Supplementary Results for Learning to Assemble: Estimating 6D Poses for Robotic Object-Object Manipulation

Stefan Stevšić, Sammy Christen, Otmar Hilliges

AIT Lab, Department of Computer Science, ETH Zürich, Switzerland

{stefan.stevsic, sammy.christen, otmar.hilliges}@inf.ethz.ch

Introduction

In this document, we provide detailed results of experiments conducted in the main paper and examples of all objects used for recording the test dataset. In Section VI-B of the main paper, we present average results per task. Here, we present results from the same experiment for each object in the test dataset. Object 1 is presented separately because this is the example object for which the geometry is available at training time. Object 1 is used to show the contrast between the case when the full geometry is known and when the geometry is not available. The example objects with ground truth annotations are shown together with results from the respective task.

Evaluation Results for all Objects in the Dataset

Task 1
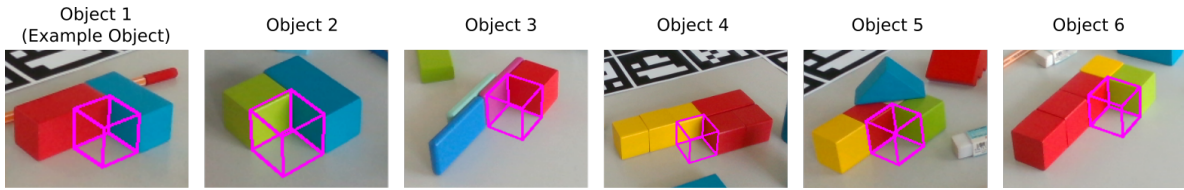
Object 1 (Example Object) | Object 2 | Object 3 | Object 4 | Object 5 | Object 6

Object 1

ADD success rates on object 1

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	14.8	55.5	**17.5**	**56.0**	**31.8**	**92.1**	16.3	60.3

ADD-S error success rates on object 1

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**47.2**	76.3	45.9	**80.3**	**87.3**	**97.7**	50.5	79.5

ADD success rates on object 1 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	20.1	**71.7**	**23.6**	66.9	**47.3**	**97.6**	26.0	74.6

ADD-S success rates on object 1 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**71.1**	79.5	65.7	**83.7**	**97.0**	**98.7**	74.3	84.4

Object 2 - 6

ADD success rates on objects 2-6

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	0.0	3.0	**11.8**	**48.6**	0.7	3.6	**2.8**	**21.7**
Object 3	0.3	2.9	**1.9**	**14.8**	0.0	0.0	**10.2**	**54.1**
Object 4	0.0	0.3	**18.9**	**67.3**	0.0	2.5	**8.1**	**37.7**
Object 5	**14.7**	**48.4**	5.9	30.7	1.5	23.3	**4.5**	**27.8**
Object 6	0.0	0.7	**18.3**	**59.3**	0.0	7.3	**14.9**	**35.8**
Mean	3.0	11.1	**11.4**	**44.1**	0.5	7.3	**8.1**	**35.4**

ADD-S success rates on objects 2-6

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	2.0	10.8	**39.9**	**80.1**	2.5	11.3	**15.9**	**61.7**
Object 3	2.1	7.5	**11.9**	**28.7**	0.0	0.1	**44.0**	**79.5**
Object 4	0.3	5.1	**57.7**	**88.5**	1.5	10.7	**31.9**	**63.2**
Object 5	**39.3**	**78.3**	26.7	63.7	17.0	54.2	**20.8**	**57.9**
Object 6	0.4	5.9	**53.1**	**80.1**	3.5	30.4	**32.9**	**56.3**
Mean	8.8	21.5	**37.9**	**68.2**	4.9	21.3	**29.1**	**63.7**

ADD success rates on objects 2-6 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	0.2	7.9	**22.3**	**74.3**	0.2	4.3	**14.9**	**61.1**
Object 3	0.7	5.7	**8.5**	**29.7**	0.0	0.6	**38.0**	**74.7**
Object 4	0.3	4.1	**39.5**	**79.7**	3.1	10.7	**32.1**	**64.1**
Object 5	**28.3**	57.9	20.9	**61.3**	14.7	**51.5**	17.2	49.7
Object 6	0.9	4.7	**26.0**	**66.0**	4.6	25.1	**25.8**	**59.1**
Mean	6.1	16.0	**23.4**	**62.2**	4.5	18.5	**25.6**	**61.7**

ADD-S success rates on objects 2-6 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	9.0	25.7	**73.5**	**87.1**	4.1	21.2	**60.9**	**75.3**
Object 3	5.2	11.9	**29.3**	**37.4**	0.6	4.5	**74.3**	**81.7**
Object 4	4.0	8.9	**79.4**	**92.4**	10.5	23.3	**62.9**	**73.2**
Object 5	54.3	**78.7**	60.5	68.2	**51.6**	61.7	47.2	**64.9**
Object 6	4.7	18.3	**65.2**	**84.2**	23.7	53.8	**58.8**	**70.9**
Mean	15.4	28.7	**61.6**	**73.9**	18.1	32.9	**60.8**	**73.2**

Task 2
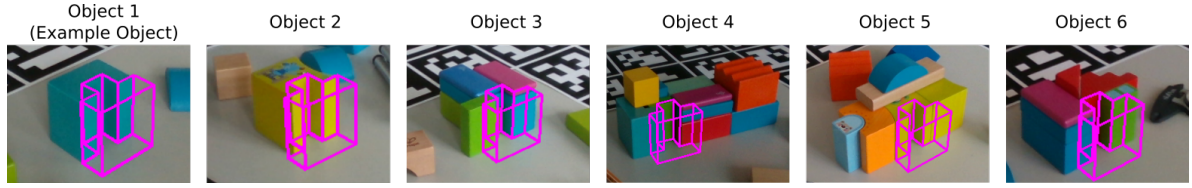
Object 1 (Example Object) | Object 2 | Object 3 | Object 4 | Object 5 | Object 6

Object 1

ADD success rates on object 1

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**57.6**	**96.7**	46.0	95.9	**73.3**	**99.9**	31.9	84.5

ADD-S success rates on objects 1

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**96.7**	97.2	95.7	**99.9**	99.9	99.9	85.7	**100.0**

ADD success rates on object 1 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	93.1	**97.2**	94.6	99.9	**96.8**	**99.9**	92.6	99.6

ADD-S success rates on object 1 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	97.2	97.2	**99.9**	**99.9**	**99.9**	99.9	99.6	**100.0**

Object 2 - 6

ADD success rates on objects 2-6

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	4.5	23.0	**18.3**	**66.4**	15.2	46.6	**16.0**	56.6
Object 3	0.0	0.2	**16.0**	**54.9**	0.3	7.7	**20.2**	**61.3**
Object 4	0.0	0.0	**12.3**	**37.7**	0.1	0.5	**13.3**	34.0
Object 5	0.3	1.1	**45.9**	83.5	2.1	10.0	**35.5**	**84.3**
Object 6	0.0	0.4	**18.9**	53.9	1.7	15.3	**17.0**	**55.1**
Mean	1.0	4.9	**22.3**	**59.3**	3.9	16.0	**20.4**	58.3

ADD-S success rates on objects 2-6

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	20.7	62.7	**67.3**	**98.1**	47.9	80.5	**57.4**	**90.6**
Object 3	0.1	0.7	**55.6**	**86.6**	7.9	15.8	**61.2**	**84.5**
Object 4	0.0	0.5	**37.3**	**75.0**	0.5	1.5	**33.9**	**67.4**
Object 5	0.7	5.5	**84.9**	**96.7**	9.1	23.5	**85.0**	**97.2**
Object 6	0.4	1.7	**55.2**	**77.8**	17.1	32.7	**55.3**	**74.1**
Mean	4.4	14.3	**60.1**	**86.9**	16.5	30.8	**58.6**	**82.8**

ADD success rates on objects 2-6 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	31.9	65.9	**60.6**	**92.6**	51.8	86.1	**55.5**	**87.8**
Object 3	0.1	0.5	**78.1**	**85.9**	11.3	16.3	**76.8**	**86.2**
Object 4	0.2	0.3	**43.3**	**64.4**	1.2	1.5	**39.4**	**57.3**
Object 5	10.6	11.6	**89.8**	**92.5**	26.8	28.3	**90.5**	**95.5**
Object 6	0.7	1.3	**73.7**	**79.2**	24.0	30.1	**75.7**	**79.1**
Mean	8.7	15.9	**69.1**	**82.9**	23.0	32.5	**67.6**	**81.2**

ADD-S success rates on objects 2-6 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	67.5	83.6	**93.4**	**99.0**	86.7	92.4	**89.4**	**96.4**
Object 3	0.7	1.2	**86.7**	**89.9**	17.7	27.6	**87.3**	**90.8**
Object 4	0.5	1.7	**65.8**	**83.7**	2.1	3.1	**59.3**	**81.8**
Object 5	12.1	14.5	**93.7**	**98.1**	30.3	43.4	**96.0**	**98.3**
Object 6	1.8	3.7	**79.6**	**79.8**	32.1	36.5	**79.3**	**79.7**
Mean	16.5	20.9	**83.9**	**90.1**	33.8	40.6	**82.3**	**89.4**

Task 3

| Object 1 (Example Object) | Object 2 | Object 3 | Object 4 | Object 5 | Object 6 |
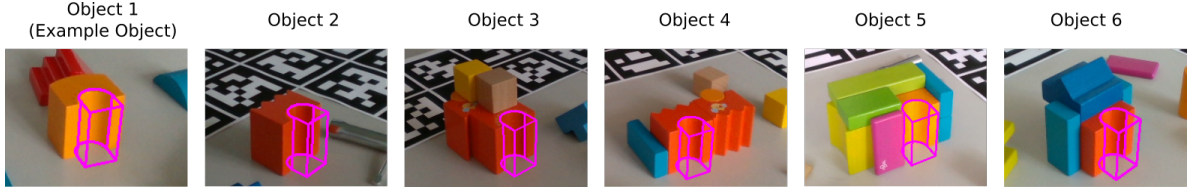
Object 1

ADD error success rates on object 1

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**69.3**	**99.9**	35.8	83.8	**73.6**	**99.8**	31.3	81.5

ADD-S success rates on object 1

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**99.8**	**99.9**	77.6	97.7	**99.1**	**100.0**	72.7	99.2

ADD success rates on object 1 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**61.3**	**99.9**	59.3	98.7	**63.7**	**100.0**	62.7	99.6

ADD-S success rates on object 1 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**99.9**	**99.9**	97.1	99.6	**100.0**	**100.0**	98.9	100.0

Objects 2-6

ADD success rates on object 2-6

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	**59.0**	**97.4**	30.4	82.8	23.2	**92.7**	**27.8**	83.8
Object 3	2.1	8.6	**12.1**	**41.2**	10.2	44.2	**19.5**	**66.2**
Object 4	4.9	24.1	**23.5**	**71.5**	14.4	51.8	**24.5**	**68.8**
Object 5	1.4	5.7	**6.5**	**26.8**	2.9	14.5	**7.4**	**37.1**
Object 6	3.7	18.1	**16.1**	**55.0**	2.0	9.1	**20.1**	**66.0**
Mean	14.2	30.8	**17.7**	**55.5**	10.5	42.5	**19.8**	**64.4**

ADD-S success rates on objects 2-6

	Model from [2]				Model from [3]			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	**95.3**	98.3	72.7	**98.7**	**83.2**	**100.0**	74.6	99.3
Object 3	7.2	12.0	**33.9**	**51.9**	32.6	74.9	**56.1**	**91.1**
Object 4	16.7	44.7	**61.5**	**89.3**	41.7	74.9	**59.8**	**86.3**
Object 5	4.3	9.9	**22.7**	**60.7**	11.3	27.9	**28.7**	**63.9**
Object 6	14.2	34.5	**47.5**	**70.9**	6.6	26.5	**58.3**	**85.1**
Mean	27.5	39.9	**47.6**	**74.3**	35.1	60.9	**55.5**	**85.1**

ADD success rates on objects 2-6 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	**58.8**	**98.3**	53.1	97.1	47.3	**99.8**	49.5	99.4
Object 3	7.7	11.9	**36.3**	**51.3**	41.7	74.9	**57.9**	**89.4**
Object 4	24.5	44.6	**44.3**	**89.2**	39.2	77.0	**48.9**	**83.5**
Object 5	4.7	9.6	**10.0**	**47.3**	13.3	29.2	**15.5**	**57.7**
Object 6	23.7	34.2	**38.7**	**68.9**	12.1	21.9	**56.4**	**86.1**
Mean	23.9	39.7	**36.5**	**70.8**	30.7	60.6	**45.6**	**83.2**

ADD-S success rates on objects 2-6 after ICP refinement

	Model from [2] + ICP				Model from [3] + ICP			
	Tex. DR		Tex.+Shape DR		Tex. DR		Tex.+Shape DR	
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	**98.3**	**98.7**	96.5	98.2	**99.7**	**100.0**	99.1	99.7
Object 3	11.9	12.9	**50.9**	**57.3**	74.7	85.5	**89.3**	**96.8**
Object 4	41.7	67.2	**87.9**	**91.3**	73.7	83.5	**81.1**	**89.4**
Object 5	9.5	16.3	**45.0**	**87.5**	29.5	38.3	**55.8**	**88.1**
Object 6	34.2	40.1	**68.9**	**76.5**	22.3	38.9	**86.2**	**88.5**
Mean	39.1	47.0	**69.8**	**82.2**	60.0	69.2	**82.3**	**92.5**

Task 4
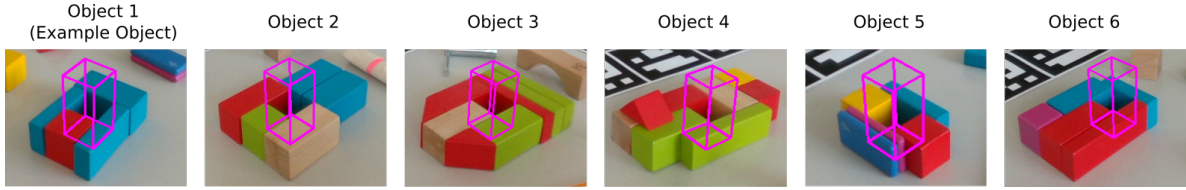
Object 1 (Example Object)   Object 2   Object 3   Object 4   Object 5   Object 6

Object 1

ADD success rates on object 1

| | Model from [2] | | | | Model from [3] | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**21.6**	**86.6**	18.6	66.1	**33.5**	**91.9**	19.3	70.5

ADD-S success rates on object 1

| | Model from [2] | | | | Model from [3] | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**76.3**	**97.5**	64.7	96.9	**86.3**	**95.8**	67.3	91.5

ADD success rates on object 1 after ICP refinement

| | Model from [2] + ICP | | | | Model from [3] + ICP | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**48.9**	**97.7**	32.5	84.7	**48.8**	**96.3**	36.5	81.9

ADD-S success rates on object 1 after ICP refinement

| | Model from [2] + ICP | | | | Model from [3] + ICP | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 1	**96.2**	**98.9**	86.7	98.8	**95.5**	96.8	84.6	**97.1**

Objects 2-6

ADD success rates on objects 2-6

| | Model from [2] | | | | Model from [3] | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	0.0	2.5	**13.6**	**69.1**	0.6	12.1	**14.3**	**56.2**
Object 3	0.0	0.7	**18.1**	**73.0**	0.0	11.3	**22.0**	**65.6**
Object 4	0.7	10.1	**24.0**	**74.8**	0.7	6.5	**22.0**	**73.5**
Object 5	0.0	0.0	**14.2**	**55.1**	0.0	0.3	**13.3**	**57.0**
Object 6	0.0	7.1	**10.9**	**68.7**	0.0	14.9	**25.8**	**65.1**
Mean	0.1	4.1	**16.2**	**68.1**	0.3	9.0	**19.5**	**63.5**

ADD-S success rates on objects 2-6

| | Model from [2] | | | | Model from [3] | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	16.7	26.2	**68.9**	**93.7**	19.8	48.2	**54.5**	**86.3**
Object 3	2.0	5.7	**72.3**	**99.6**	10.9	29.4	**66.1**	**95.7**
Object 4	6.3	22.7	**71.1**	**97.6**	5.7	11.8	**73.8**	**93.1**
Object 5	0.0	0.1	**57.4**	**87.9**	0.9	23.1	**56.7**	**91.2**
Object 6	5.0	34.5	**63.6**	**97.6**	8.3	44.9	**71.4**	**93.5**
Mean	6.0	17.8	**66.7**	**95.3**	9.1	31.5	**64.5**	**92.0**

ADD success rates on objects 2-6 after ICP refinement

| | Model from [2] + ICP | | | | Model from [3] + ICP | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	0.1	19.8	**29.4**	**87.1**	3.8	36.9	**28.8**	**77.3**
Object 3	0.1	3.3	**33.3**	**92.7**	1.3	19.9	**33.0**	**83.5**
Object 4	2.7	20.5	**35.1**	**85.8**	3.1	11.1	**36.2**	**88.5**
Object 5	0.0	0.1	**14.7**	**79.2**	0.0	5.8	**18.7**	**79.7**
Object 6	2.5	27.4	**13.5**	**83.2**	3.4	39.2	**17.9**	**79.7**
Mean	1.1	14.2	**25.2**	**85.6**	2.3	22.6	**26.9**	**81.7**

ADD-S success rates on objects 2-6 after ICP refinement

| | Model from [2] + ICP | | | | Model from [3] + ICP | | | |
| | Tex. DR | | Tex.+Shape DR | | Tex. DR | | Tex.+Shape DR | |
	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm	<0.1d	<2 cm
Object 2	24.7	28.7	**86.7**	**94.4**	43.5	59.5	**77.7**	**88.1**
Object 3	4.5	9.9	**90.7**	**99.7**	20.8	37.0	**84.5**	**97.3**
Object 4	17.4	33.7	**85.5**	**98.1**	10.1	17.2	**88.6**	**94.3**
Object 5	2.1	17.4	**81.5**	**91.9**	16.7	37.8	**82.8**	**94.9**
Object 6	24.3	50.4	**88.3**	**98.9**	34.7	58.0	**84.9**	**94.3**
Mean	14.6	28.0	**86.6**	**96.6**	25.2	41.9	**83.7**	**93.8**