Training semantic segmentation of aerial imagery using synthetic data

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Content

- Motivation
- Related Work
- Objectives
- Research Questions
- Methodology
- Conclusions
- Discussion
- Future Work

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Motivation

Semantic segmentation and Deep Learning

- Change Detection
- Land cover
- Updating Cartography

Image taken from: https://beyondminds.ai/blog/a-simple-guide-to-semantic-segmentation/

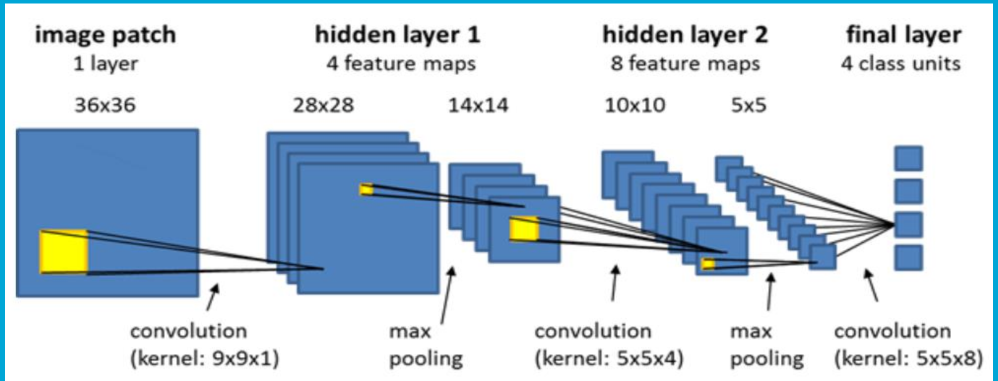

Image taken from: https://docs.ecognition.com/eCognition_documentation/

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Related Work

Maggioroi et. al (2017)
Kampffmeyer et. al (2016)

Limitations

•Same training and testing area
•Do not talk about the quality of training data
•Model Oriented Focus

Deep Learning Projects

80% time for Data Processing (cleaning training data)

Image taken from: https://docs.ecognition.com/eCognition_documentation/

Synthetic Data

- SYNTHIA (2018)
- SYNTHINEL (2021)

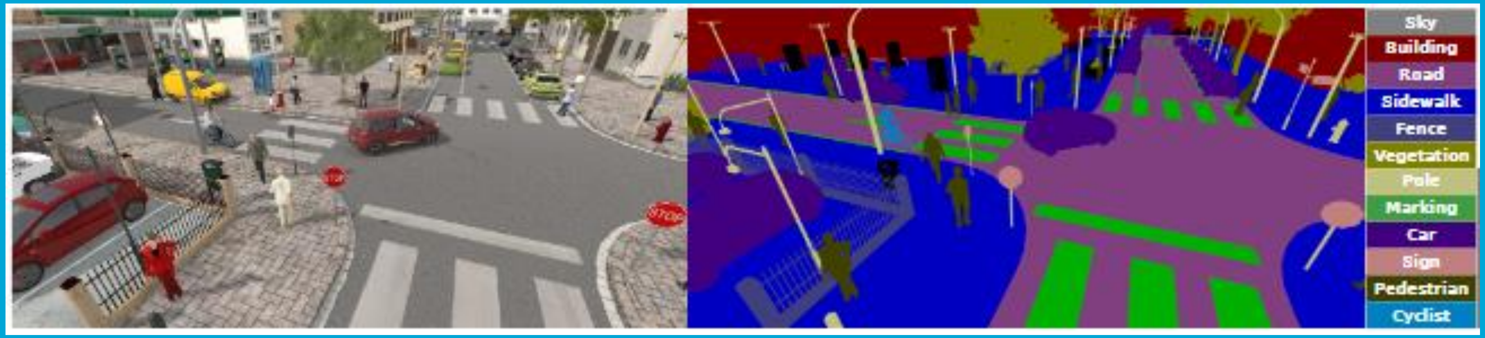


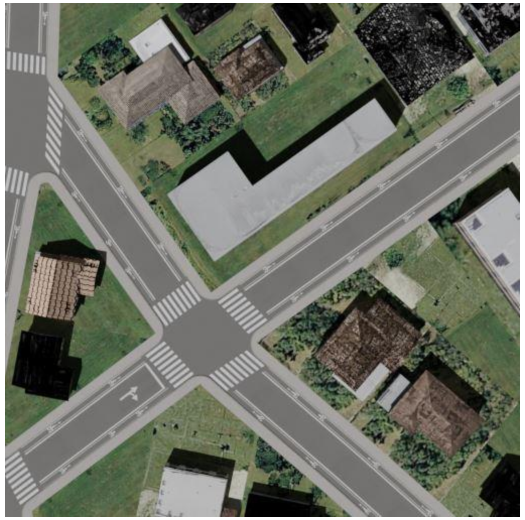
Image taken from: G. Ros, L. Sellart, J. Materzynska, D. Vazquez, and A. M. Lopez. The SYNTHIA Dataset: A Large Collection of Synthetic Images for Semantic Segmentation of Urban Scenes. Technical report, 2016.

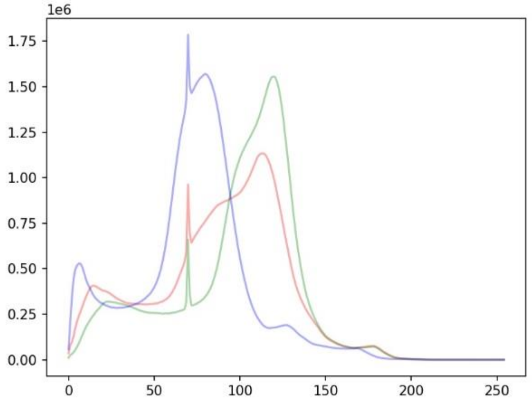
Image taken from: F. Kong, B. Huang, K. Bradbury, and J. Malof. The Synthinel-1 dataset: a collection of high resolution synthetic overhead imagery for building segmentation. 1089, 2019.

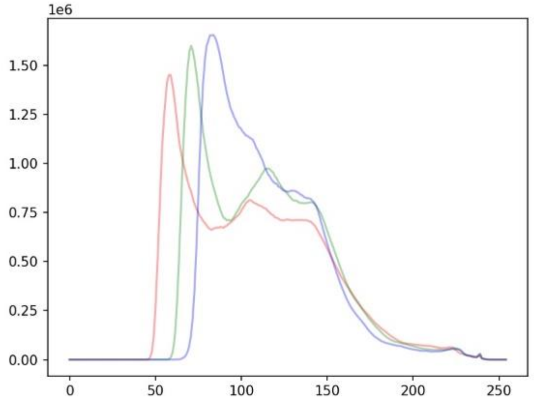
Domain Adaptation

Transfer Learning

Generative Adversarial Networks







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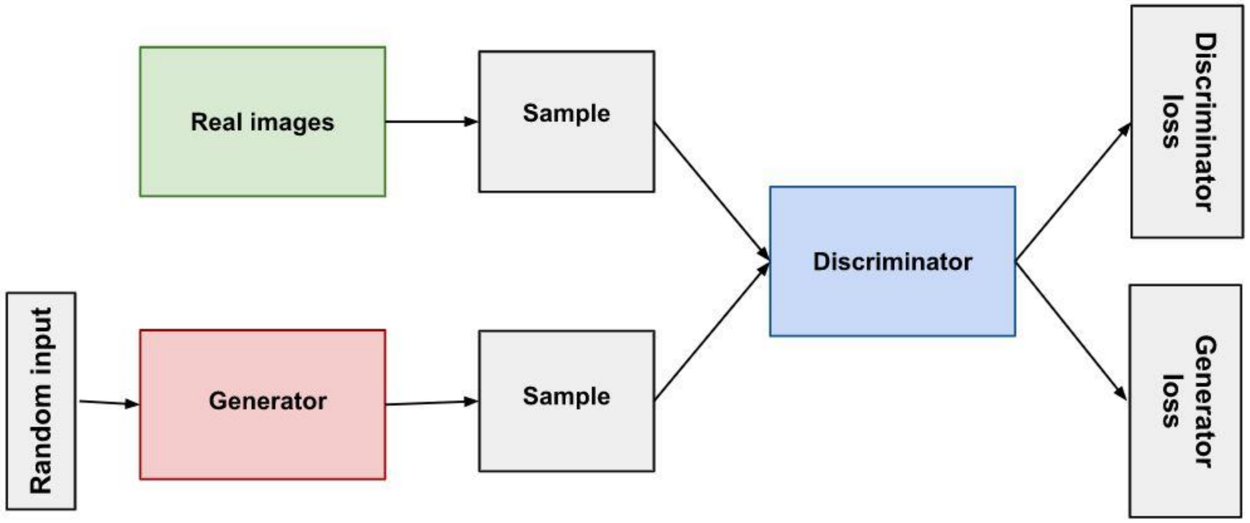
Domain Adaptation

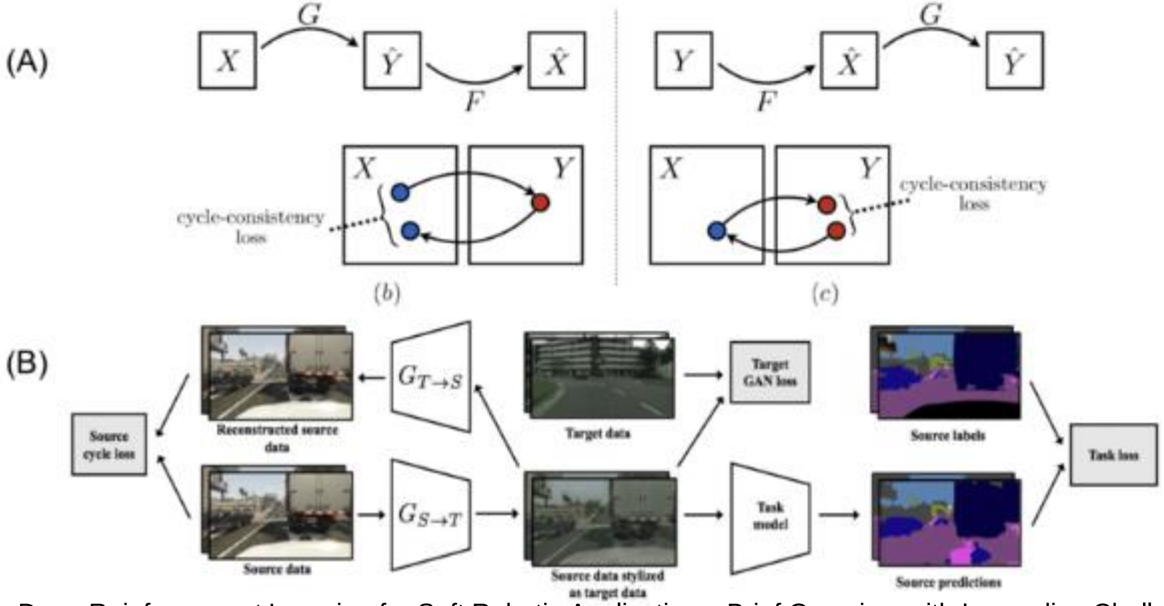
CORAL

$$\min_A \|A^T C_s A - C_t\|_F^2$$

Generative Adversarial Networks



Shor, J. (2022). GANs. https://developers.google.com/machine-learning/gan



Deep Reinforcement Learning for Soft Robotic Applications: Brief Overview with Impending Challenges - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/A-Training-Architecture-of-CycleGAN-B-Training-Architecture-of-a-CyCADA_fig7_329368817 [accessed 23 May, 2022]

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Objective

Evaluate the use of synthetic images for deep learning in aerial imagery

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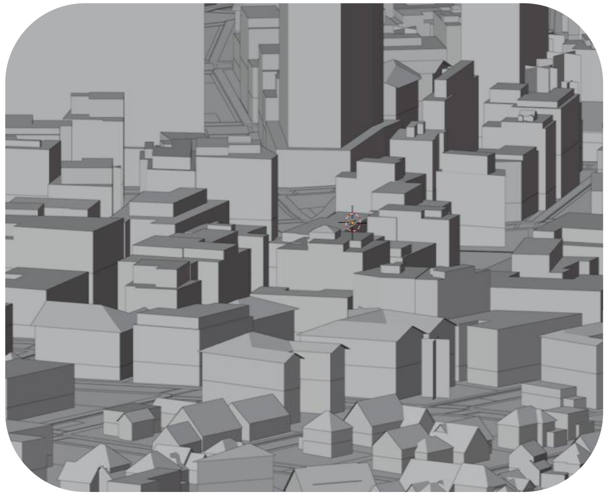
Research Questions

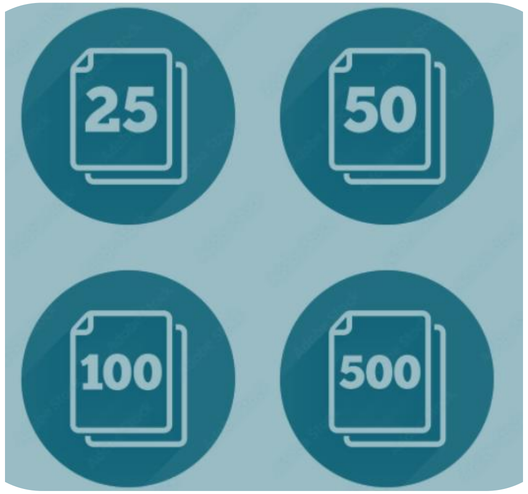
To what extent can synthetic data improve the current Deep Learning-based models for automated semantic segmentation for aerial images?

Sub-questions:

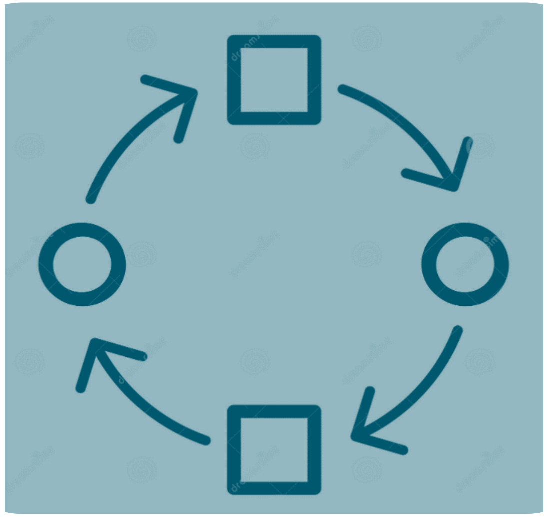
Creation of Synthetic City



3D Models

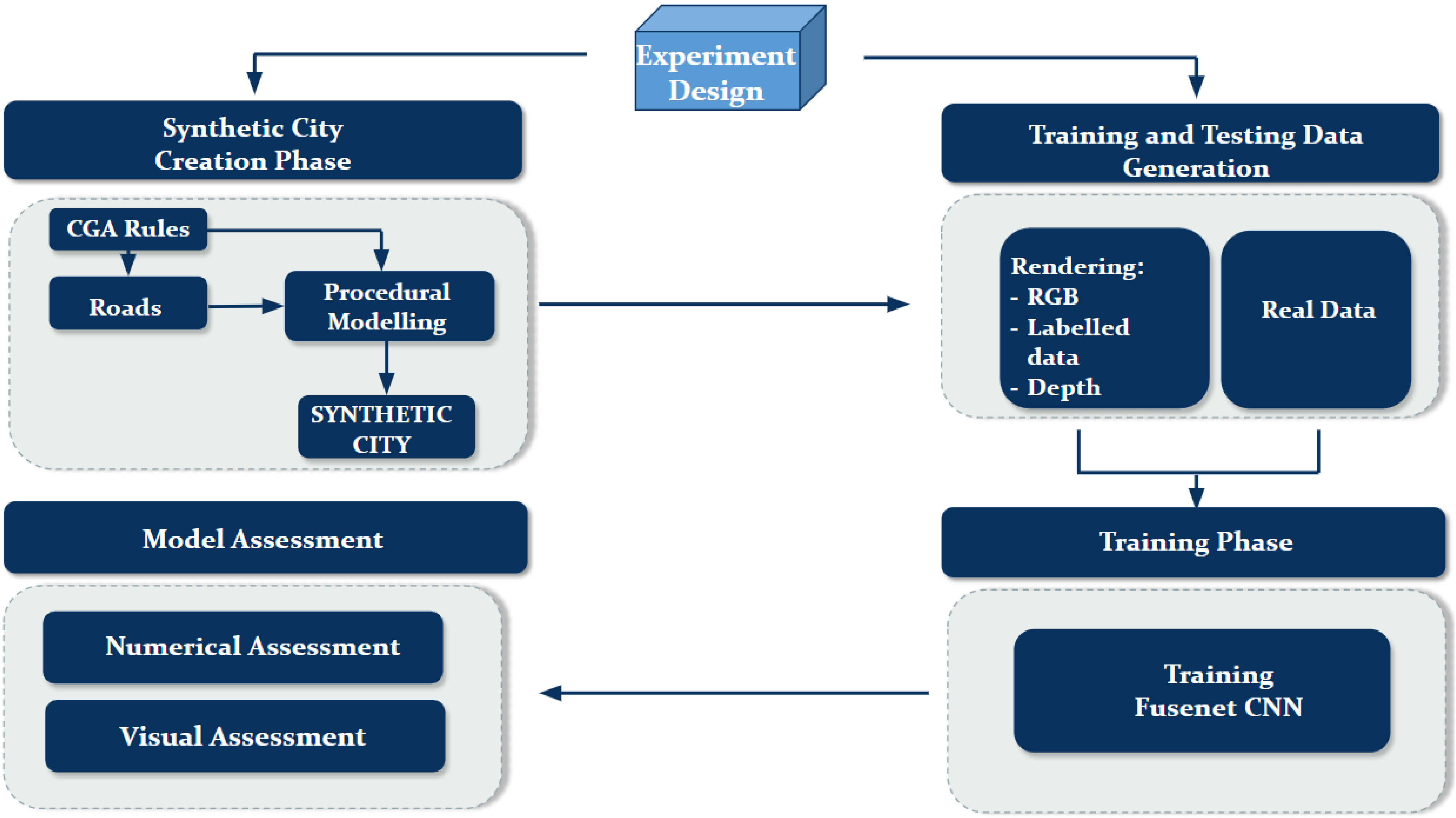


Quantity, Mix



Cross-Domain, Domain Adaptation

Methodology



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City Engine

Procedural Modelling

Computed Generated Architecture Shaped Grammar

Synthetic City Creation

Datasets

Training Model

Assessment

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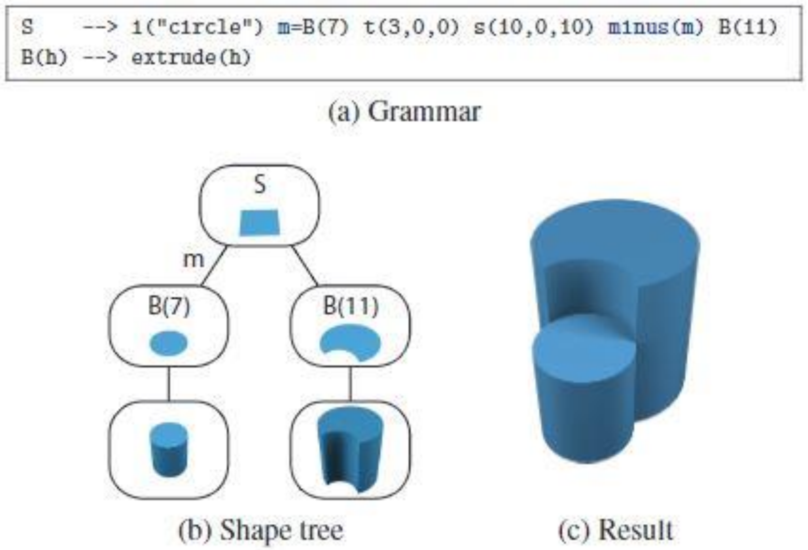

Image taken from: Muller, M. and Schwarz, P. (2015). Advanced Procedural Modeling of Architecture. ACM
Trans. Graph, 34

Synthetic Data Creation

Synthetic City Creation

Datasets

Training Model

Assessment

City Engine

Blender

Training and Testing Data

Synthetic Dataset

Synthetic City Creation	Datasets
Training Model	Assessment

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Haaksbergen

Potsdam

Building
Road
Other

Real Dataset

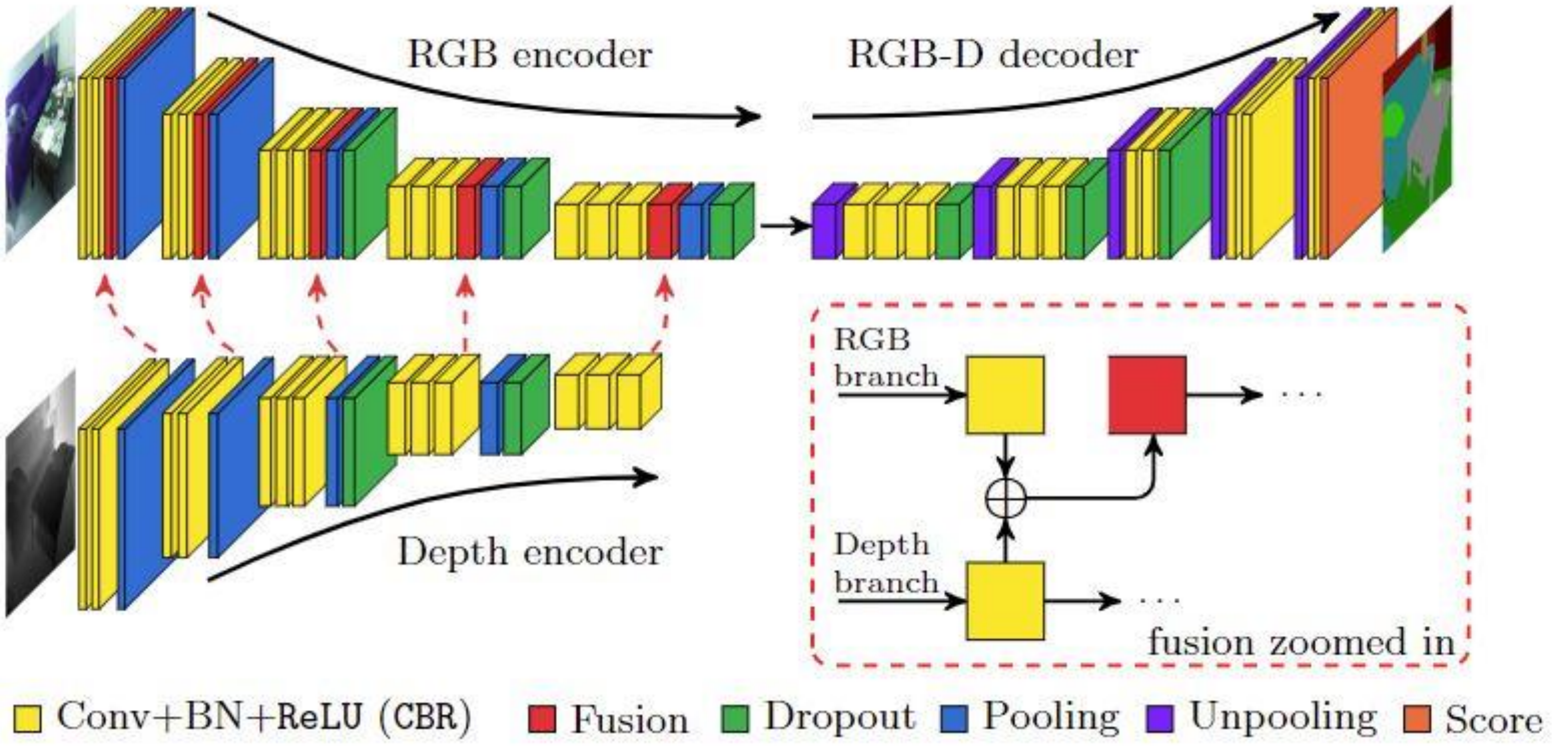
Training Phase

Synthetic City Creation

Datasets

Training Model

Assessment



Train to detect Buildings, Roads and Other

FuseNet Architecture

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Assessment

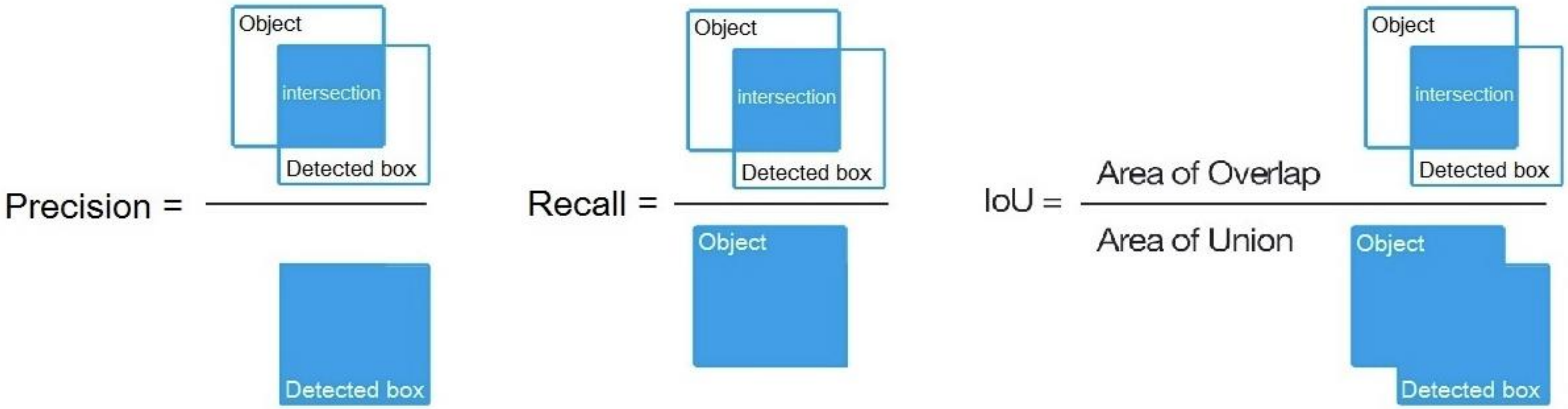
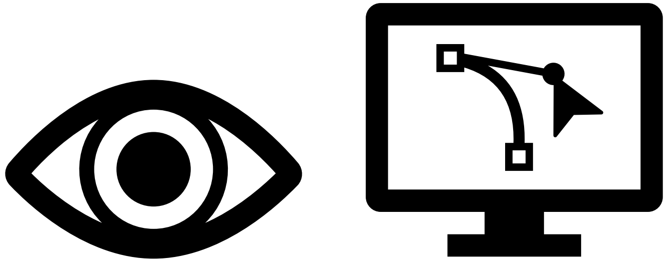


Image taken from: http://www.gabormelli.com/



Synthetic City Creation

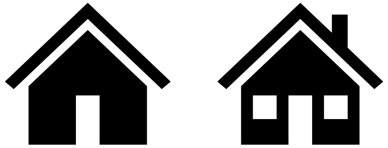
Datasets

Training Model

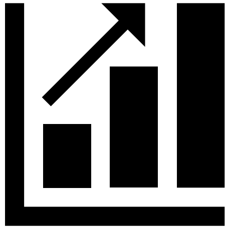
Assessment

Visual Assessment

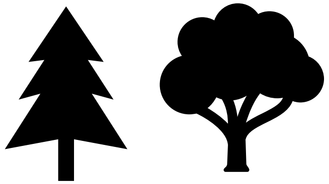
Experiment Design



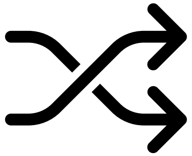
1. Building Models



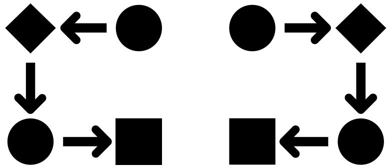
4. Quantity Images



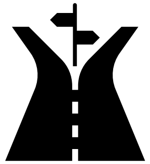
2. Tree Models



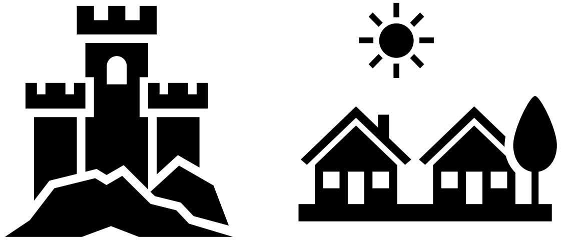
5. Mix between real and synthetic



7. Domain Adaptation



3. Road Patterns



6. Cross–Domain

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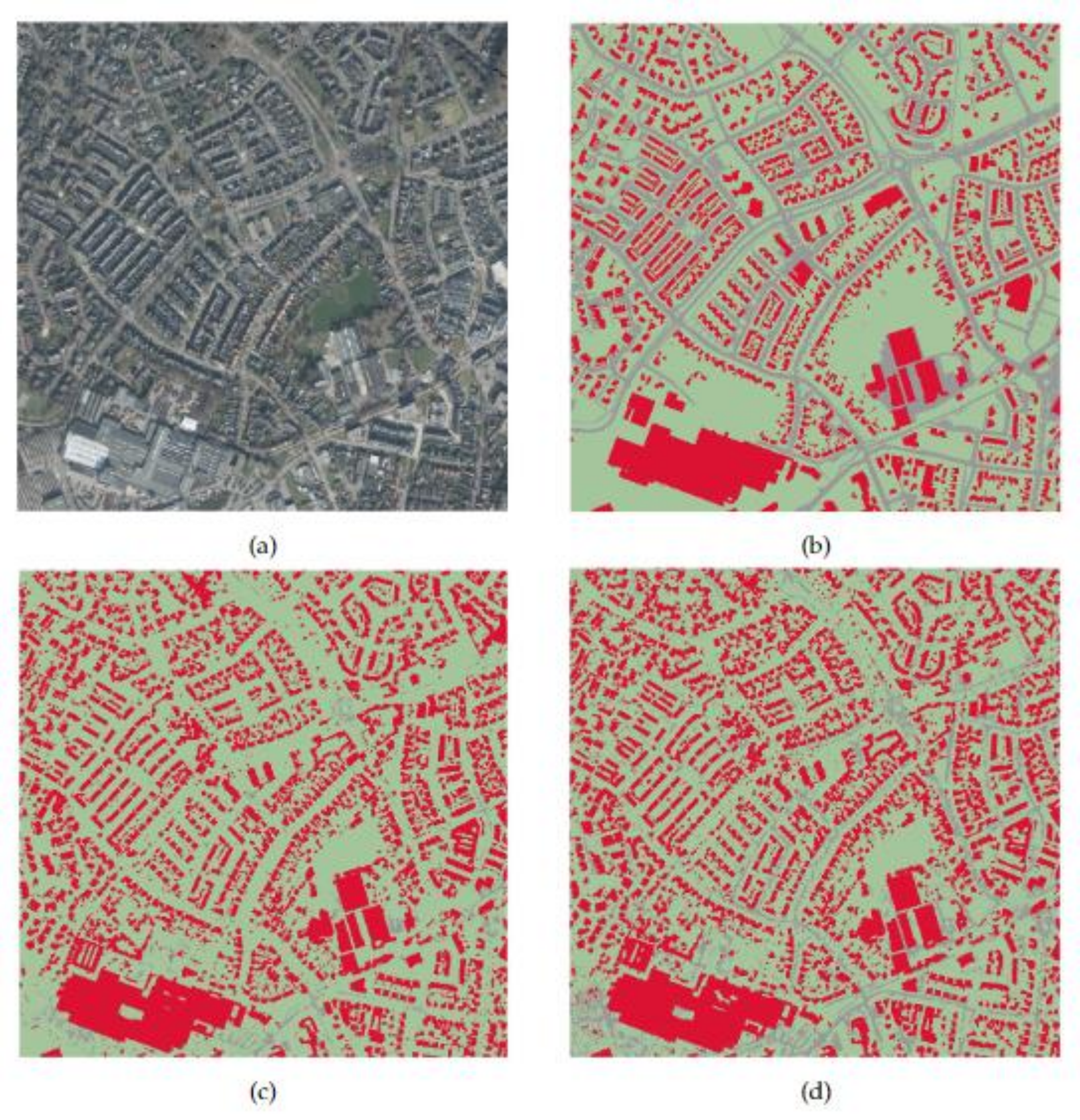
Building Models

Model	IoU Building	IoU Road	IoU Other	mIoU
Dutch City	**0.58**	**0.20**	**0.59**	**0.46**
International City (Default)	0.57	0.04	**0.59**	0.40

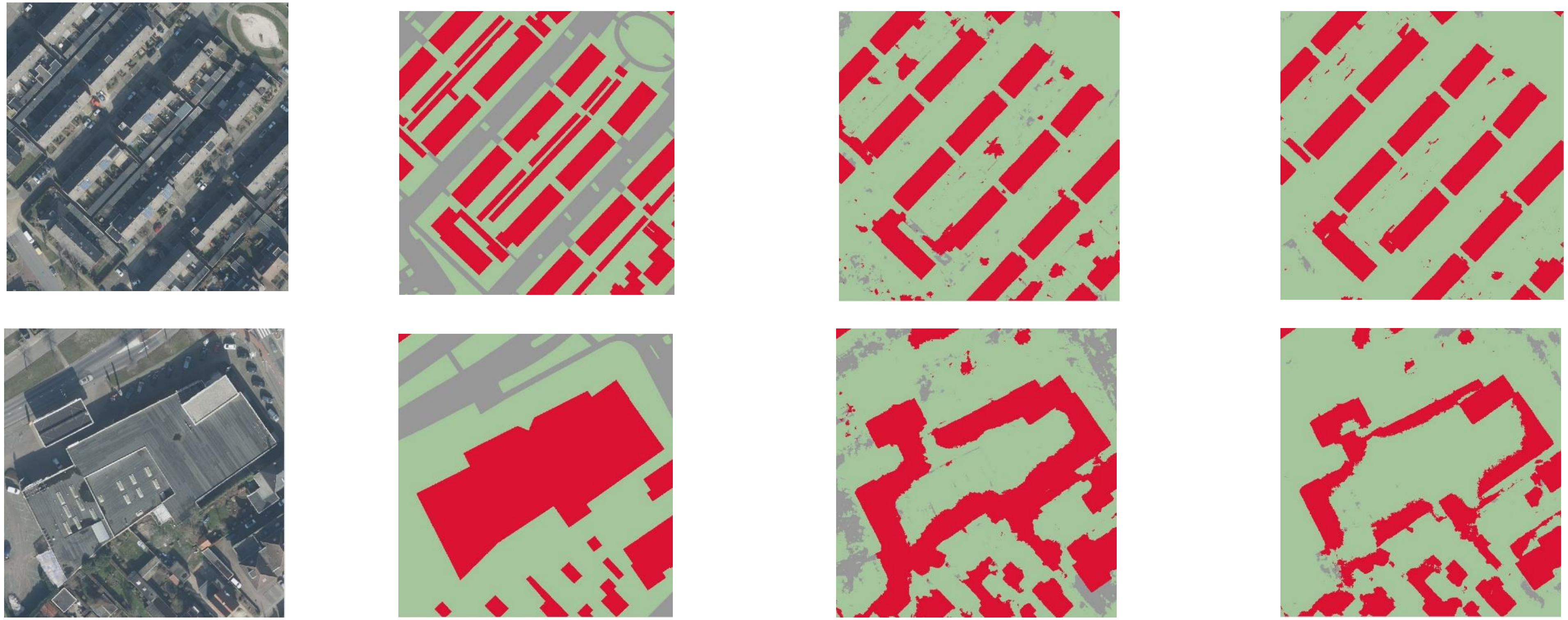
Table 2. Buildings Performance

Building
Road
Other



(a) True Ortho
(b) Ground Truth
(c) International City
(d) Dutch City

Visual Assessment

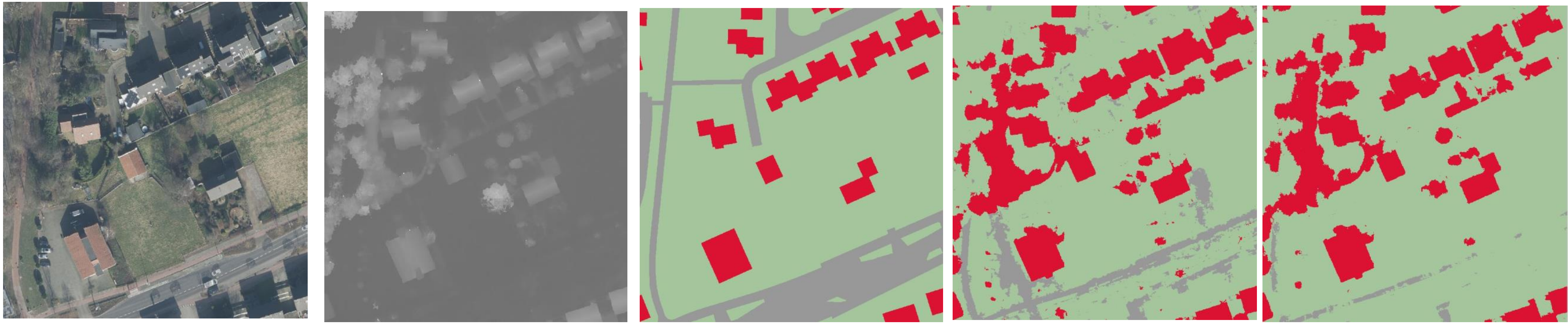


True Ortho | Ground Truth | Dutch City | International City

Building
Road
Other

Visual Assessment

Building
Road
Other

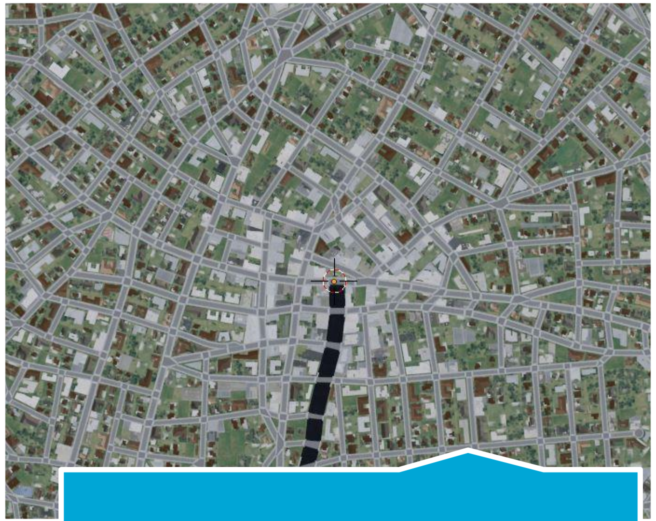


True Ortho | DSM | Ground Truth | Dutch City | International City

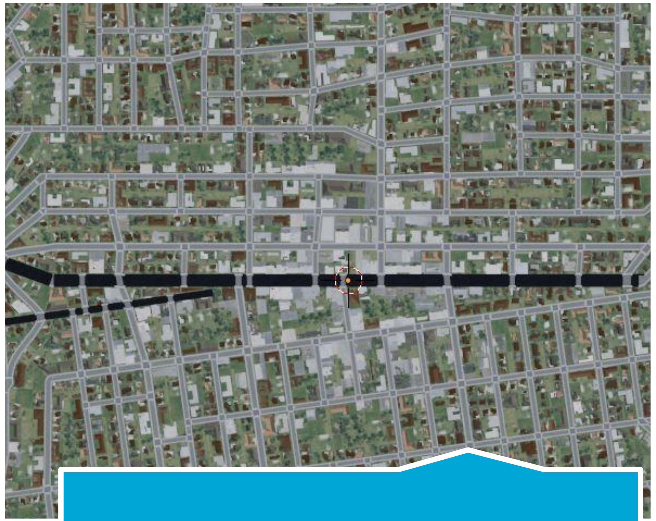
Road Patterns

Model	IoU building	IoU roads	IoU other	mIoU
Organic	0.45	0.28	**0.54**	0.42
Raster	**0.49**	**0.36**	0.48	**0.44**
Organic - Raster	0.43	0.30	0.43	0.39
Radial	0.46	**0.36**	0.22	0.35

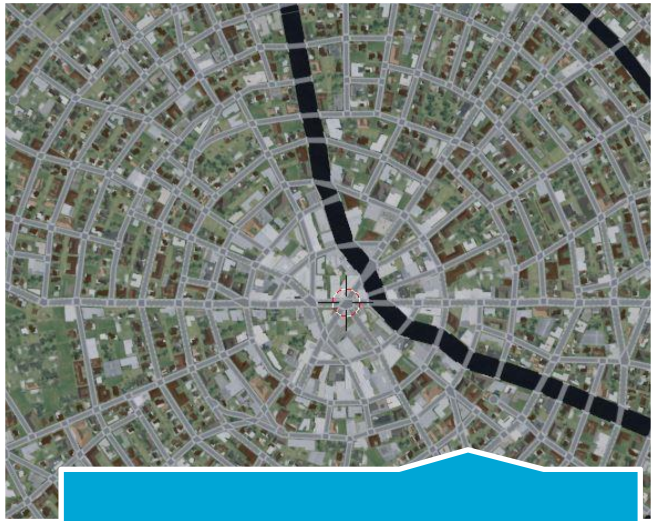
Table 2. Road Pattern Performance



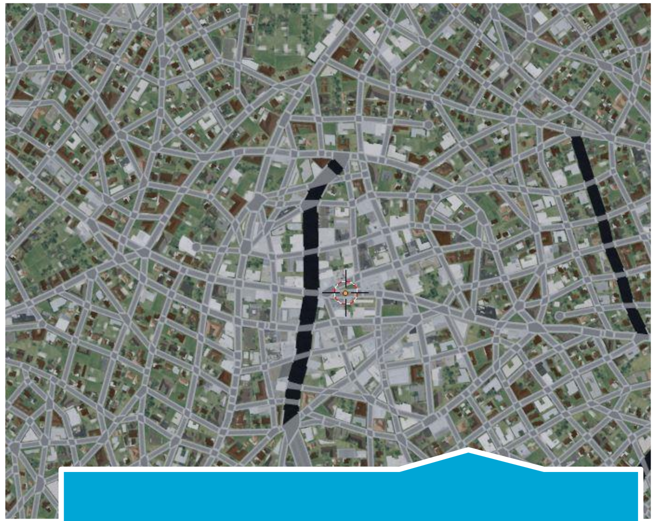
Organic Raster



Raster

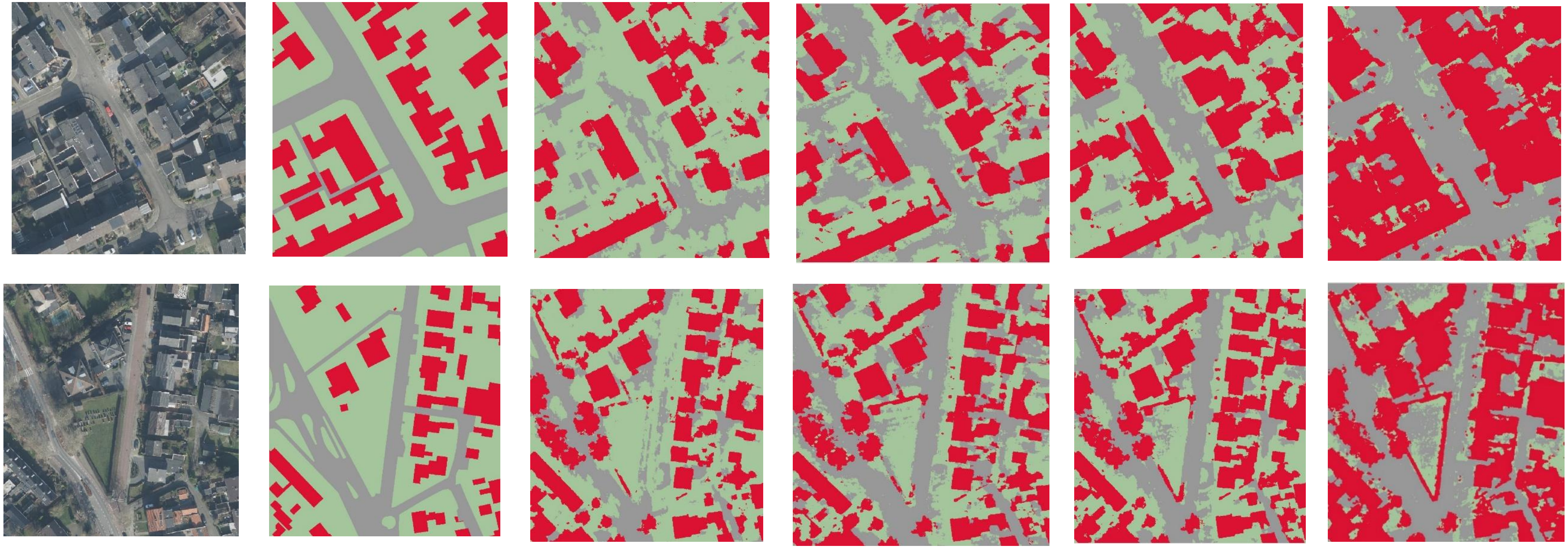


Radial



Organic

Visual Assessment



True Ortho | Ground Truth | Organic | Organic - Raster | Raster | Radial

Building
Road
Other

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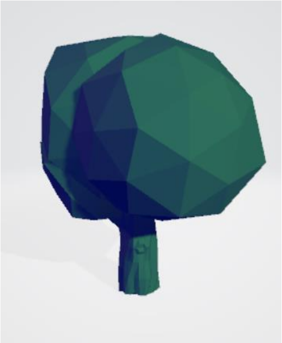
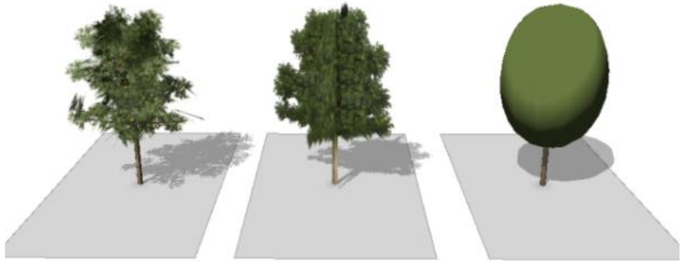
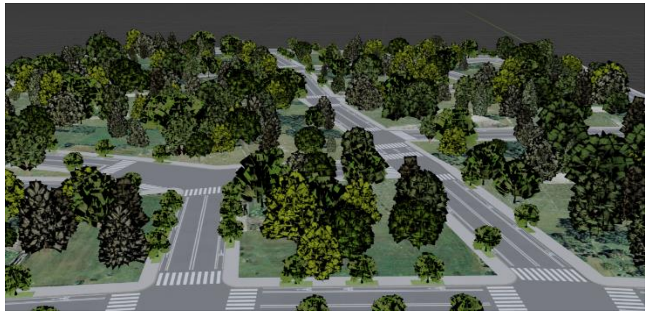
Tree Models



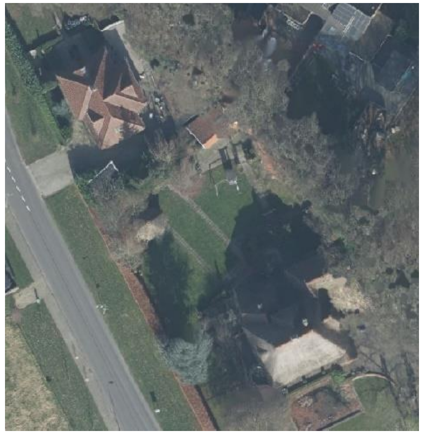




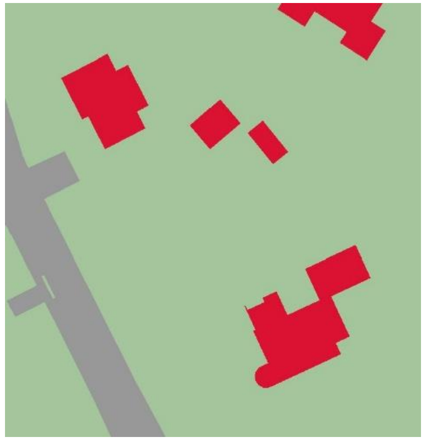
Model	IoU building	IoU roads	IoU other	mIoU
No trees	0.43	**0.30**	**0.43**	**0.39**
Poly Tree	0.43	**0.30**	0.42	**0.39**
Fan Tree	0.40	0.22	0.29	0.30
Realistic Tree	**0.57**	0.29	0.29	0.38

Table 3. Trees Performance

Visual Assessment



True Ortho



Ground Truth

No Trees

Poly Tree

Fan Tree

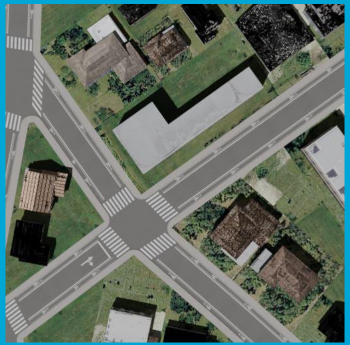
Realistic Tree

Building
Road
Other

Domain Adaptation

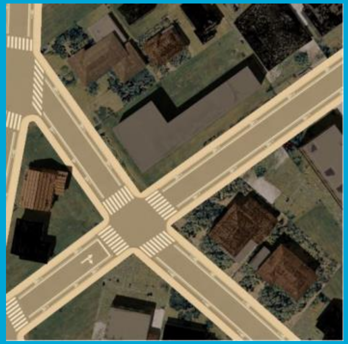
Model	IoU building	IoU roads	IoU other	mIoU
Synthetic City	**0.56**	0.26	0.53	0.45
Coral	0.46	0.05	0.58	0.36
Coral by Classes	0.44	0.04	**0.59**	0.36
Cycle GAN	0.51	**0.40**	0.55	**0.49**
Cycada	0.52	0.39	0.56	**0.49**

Table 8. Domain Adaptation



Synthetic

Coral



Coral by class

Cycle GAN

Cycada

Quantity of synthetic images

Model	IoU building	IoU roads	IoU other	mIoU
188	0.47	0.23	0.21	0.31
378	0.52	0.31	0.51	0.44
756	**0.56**	0.26	0.53	0.44
1512	0.52	**0.33**	**0.57**	**0.48**
3024	0.50	0.32	0.56	0.46

Table 4. Quantity Performance

Graph 1. Synthetic Learning Curve

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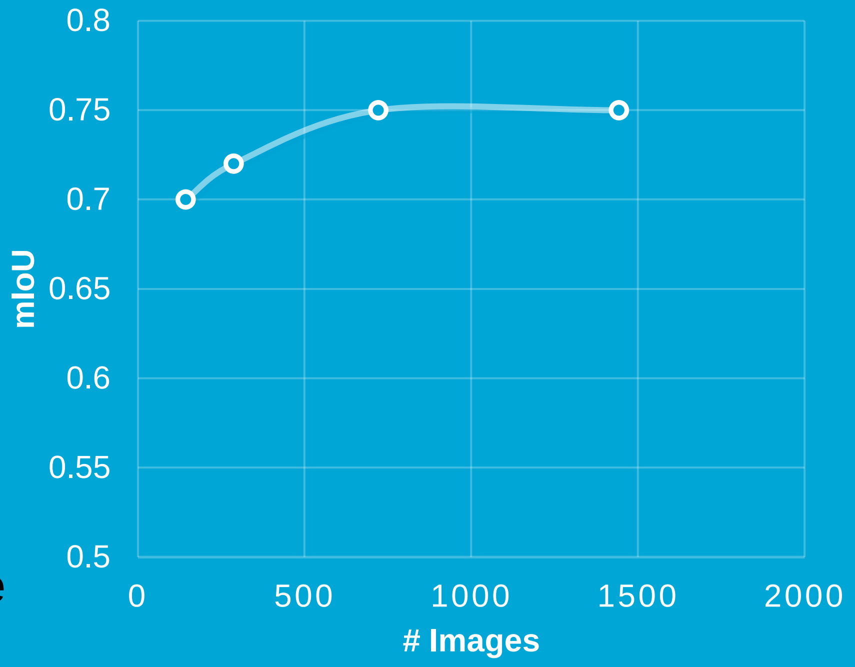
A mix of Real and Synthetic Data

Model	IoU building	IoU roads	IoU other	mIoU
Real 100% (1444 img)	**0.82**	0.66	**0.79**	0.75
Real 80% (1156 img) Synt 20% (288 img)	0.81	**0.67**	**0.79**	**0.76**
Real 50% (722 img) Synt 50% (722 img)	0.81	0.65	**0.79**	0.75
Real 20% (288 img) Synt 80% (1156 img)	0.79	0.60	0.76	0.71
Synt 100% (1444 img)	0.49	0.39	0.31	0.35

Table 5. Mix real and synthetic data

Model	IoU building	IoU roads	IoU other	mIoU
1444	**0.82**	**0.66**	**0.79**	**0.75**
722	0.81	0.65	**0.79**	**0.75**
288	0.79	0.61	0.77	0.72
144	0.79	0.58	0.76	0.70

Table 6. Training with 100% real imagery



Graph 2. Real Learning Curve

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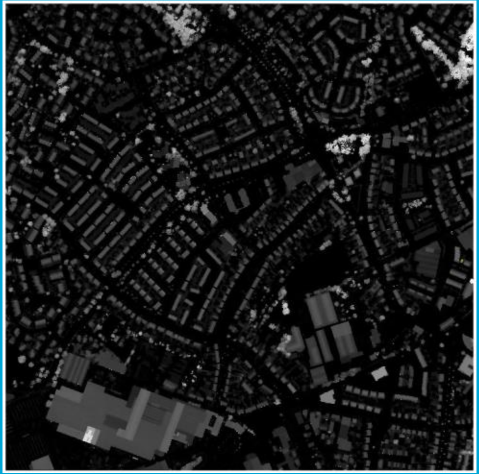
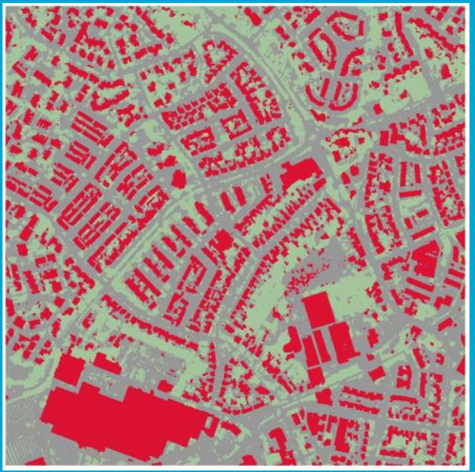
Cross-domain Visual Assessment

Haaksbergen

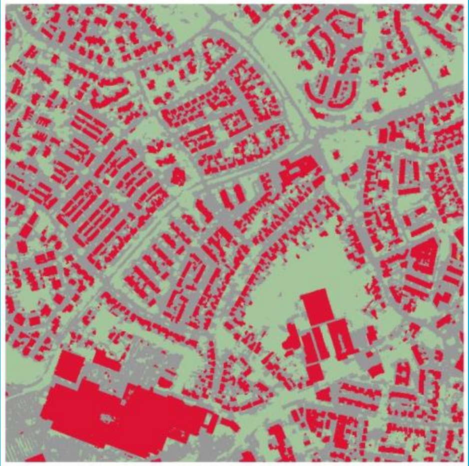


DSM

Ground Truth



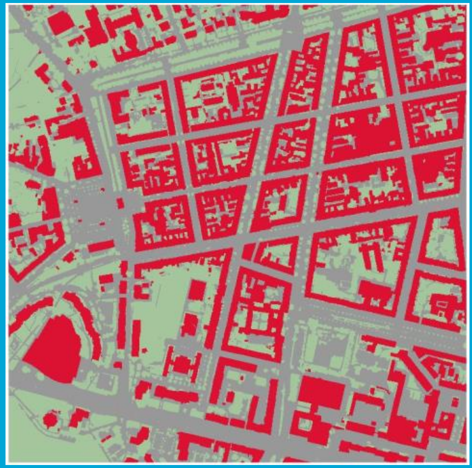
Potsdam



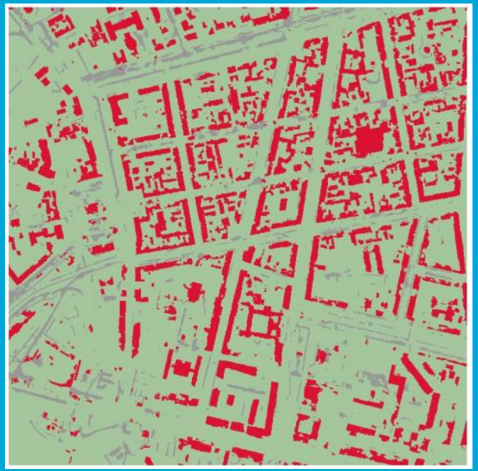
Potsdam - Synthetic

Potsdam

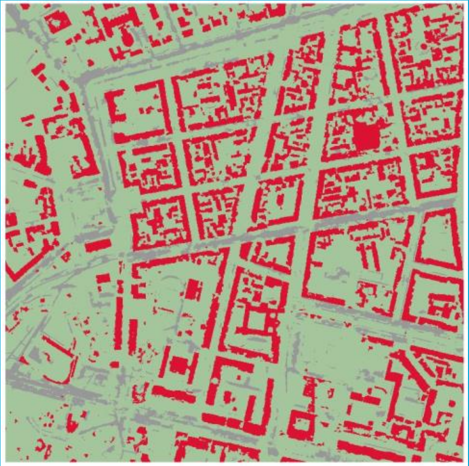
DSM



Ground Truth



Haaksbergen



Haaksbergen - Synthetic

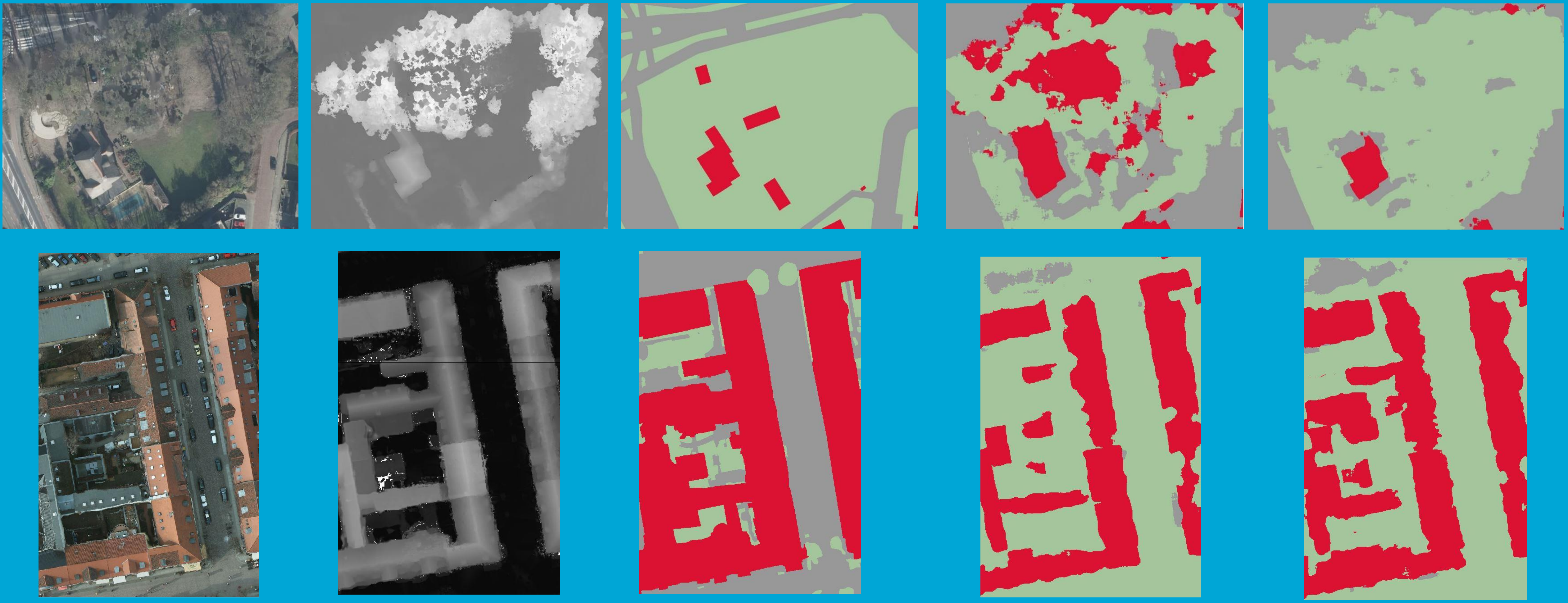
Building
Road
Other

Cross – Domain Scenarios

Training	Testing	IoU building	IoU roads	IoU other	mIoU
Potsdam	**Haaksbergen**	0.62	**0.35**	0.39	0.45
50% Potsdam – 50 % Synthetic	**Haaksbergen**	**0.75**	0.31	**0.40**	**0.49**
Haaksbergen	**Potsdam**	0.54	0.13	0.35	0.34
50% Haaksbergen – 50% Synthetic	**Potsdam**	**0.66**	**0.20**	**0.38**	**0.42**

Table 7. Cross-Domain Scenarios

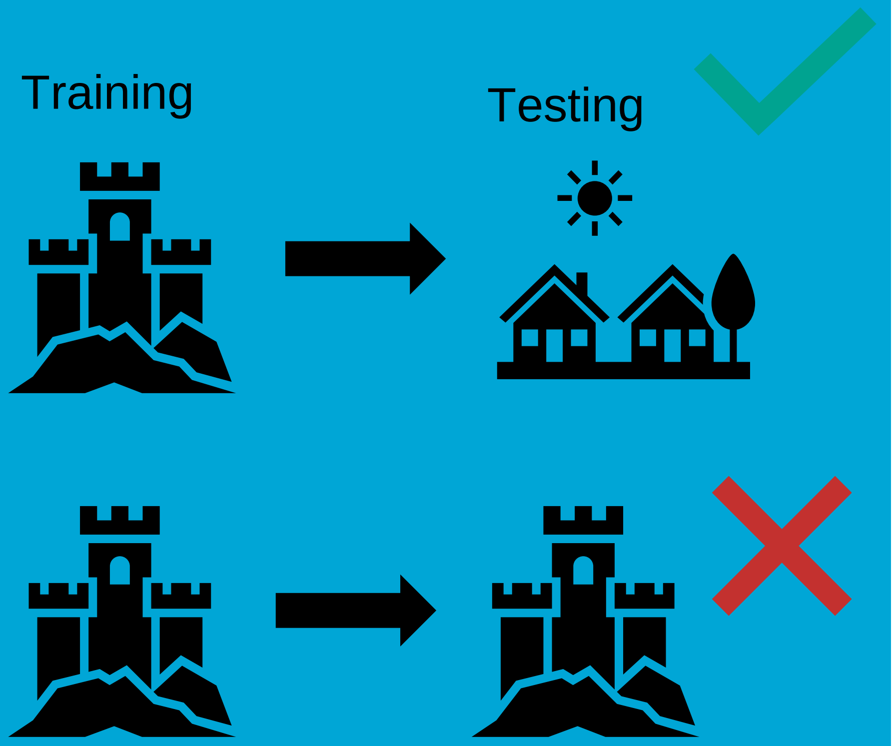
Cross-domain Visual Assessment



True Ortho DSM Ground Truth 100% Real 50% real – 50% Synthetic

Building
Road
Other

Conclusions



To what extent can **synthetic data improve the current Deep Learning-based models** for automated semantic segmentation for aerial images?

+	−
Synthetic data improves performance when gap between domains is big	Real data with small gap has a robust performance

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Contributions

Cross-Domain Projects: Synthetic imagery helps to improve performance when lack of label data

Understanding the learning of Deep Learning models: Freedom of design helps to understand the learning process of the model

Starting Point to produce synthetic data: The potential of synthetic data is high → Detects aprox. 95% of building pixels

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Limitations

- Massive graphic computation for the creation of a virtual world
- Limited realism of synthetic city
- Insufficient size of texture's Library
- Regular quality of training and testing data

Future Work

Use of gaming engines to achieve more realism

Employ 3D models as City models for labelling process

A review of Deep Learning models trained with synthetic data

Thank you for your attention

Camilo Caceres

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FuseNet Hyper-Parameters

Hyper-Parameters	Value
Loss Function	Weighted Cross Entropy
Optimizer	Adam
Optimizer Learning Rate	0.0001
Batch Size	4
Number of epochs of no improvement	20

The models are trained using a single GPU
(rtx2080ti 12 GB)

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