

### CELL COMPLEXES TOPOLOGICAL LINKS FOR BUILDINGS IN CITYGML

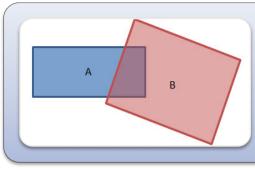
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### Introduction



#### **Topological Information**

- Describe connectivity information between buildings (Krämer & Huhnt, 2009)
- Comprehensive connectivity information is required to support 3D exploratory analyses (Isikdag et al., 2013; Moser et al., 2010; Ellul, 2007)



#### CityGML

- XML links or "XLink" mechanism relates explicitly stored objects (Kolbe, 2009)
- No maintenance of relationships between 0D,1D, and 2D primitives (Ghawana & Zlatanova, 2012)
- Neighbouring buildings often modelled using separate ("invisible") surfaces to facilitate efficient and consistent visualisation (Gröger et al., 2005)



#### Cell Complexes Topological Links

- Clear storage of topological information in a topological data structure is preferable for extraction of connectivity information (Boguslawski et al., 2011)
- Traverse via decomposed lower dimension primitives such as 0D points, 1D lines and 2D surfaces to make up a 3D object while preserving connectivity information



## Methodology

Extraction of geometrical properties

Generate topological links based on the extracted properties



#### **CityGML** Datasets

Dataset B: Two disjointed buildings bigbuilding bigbui	✓ FZK Viewer x64 V 4.7 - LoD2_311_5606_1_NW       -       ×         File       View Representations Display Query Extras Window ?       -       ×	
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Dataset A: Two	Dataset A: Two	
connected buildings	connected buildings	
Ready		

\*The CityGML datasets used in this study were obtained freely from Nordrhein-Westfalen Open Data



#### **Extraction of Geometric Properties**

FIIC	About	Help				
Polygor	n ID: "GU	ID_143982740605	6 1021004 2 6"			~
Linear I	Ring ID: "		056_1021004_2_6_			
Point:		311949.492	5606352.601	309.595		
Point:			5606351.235			
Point:	16	311952.027	5606351.918	310.456		
Roof St	urface ID	: "UUID_3082ab26	-124e-4853-8c02-1ab	3id06fdca''		
Polygor	n ID: "GU	ID 143982740605	6 1021004 2 7"			
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Point:		311951.342	5606359.492	309.595		
Point:	5	311949.492	5606352.601	309.595		
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2 Buildings 15 Surfaces 16 Nodes	Da	taset A:
	2	Buildings
16 Nodes	1	5 Surfaces
	1	6 Nodes

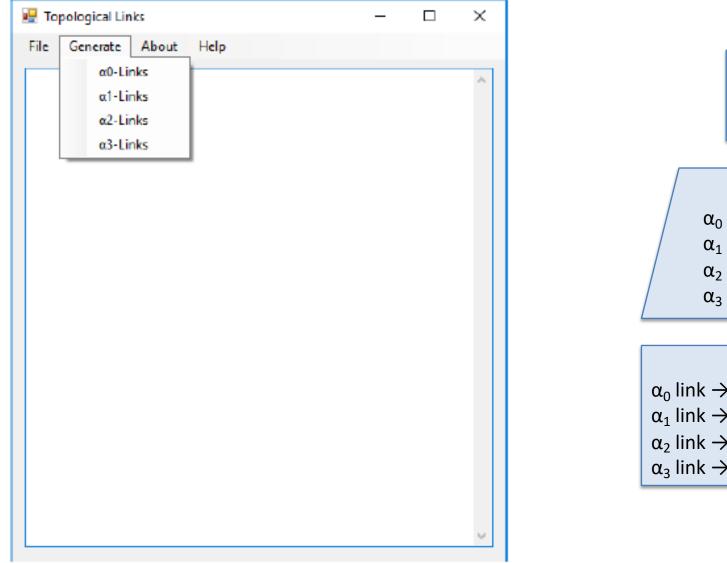
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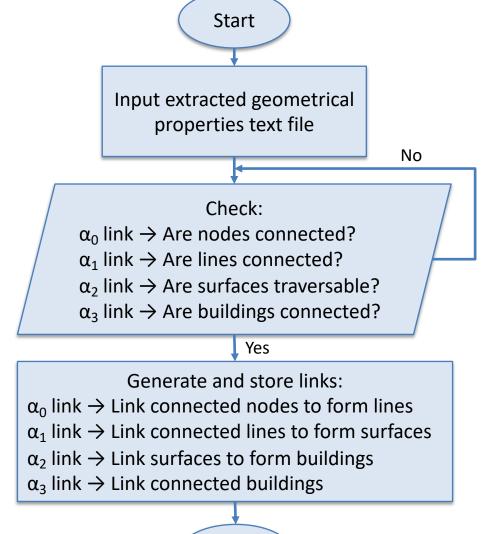
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faces des	Polygon ID: "GUID_1439827406056_1100214_2_6"           Linear Ring ID: "GUID_1439827406056_1100214_2_6_0_"           Point:         11           313177.113         5615994.494           330.411           Point:         17           313179.751         5615989.933           9oint:         20           313178.432         5615992.214           331.218		<
	Roof Surface ID: "UUID_b034e5c6-734a-4c07-97a7-efd4931e35bc"           Polygon ID: "GUID_1439827406056_1100214_2_7"           Linear Ring ID: "GUID_1439827406056_1100214_2_7_0_"           Point: 12         313191.402           5616002.562         330.411           Point: 11         313177.113           S615992.414         331.218           Point: 19         313192.695         5616000.258		
	Boof Surface ID: "UUID_a50756e0-2753-45de-8df2-dfde3a58df91"           Polygon ID: "GUID_1439827406056_1100214_2_8"           Linear Ring ID: "GUID_1439827406056_1100214_2_8_0_"           Point: 17         313179.751           5615989.933         330.411           Point: 15         313193.988         5615997.954           Point: 19         313192.695         5616000.258         331.218           Point: 20         313178.432         5615992.214         331.218		
	Ground Surface ID: "UUID_37cff9ed-54f4-4273-aa5c-afefd3a77b25" Polygon ID: "GUID_1439827406056_1100214_2_0" Linear Ring ID: "GUID_1439827406056_1100214_2_0_0_"		
Dataset B: 2 Buildings 18 Surfaces 20 Nodes	Point: 14 313177.113 5615994 494 494 327.082 Point: 13 313191.402 5616002.562 327.082 Point: 16 313193.988 5615997.954 327.082 Point: 18 313179.751 5615989.933 327.082 Number of building(s): 2 Number of building part(s): 0 Number of surfaces of building(s): 18		2

## **Generating Topological Links**





End

# Results (1D $\alpha_0$ links)

a <sub>o</sub> Links for Dataset A	$\alpha_{\circ}$ Links for Dataset B
🖷 Topological Links - 🗆 🗙	💀 Topological Links – 🗆 🗙
File Generate About Help	File Generate About Help
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Wal Surface Links Wal Surface ID: "UUID_28757b10-1322-413c-88da-a38753f9ae55" $\alpha 0(4)$ : 2-5 $\alpha 0(5)$ : 5-6 $\alpha 0(5)$ : 5-6 $\alpha 0(6)$ : 6-3 $\alpha 0(7)$ : 3-2	Wall Surface Links Wall Surface ID: "UUID_dc6ab620-dcfe-4c90-b017-ebd7f6c6d392" α0(4): 2-5 α0(5): 5-6 α0(6): 6-3 α0(7): 3-2
Wal Surface Links           Wal Surface ID: "UUID_86d24b7f-8ec7-44a5-aaa5-dc26c9fe301d"           α0(8): 5-7           α0(9): 7-8           α0(10): 8-6           α0(11): 6-5	Wall Surface Links Wall Surface ID: "UUID_b49a8e3e-bbd2-4beb-b10c-c91a5540dcf4" α0(8): 5-7 α0(9): 7-8 α0(10): 8-6 α0(11): 6-5
Wal Surface Links Wal Surface ID: "UUID_fc7d834e-73e6-459a-a4eb-5b88031642c6" $\alpha$ 0(12): 7-1 $\alpha$ 0(13): 1-4 $\alpha$ 0(14): 4-8 $\alpha$ 0(15): 8-7	Wall Surface Links Wall Surface ID: "UUID_80854e2f-67f9-4e8d-8fe7-93f2c1bb9177" α0(12): 7-1 α0(13): 1-4 α0(14): 4-8 α0(15): 8-7
Roof Surface Links Roof Surface ID: "UUID_d7364243-07f3-4a2a-bee4-c617c215dcbe" α0(16): 7-5	Wall Surface Links Wall Surface ID: "UUID_b8c91e84-39af-4872-9cb7-0148d36fa547" α0(16): 5-2

# Results (2D $\alpha_1$ links)

$\alpha_1$ Links for Dataset A	$\alpha_{\scriptscriptstyle 1}$ Links for Dataset B
Topological Links – 🗆 🗙	Topological Links – 🗆 X
File Generate About Help	File Generate About Help
$ \begin{array}{l} \mbox{Building ID: "DENW39AL1000msO"} \\ \mbox{Wall Surface Links} \\ \mbox{Wall Surface ID: "UUID_35d21856-d9fd-48fe-9cbf-ffefb7a} \\ \mbox{a1(0): a0(0) - a0(1) - a0(2) - a0(0)} \\ \mbox{Wall Surface ID: "UUID_28757b10-1322-413c-88da-a387} \\ \mbox{Wall Surface ID: "UUID_28757b10-1322-413c-88da-a387} \\ \mbox{a1(2): a0(4) - a0(5) - a0(6) - a0(7) - a0(4)} \\ \mbox{Wall Surface Links} \\ \mbox{Wall Surface ID: "UUID_86d24b7-8ec7-44a5-aaa5-dc26c9fe301d"} \\ \mbox{a1(2): a0(8) - a0(9) - a0(11) - a0(8)} \\ \mbox{Wall Surface ID: "UUID_fc7d834e-73e6-459a-a4eb-5b88031642c6"} \\ \mbox{a1(3): a0(12) - a0(13) - a0(14) - a0(15) - a0(12)} \\ \mbox{Roof Surface ID: "UUID_d7364243-073-4a2a-bee4-c617c215dcbe"} \\ \mbox{a1(4): a0(16) - a0(17) - a0(18) - a0(19) - a0(16)} \\ \mbox{Ground Surface ID: "UUID_3ecc583d-4508-44d5-ad93-c33f6151e952"} \\ \mbox{a1(6): a0(20) - a0(22) - a0(22) - a0(23) - a0(20)} \\ \mbox{Building ID: "DENW39AL1000mH4"} \\ \mbox{Wall Surface Inks} \\ \mbox{Wall Surface Inks} \\ \mbox{Wall Surface Inks} \\ \mbox{Ground Surface Inks} \\ \mbox{Ground Surface Inks} \\ \mbox{Ground Surface Inks} \\ \mbox{Ground Surface Inc} : "UUID_3ecc583d-4508-44d5-ad93-c33f6151e952" \\ \mbox{a1(5): a0(20) - a0(21) - a0(22) - a0(23) - a0(20)} \\ \mbox{Building ID: "DENW39AL1000mH4"} \\ \mbox{Wall Surface Inks} \\ \mbox{Wall Surface Inks} \\ \mbox{Wall Surface Inks} \\ \mbox{Wall Surface Inks} \\ \mbox{Ground Surface Inks} \\ \mbox{Ground Surface Inks} \\ \mbox{Ground Surface Inks} \\ \mbox{Wall Surface Inks} \\ Wal$	$ \begin{array}{c} \mbox{Bulding ID: "DENW40AL1000GSFN"} \\ \mbox{Wall Surface Links} \\ \mbox{Wall Surface Links} \\ \mbox{Wall Surface ID: "UUID_deba5b31-8528-43a7-a539-a} \\ \mbox{$\alpha$} 1(0): $\alpha$0(0) - $\alpha$0(2) - $\alpha$0(2) - $\alpha$0(3) - $\alpha$0(0) \\ \mbox{Wall Surface ID: "UUID_dc6ab620-dcfe-4c90-b017-et} \\ \mbox{$\alpha$} 1(1): $\alpha$0(4) - $\alpha$0(5) - $\alpha$0(6) - $\alpha$0(7) - $\alpha$0(4) \\ \mbox{Wall Surface ID: "UUID_dc6ab620-dcfe-4c90-b017-et} \\ \mbox{$\alpha$} 1(2): $\alpha$0(3) - $\alpha$0(10) - $\alpha$0(11) - $\alpha$0(8) \\ \mbox{Wall Surface ID: "UUID_b49a8e3e-bbd2-4beb-b10c-c91a5540dcf4" \\ \mbox{$\alpha$} 1(2): $\alpha$0(12) - $\alpha$0(13) - $\alpha$0(11) - $\alpha$0(18) \\ \mbox{Wall Surface ID: "UUID_80854e2f-679-4e8d-8fe7-93f2c1bb9177" \\ \mbox{$\alpha$} 1(3): $\alpha$0(12) - $\alpha$0(13) - $\alpha$0(16) \\ \mbox{Wall Surface ID: "UUID_b6e91e84-39af-4872-9cb7-0148d36fa547" \\ \mbox{$\alpha$} 1(4): $\alpha$0(16) - $\alpha$0(17) - $\alpha$0(18) - $\alpha$0(16) \\ \mbox{Wall Surface ID: "UUID_b724c4ee-5ab8-4b1f-bb71f37e5c630d4c" \\ \mbox{$\alpha$} 1(5): $\alpha$0(19) - $\alpha$0(21) - $\alpha$0(19) \\ \mbox{Roof Surface ID: "UUID_4a7a543b-4f47-476d-bae6-12f6abb33747" \\ \mbox{$\alpha$} 1(5): $\alpha$0(22) - $\alpha$0(23) - $\alpha$0(25) - $\alpha$0(22) \\ \mbox{Roof Surface Inks} \\ \mbox{Wall Surface ID: "UUID_4a7a543b-4f47-476d-bae6-12f6abb33747" \\ \mbox{$\alpha$} 1(5): $\alpha$0(22) - $\alpha$0(23) - $\alpha$0(25) - $\alpha$0(22) \\ \mbox{Roof Surface Inks} \\ R$
Wall Surface Links	Roof Suiface ID: "UUID_f0059410-d318-40b7-ab24-2b797544f342" α1(7): α0(26) - α0(27) - α0(28) - α0(29) - α0(26)



# Results (3D $\alpha_2$ links)

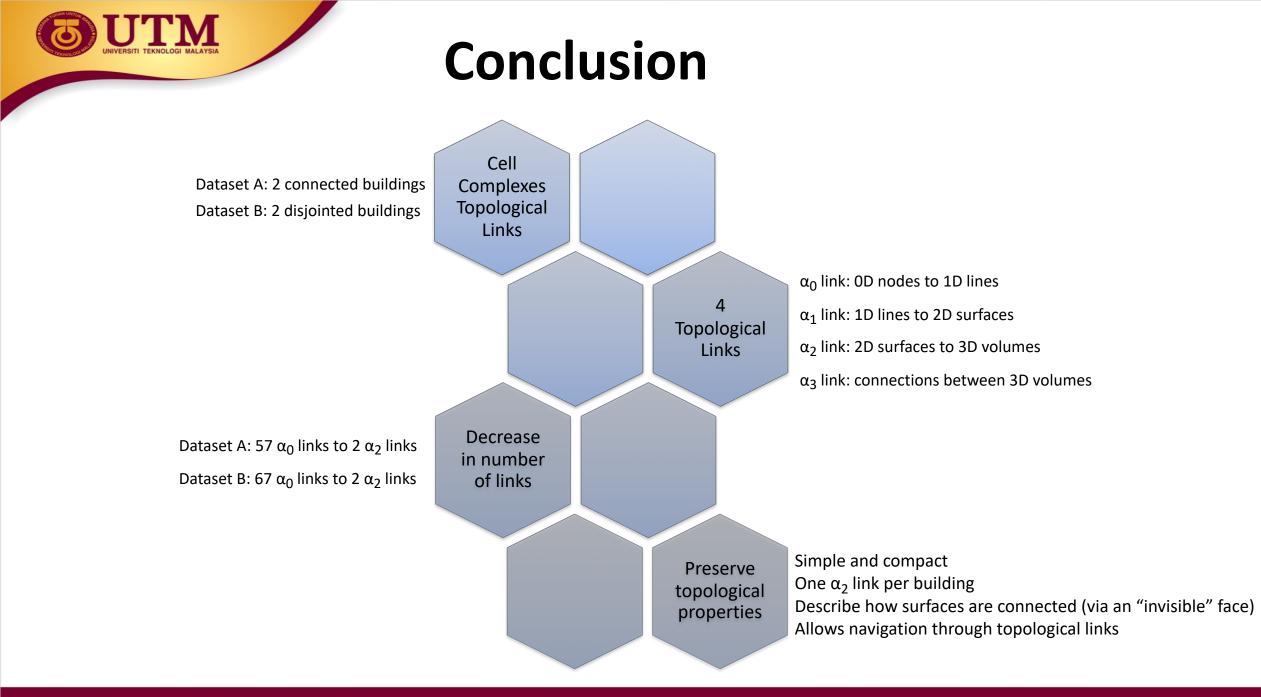
$\alpha_2$ Links for Dataset A	$\alpha_2$ Links for Dataset B
$\begin{tabular}{ c c c c c c c c c c c c c c c c c c c$	$\begin{tabular}{ c c c c c c c } \hline & & & & & & & & & & & & & & & & & & $
15 $\alpha_1$ links $\rightarrow$ 2 $\alpha_2$ links	18 $\alpha_1$ links $\rightarrow$ 2 $\alpha_2$ links



# Results (α<sub>3</sub> links)

α <sub>3</sub> Links for Datase	t A		α <sub>3</sub> Links for Dataset B	
🖳 Topological Links	_	×	🖳 Topological Links – 🗆 🗙	:
File Generate About Help			File Generate About Help	
Alpha-3 Links α3(0): α2(0) - α2(1) α3(1): α2(1) - α2(0)		^	No α3 Links.	
$2 \alpha_2 \text{ links} \rightarrow 2 \alpha_3 \text{ links}$			No connected buildings	

The  $\alpha_3$  links describe the connection between the buildings of Dataset A which could not be referenced in CityGML due to being connected via an "invisible" face.





### **Future Research**

- *n*-dimensional case study
- 3D Smart Cities
- BIM
- Urban Pollutions (multi-dimensional)
- Visual Positioning System (VPS) Integration (local positioning)



## Acknowledgements

- The CityGML datasets used in this study were obtained freely from Nordrhein-Westfalen Open Data.
- The CityGML viewer used in this study is the FZK Viewer developed by Karlsruhe Institute of Technology.
- This work is supported by the UTM Research University Grant, Vot Q.J.130000.2527.15H49 and Vot Q.J.130000.2527.11H78.



## Thank you

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