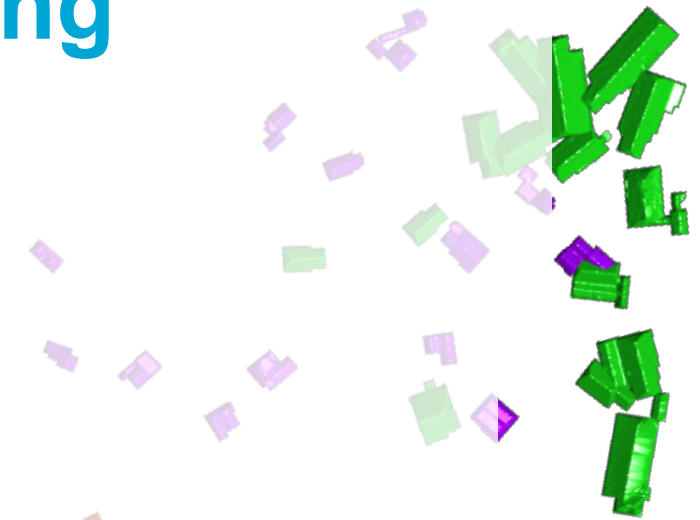
Shape based classification of seismic building structural types



Final presentation

Raphael Sulzer

Mentor #1: Dr. Pirouz Nourian
Mentor #2: Dr. Jan van Gemert
External Mentor: Dr. Michele Palmieri

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Seismic building structural type

- *Describes **main load bearing structure** of a building and therefore its behaviour under seismic load*

- ***Motivation:***
  - *Important input for **seismic risk assessment***

- ***Problem:***
  - *Commonly **not available on large scale***

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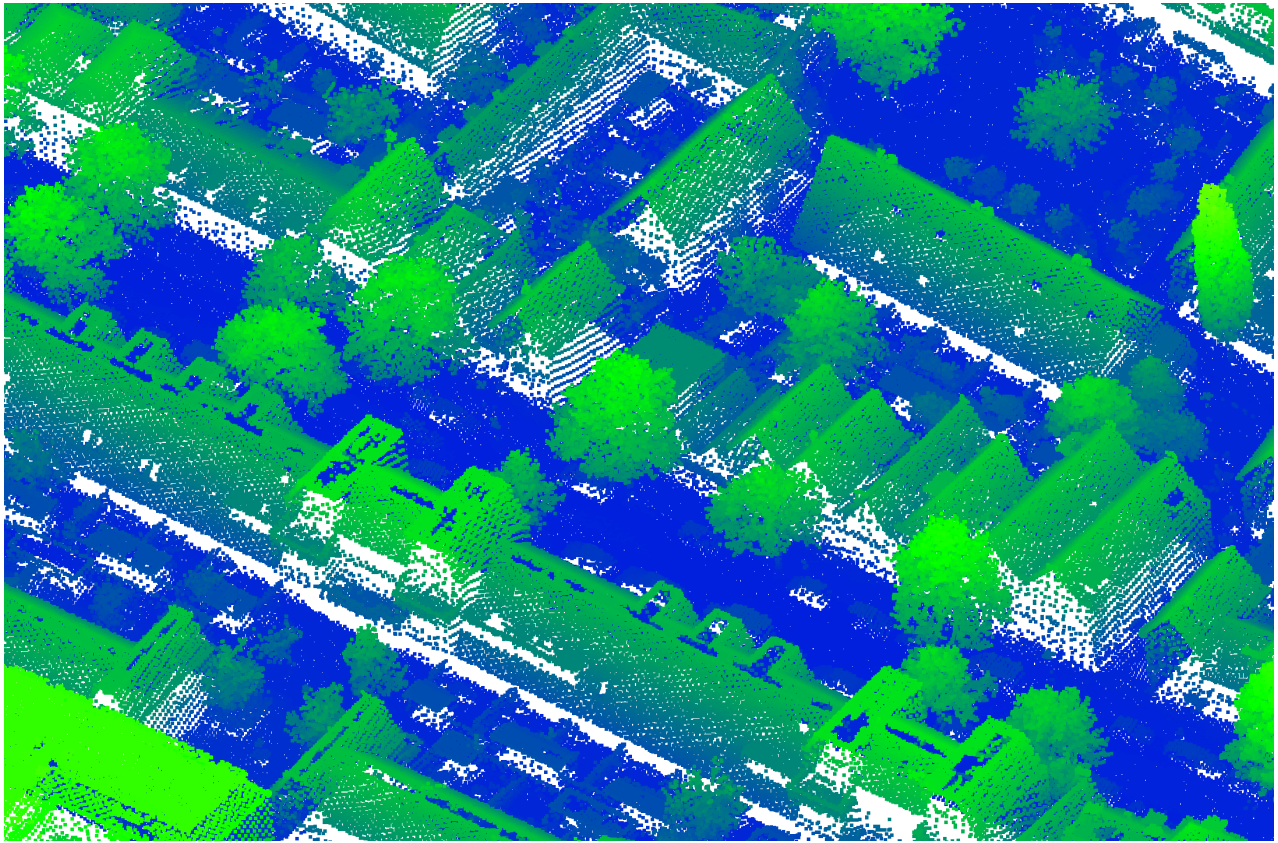
Aerial laser scan



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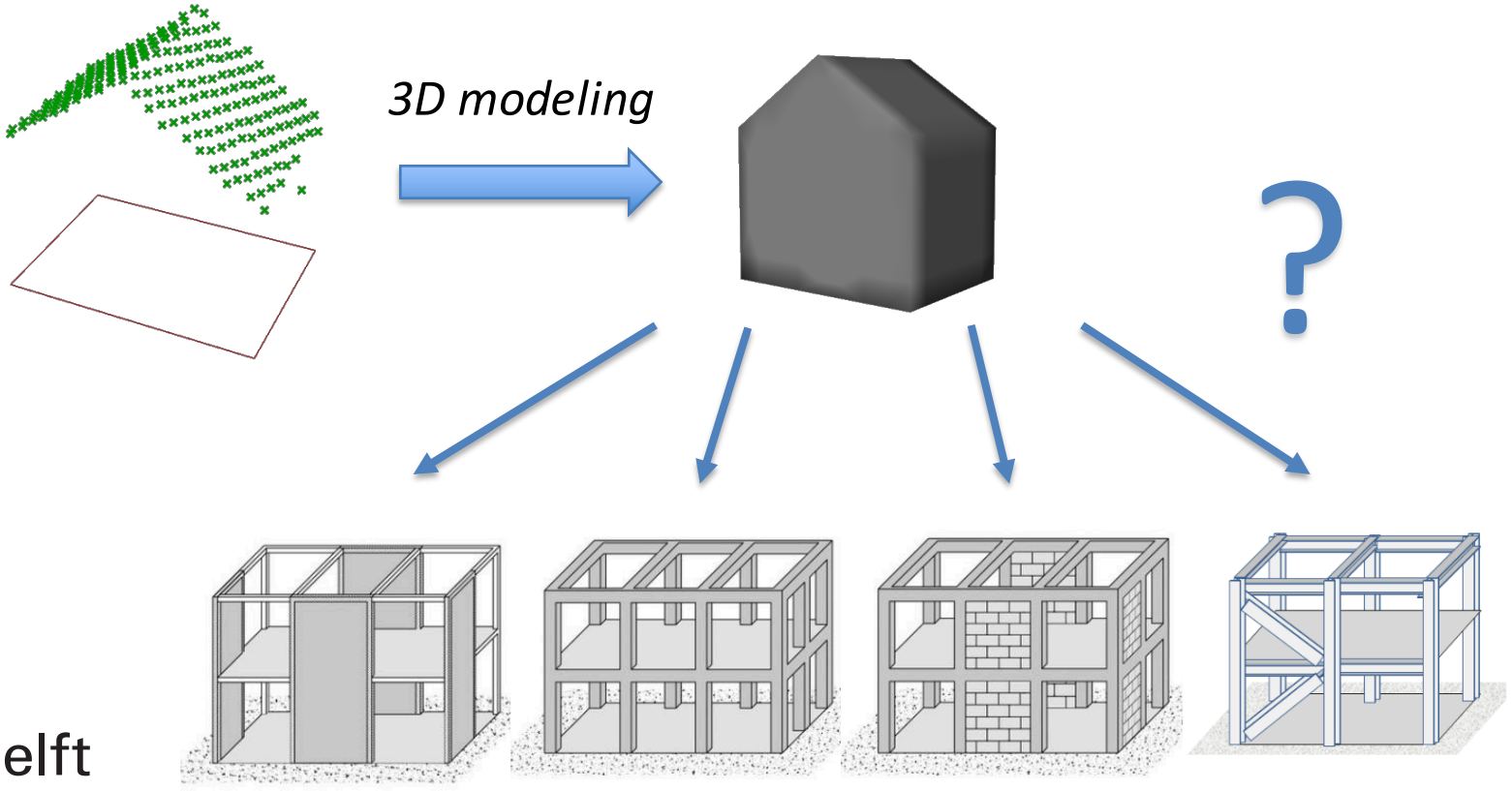
Seismic building structural type



Objective

- Develop and implement a machine learning algorithm that can **automatically** classify seismic building structural types (SBSTs)

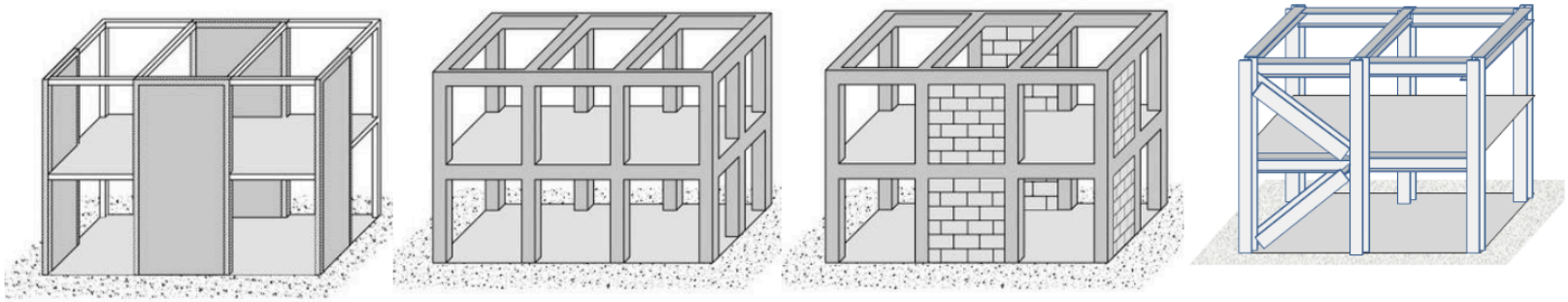
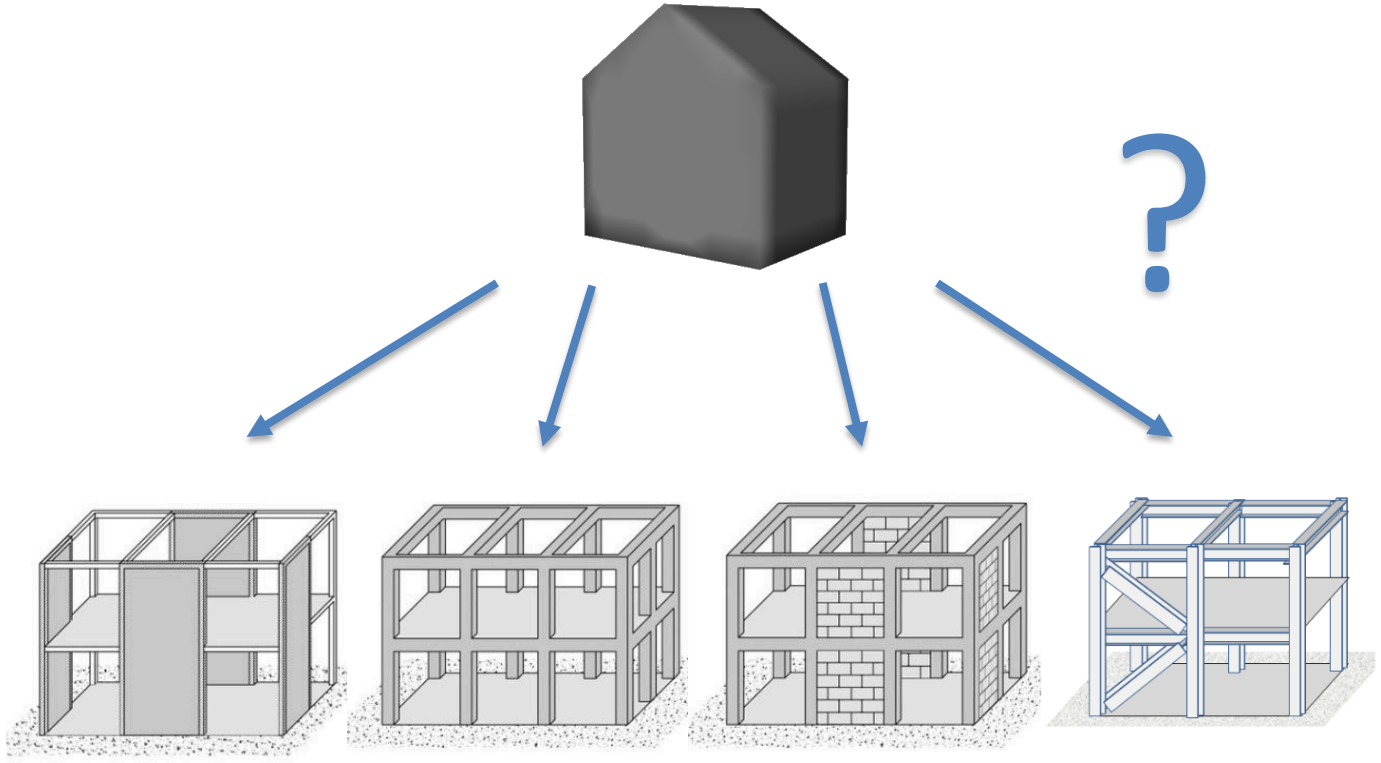
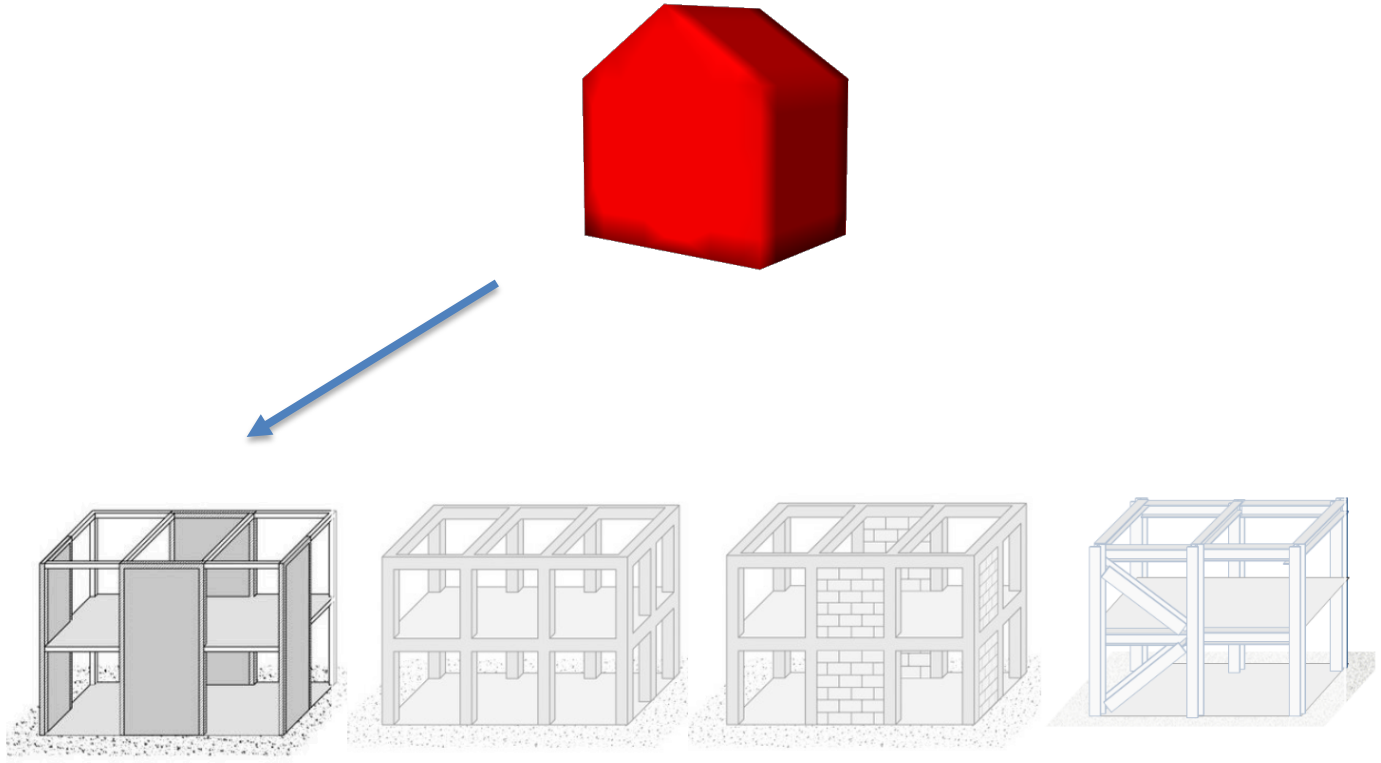


Image source: GEM foundation [1]

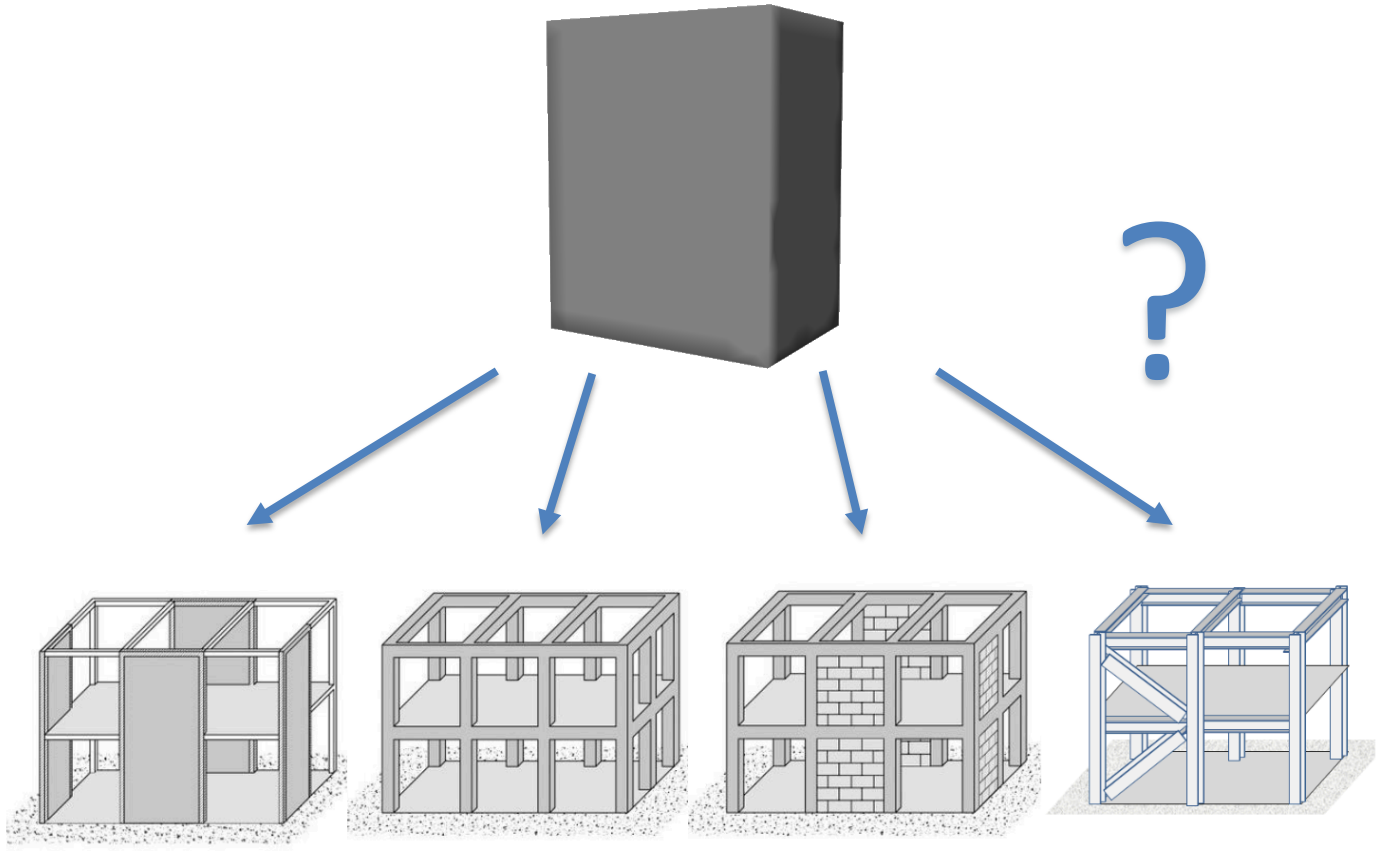
Automatic classification



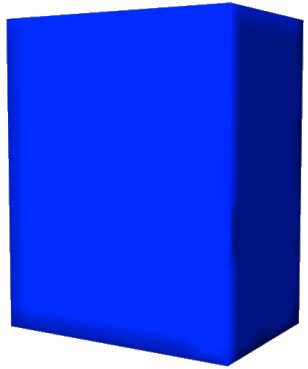
Automatic classification

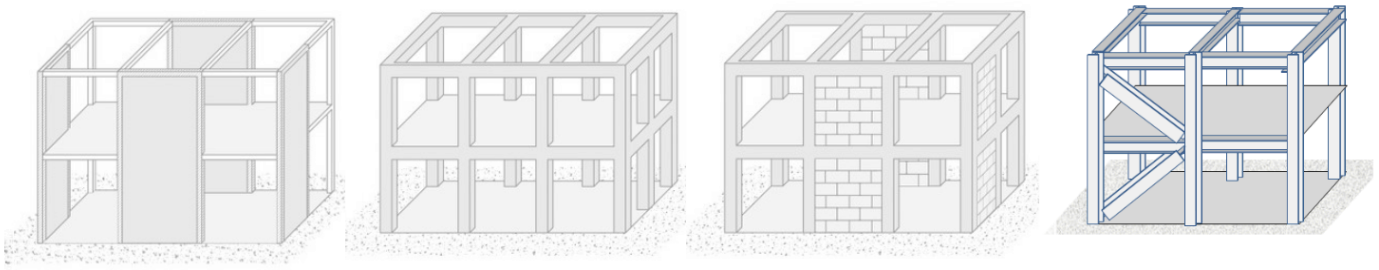


Automatic classification

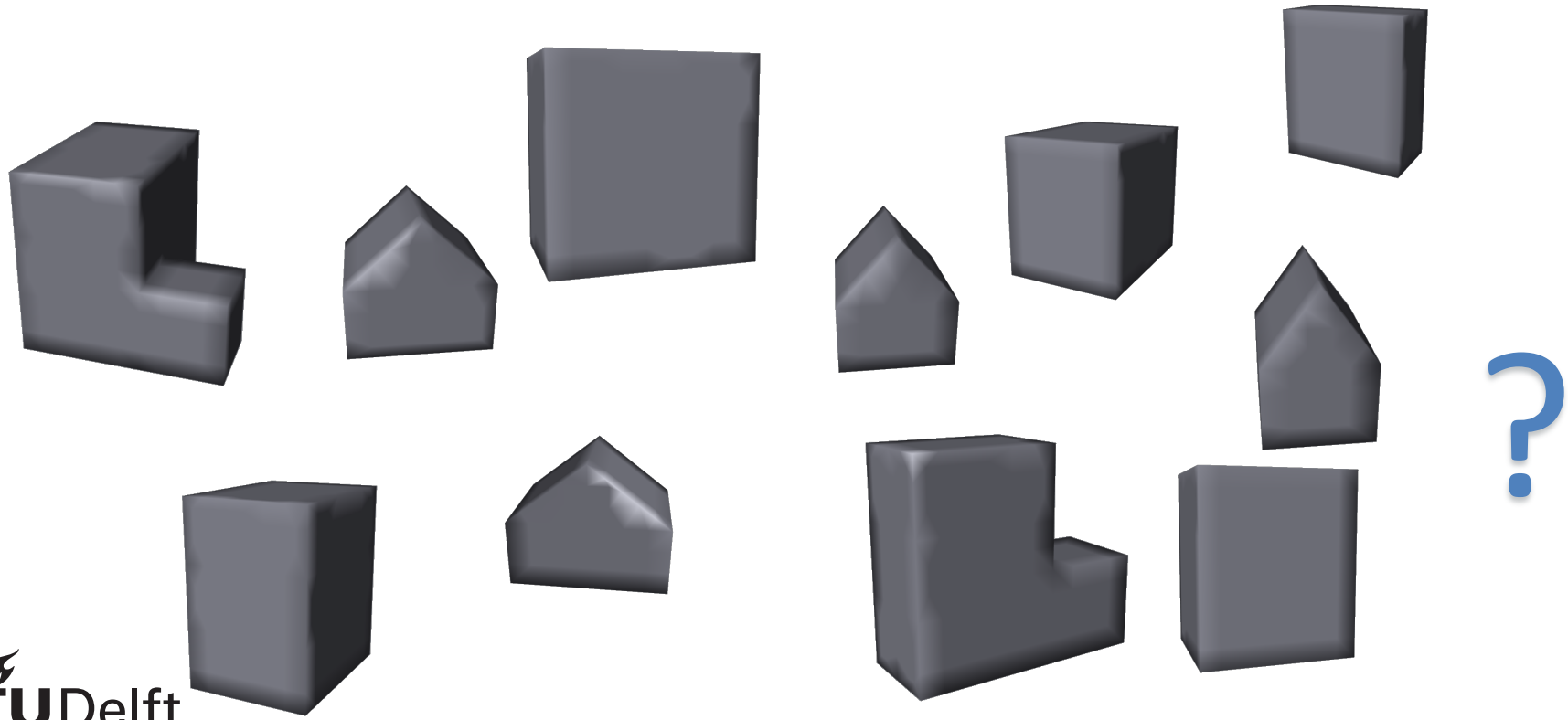


Automatic classification





Automatic classification



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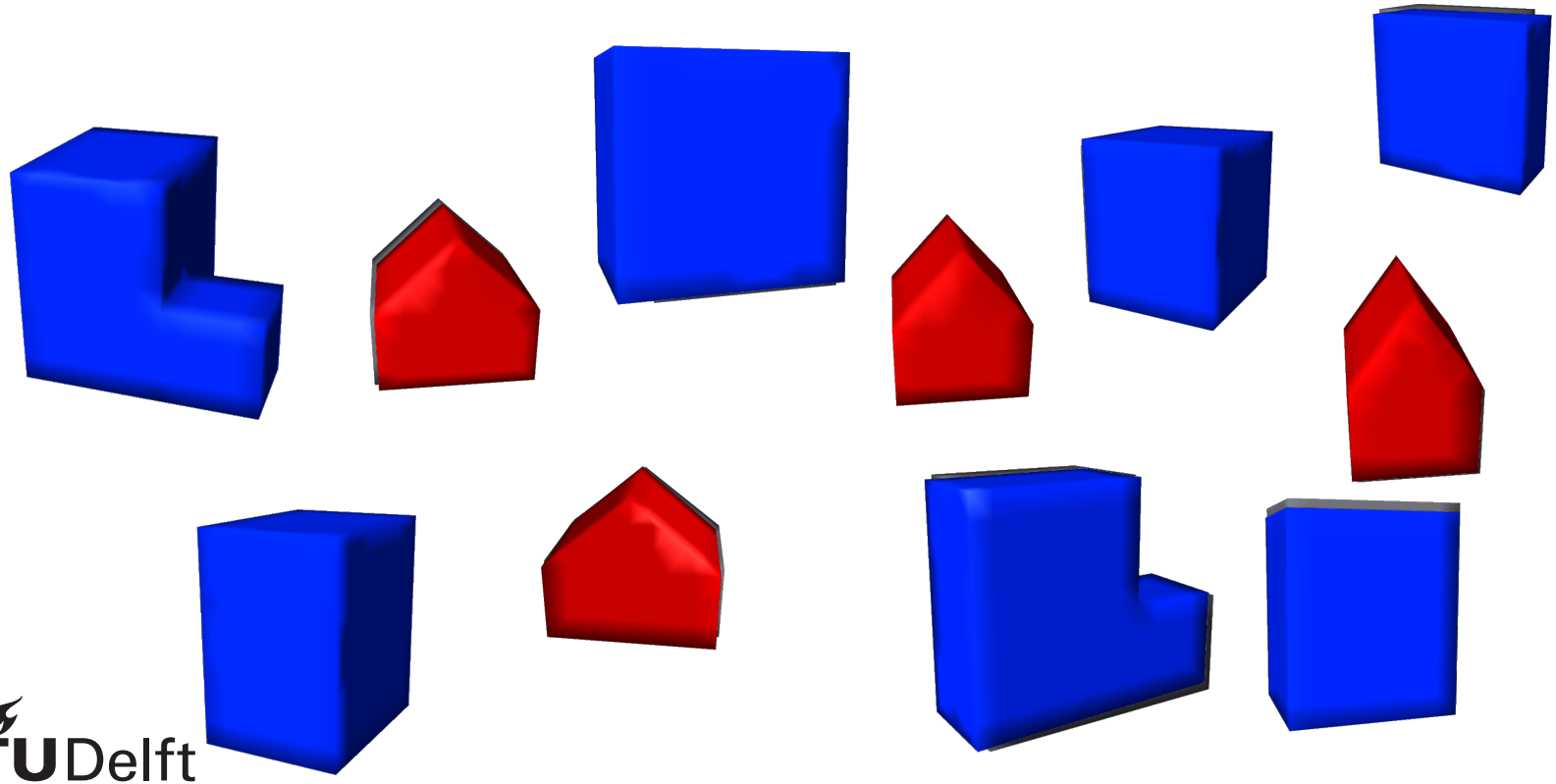
Automatic classification



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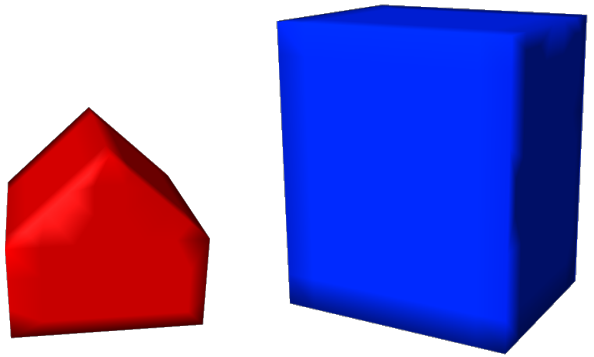
Research question

- Classification based on the **geometric shape** of a building
- Make use of a so-called **shape descriptor**
- *To which extent is it possible to describe geometric similarities of buildings using* ***Shape DNA****?*

$$\Delta f := div\,(grad\,f)$$



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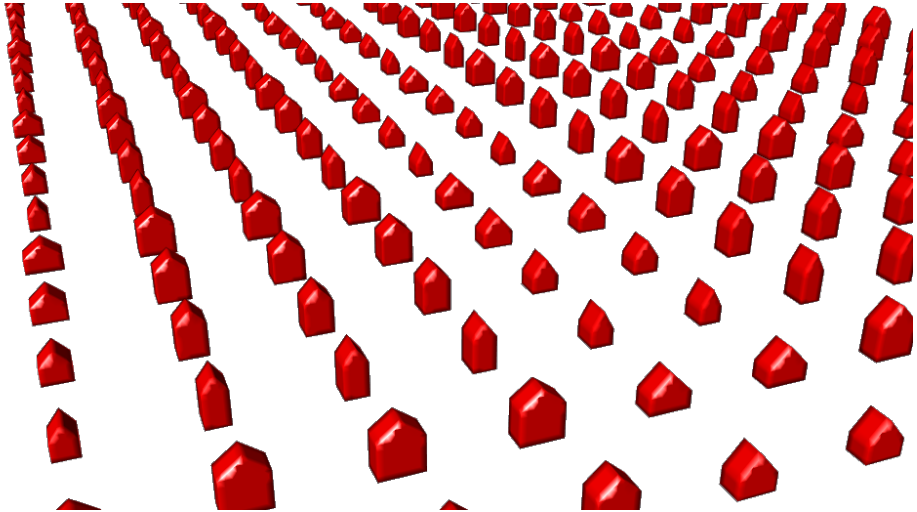
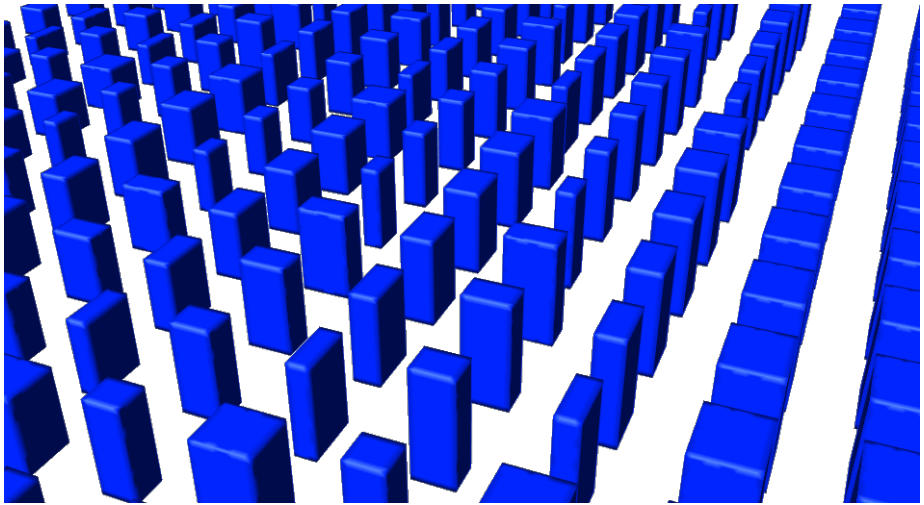
Methodology

- *…come back to Shape DNA later*

- *Let's first implement the machine learning algorithm…*
  - *A supervised learning algorithm*

Training samples





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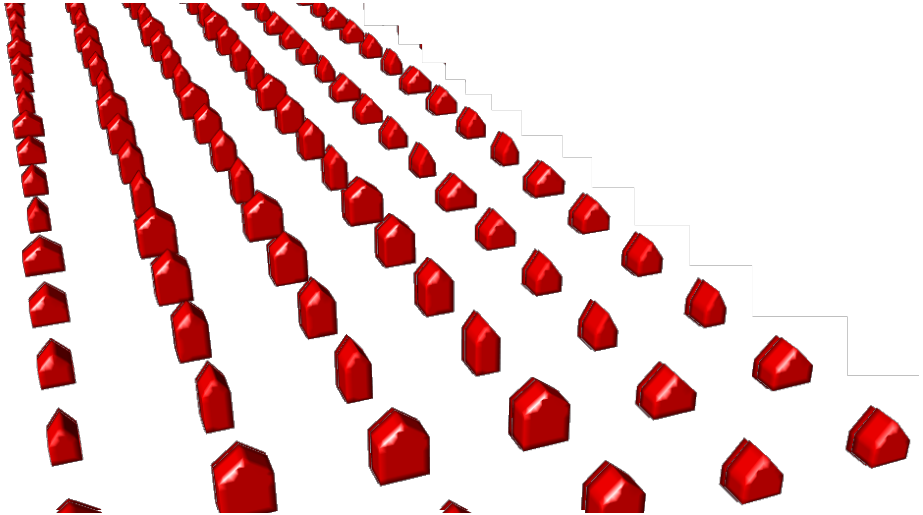
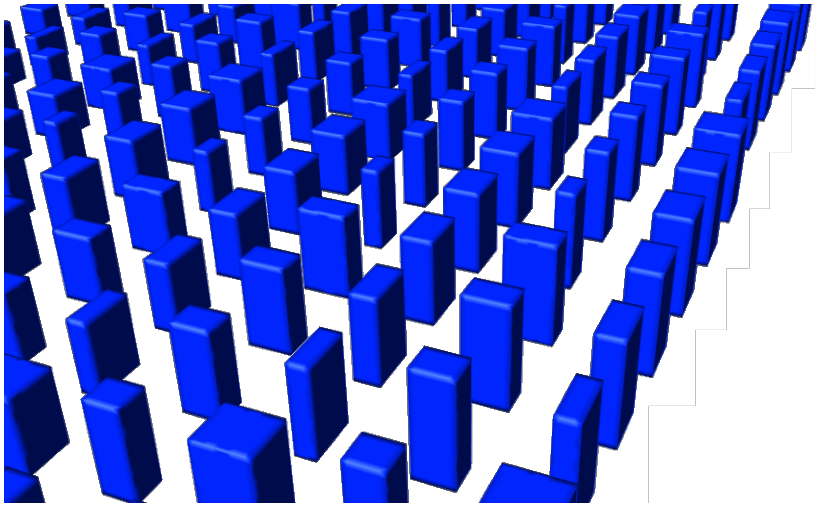
Training samples





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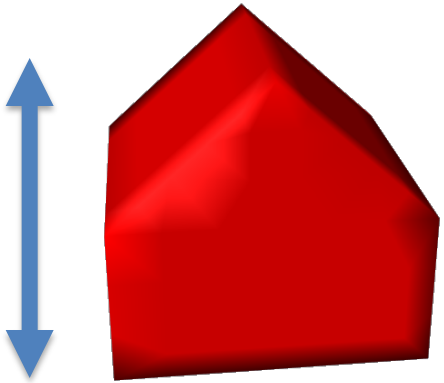
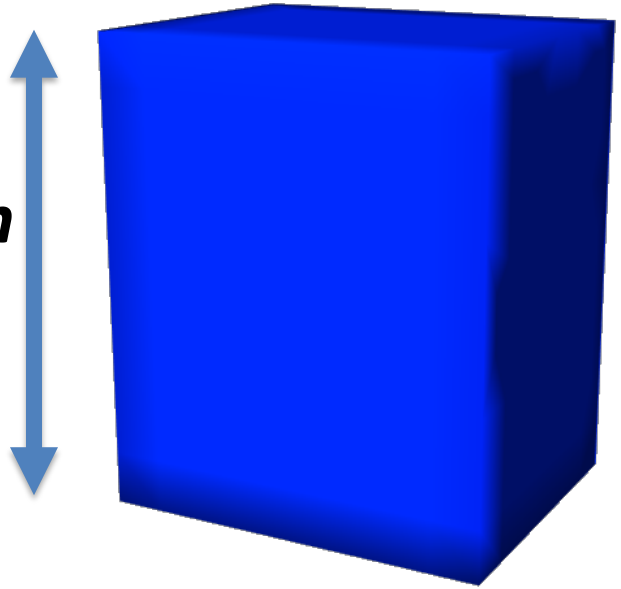
Feature extraction



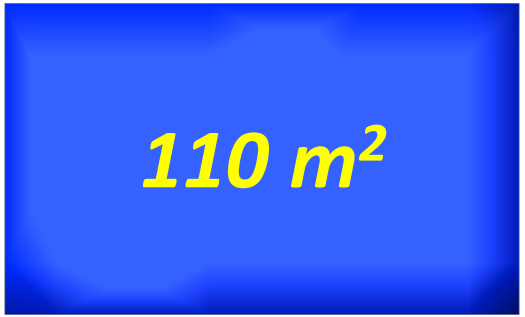
height

6.70 m



13.25 m

footprint area



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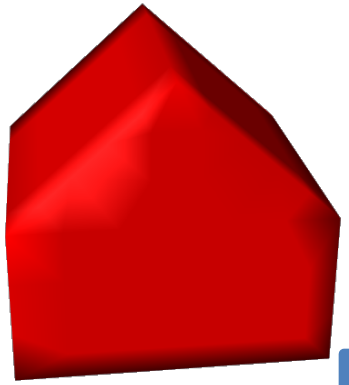
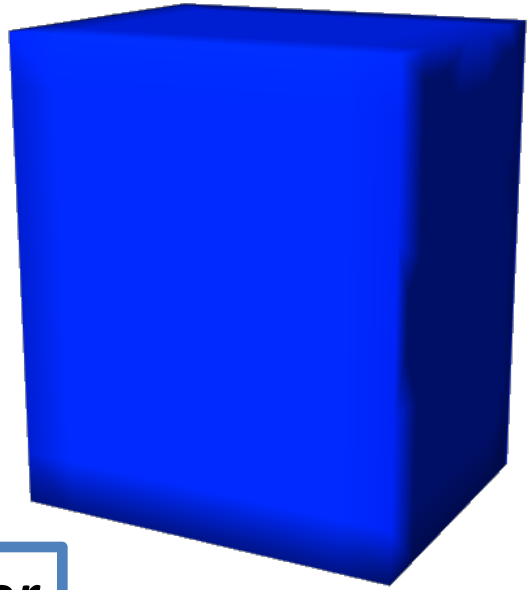
Feature extraction

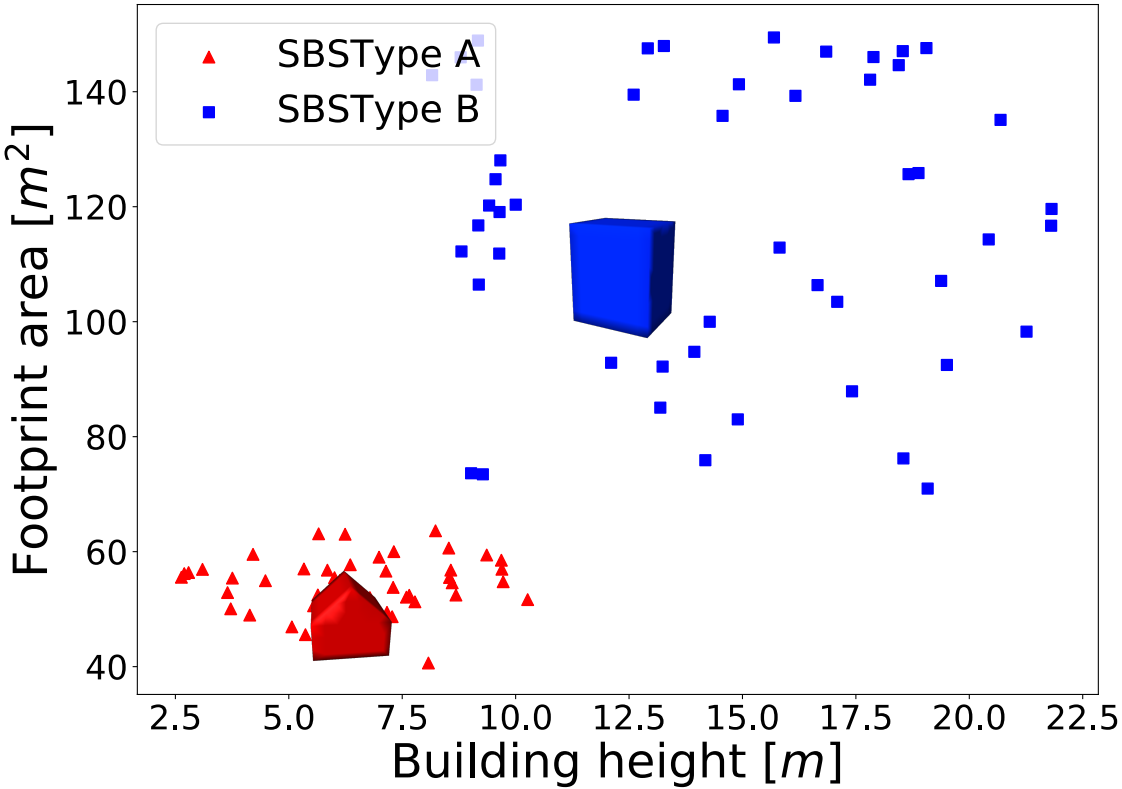




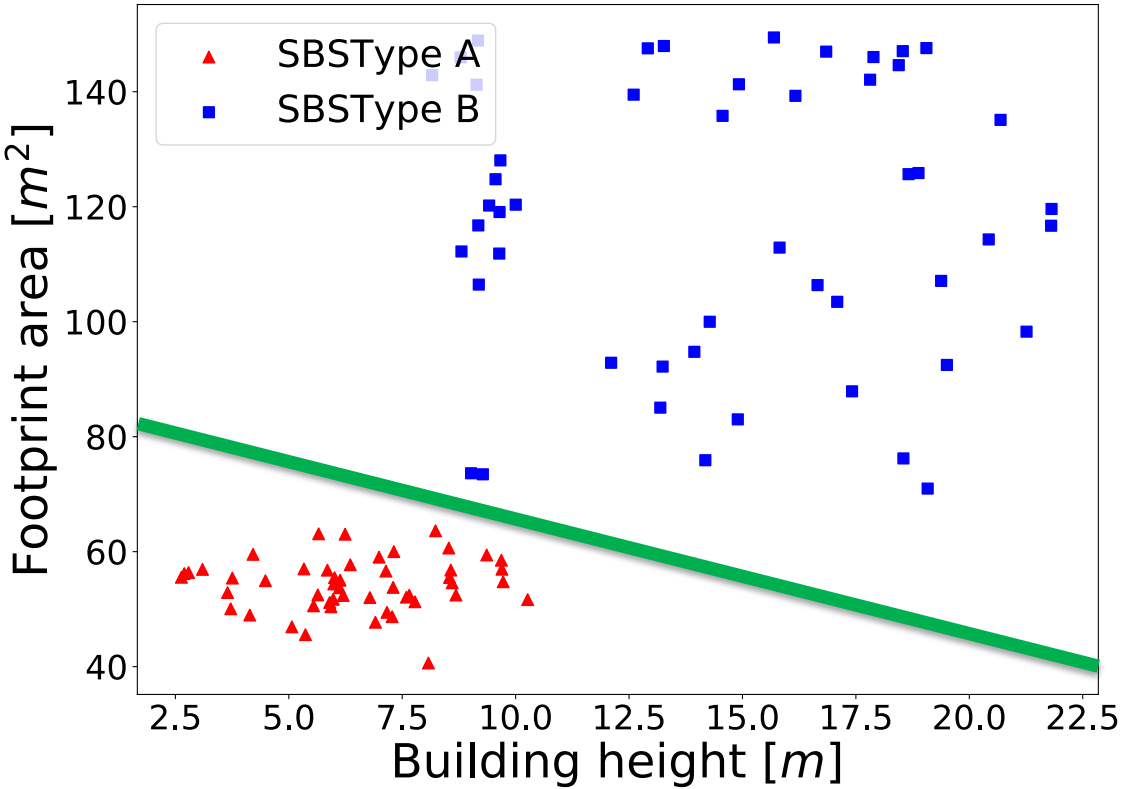
Feature vector

$$\begin{pmatrix} height \\ area \end{pmatrix} = \begin{pmatrix} 6.70 \\ 57 \end{pmatrix} \quad \begin{pmatrix} height \\ area \end{pmatrix} = \begin{pmatrix} 13.25 \\ 110 \end{pmatrix}$$

Feature based representation



Separate feature space



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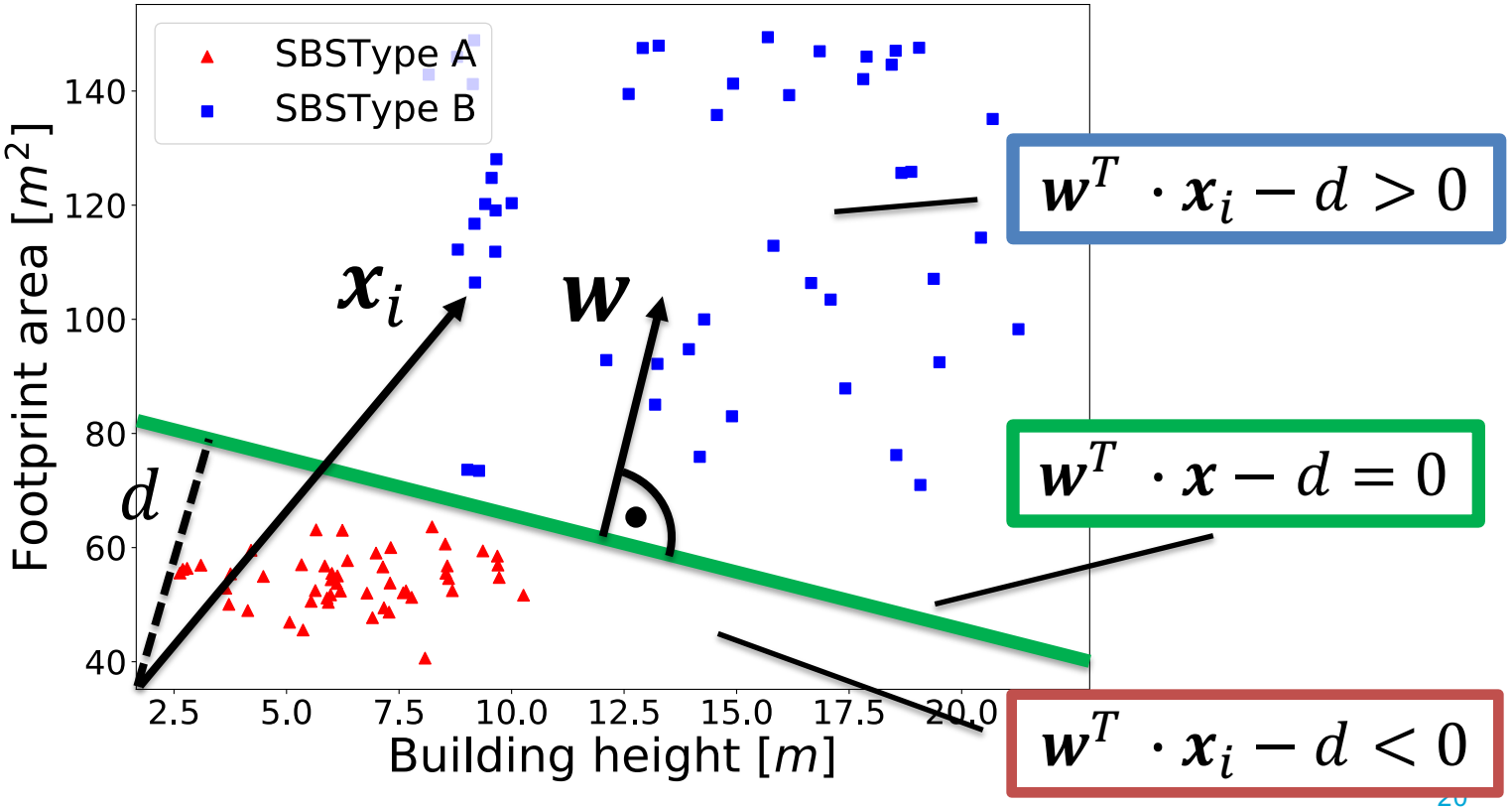
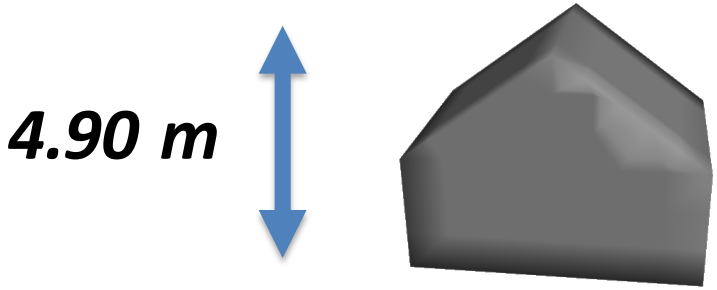
Support vector machine



Automatic classification



Building with unknown type

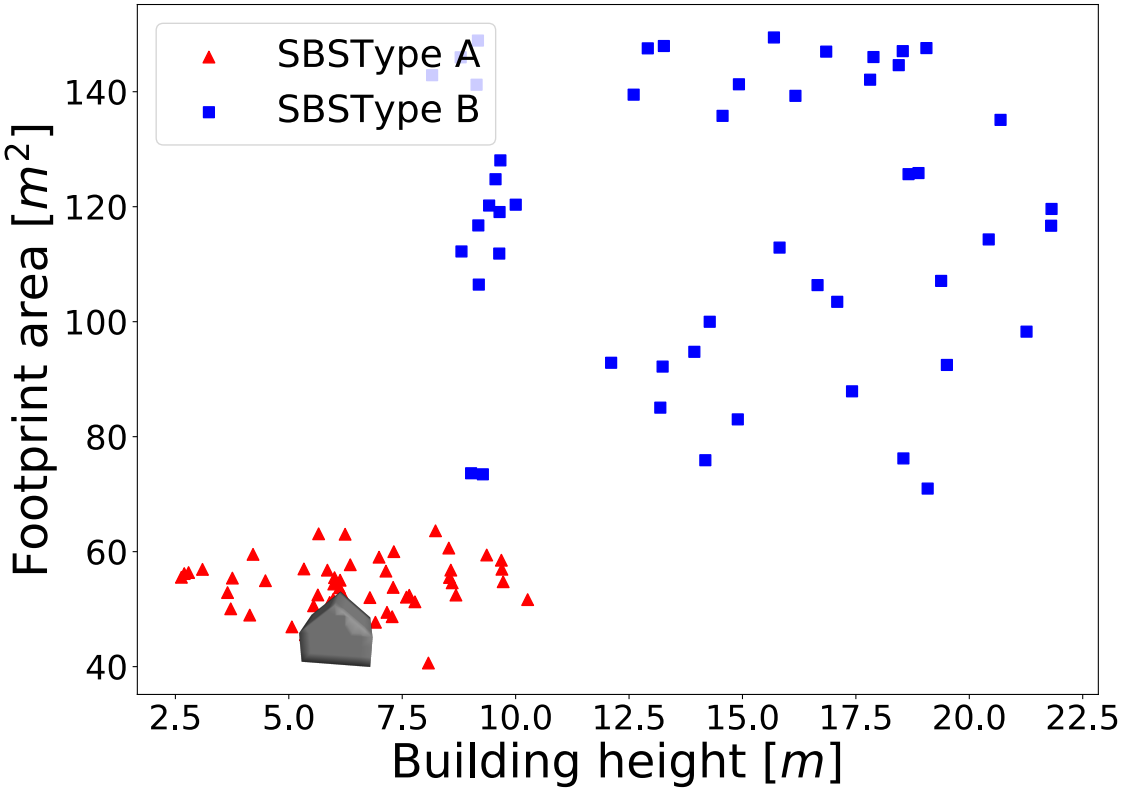
50 m²

$$\begin{pmatrix} height \\ area \end{pmatrix} = \begin{pmatrix} 4.90 \\ 50 \end{pmatrix} = \boldsymbol{x}_1$$

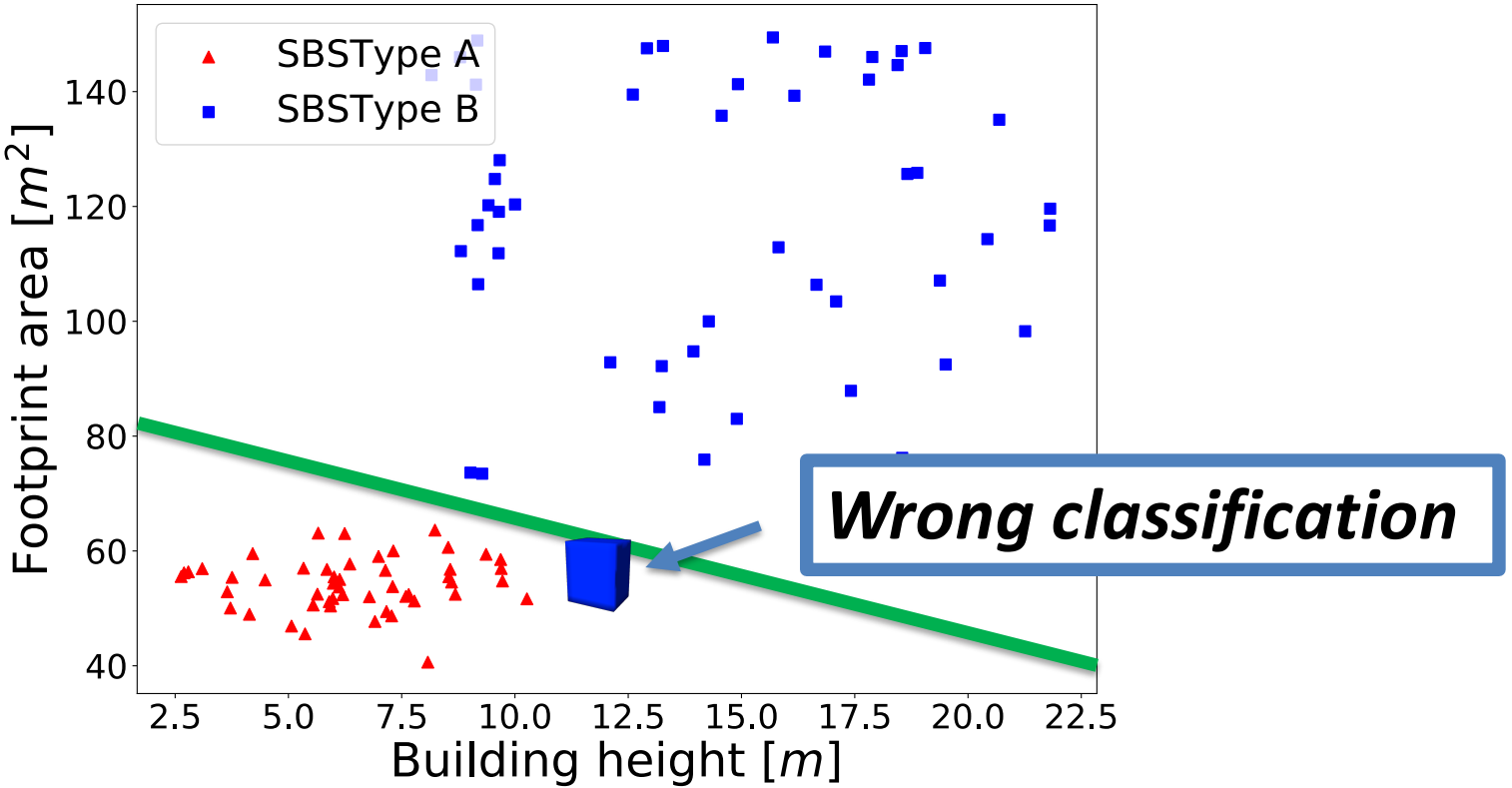
$$\boldsymbol{w}^T \cdot \boldsymbol{x}_1 - d = -0.8$$

It's red!

Automatic classification



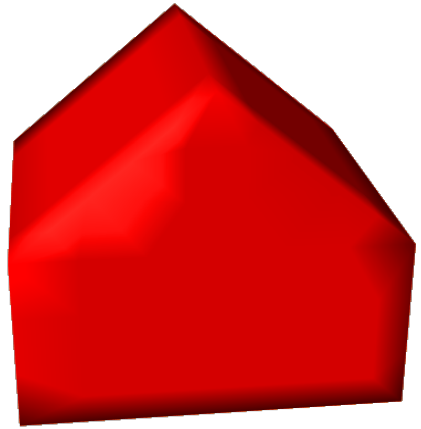
Evaluation


SBSType A
SBSType B
Footprint area [m^2]
140
120
100
80
60
40
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
Building height [m]
Wrong classification

Evaluation

We already know its Type A

6.20 m



61 m²

$$\begin{pmatrix} height \\ area \end{pmatrix} = \begin{pmatrix} 6.20 \\ 61 \end{pmatrix}$$

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Evaluation

Doing this many times with different buildings gives reliable measure of classification accuracy

$$\boldsymbol{x}_2 = \begin{pmatrix} height \\ area \end{pmatrix} = \begin{pmatrix} 6.20 \\ 61 \end{pmatrix}$$

$$\boldsymbol{w}^T \cdot \boldsymbol{x}_2 - d = -0.55$$

Correct!

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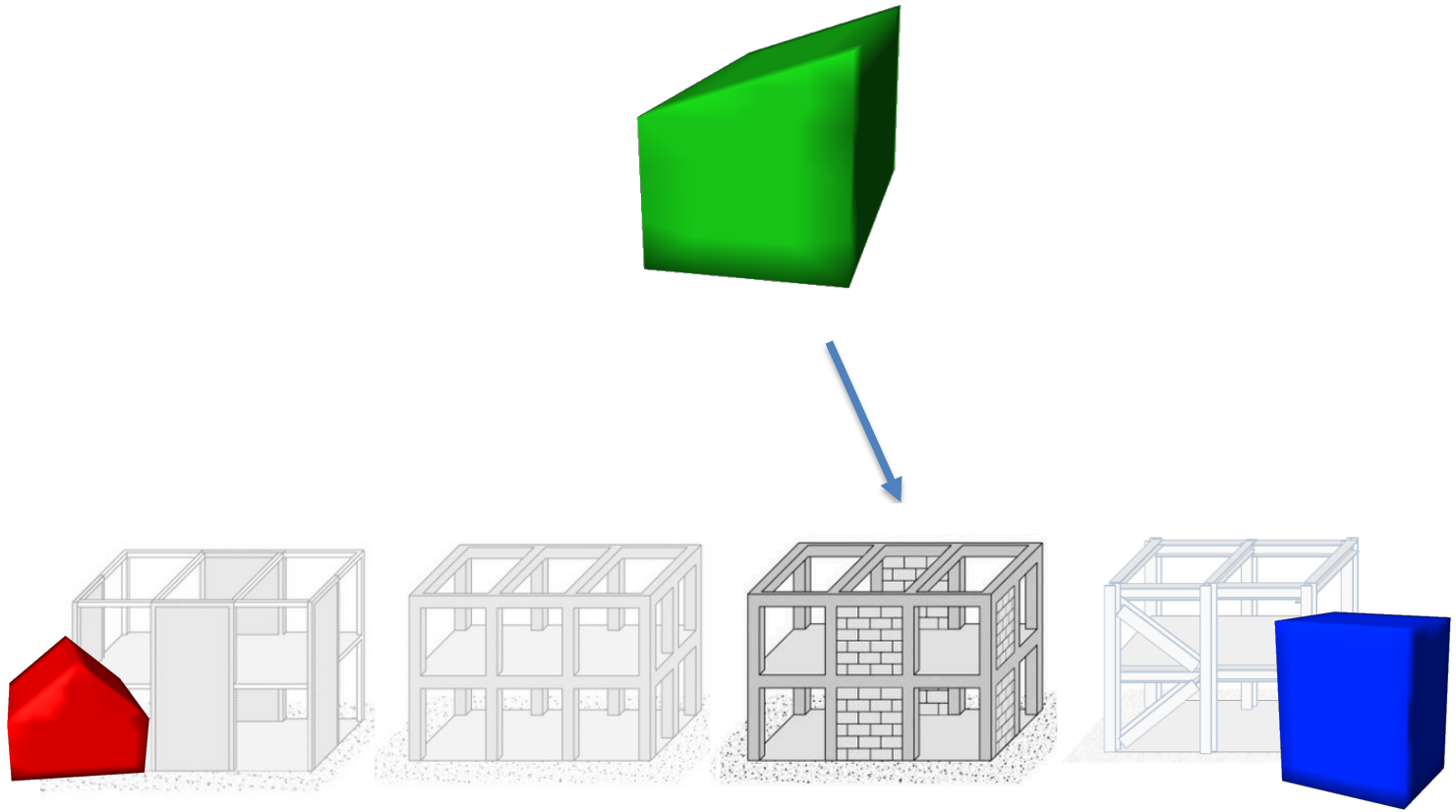
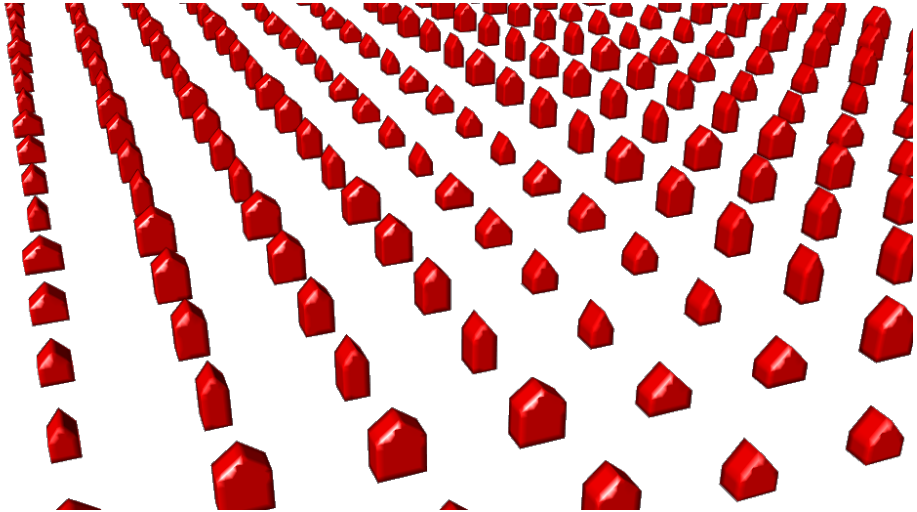
Methodology

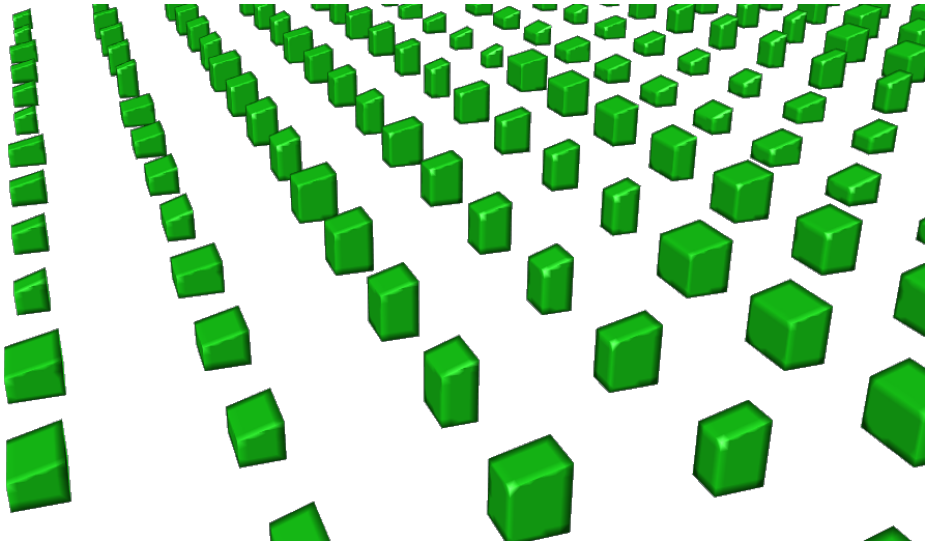
- *...come back to Shape DNA later*
- *Let's first implement the machine learning algorithm…*
  - *A supervised learning algorithm*

Seismic building structural type



Training samples





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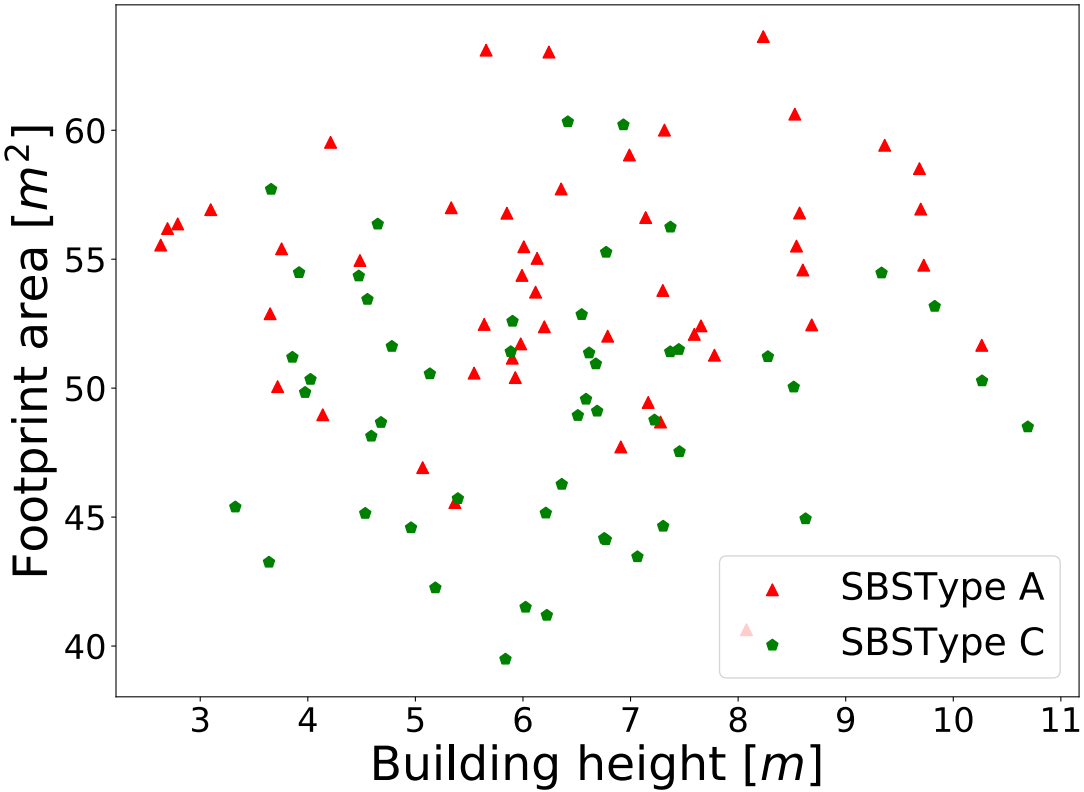
Feature based representation



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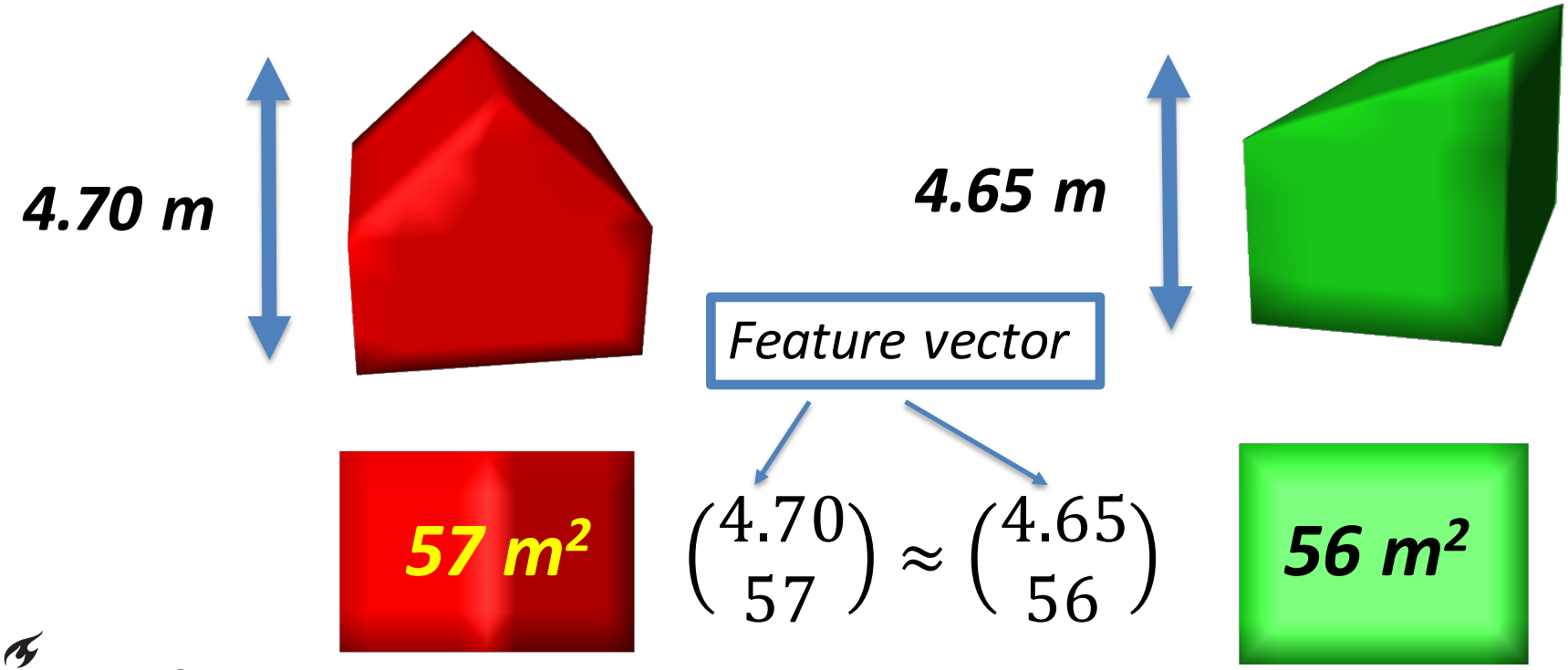
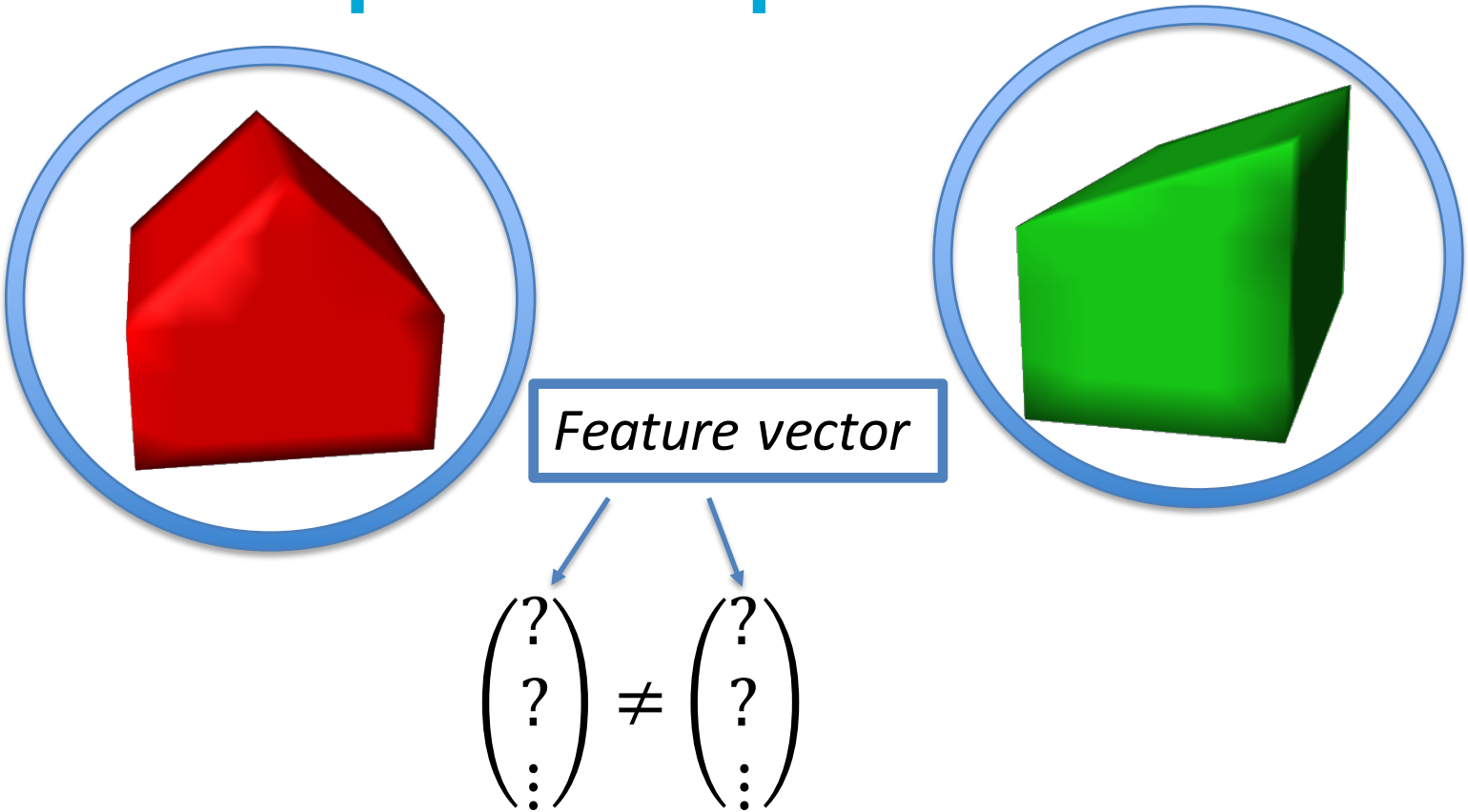
Local shape descriptor

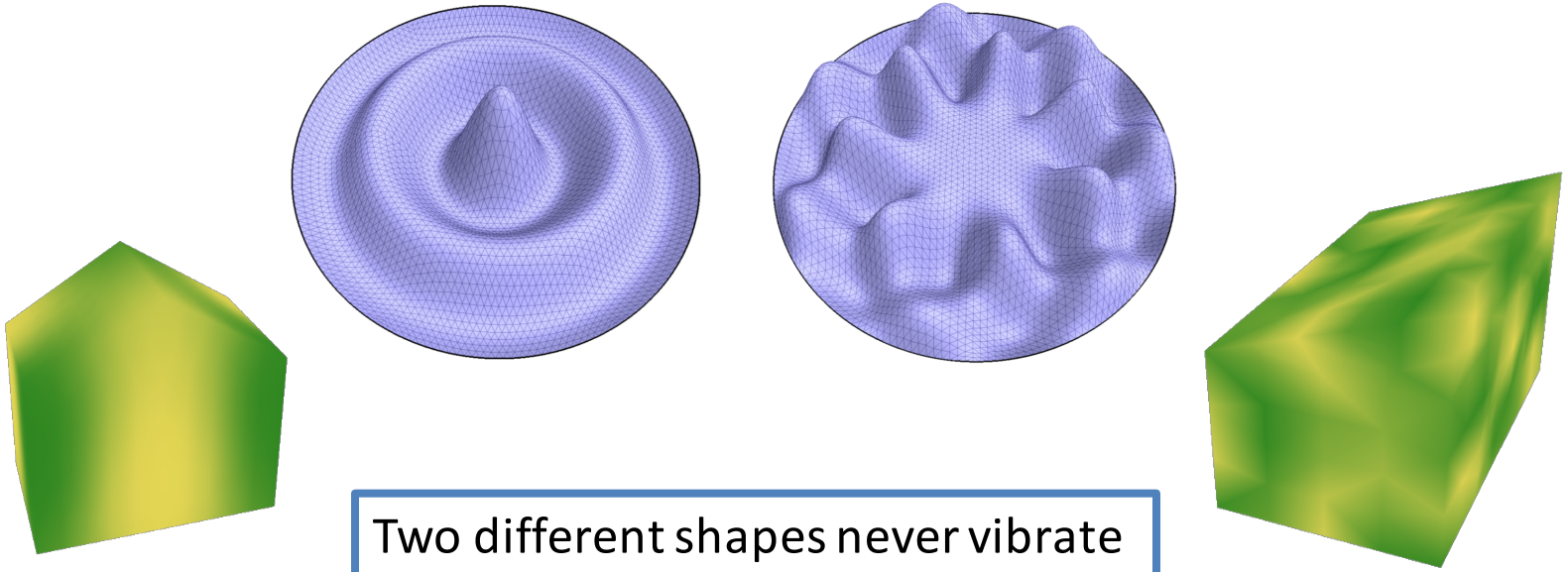


Global shape descriptor



Shape DNA

“Can you hear the shape of a drum?”

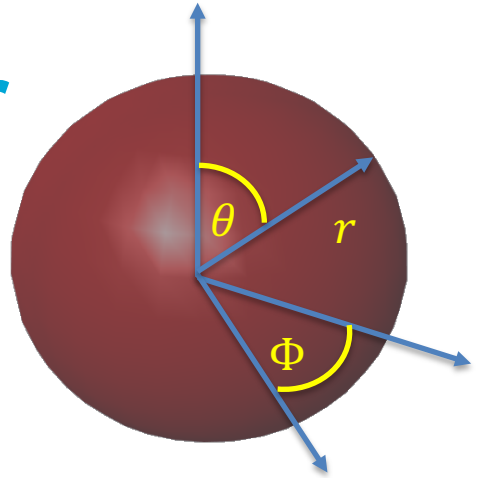


Two different shapes never vibrate at the same frequencies

Image source: Reuter et al. [2]

Laplace - Beltrami operator

continuous case on a sphere S



$$\Delta f := div\,(grad\, f)$$

$$f : S \to \mathbb{R}$$

$$\Delta_S = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\phi^2}.$$

Helmholtz equation:

$$\Delta f = -\lambda f$$

λ is our shape descriptor

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Shape DNA

- Laplace-Beltrami spectra as 'Shape-DNA' of surfaces and solids [2]:

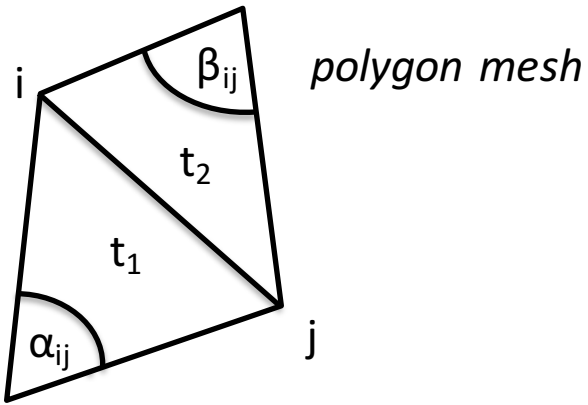
$$\Delta f = -\lambda f$$

$$A_{\cot}\mathbf{f} = -\lambda B\mathbf{f}, \quad \mathbf{f} := (f(\mathbf{p}_i))_{i=1}^{n},$$

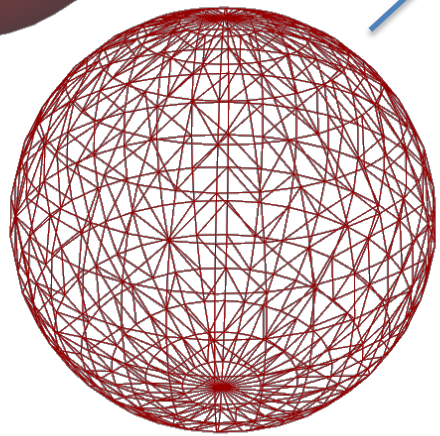
where

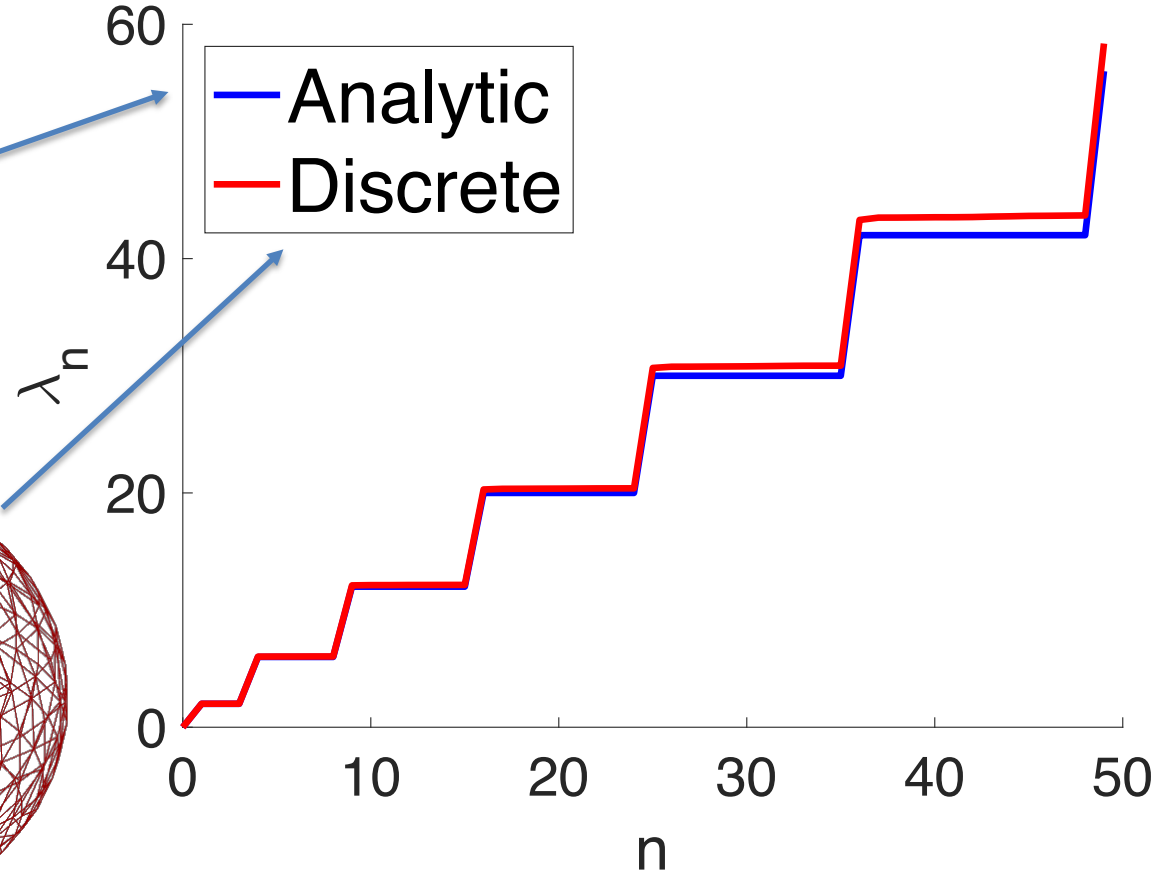
$$A_{\cot}(i,j) := \begin{cases} \dfrac{\cot \alpha_{ij} + \cot \beta_{ij}}{2} & (i,j) \text{ edge}, \\ -\sum\limits_{k \in N(i)} A_{\cot}(i,k) & i = j, \end{cases}$$

$$B(i,j) := \begin{cases} \dfrac{|t_1| + |t_2|}{12} & (i,j) \text{ edge}, \\ \dfrac{\sum_{k \in N(i)} |t_k|}{6} & i = j, \end{cases}$$



Shape DNA





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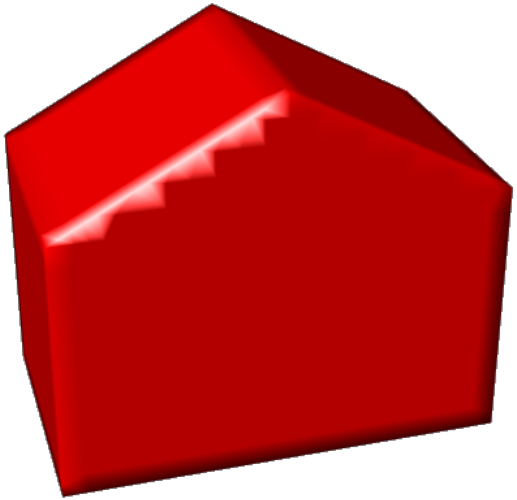
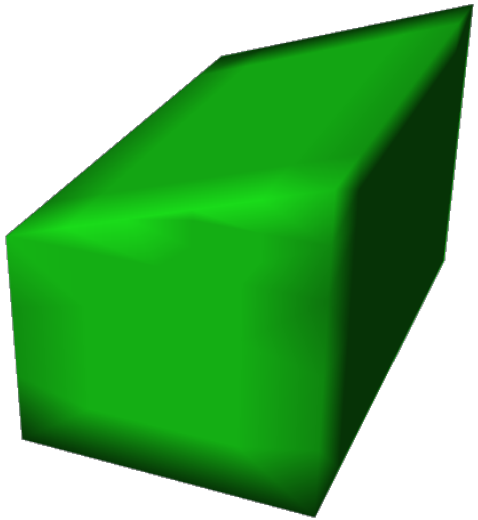
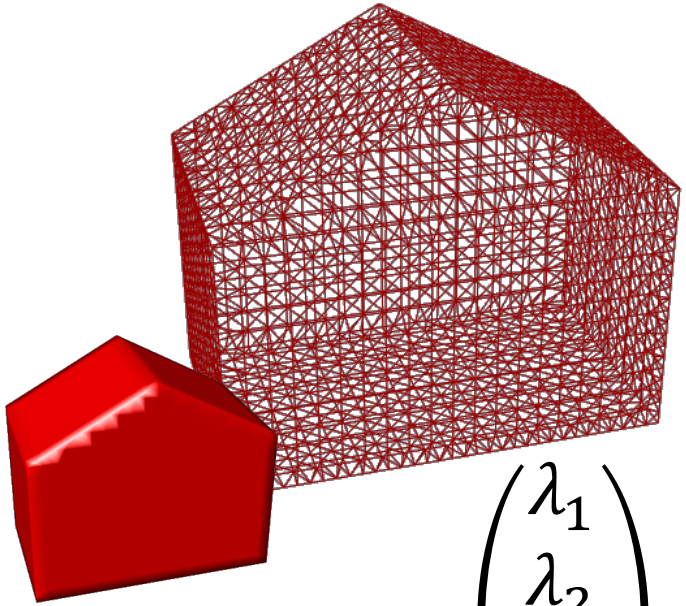
Local shape descriptor

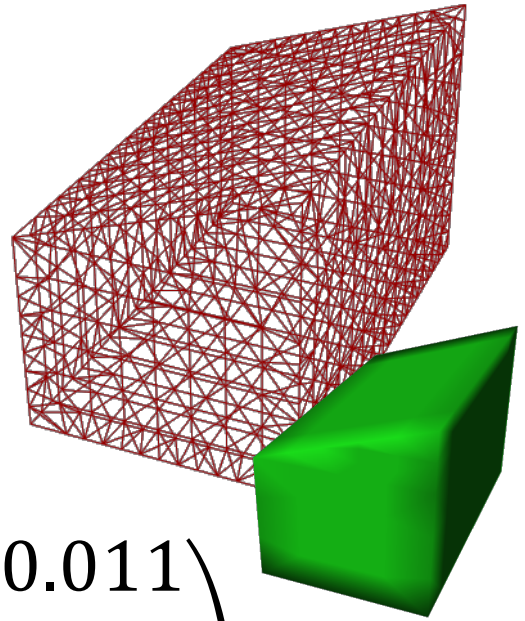




$$\begin{pmatrix} height \\ area \end{pmatrix} \quad \begin{pmatrix} 4.70 \\ 57 \end{pmatrix} \approx \begin{pmatrix} 4.65 \\ 56 \end{pmatrix}$$

Shape DNA





$$\begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \end{pmatrix} \begin{pmatrix} 0.021 \\ 0.032 \\ 0.051 \\ \vdots \end{pmatrix} \neq \begin{pmatrix} 0.011 \\ 0.029 \\ 0.038 \\ \vdots \end{pmatrix}$$

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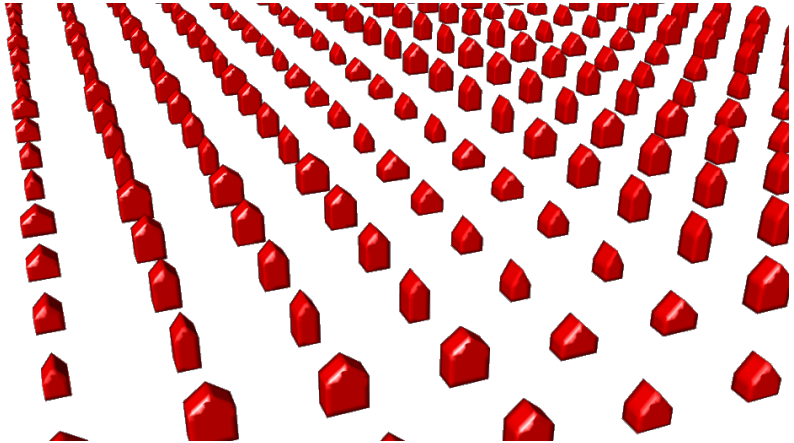
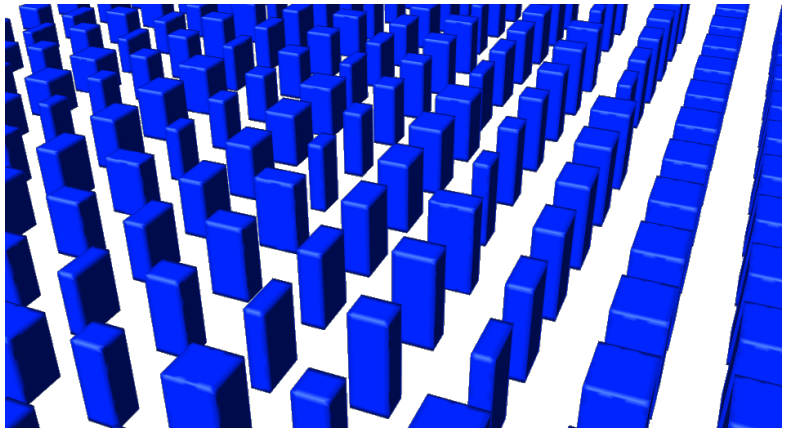
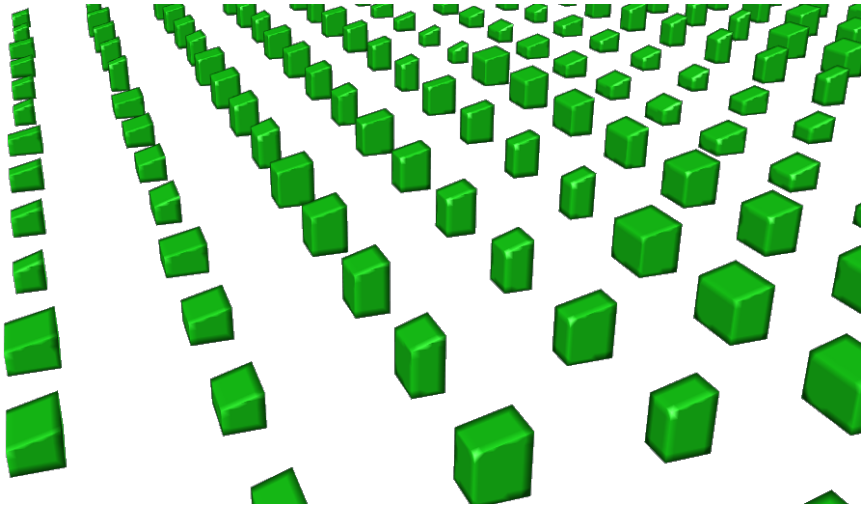
Training samples







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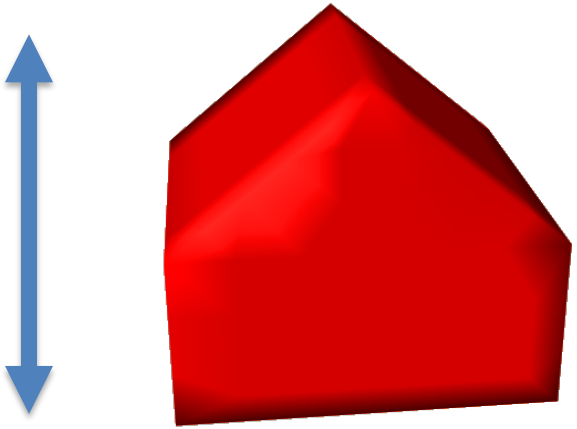
Evaluation

We already know its Type A

6.20 m



61 m²

$$\begin{pmatrix} height \\ area \end{pmatrix} = \begin{pmatrix} 6.20 \\ 61 \end{pmatrix}$$

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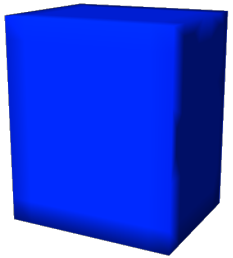
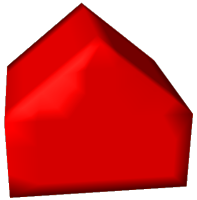
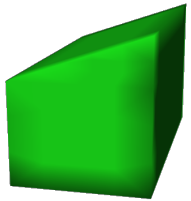
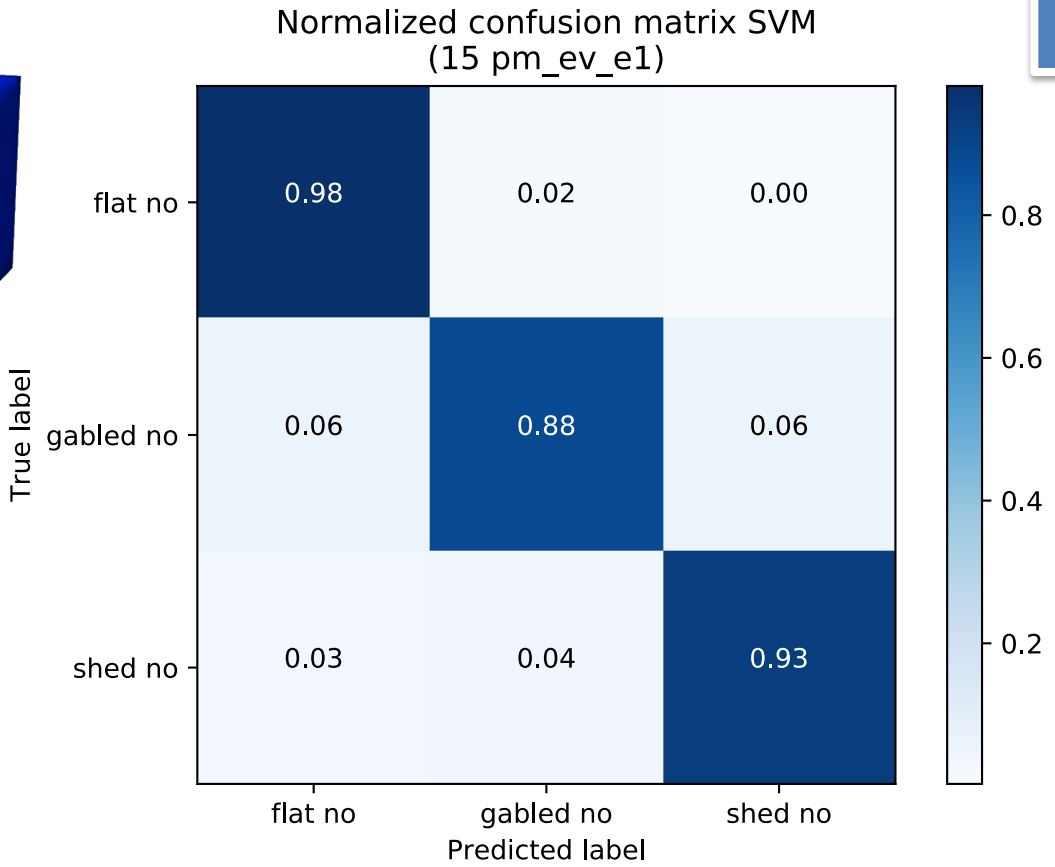
Classification w/ Shape DNA

93 %









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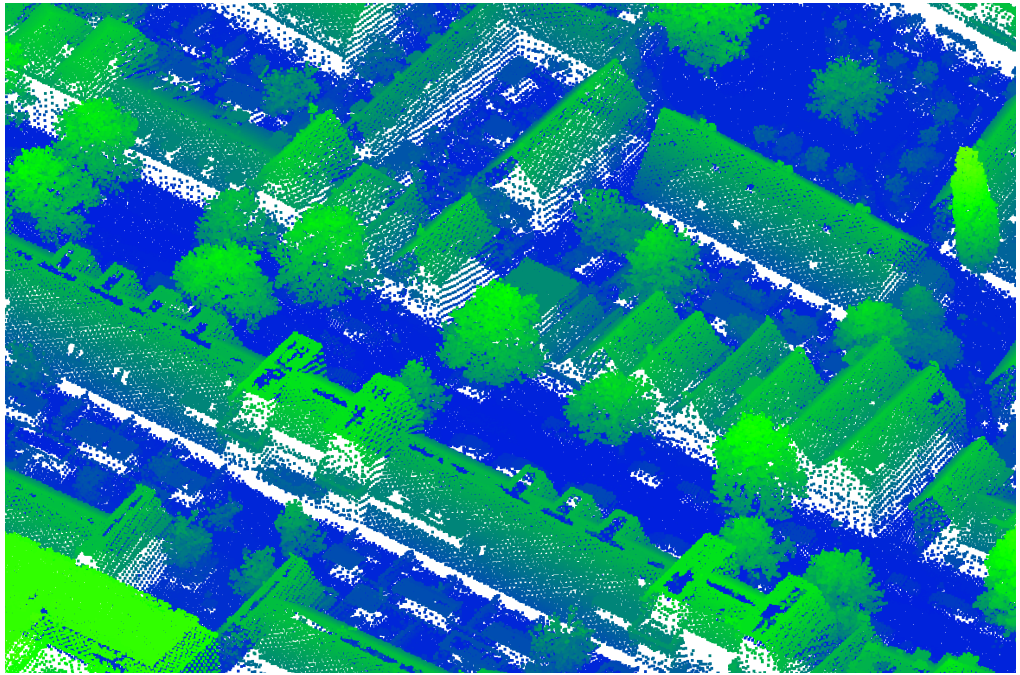
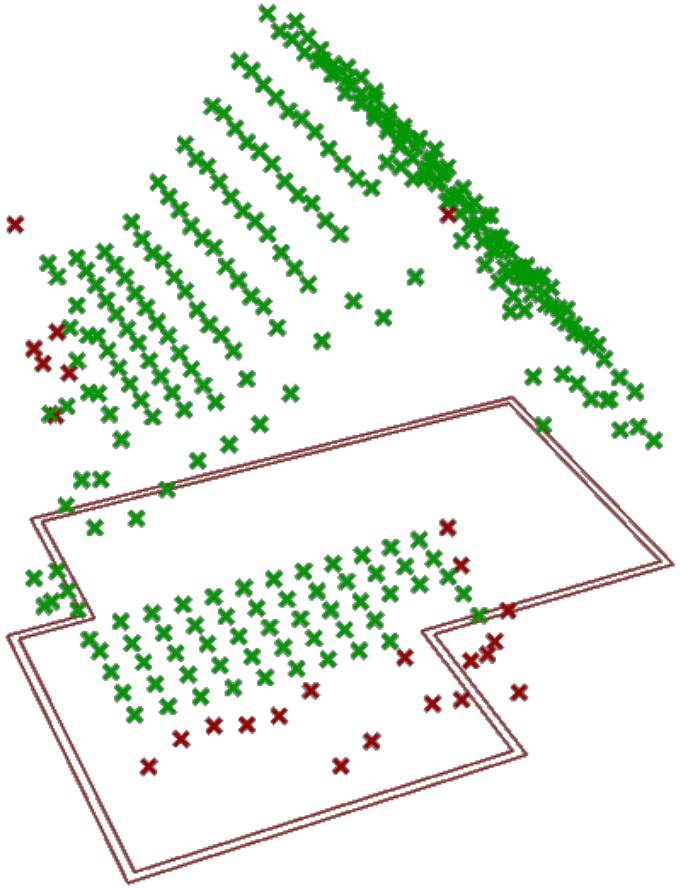
Methodology

- *...come back to Shape DNA later*

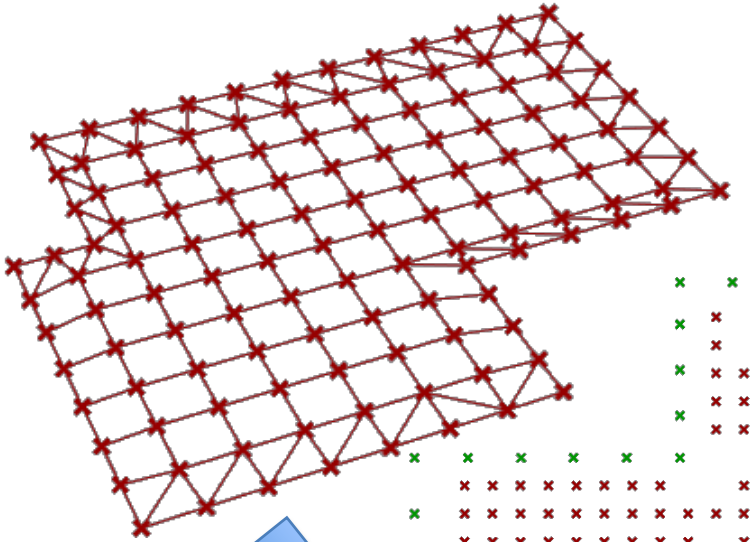
- *Let's first implement the machine learning algorithm…*
  - *A supervised learning algorithm*

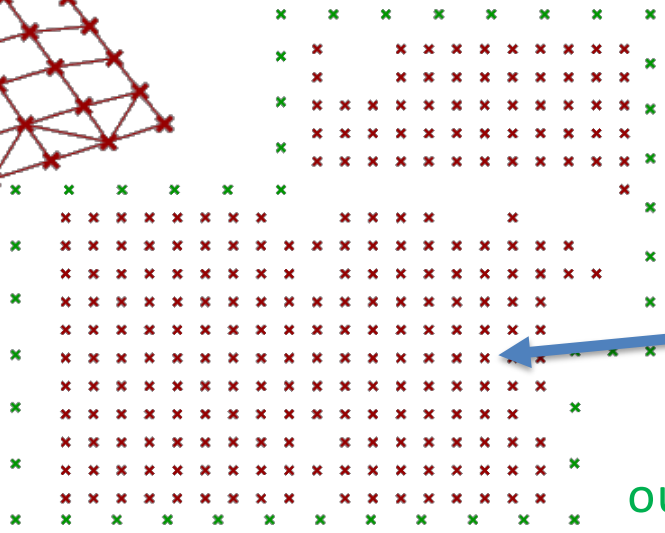
Create building model

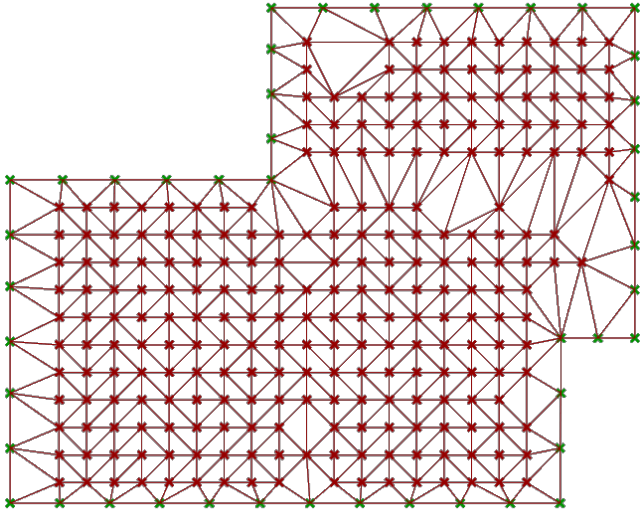




Create building mesh





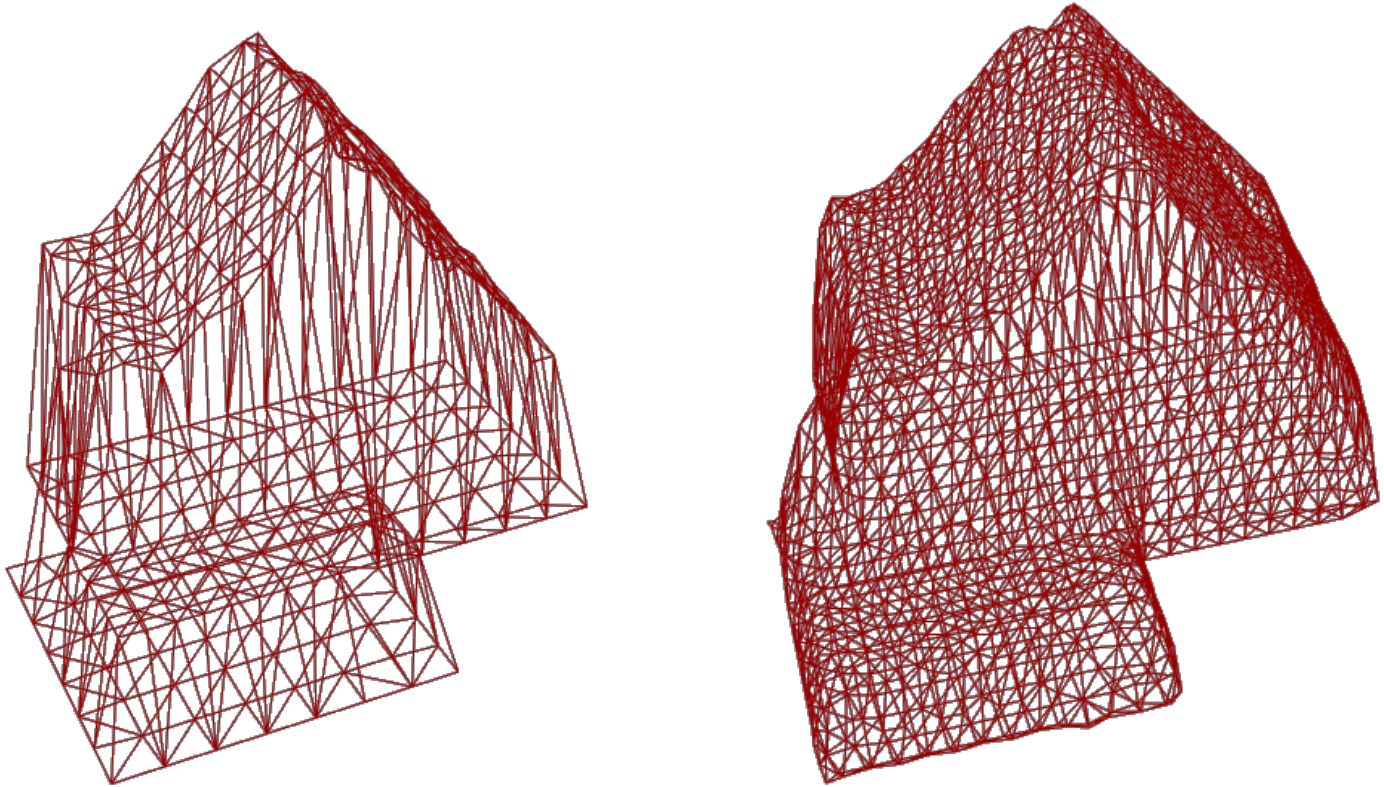


Delaunay triangulation

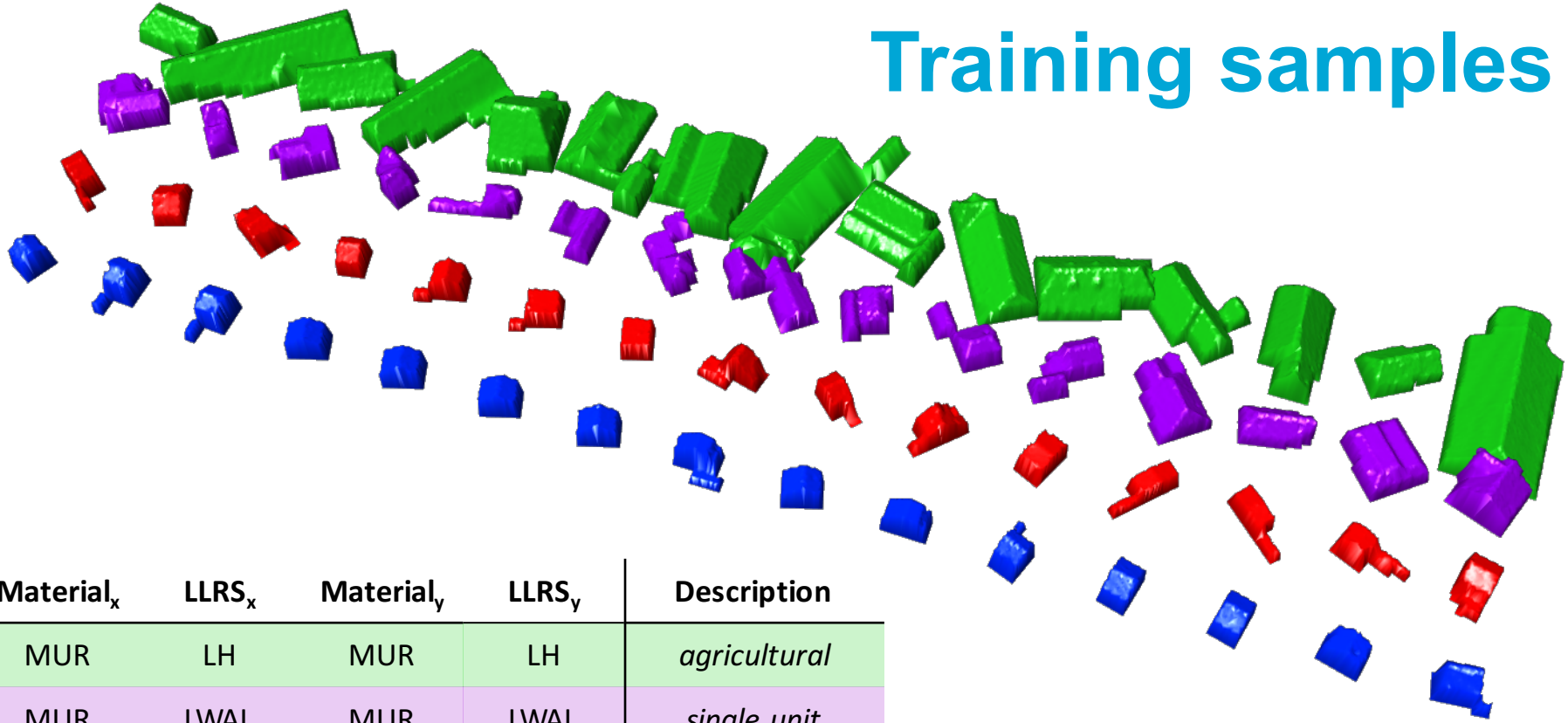
2D projection of roof point cloud

outer vertices of footprint

Create building mesh



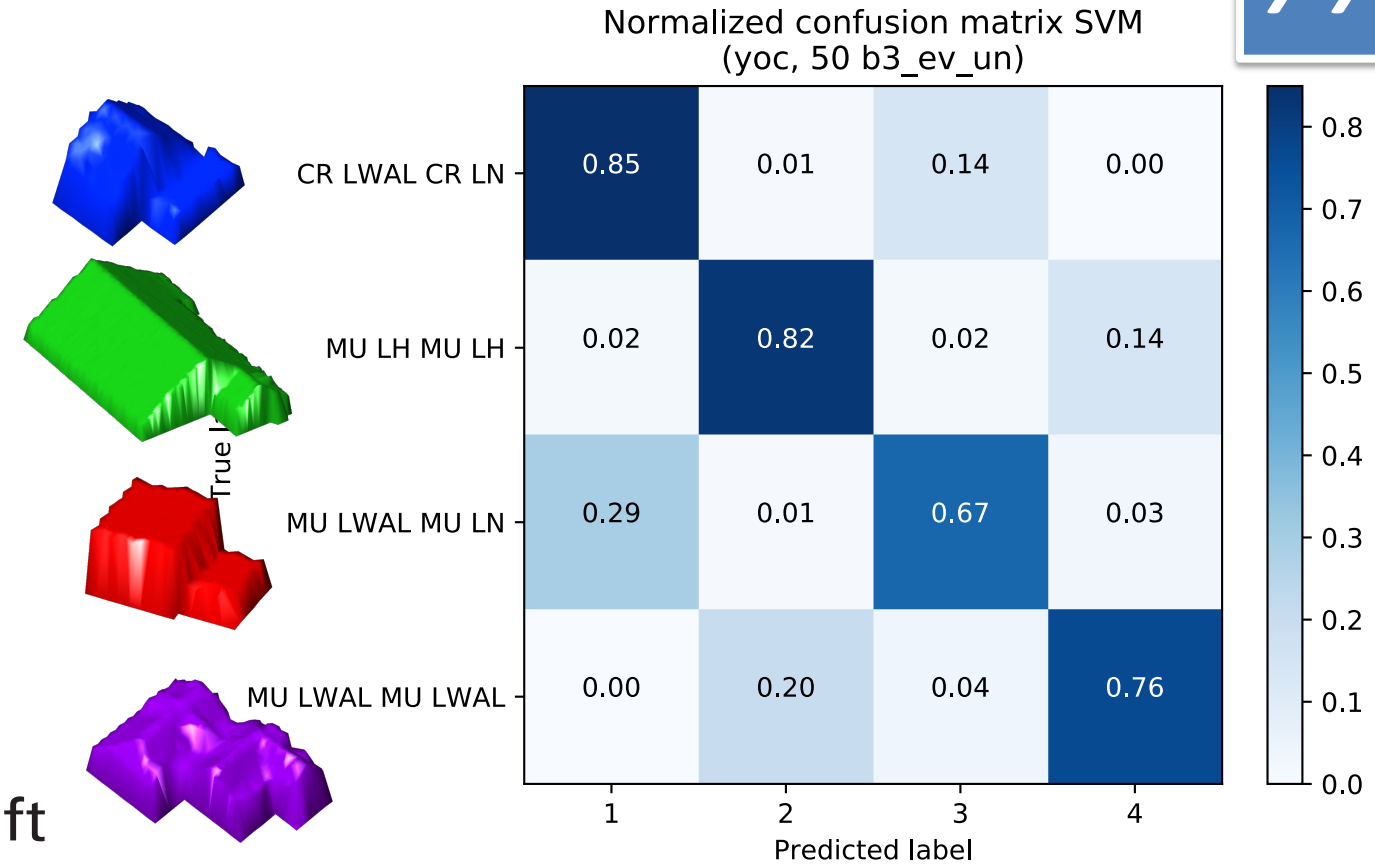
Training samples



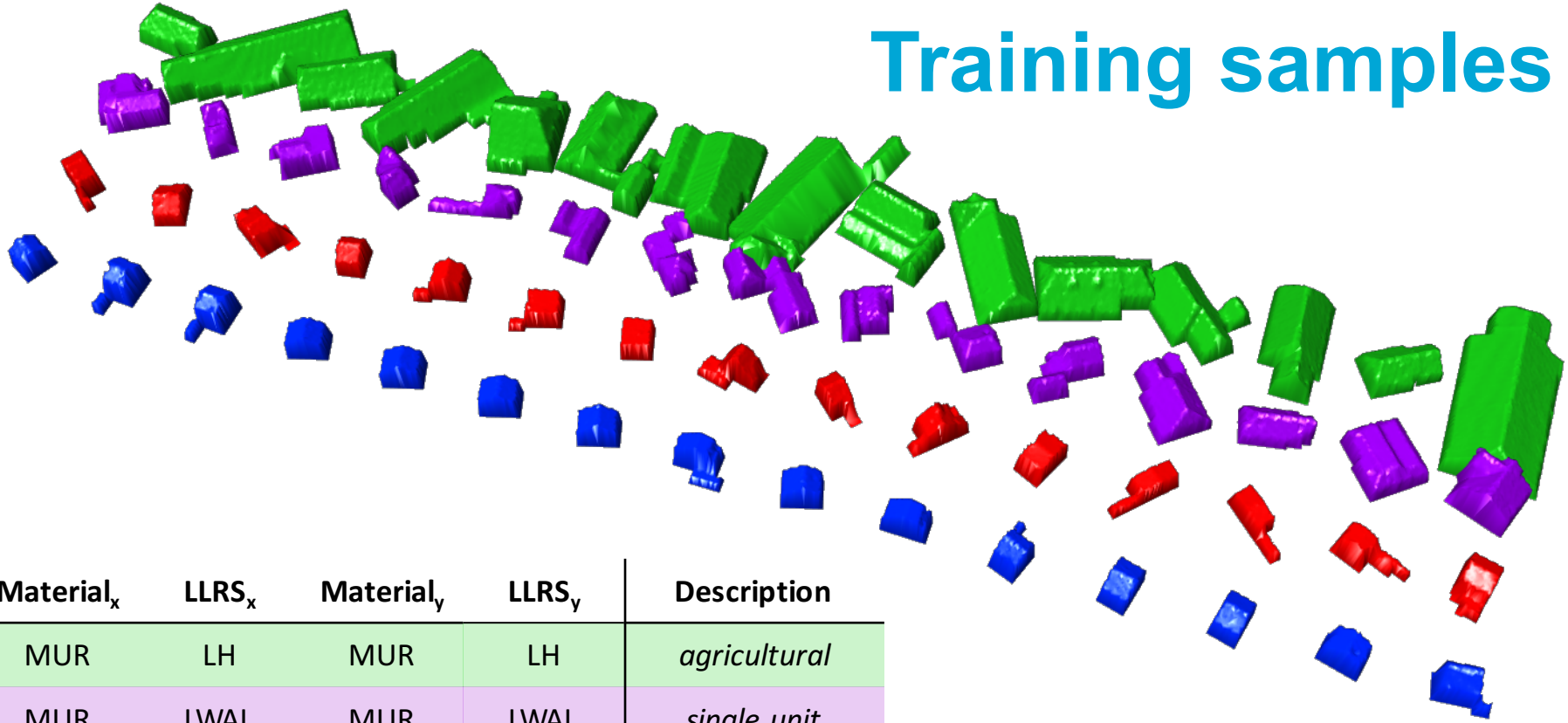
$Material_x$	$LLRS_x$	$Material_y$	$LLRS_y$	Description
MUR	LH	MUR	LH	*agricultural*
MUR	LWAL	MUR	LWAL	*single unit*
MUR	LWAL	MUR	LN	*terraced*
CR	LWAL	CR	LN	*terraced*

Classification

77 %



Training samples



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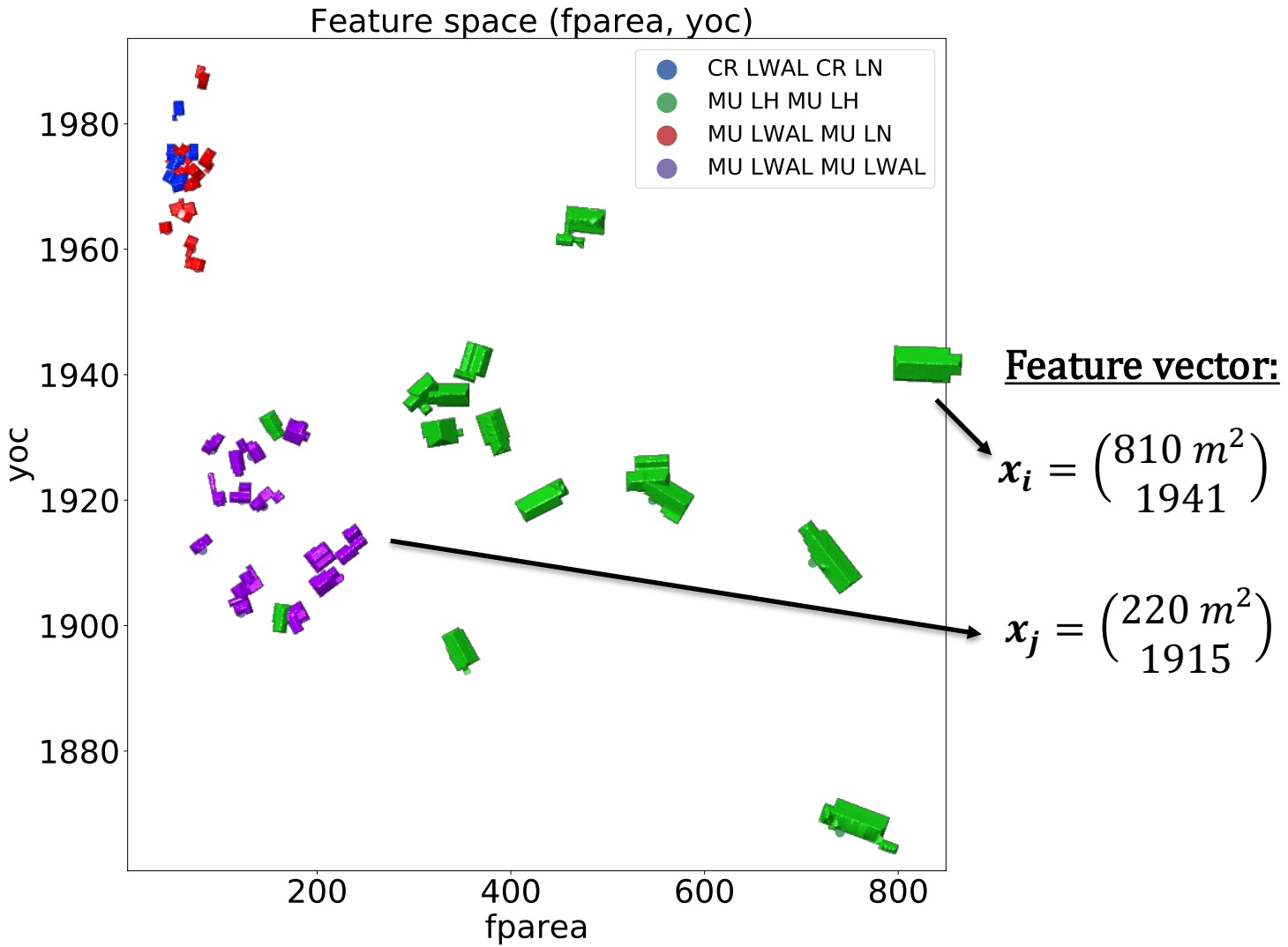
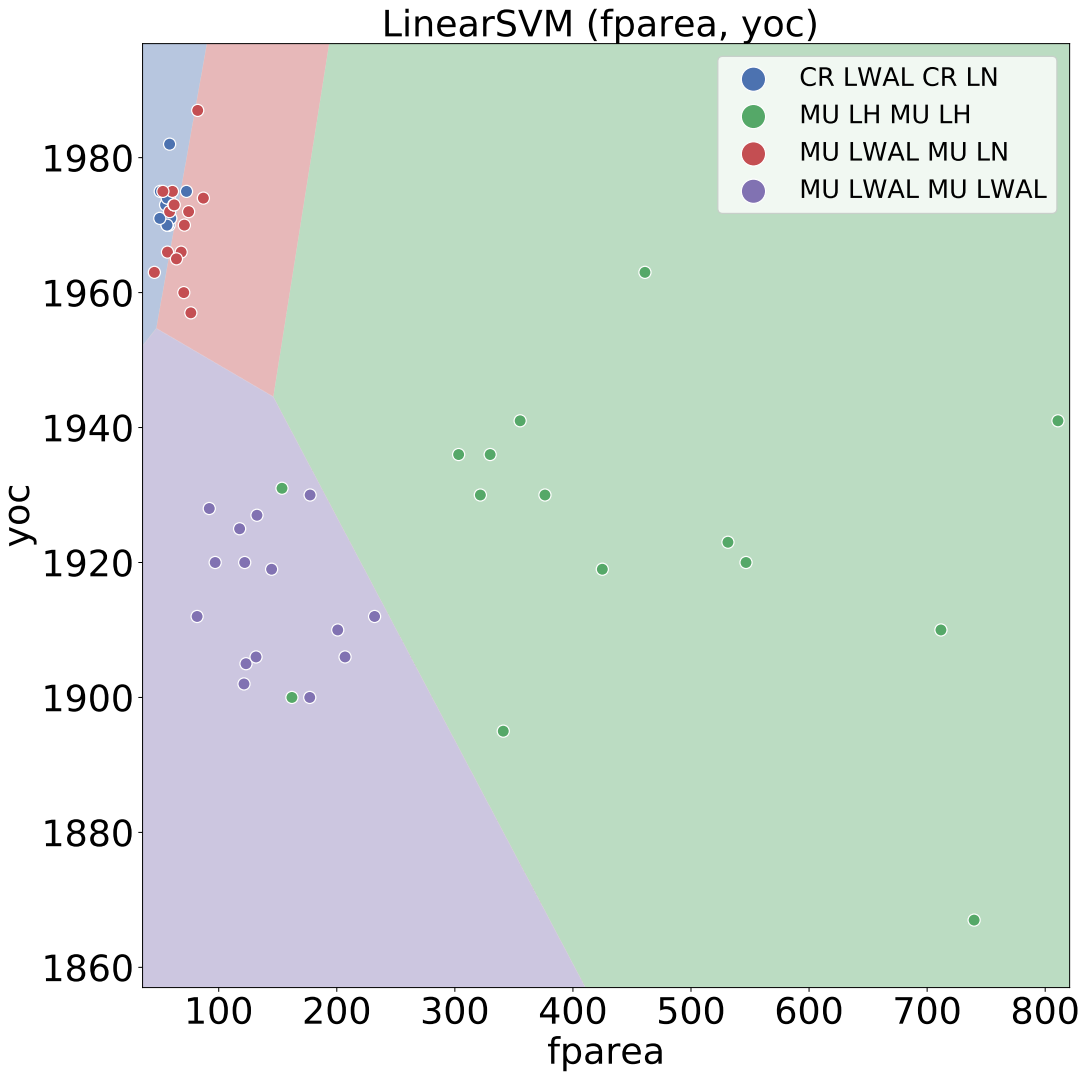
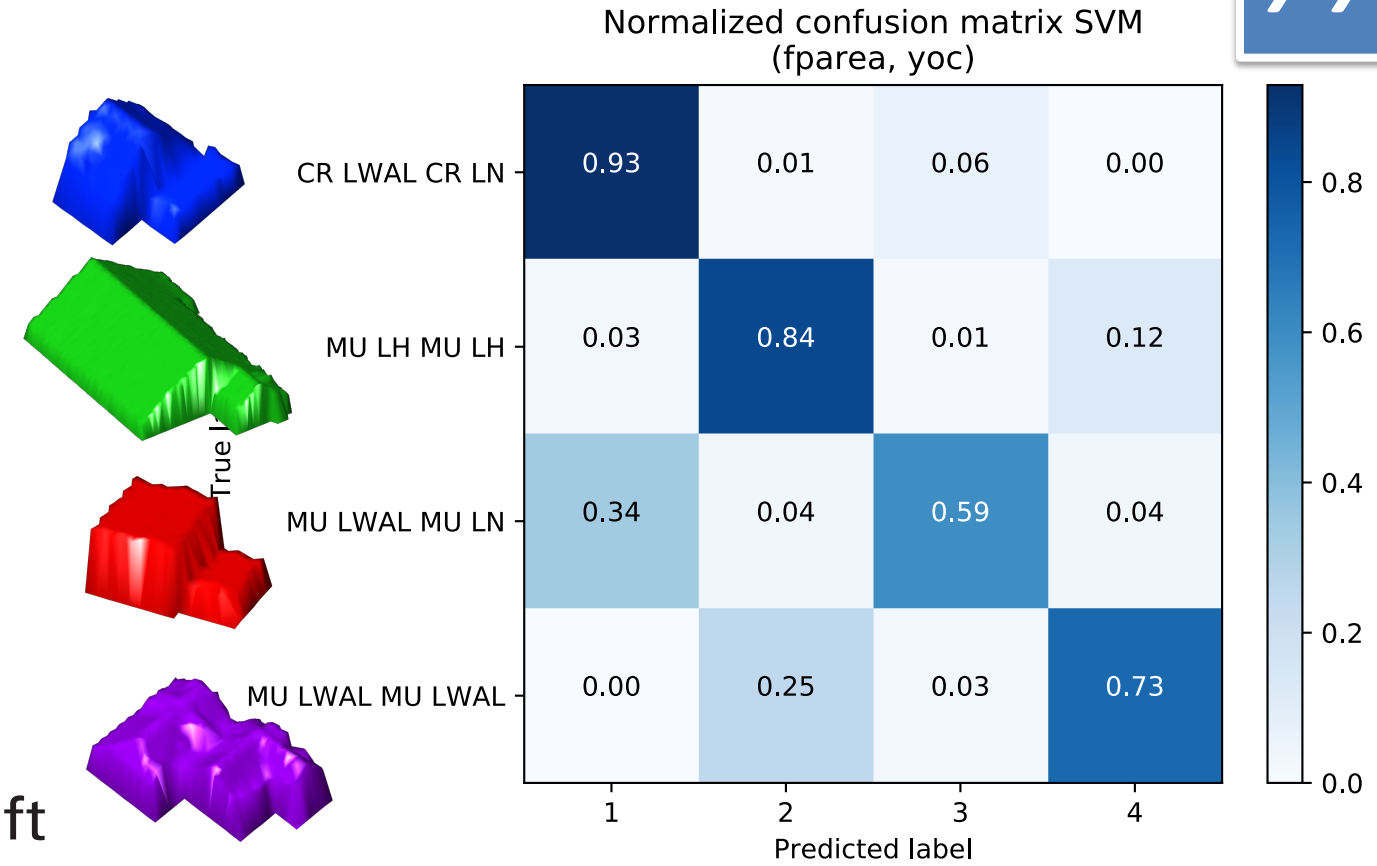

Feature space (fparea, yoc)
CR LWAL CR LN
MU LH MU LH
MU LWAL MU LN
MU LWAL MU LWAL
yoc
1980
1960
1940
1920
1900
1880
200
400
600
800
fparea
Feature vector:
$x_i = \begin{pmatrix} 810\ m^2 \\ 1941 \end{pmatrix}$
$x_j = \begin{pmatrix} 220\ m^2 \\ 1915 \end{pmatrix}$


LinearSVM (fparea, yoc)
CR LWAL CR LN
MU LH MU LH
MU LWAL MU LN
MU LWAL MU LWAL
yoc
1980
1960
1940
1920
1900
1880
1860
100
200
300
400
500
600
700
800
fparea

TU Delft

Classification

77 %



Conclusion – SBST classification

- Develop and implement a machine learning algorithm that can automatically classify seismic building structural types (SBSTs)
- **Start simple…**
  - Using the **footprint area** and **year of construction** of a building can identify the SBST with **77% accuracy** on our dataset

Recommendations – SBST classification

- **…continue simple**
- Add more types to the classification to classify every building in a city
- If necessary focus feature and/or classifier development on classes that achieve lowest accuracies at the moment

Conclusion – Shape DNA

- *To which extent is it possible to describe geometric similarities of buildings using Shape DNA?*
- Shape DNA describes the **global shape** of a building with a one-dimensional vector and, thus, can be used to measure geometric similarities of buildings
- **BUT:** only useful if relevant **local shape** features, such as the footprint area, **can not** be extracted, as they usually lead to better results

Recommendations – Shape DNA

- Try on different use case than SBST classification, such as roof type classification
- Continue investigation with synthetic building models with a distinct geometric shape to get more insight what Shape DNA can do

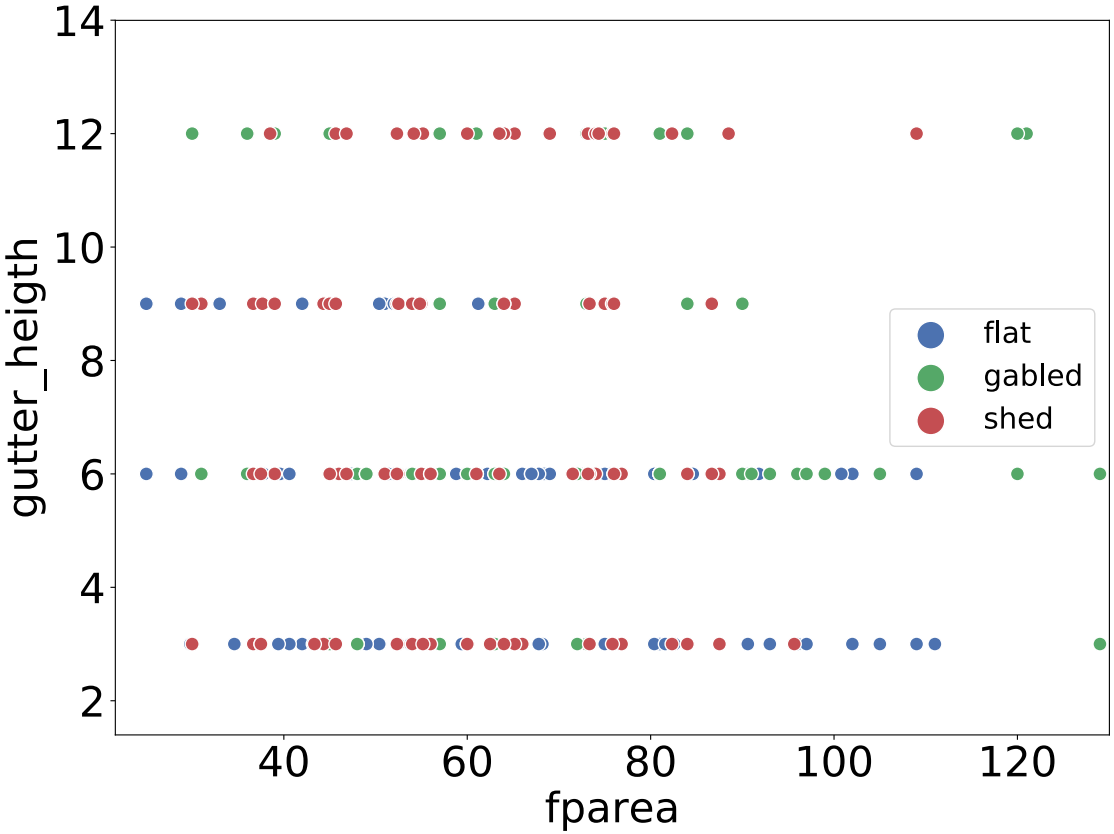
Bibliography

1. GEM Foundation [2017], 'Global earthquake model.
   URL: *https://www.globalquakemodel.org/*
2. Geiß, C., Aravena Pelizari, P., Marconcini, M., Sengara, W., Edwards, M., Lakes, T. and Taubenboek, H. [2015], 'Estimation of seismic building structural types using multi-sensor remote sensing and machine learning techniques', *ISPRS Journal of Photogrammetry and Remote Sensing* **104**, 175–188.
   URL: *http://www.sciencedirect.com/science/article/pii/S0924271614002007*

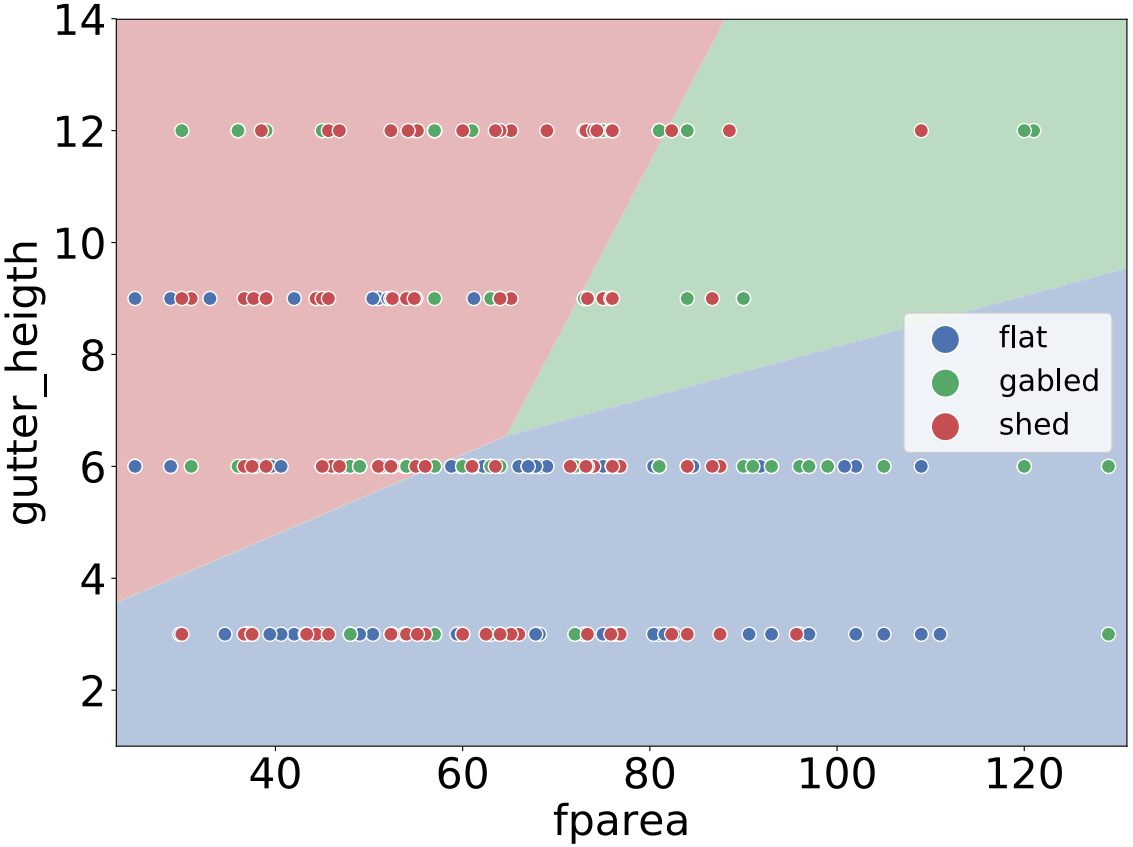
End

- **Thank you for your attention!**

Feature based representation

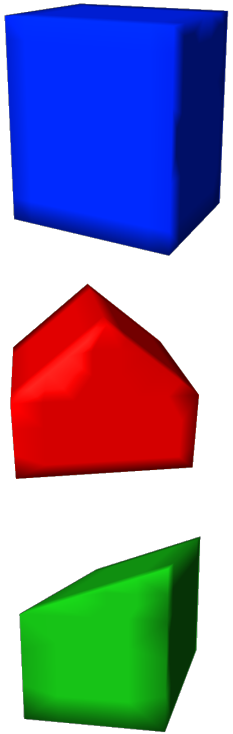


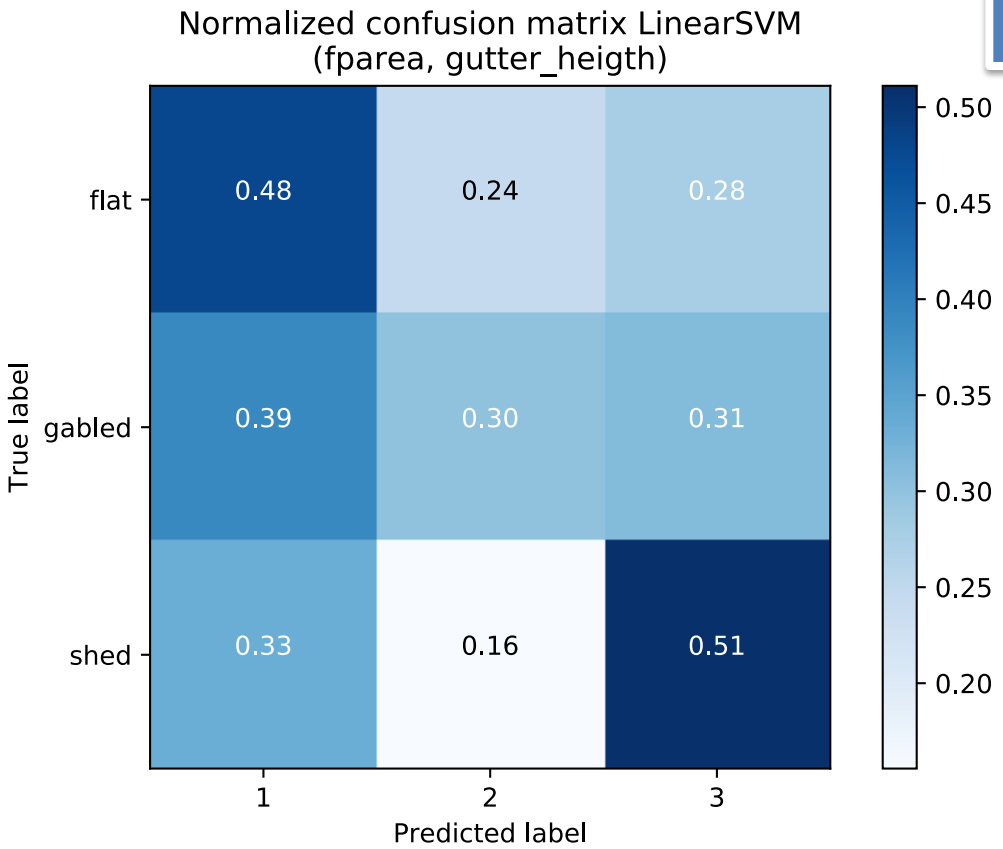
Feature based representation



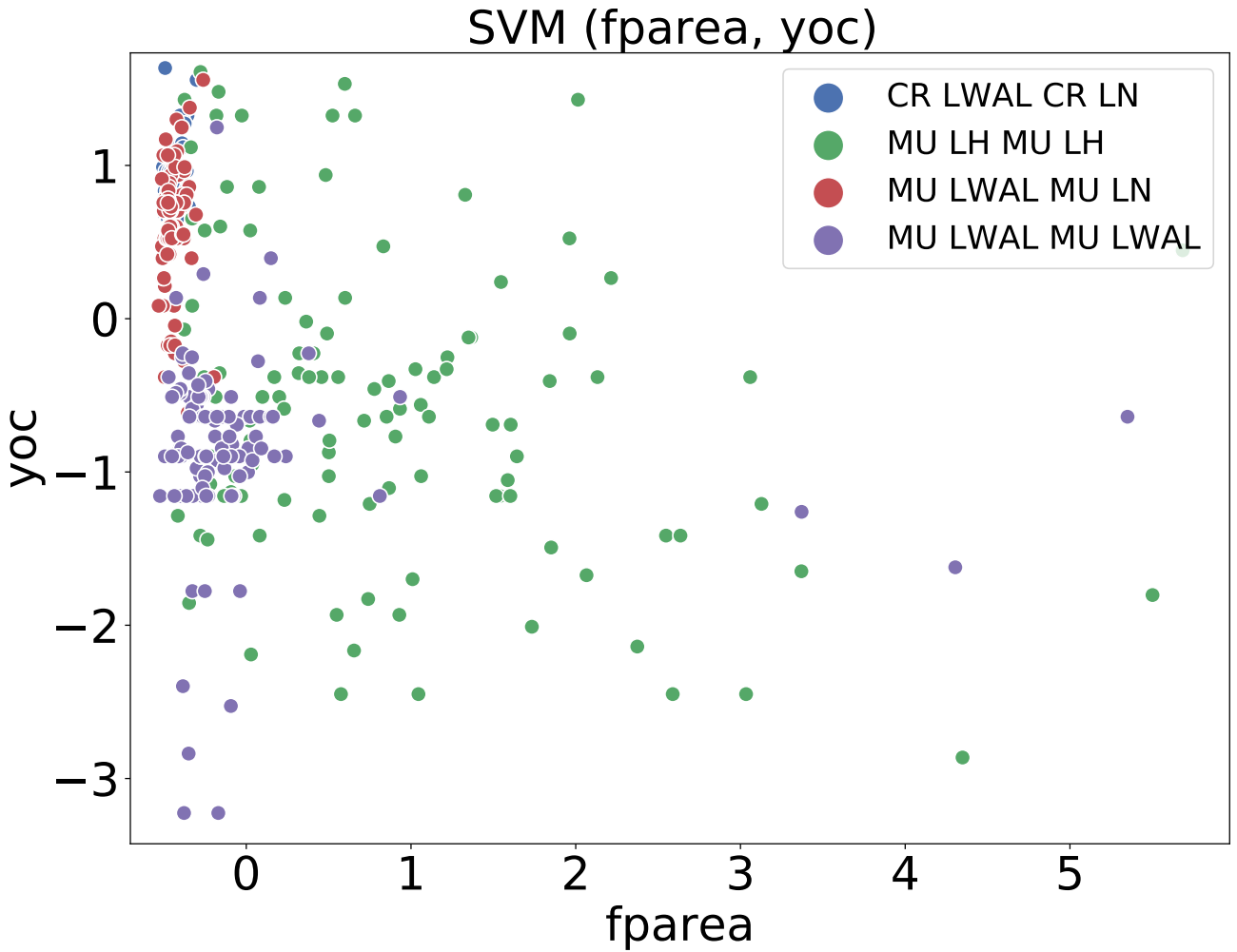
Classification

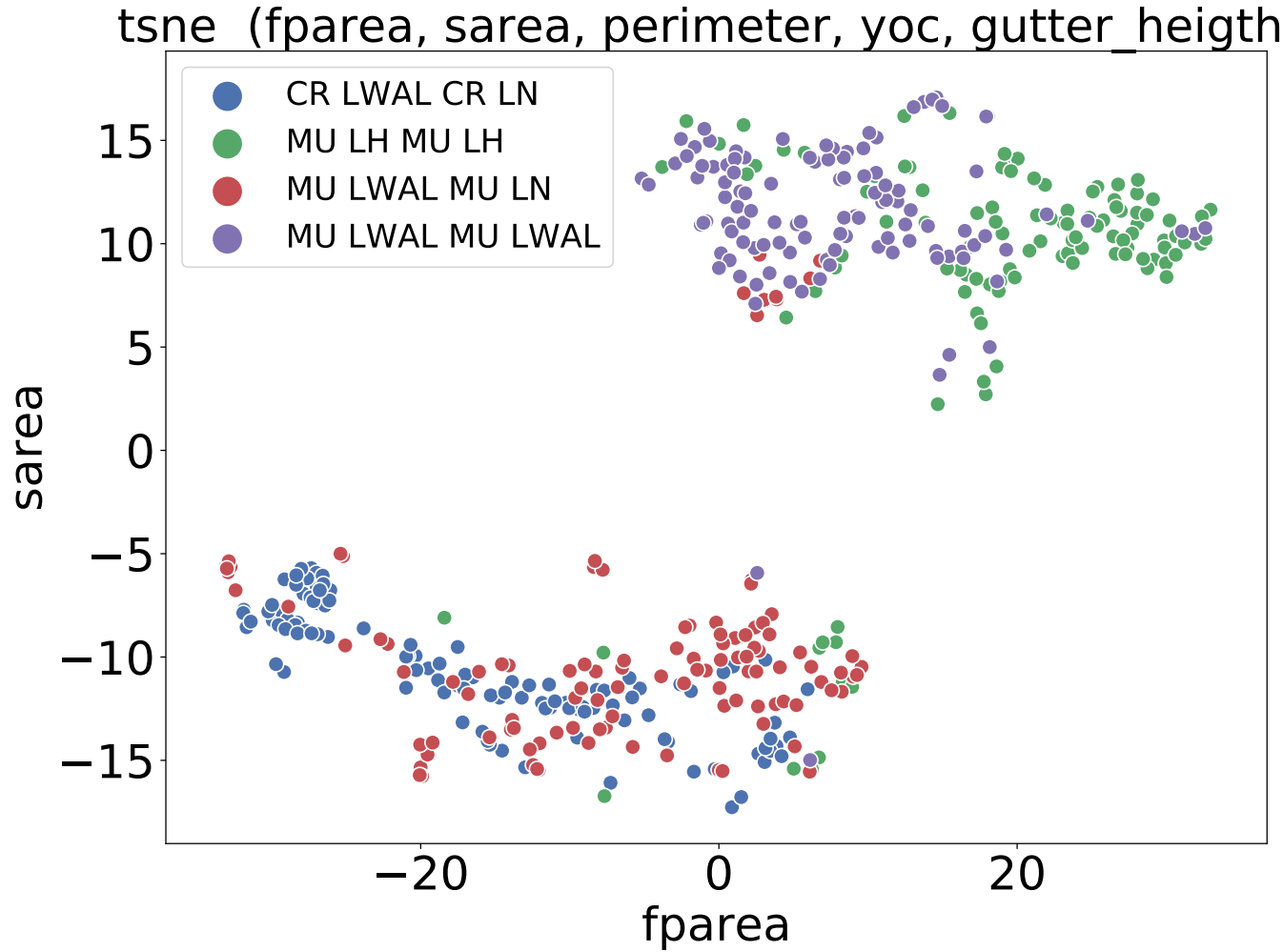
40 %



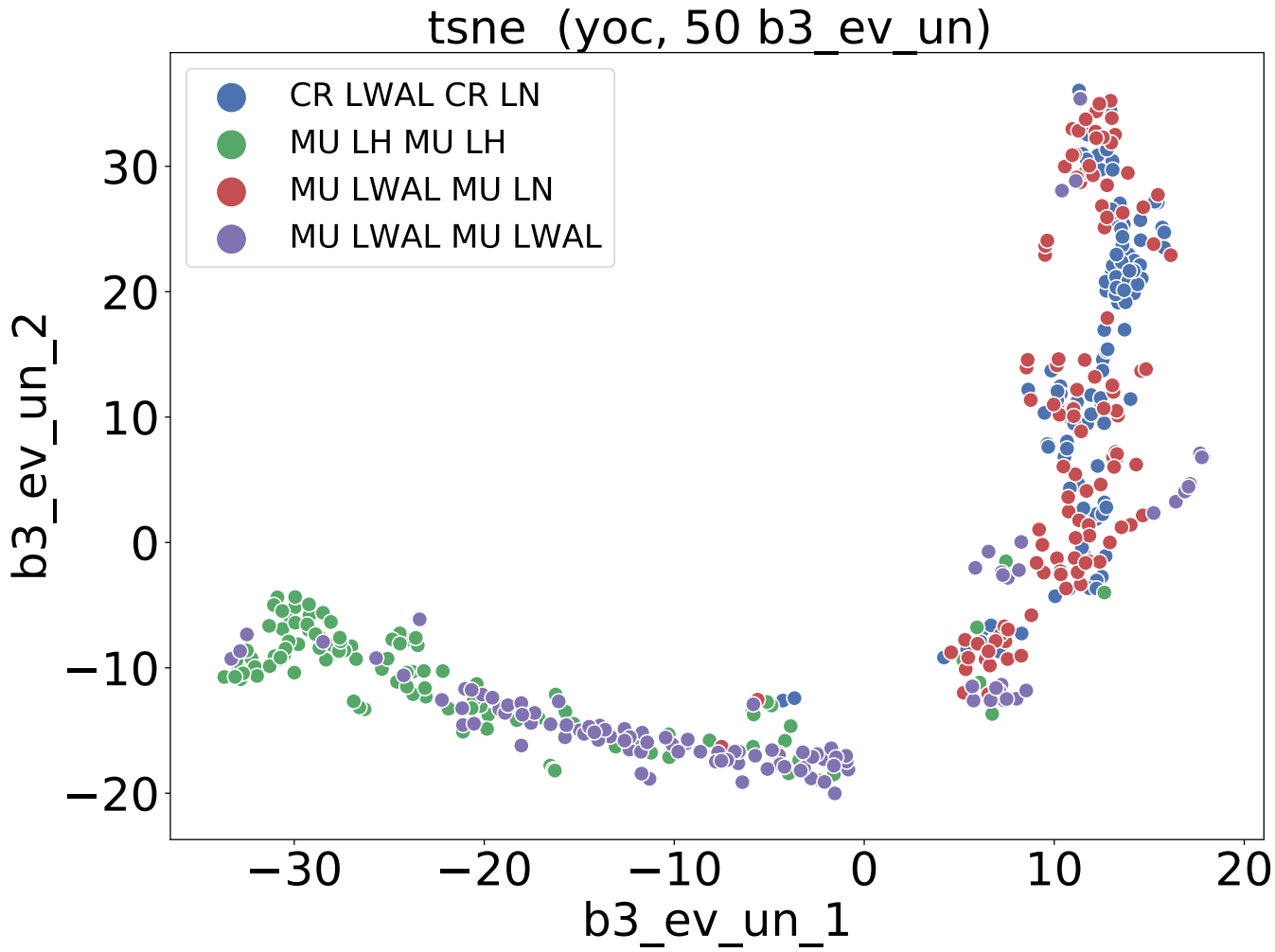


TU Delft


SVM (fparea, yoc)
CR LWAL CR LN
MU LH MU LH
MU LWAL MU LN
MU LWAL MU LWAL
yoc
fparea
1
0
−1
−2
−3
0
1
2
3
4
5


tsne (fparea, sarea, perimeter, yoc, gutter_heigth)
CR LWAL CR LN
MU LH MU LH
MU LWAL MU LN
MU LWAL MU LWAL
sarea
15
10
5
0
−5
−10
−15
−20
0
20
fparea

TU Delft


tsne (yoc, 50 b3_ev_un)
CR LWAL CR LN
MU LH MU LH
MU LWAL MU LN
MU LWAL MU LWAL
b3_ev_un_2
30
20
10
0
−10
−20
−30
−20
−10
0
10
20
b3_ev_un_1

TU Delft