKS is a major mid-range CAD system and it can be used to generate 3D models from 2D drawings arranged in a 3D environment. However, the conversion is largely a manual process. Although a few automatic conversion systems have been developed, such as CADPAC FUSION produced by DESIGN AUTOMATION, and new methods proposed in the literature [7], their objects have comprised of only one part and they have also only dealt with geometric elements in 2D drawings. Therefore, these systems and methods cannot be applied to most 2D assembly drawings. Also, when the simplified expressions described above are applied to them, no solutions can be generated.

7. Conclusion

A method was proposed that automatically converted 2D assembly drawings consisting of bars and plates to 3D part models. Although with previous approaches the number of solutions could easily explode when the drawings became complex, this method can usually obtain only one solution that is required by designers regardless of the complexity of the drawings. Five examples were given in this paper, and the proposed method could obtain only one solution for each of them. The possibility of multiple solutions, and ways to prevent them were discussed.

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