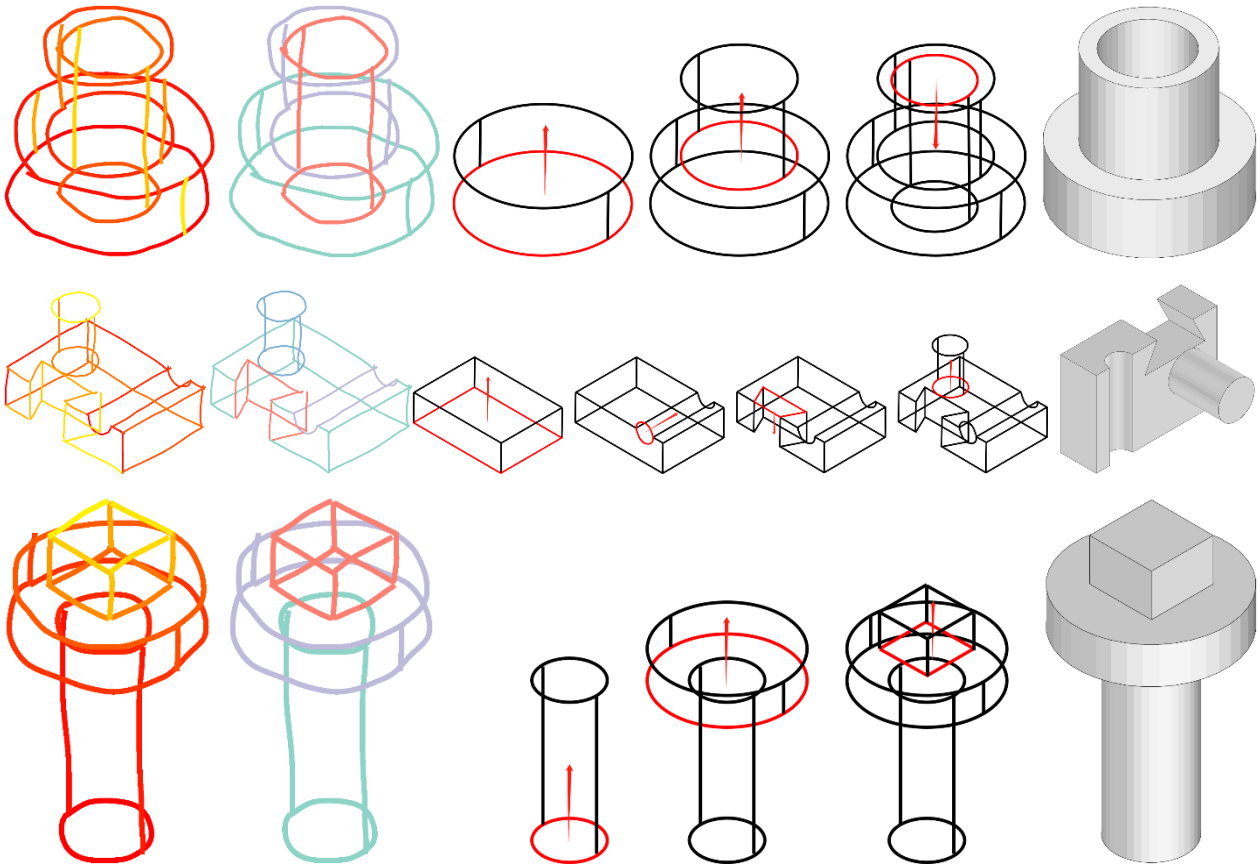
Supplementary document for “Free2CAD: Parsing Freehand Drawings into CAD Commands”

In this document, we provide additional data, from the following four aspects:

1. More sketch-based CAD modeling results.
2. Detailed neural network implementation.
3. Line perturbation scheme in data generation.
4. Detailed user study data.
5. Fusion360 dataset results.

Additional Sketch-Based CAD Modeling Results

For each result, we provide the input sketch, the segmented groups, the recovered CAD commands, and the final 3D shape.



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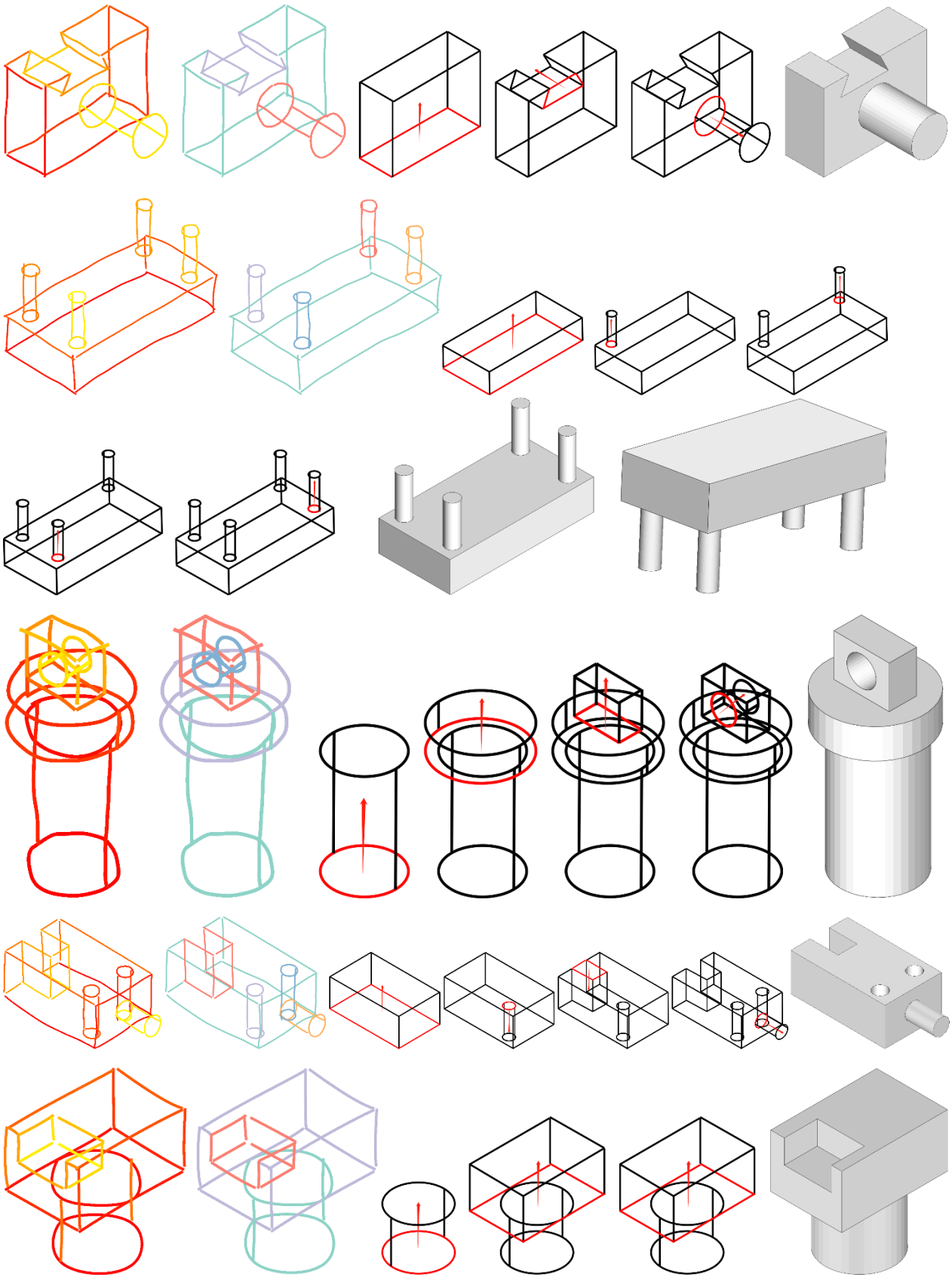

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Detailed Network Implementation

We describe the detailed network implementation, configuration, structure, etc., in what follows.

1. Stroke embedding network

This network consists of a encode E^S and a decoder D^S, where E^S converts an input 256*256 stroke image into a fixed 256-bit embedding with five 2D convolution layers and one fully-connected layer, while D^Sconverts the embedding back to a 256*256 stroke image. After training the embedding network, we only use a fixed E^S to produce stroke embeddings as the input to the Transformer encoder.

Note that the first 2D convolution layer of E^S is a CoordConv layer [3].

2. Transformer

Our implementation is adapted from the official implementation of Tensorflow for language understanding. Furthermore, we adopted the popular pre-LayerNorm variants proposed by Xiong et. al [1] to make the training more robust.

3. Segmentation Network

The segmentation network has the standard UNet structure, with two separated branches for the base curve map and base face map segmentation. The basic encoder and decoder networks are identical to the one used in Sketch2CAD [2].

Line Perturbation Scheme

Data generation scheme has been described in Section 7.1 in the main paper, here we provide more details about line perturbation scheme in stroke rendering to mimic hand-drawn inputs.

Specifically, with the 3D feature curves and the selected viewpoint, we first project each feature curve to the 2D camera space. We then perturb the endpoints of a 2D curve randomly by a Gaussian noise (i.e., within 5 pixels), and finally smooth the perturbed curve a little to produce the style of rough hand-drawn sketching.

Detailed User Study Data

Please refer to the later part of this document.

Fusion360 Dataset Results

We have evaluated our method on a large-scale Fusion 360 segmentation dataset (294 models), and showed some interesting examples in the main paper. Here, we detail the preprocess steps and all other results side-by-side.

1. Preprocessing

Since Fusion360 contains many models that are out of our scope, we preprocess them to get a reasonable subset. Specifically, we first filter examples with complex base shapes by two passes. In the first pass, we remove examples whose base shape consists of both straight lines and curves. Then in the second pass, we filter examples according to the number of base edges with a limit of 6. Also, there are many repeated models composed of a single operation, e.g., Cylinder-Extrusion, Rectangle-Extrusion, we only randomly select a small subset of those examples to balance the complexity. For stroke labels, we use similar automatic labeling process as described in our data generation scheme. Note that in Fusion360 software, users are allowed to extrude several disconnected base shapes in a single extrusion operation. For such cases, we manually separate the disconnected components and express each one as a different extrusion operation.

2. All shapes modeled by our algorithm

See the later part for more details.

Reference

[1] Xiong, R., Yang, Y., He, D., Zheng, K., Zheng, S., Xing, C., Zhang, H., Lan, Y., Wang, L. and Liu, T., 2020, November. On layer normalization in the transformer architecture. In *International Conference on Machine Learning* (pp. 10524-10533). PMLR.

[2] Li, C., Pan, H., Bousseau, A. and Mitra, N.J., 2020. Sketch2cad: Sequential cad modeling by sketching in context. *ACM Transactions on Graphics (TOG)*, *39*(6), pp.1-14.

[3] Liu, R., Lehman, J., Molino, P., Petroski Such, F., Frank, E., Sergeev, A. and Yosinski, J., 2018. An intriguing failing of convolutional neural networks and the coordconv solution. *Advances in neural information processing systems*, *31*.

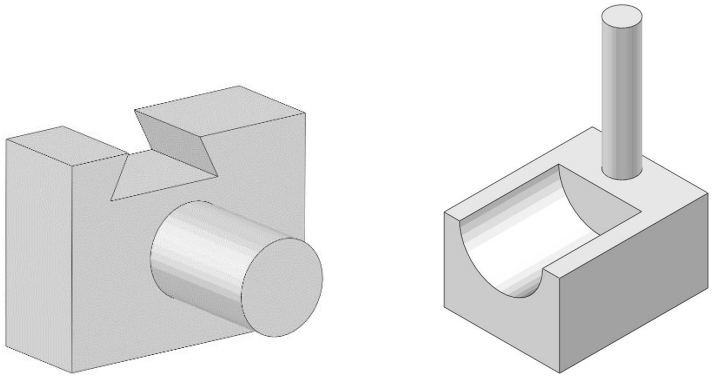
User Study description and results

User Study Protocol

1. Participants
   5 users: 3 computer science PG students, 1 researcher in video games, and 1 accountant

2. Procedure
   a. Training session
      1) Tutorial, demonstration, casual modeling
      2) Background: Level of drawing experience? Level of modeling experience?

   b. Modeling session
      Two tasks: model a similar shape using the system (does not need to be identical)



   c. Discussion session

      1) Given the target shape, was it easy to conceive the sketch?

      2) Does the result match your expectation and is it consistent with the sketch?

      3) Is the result quality as high as a CAD model?

      4) Overall rating and comments, suggestions

      Rating: [0, 5], 0-very negative; 5-very positive

User Study Results

Overall observations:

1. Due to pandemic, all user studies are conducted through online remote access. The network delay makes the drawing process unsmooth and the overall session takes more time than on-site modeling sessions.
2. All participants commented very positively about the professional appearance of our interface, and have good impressions of the robustness of the system despite inconvenience caused by network delay.
3. Users show very different drawing styles, as can be seen from their stroke ordering color coding.
4. The ratings given by users are in the high range and users feel excited by the expressiveness of such a sketch-based modeling system.

Per-user summary:

Participant #1:

1. Background

- Sketching: no
- CAD: no

2. Time:

- Learning: 17 mins
- Task1: 17 mins
- Task2: 13 mins

3. Rating

- 1). 5.0
- 2). 5.0
- 3). 5.0
- 4). 5.0

4. Comments:

- 1) The system is quite easy to learn within very short time, and the user can start playing with the system rapidly.
- 2) The ground with checkboard texture is ambiguous; the user asked to turn it off.
- 3) The interface is convenient, especially the referencing isometric lines, which provide vivid 3D feeling, just like the drawing processing with a pen and paper;

- 4) The isometric lines also provide distance measurement and allow the user to draw lines from far endpoints to existing endpoints with an inverse drawing order. For example, suppose (s0-e0-s1) represents two connected line segments, normally after s0-e0, the user will draw from e0 to s1. But now the user can draw from s1 to e0;
- 5) The sketching is quite intuitive in terms of the representation ability, that means what the user sees is what the user will get.
- 6) The user wants to be a CAD modeler using our system.

Participant #2:

1. Background

- Sketching: knows basic concepts, but has little drawing experience
- CAD: watched some video, but has not modeled something in person

2. Time

- Learning: 15 mins
- Task1: 9 mins
- Task2: 6 mins

3. Rating

- 1). 5.0
- 2). 5.0
- 3). 5.0
- 4). 5.0

4. Comments:

- 1) The network delay causes misinterpretation that the line drawing is unsmooth.
- 2) The interface looks professional for a modeling application. The line smoothness is an impressive feature for curves, and so is straight-line regularization.
- 4) The isometric lines provide strong 3D reference, which is a very desirable feature.
- 5) The drawing order is important in the sense of 3D referencing, e.g., if some lines of the coarse part are drawn first, then it is easy to anchor smaller parts on the coarse part.

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Participant #3:

1. Background

- Sketching: no
- CAD: knows a little about Blender

2. Time

- Learning: 16 mins
- Task1: 15 mins
- Task2: 19 mins

3. Rating

- 1). 5.0
- 2). 5.0
- 3). 5.0
- 4). 5.0

4. Comments:

- 1) The interface is quite professional, and it is obviously different from step-by-step primitive-based or template-based modeling systems.
- 2) It will be easier to draw if hidden lines can be avoided. But that will also be harder for precise control of result shape as the hidden part is ambiguous.
- 3) To model a shape without part decomposition or ordering, and without view changing is convenient. This is a technically hard achievement.
- 4) The user felt that it is not far from shape modeling with design sketching in practice.
- 5) The user is interested in the algorithm, and wants to know more once it is published.

Participant #4:

1. Background

- Sketching: no
- CAD: no

2. Time

- Learning: 24 mins
- Task1: 20 mins

- Task2: 8mins

3. Rating

- 1). 5.0
- 2). 5.0
- 3). 5.0
- 4). 5.0

4. Comments:

- 1) The end-to-end drawing and modeling style is quite efficient and saves many efforts.
- 2) The interface is user-friendly, especially the reference isometric lines.
- 3) At the beginning, learning to sketch with reference grid takes some time since the user is not good at 3D space imagination, but later it becomes more convenient.
- 4) If there is automatic 2D sketch symmetry detection in the interface, it would be nicer.

Participant #5:

1. Background

- Sketching: no
- CAD: no

2. Time

- Learning: 15 mins
- Task1: 12 mins
- Task2: 5 mins

3. Rating

- 1). 5.0
- 2). 5.0
- 3). 5.0
- 4). 5.0

4. Comments:

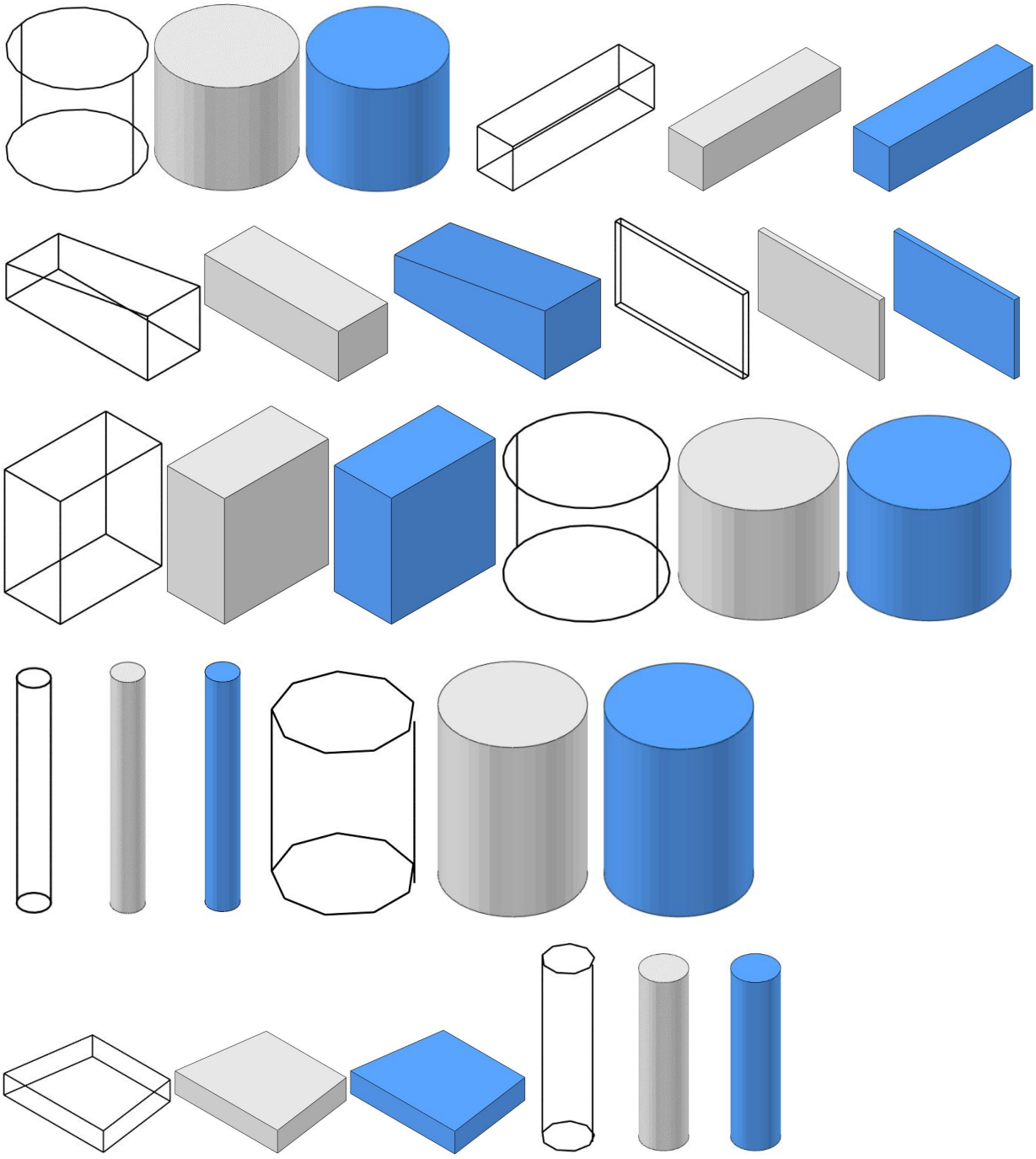
- 1) The system is robust even with some ambiguous input, e.g., overlapped strokes;

- 2) If the reference grid can be smarter, e.g., by highlighting the axes of snapped grid points for guidance, it would be even better.

Fusion Dataset Models

We provide all the models from the Fusion360 dataset that we reconstructed using our system.

For each model, we show the input strokes, our result (gray), and reference Fusion360 shape (blue).



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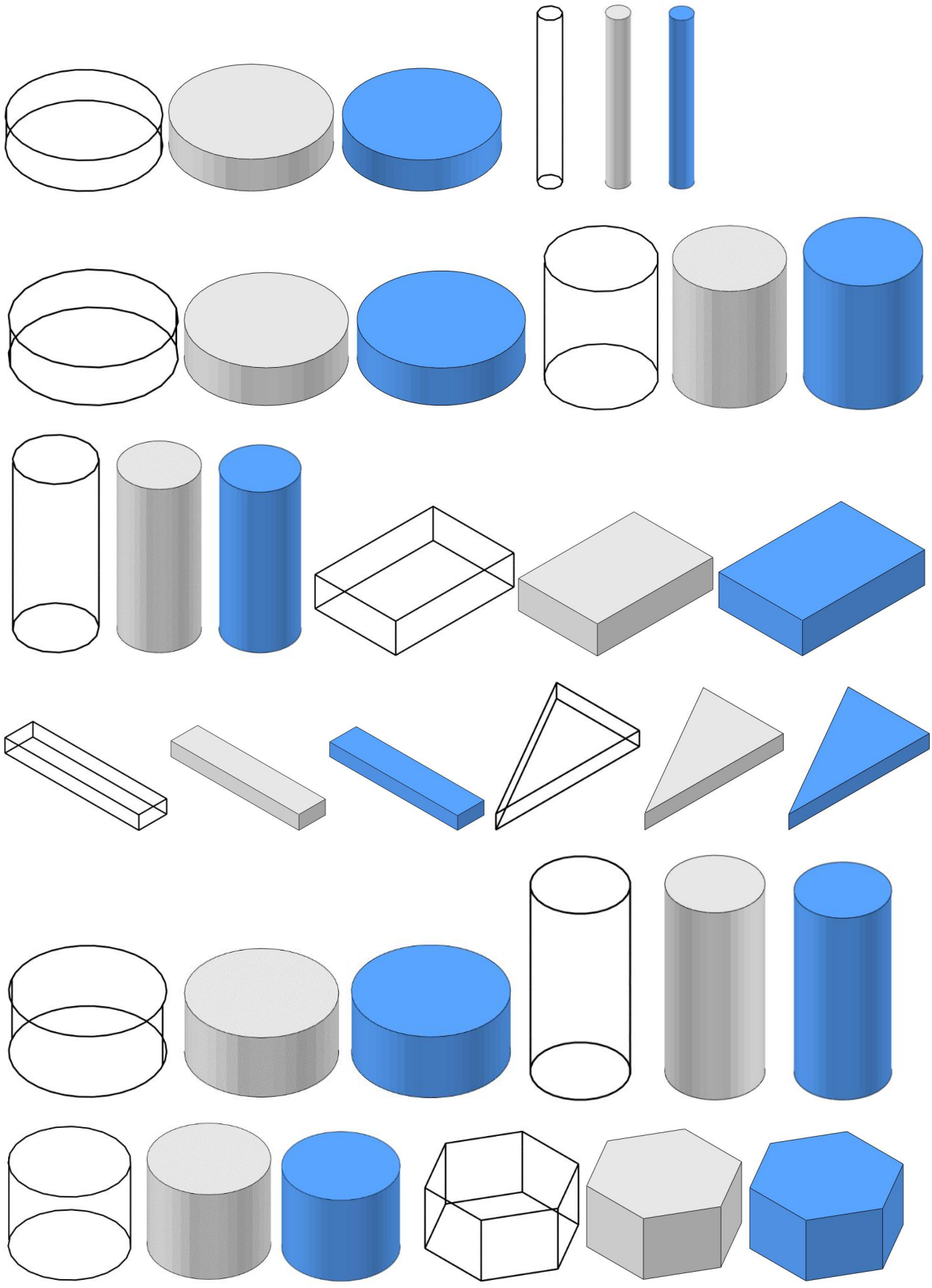

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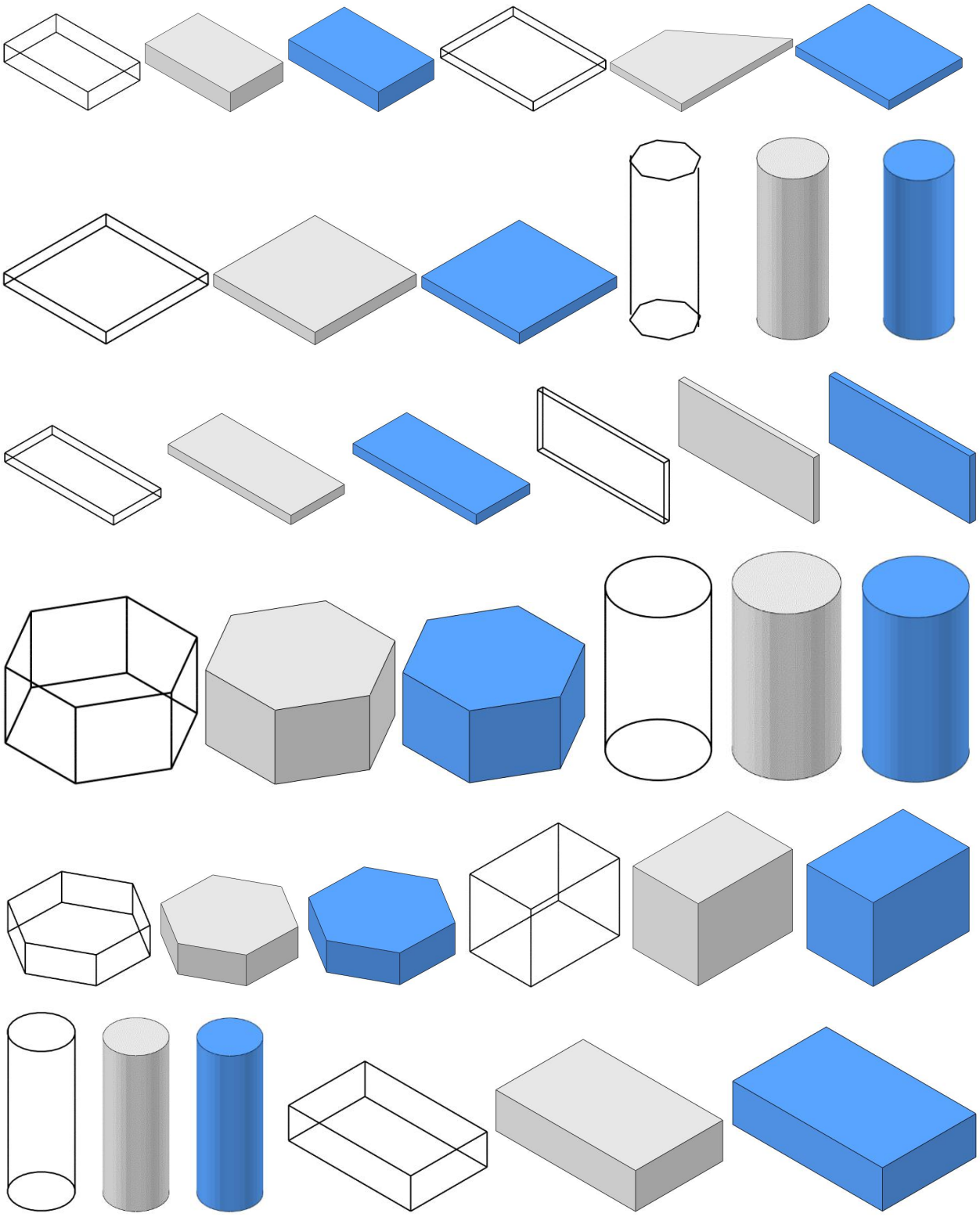

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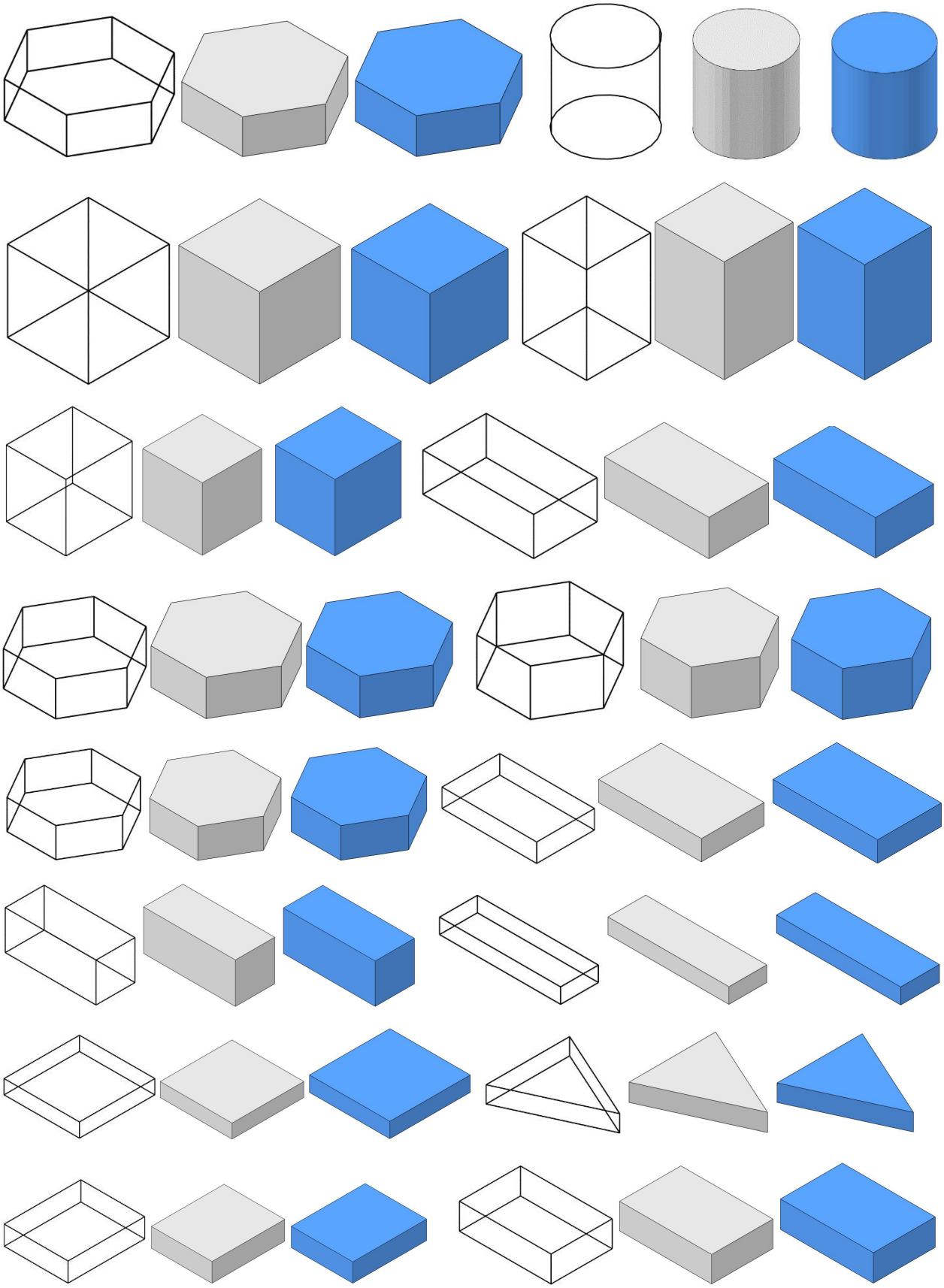

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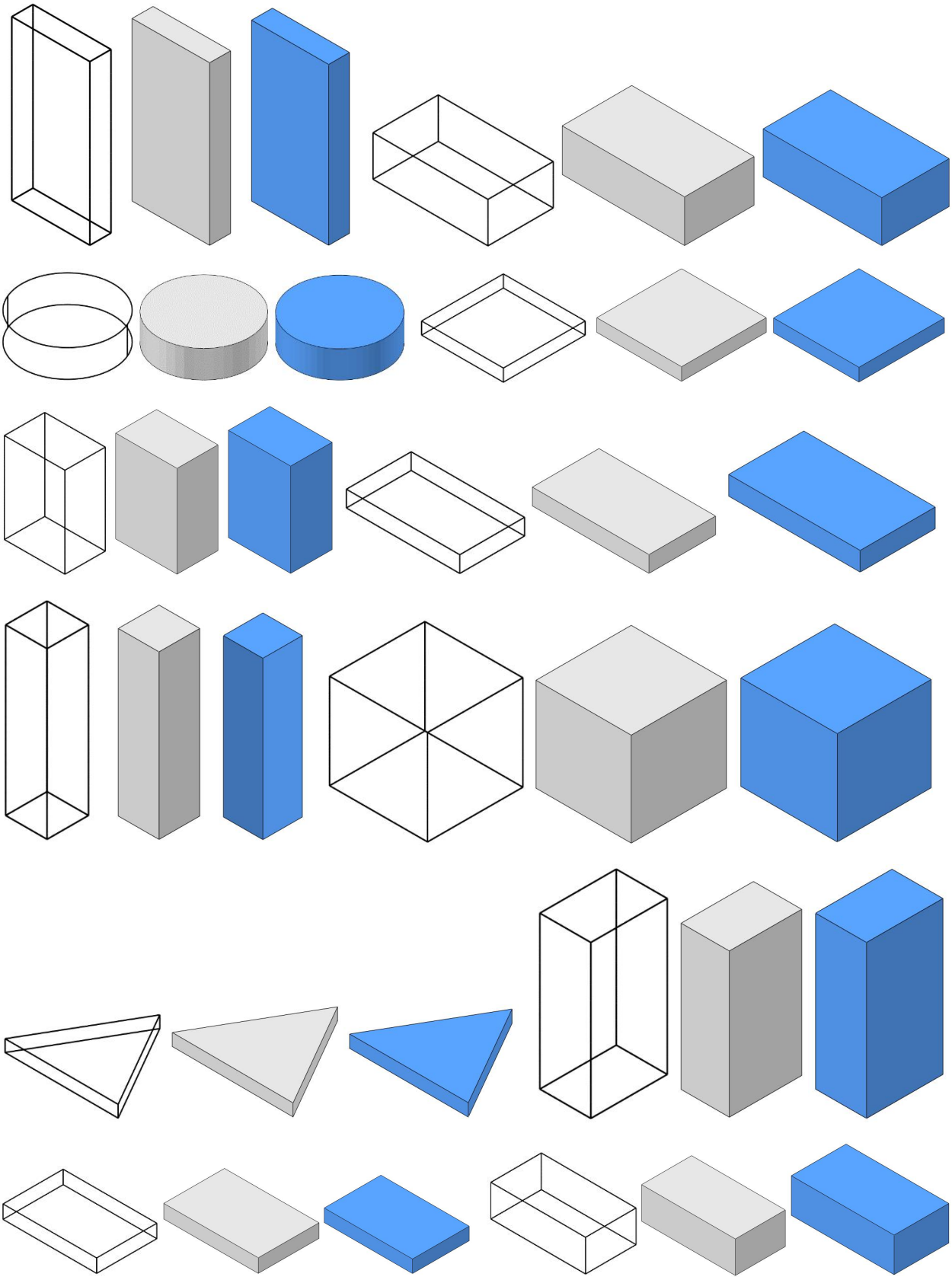

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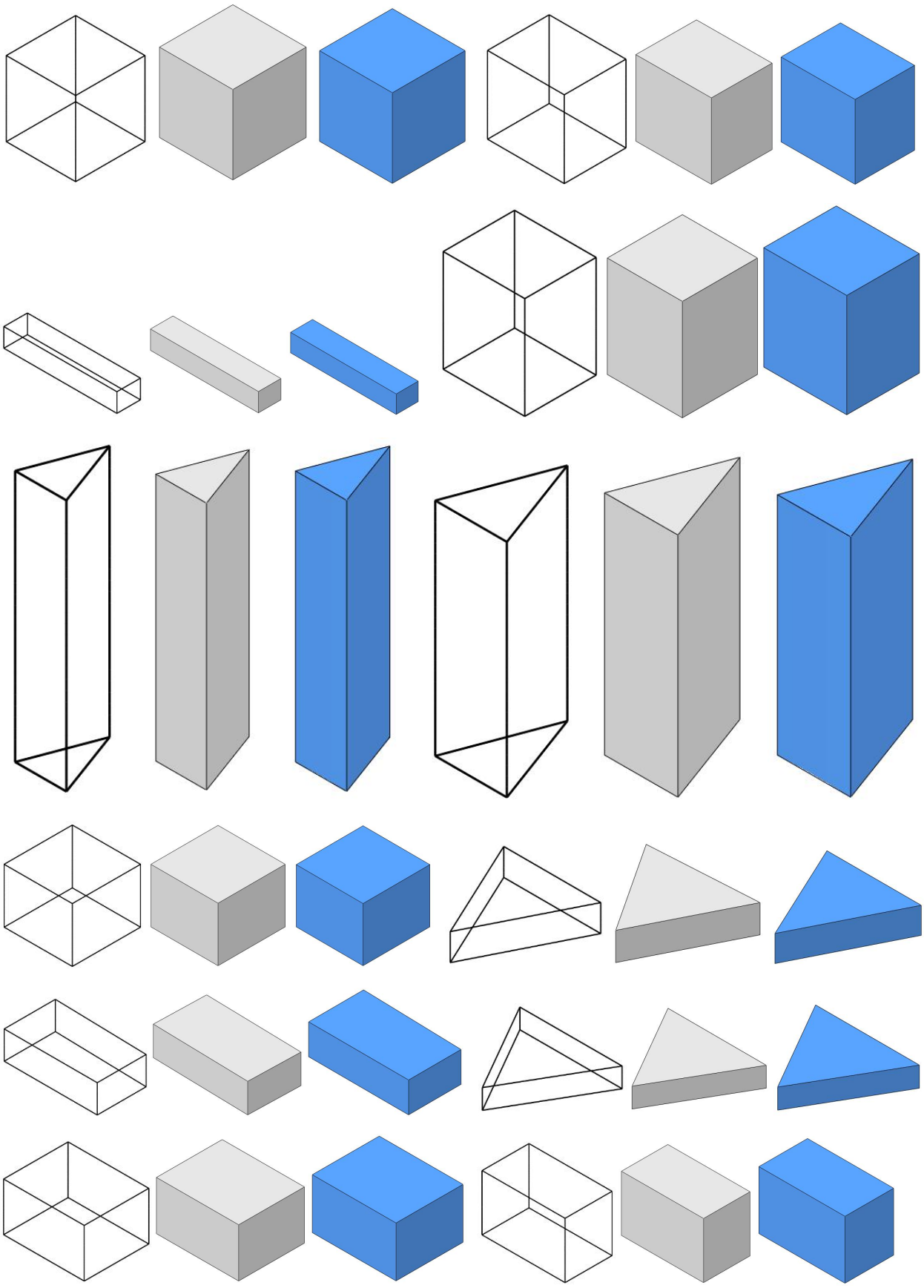

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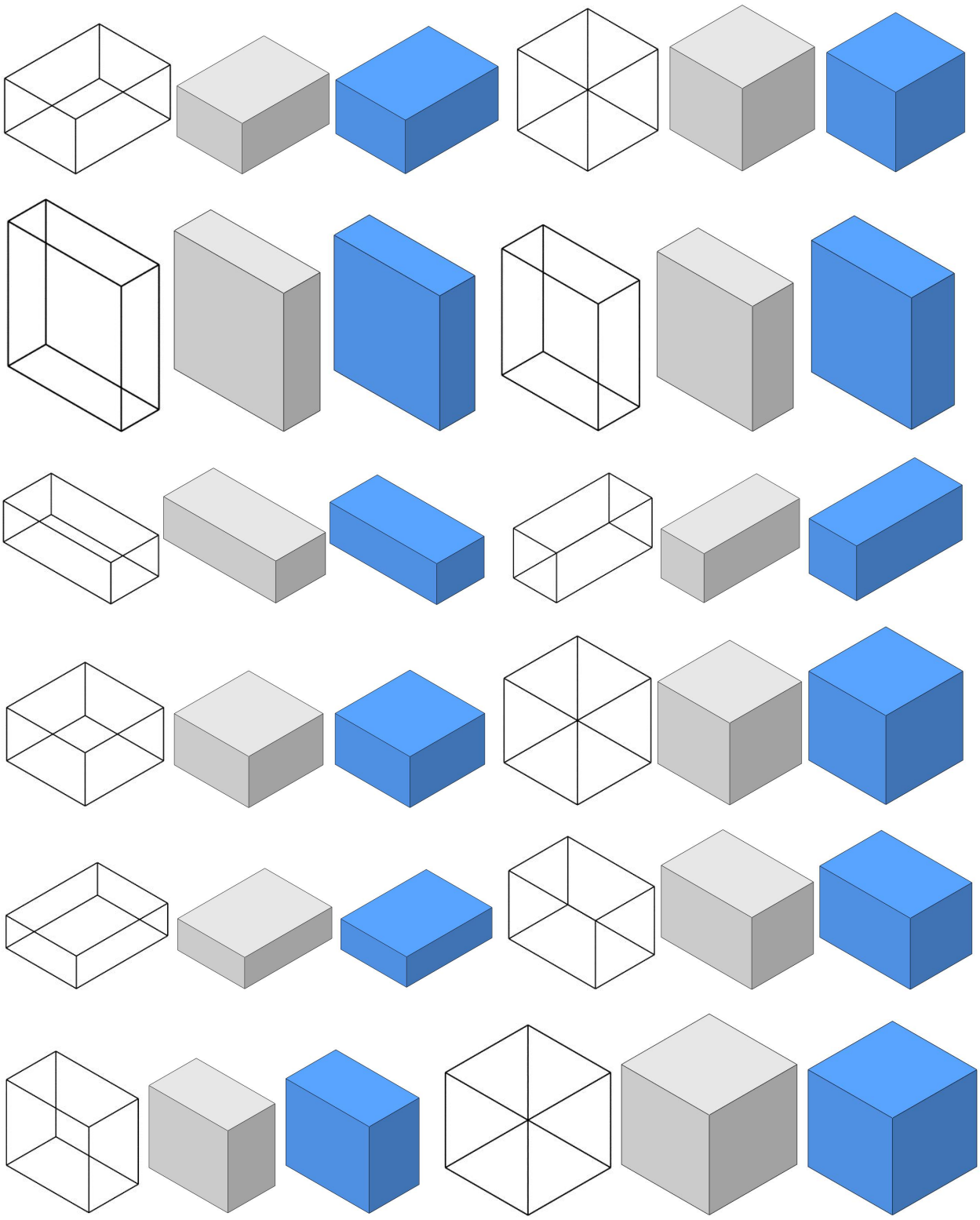

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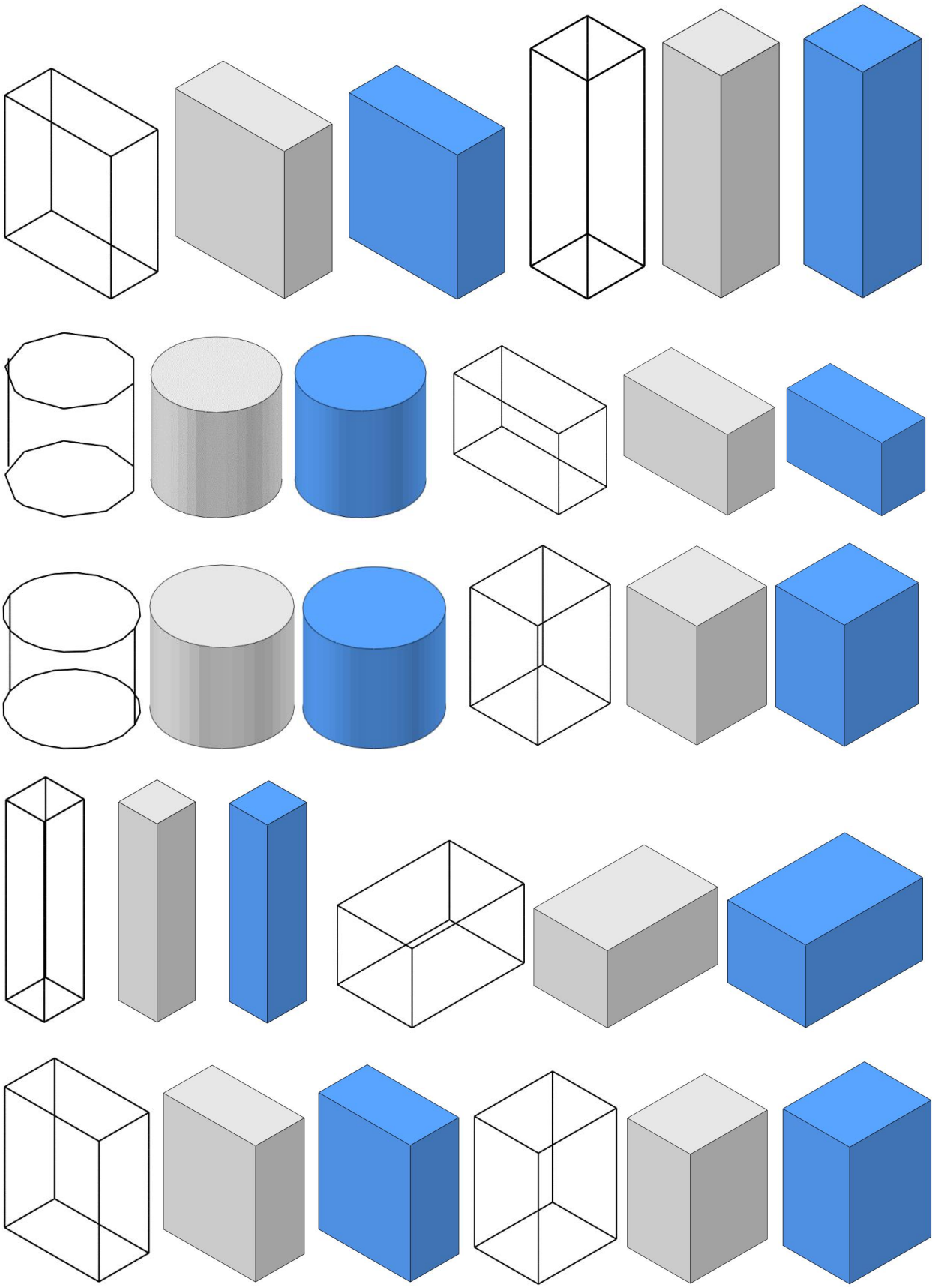

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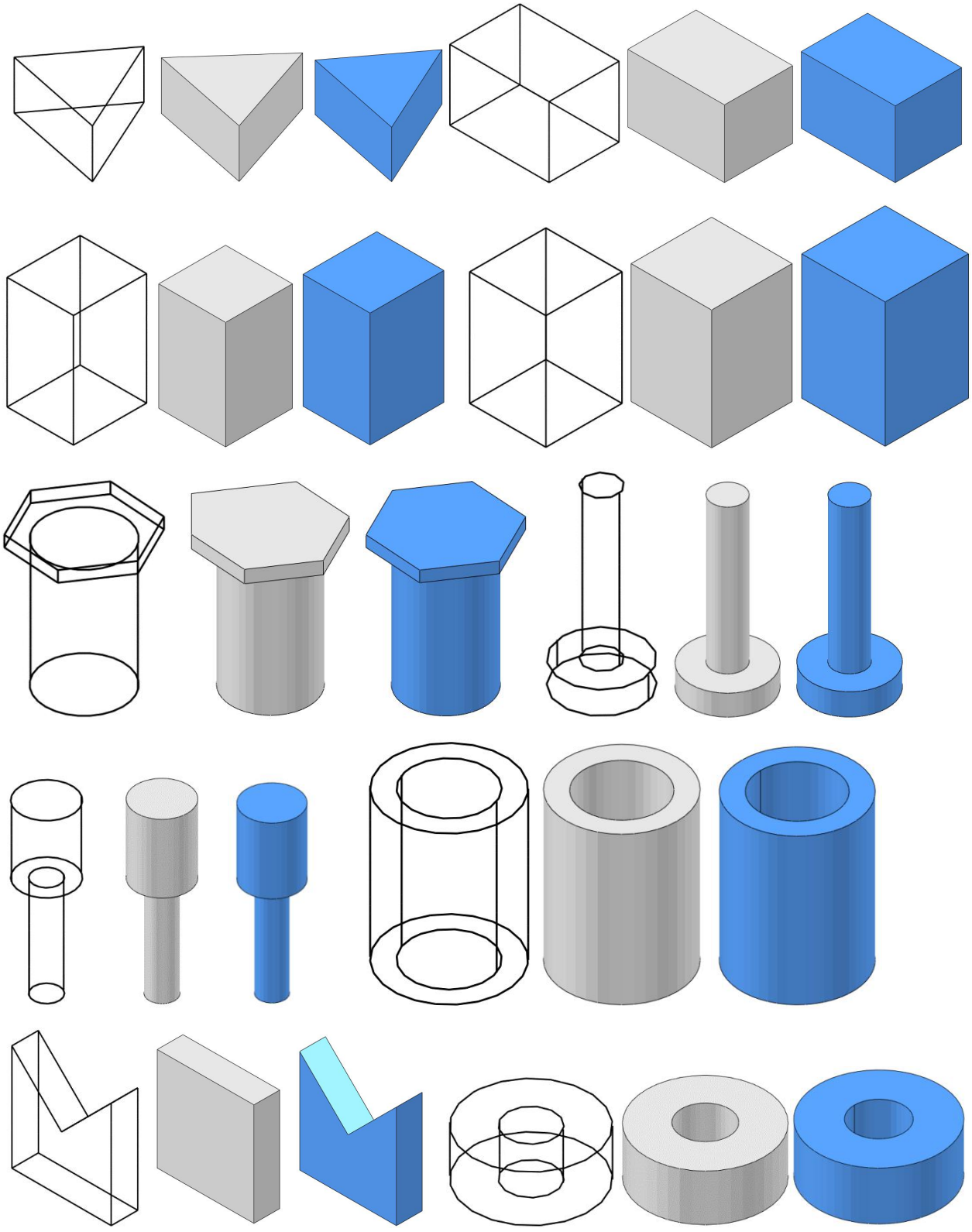

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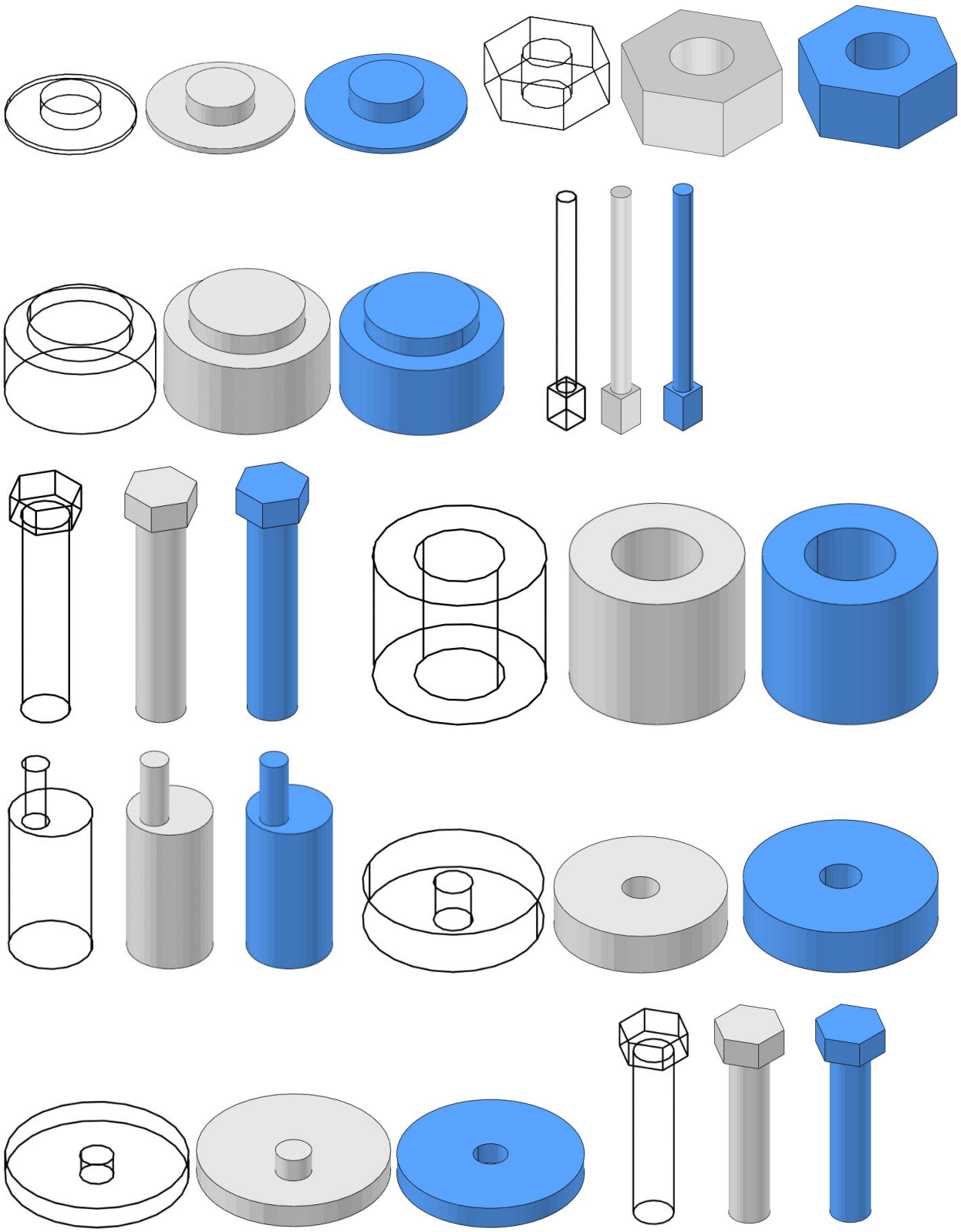

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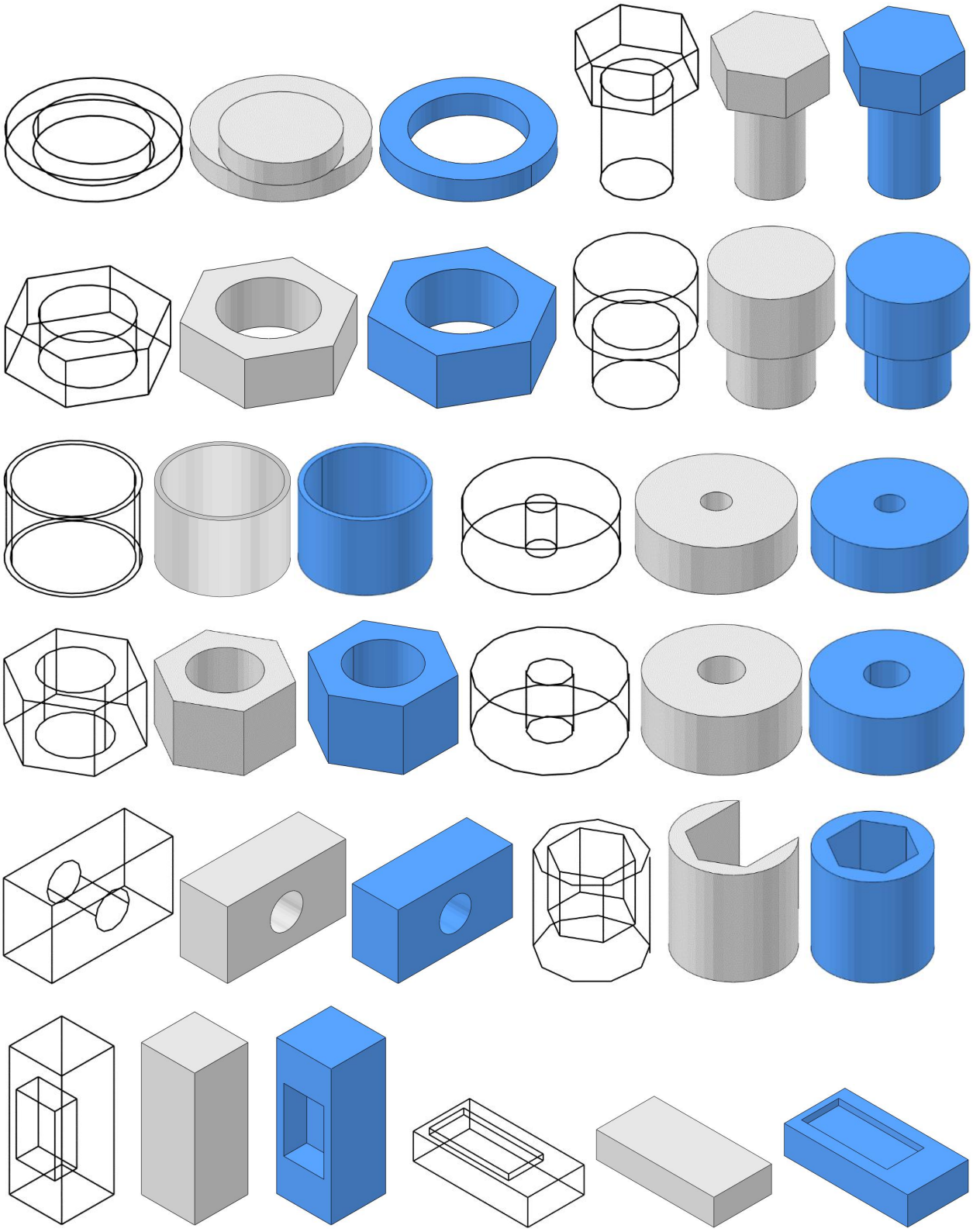

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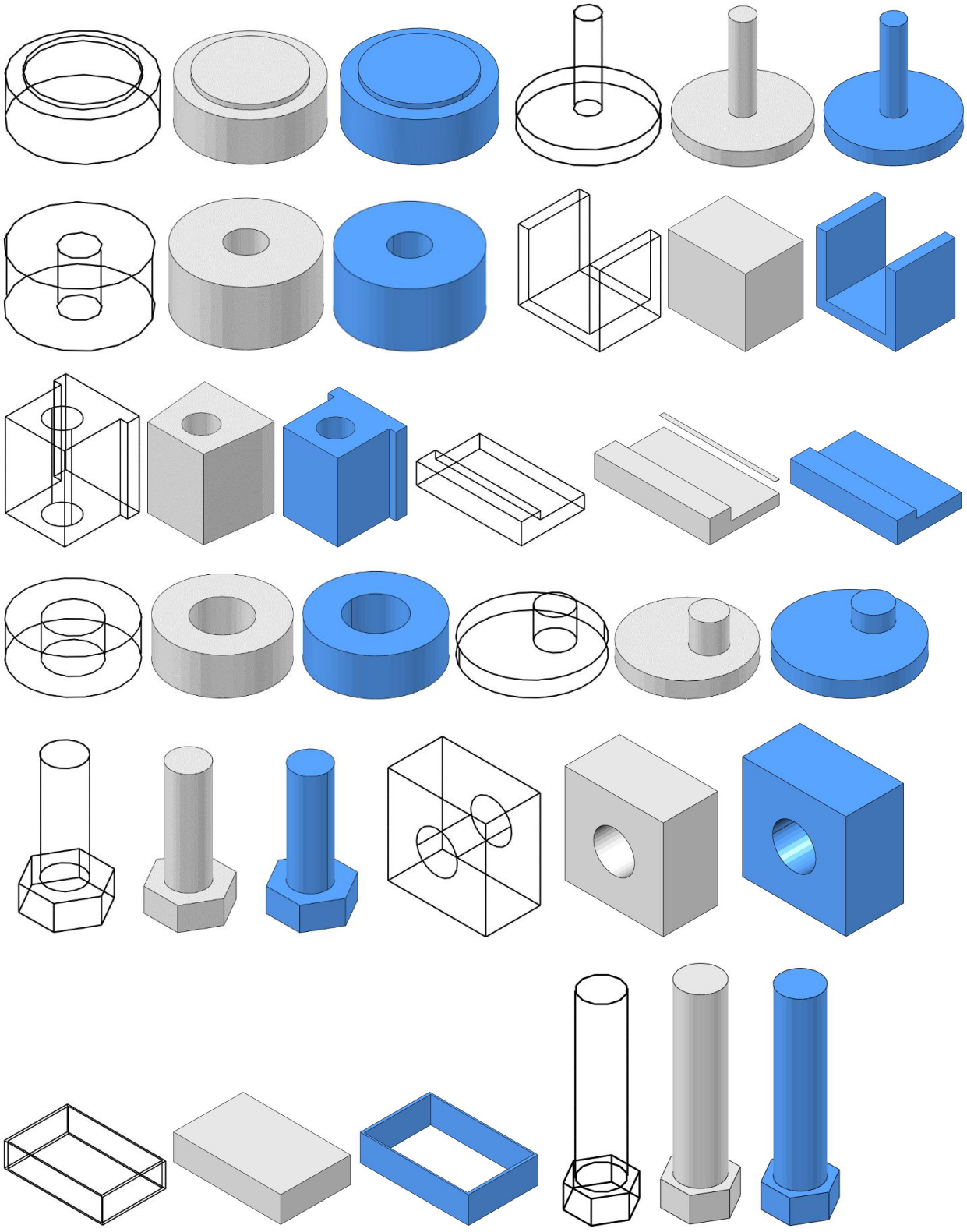

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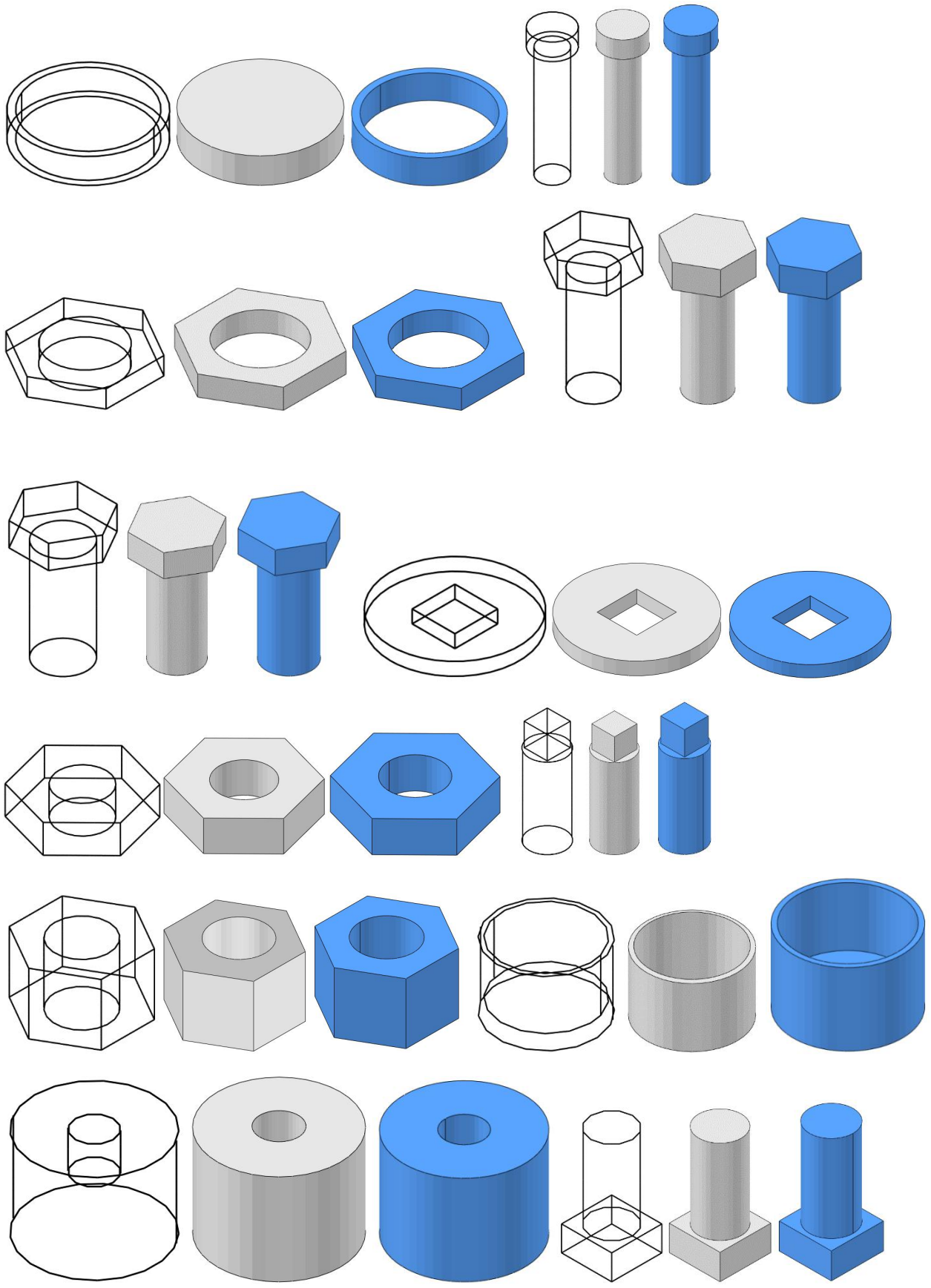

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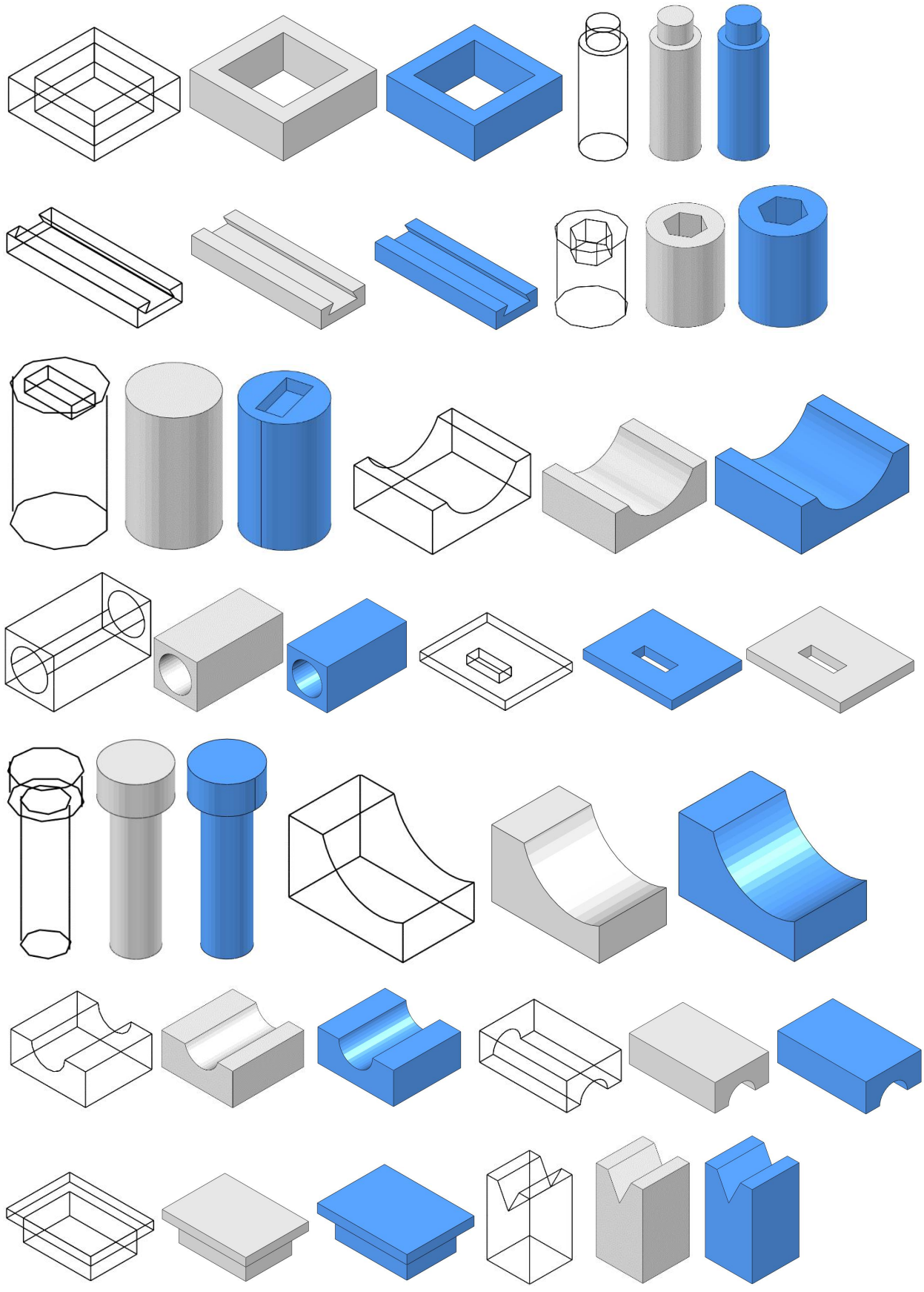

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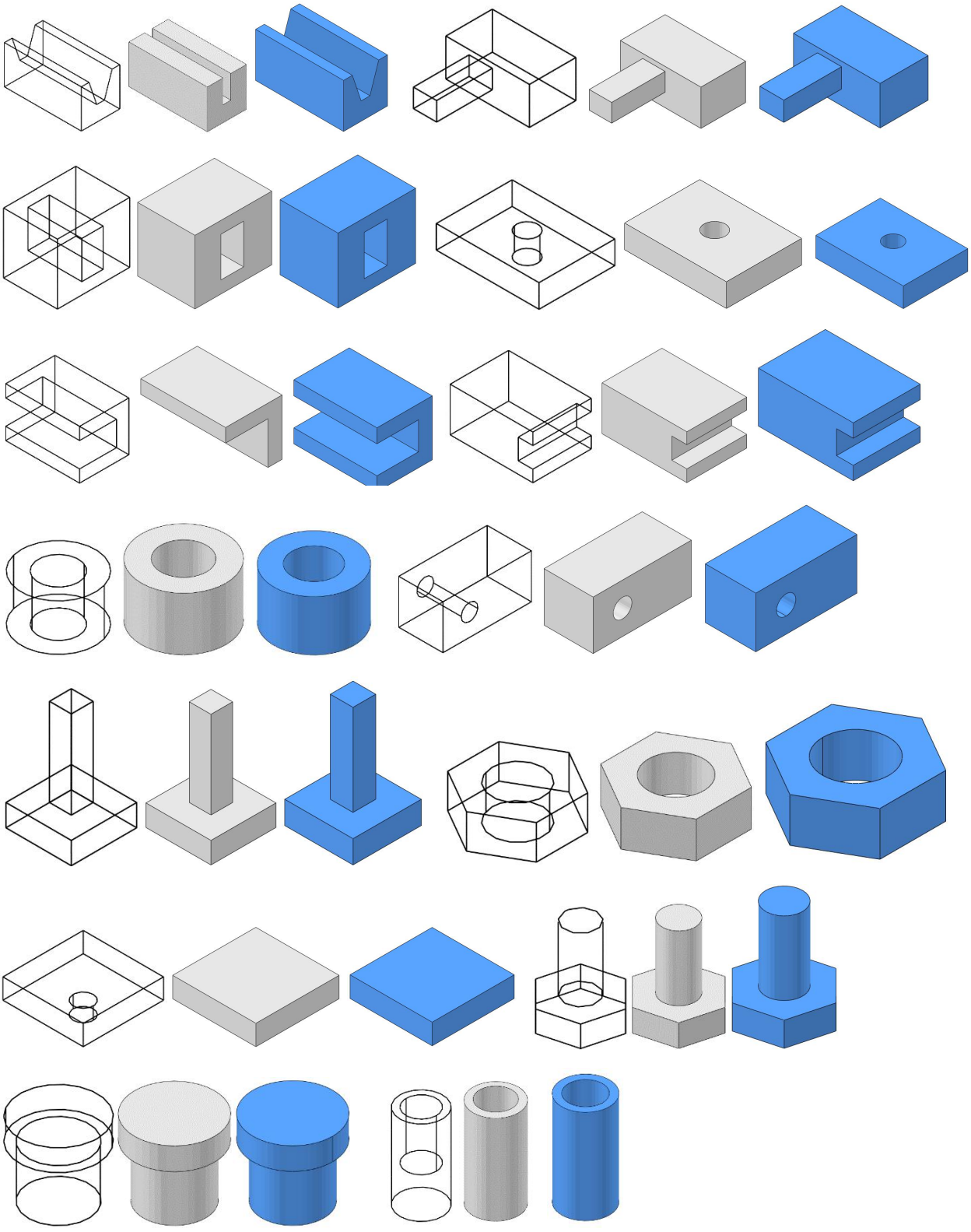

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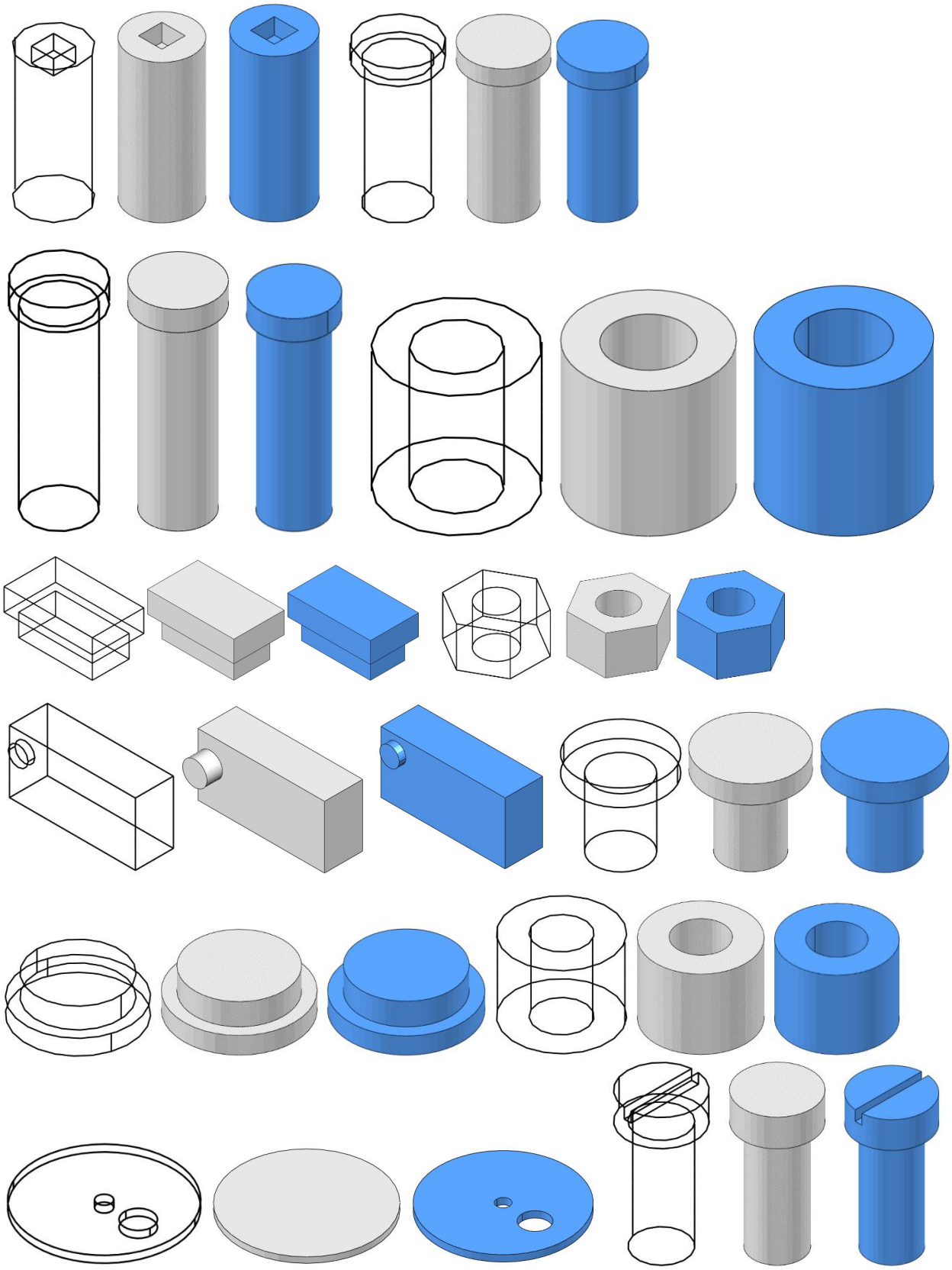

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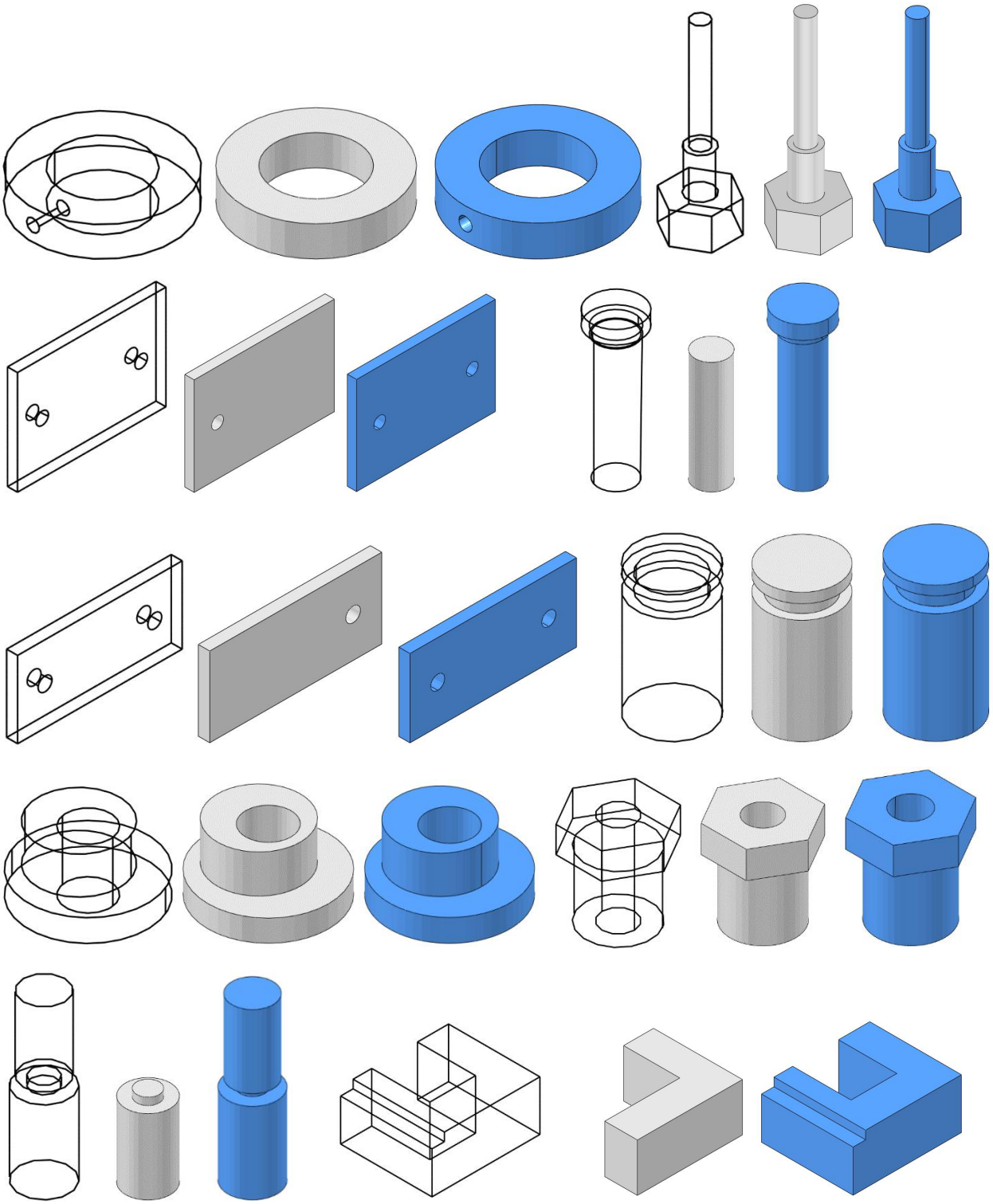

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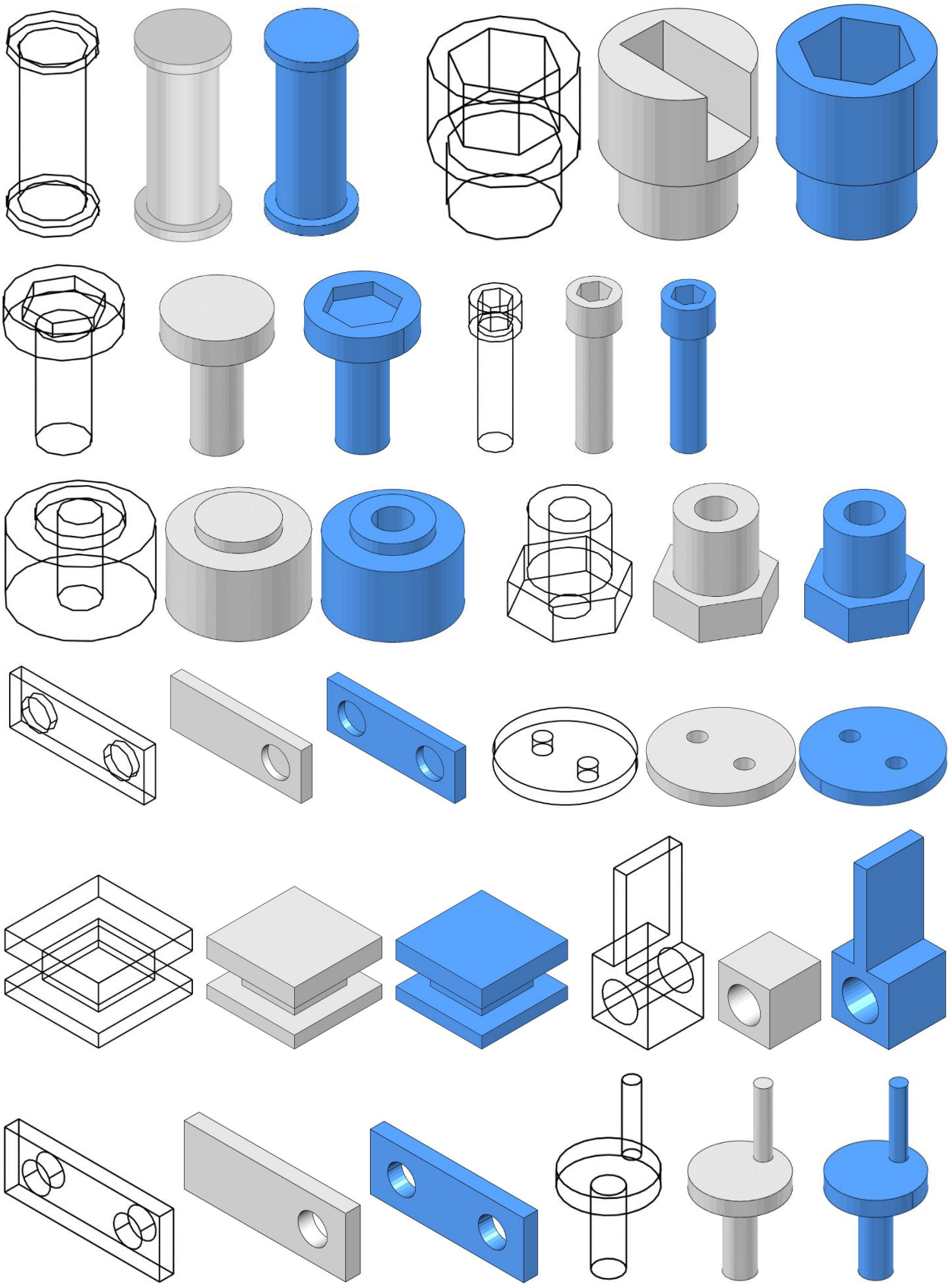

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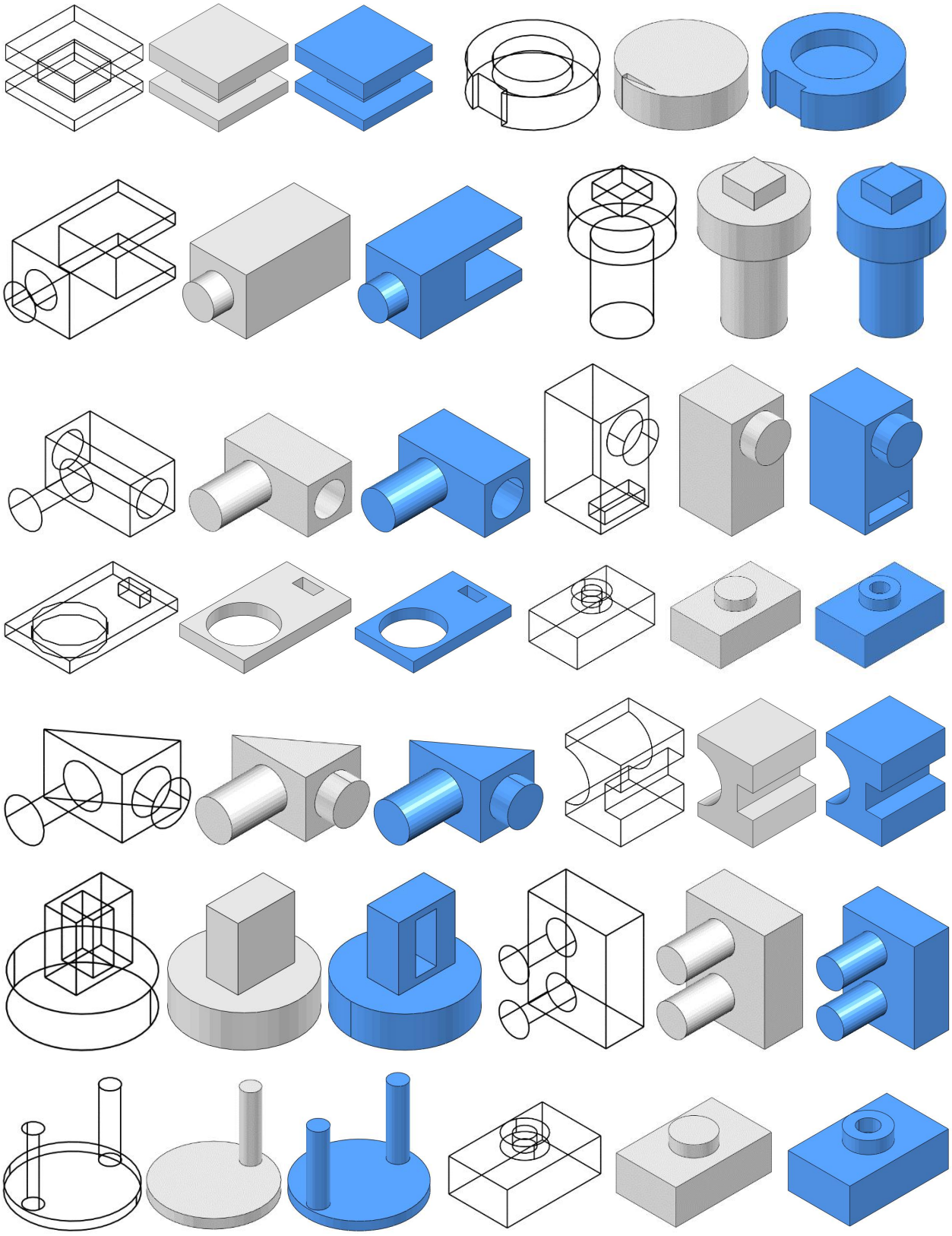

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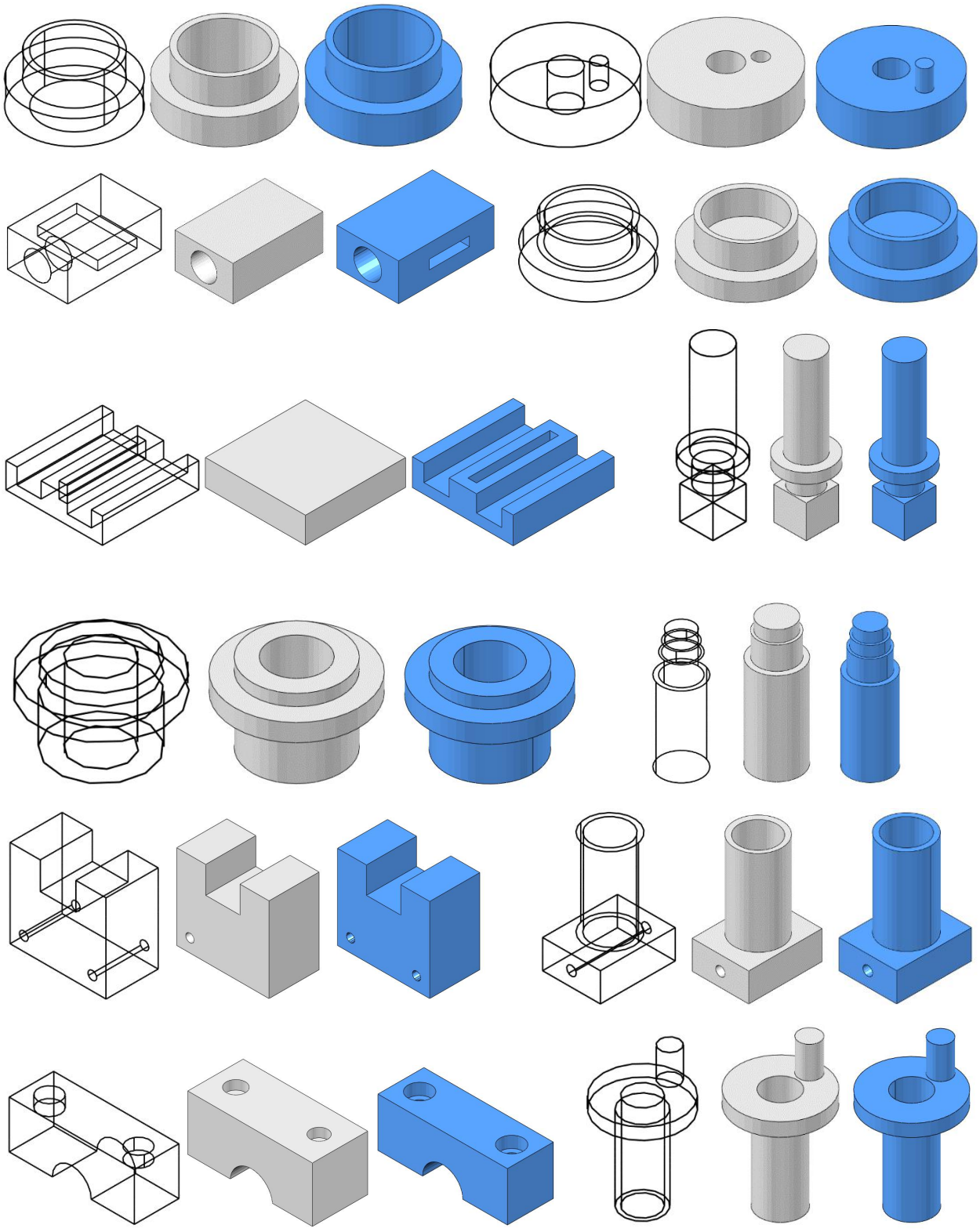

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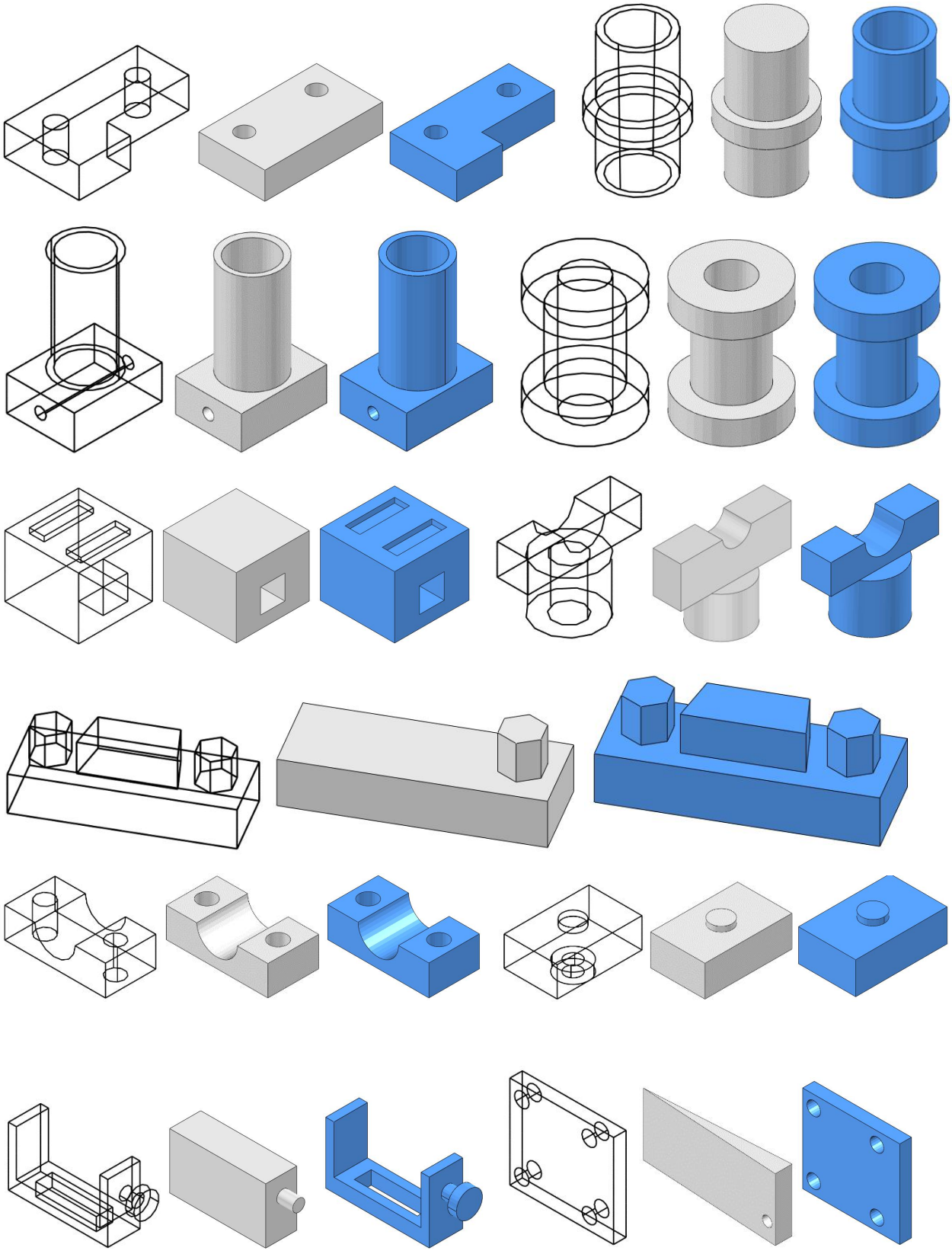

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