Eurographics 2012
Cagliari, Italy
May 13 -18
33rd ANNUAL CONFERENCE OF THE EUROPEAN ASSOCIATION FOR COMPUTER GRAPHICS

A Survey of Urban Reconstruction

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Peter Wonka
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Luc van Gool
Werner Purgathofer

Eurographics
EUROPEAN ASSOCIATION FOR COMPUTER GRAPHICS

Who are the Authors?

- **Przemyslaw Musialski:**
  - Postdoc (TU-Wien/ASU), formerly researcher at VRVis
  - Field: Graphics, Image Processing
- **Peter Wonka**
  - Associate Prof (ASU/KAUST)
  - Field: Graphics, Image Processing
- **Daniel Aliaga**
  - Associate Prof (Purdue University)
  - Field: Vision, Graphics
- **Michael Wimmer**
  - Associate Prof (TU-Wien)
  - Field: Graphics
- **Luc van Gool**
  - Full Prof (ETH Zurich & KU Leuven)
  - Field: Vision, Photogrammetry & Remote Sensing
- **Werner Purgathofer**
  - Full Prof (TU-Wien) and Scientific Director (VRVis)
  - Field: Graphics

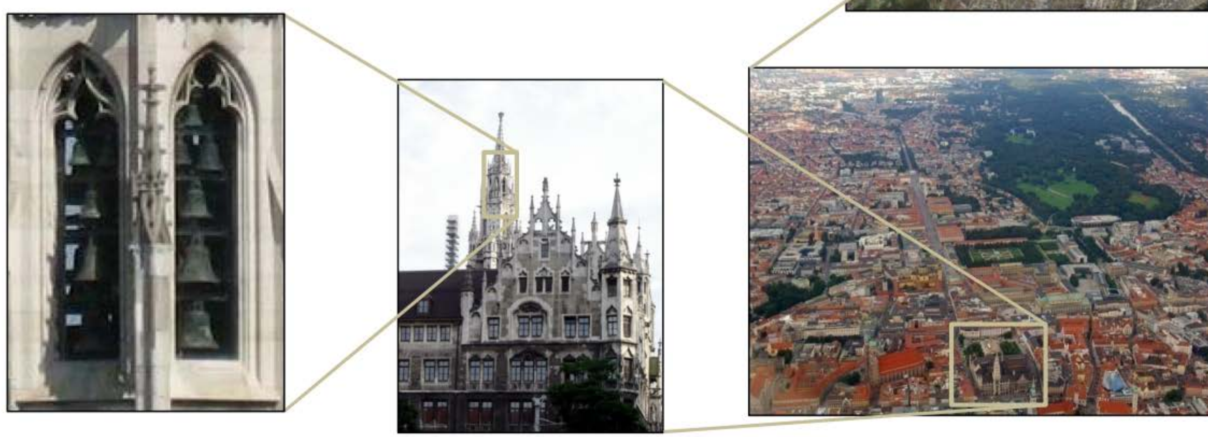





What is Urban Reconstruction?

- **Creating digital models of real cities**

- **Cities are large collections of man-made objects at many LODs**

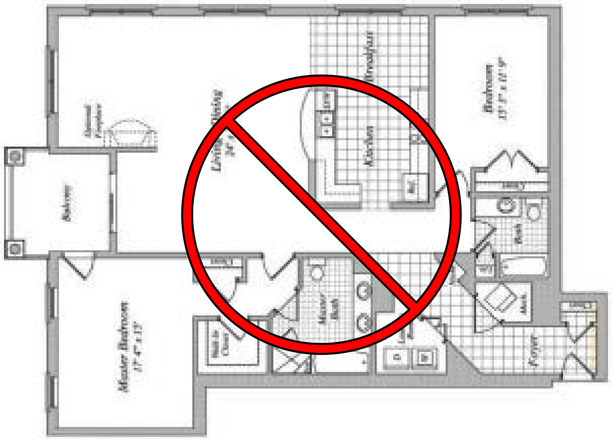


Possible Applications

- Cyber-Tourism
- Computer Games
- Movie-Industry and Entertainment Industry
- Digital Maps and Routing
- City-Planers and Architects
- Archeological Research
- More Sciences (Sociology,...)

Scope

- **We cover geometric reconstruction**
  - Graphics, Vision and some Photogrammetry & Remote Sens.
  - Different Levels of Detail
  - Interactive and Automatic Methods



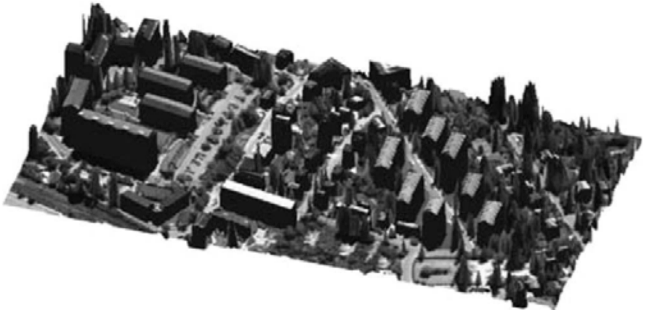
- **We do NOT cover**
  - Manual Reconstruction (CAD-Modeling)
  - Procedural Modeling
  - Mobile- and Mapping-Technology
  - Geo-Sciences
  - Architecture & Civil Engineering
  - Hardware, Sensors, Electrical Engineering

Contributions from Different Fields:

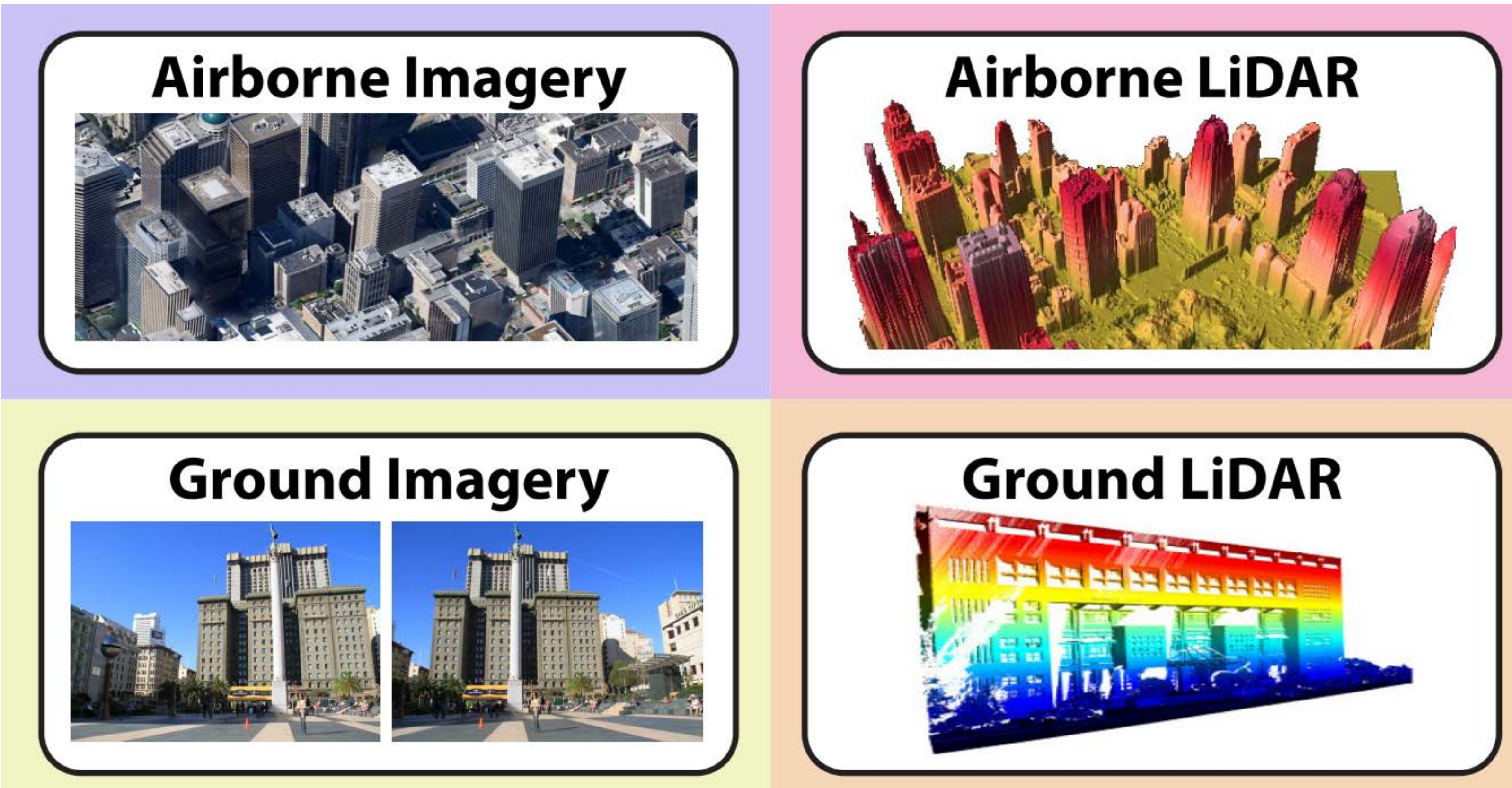
- **Computer Graphics**
  - Usually Interactive Modeling
  - Inverse Procedural Modeling
  - (Procedural Modeling)

- **Computer Vision**
  - Automatic Reconstruction
  - Inverse Procedural Modeling

- **Photogrammetry and Remote Sensing**
  - Measuring and Documenting the Earth



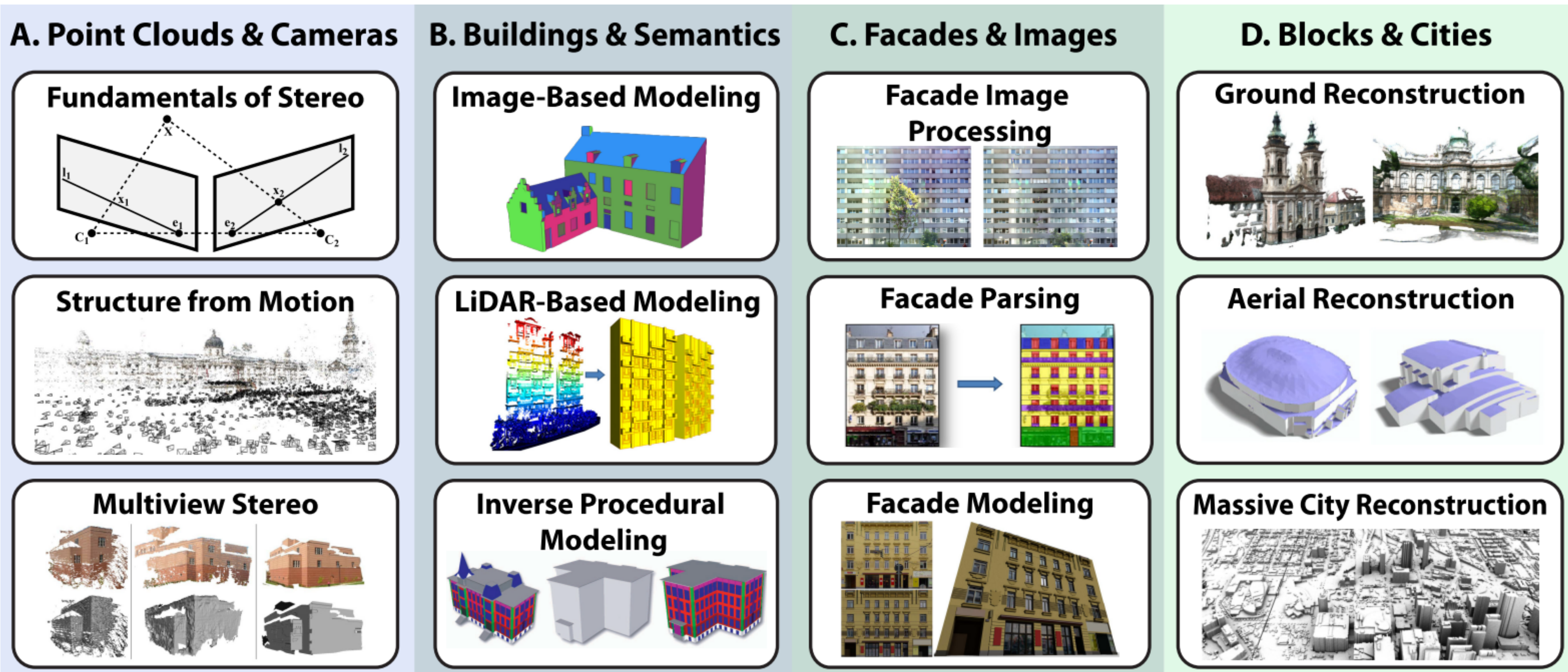
Input Data


Airborne Imagery
Airborne LiDAR
Ground Imagery
Ground LiDAR

Challenges

- **Full Automation**
  - The Chicken-Or-Egg Dilemma
  - Top-Down versus Bottom-Up
- **Quality and Scalability**
  - User-Interaction does not scale well
  - Fully-automatic systems lack production quality
- **Acquisition Constraints**
  - Real buildings are often not easy to capture
  - Occlusions, Reflections and other obstacles

Overview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LiDAR-Based Modeling
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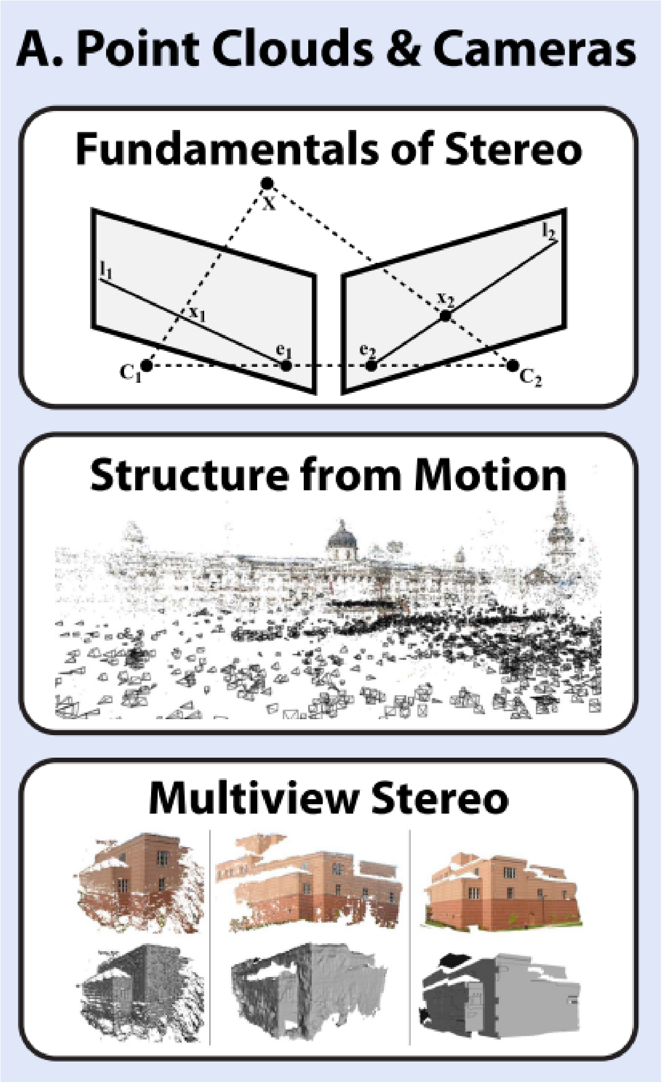

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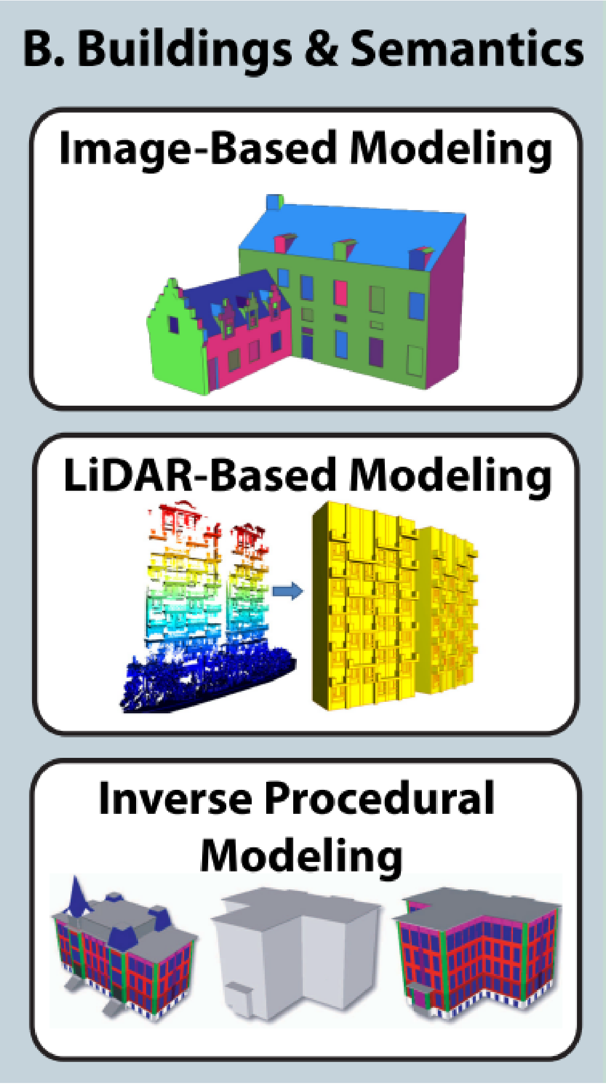

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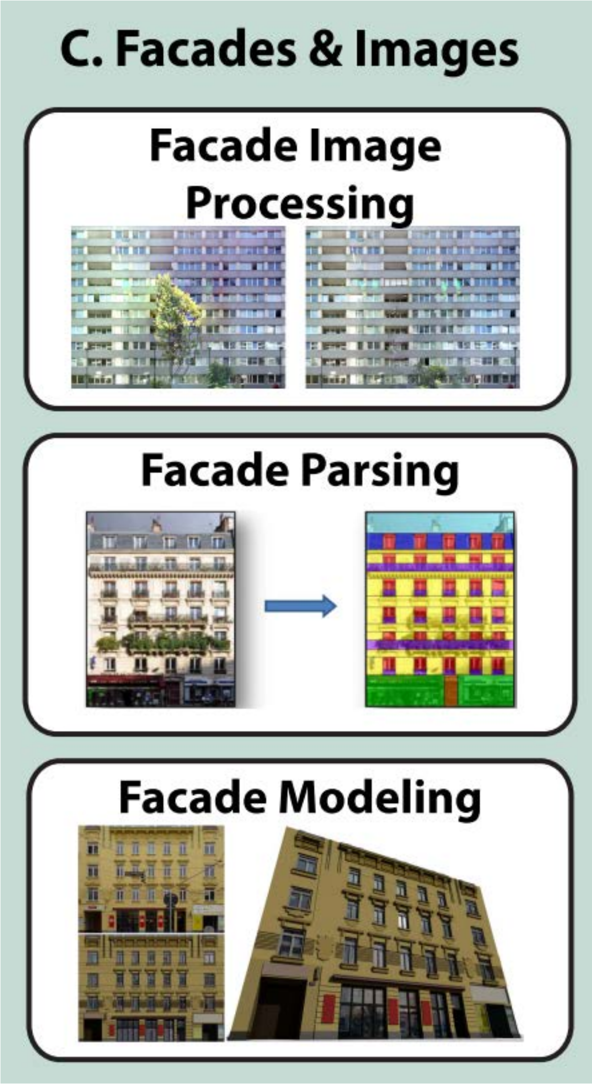

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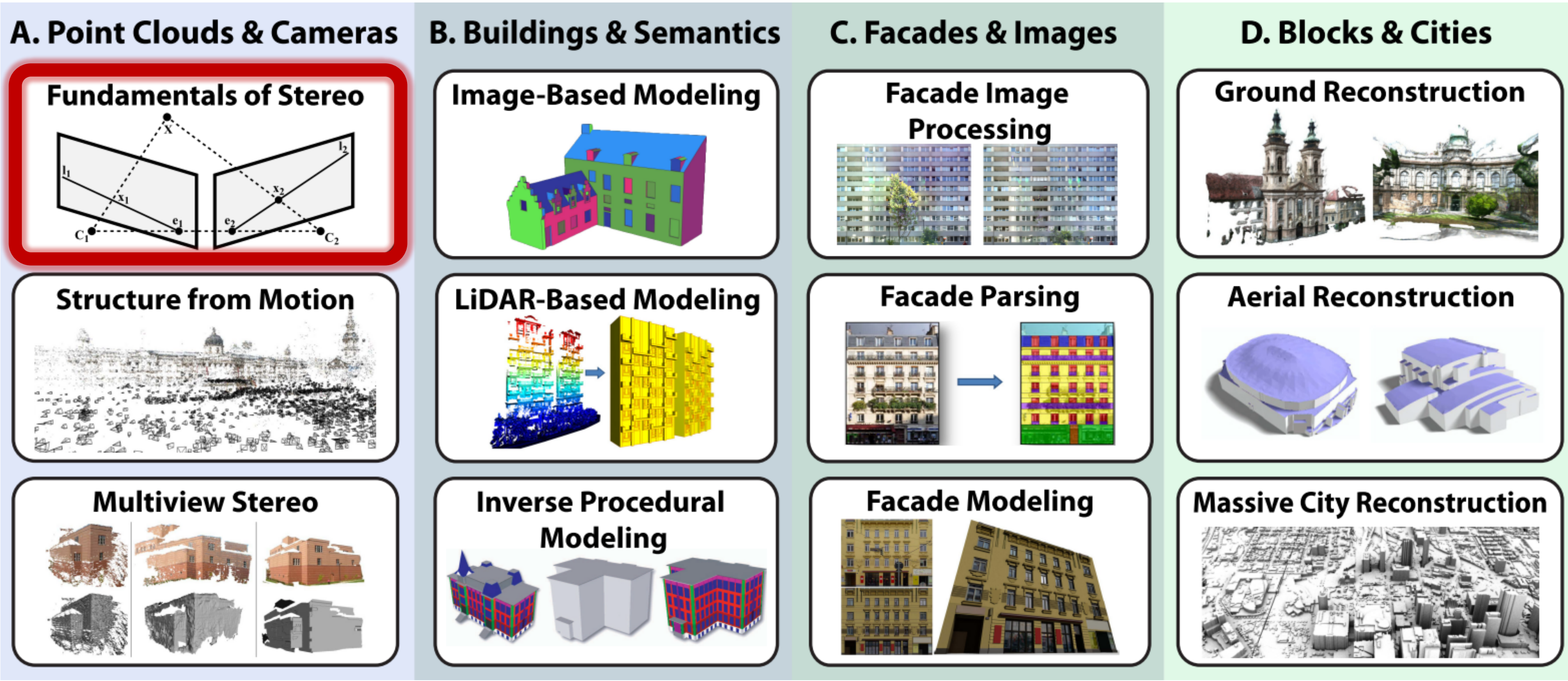
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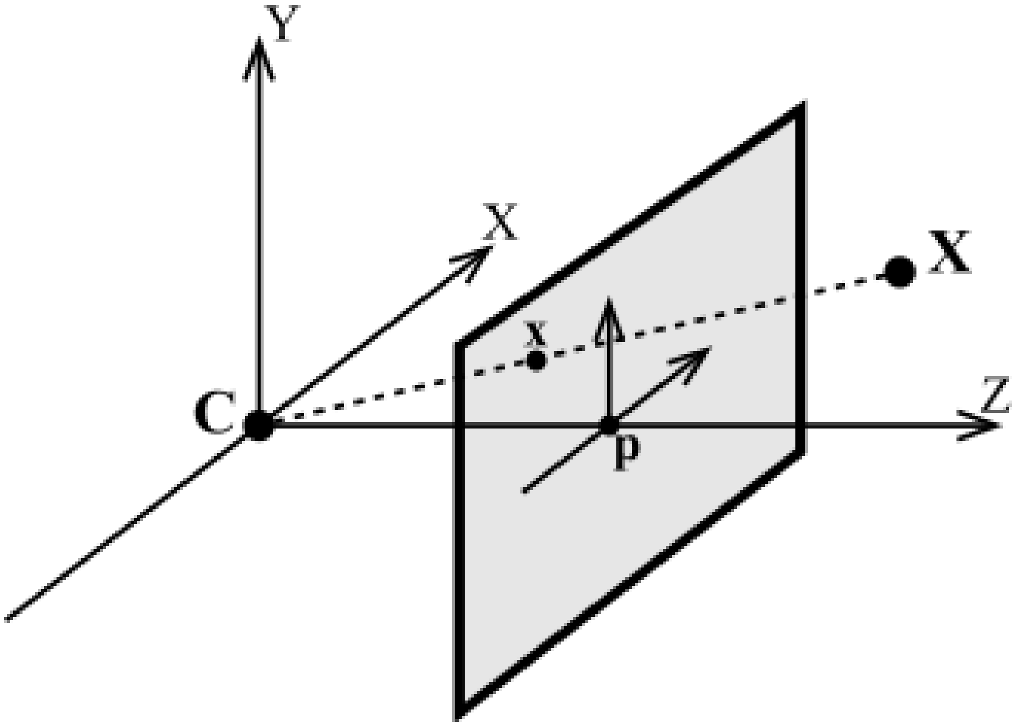
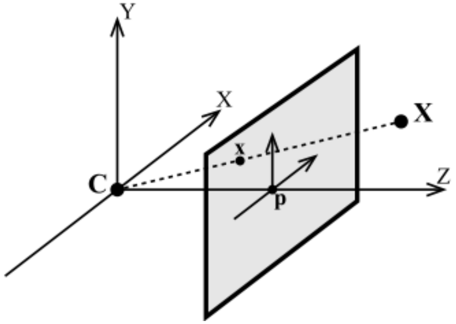
A.1 Fundamentals of Stereo

- **Camera Model**
  - Central Projection
  - Pinhole Camera



A.1 Fundamentals of Stereo

- **What is Camera Calibration?**
- **Calibration means to obtain the parameters:**
  - Intrinsic Calibration:
    - Projection Parameters
    - (Focal Length, etc.)
  - Using Markers we can infer intrinsic parameters



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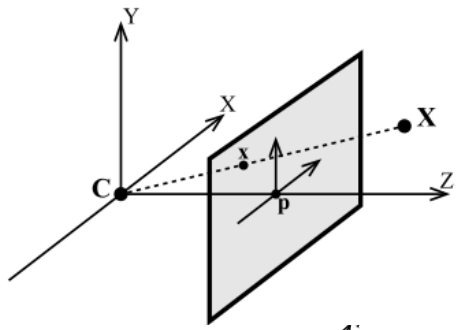
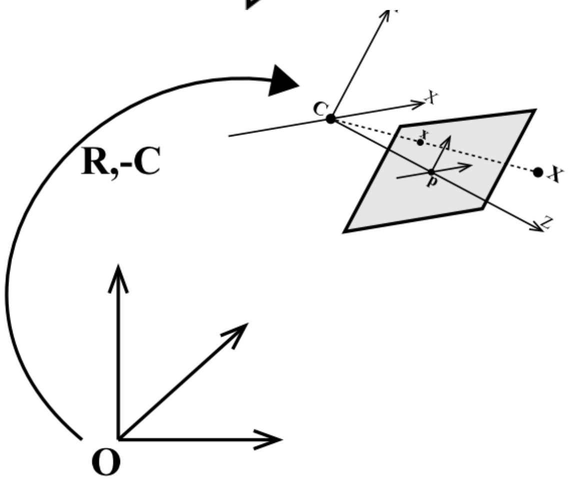


  – Extrinsic Calibration (Pose Estimation)
    - Pose of the camera in the world space



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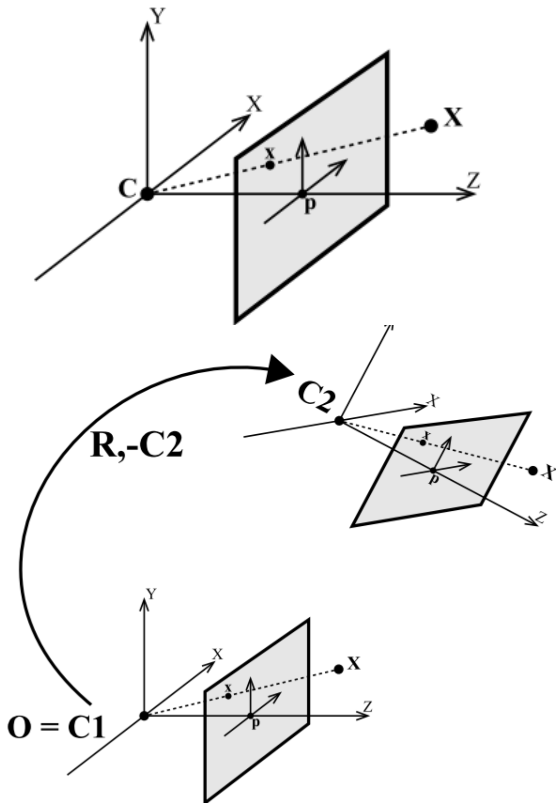

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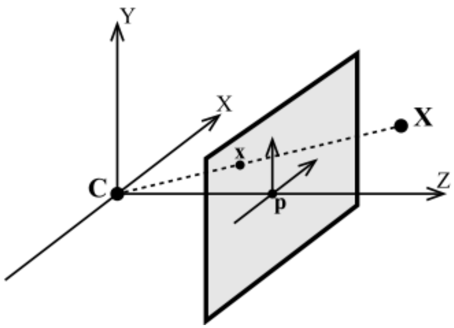
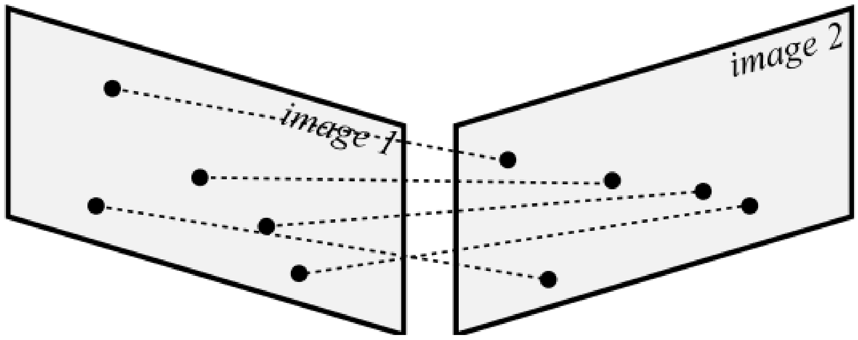
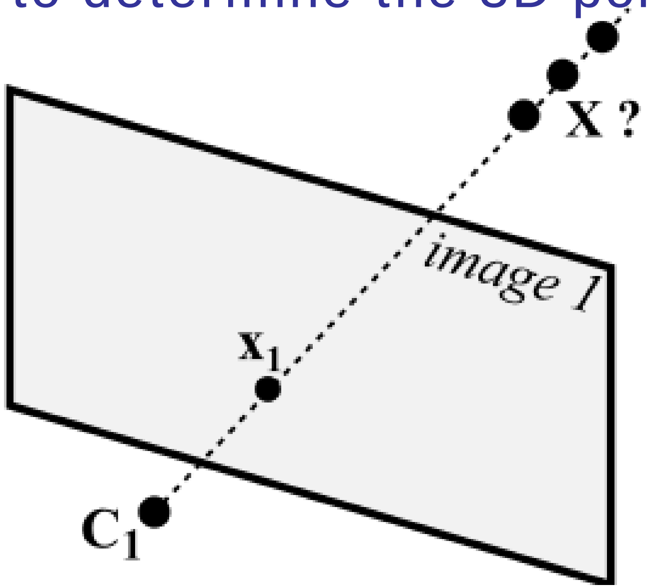


  - Extrinsic Calibration (Pose Estimation)
    - Pose of the camera in the world space
    - Can be determined from 5 (7) image correspondences



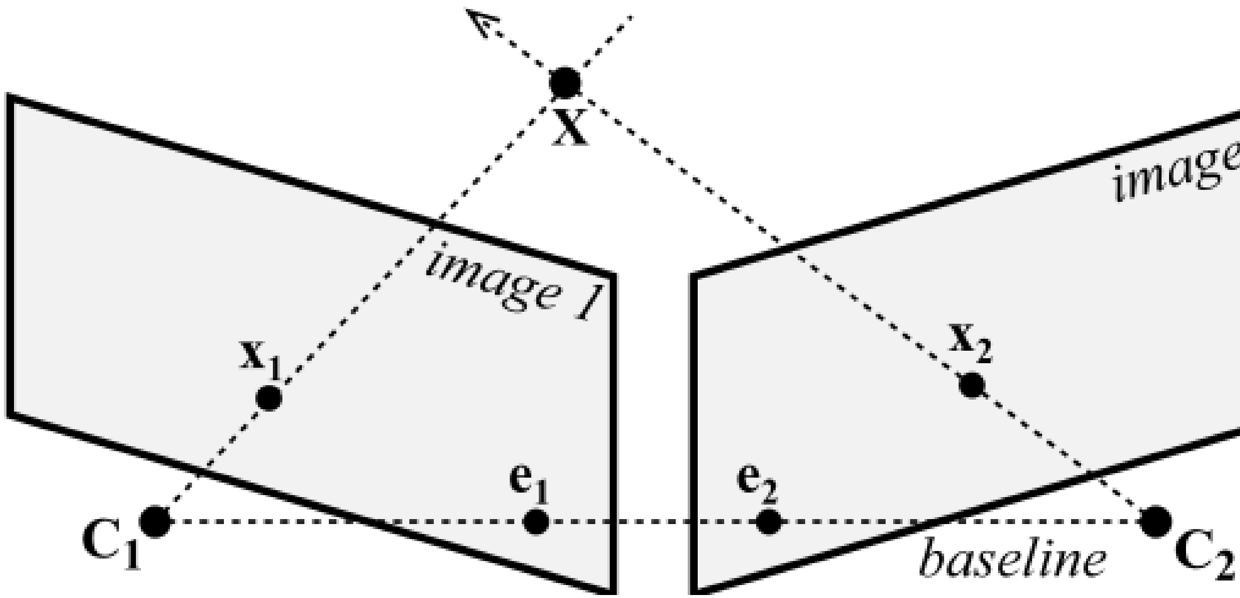
A.1 Fundamentals of Stereo

- **Stereo Geometry**
  - Given is the point x1 on the image
  - How to determine the 3D point X?



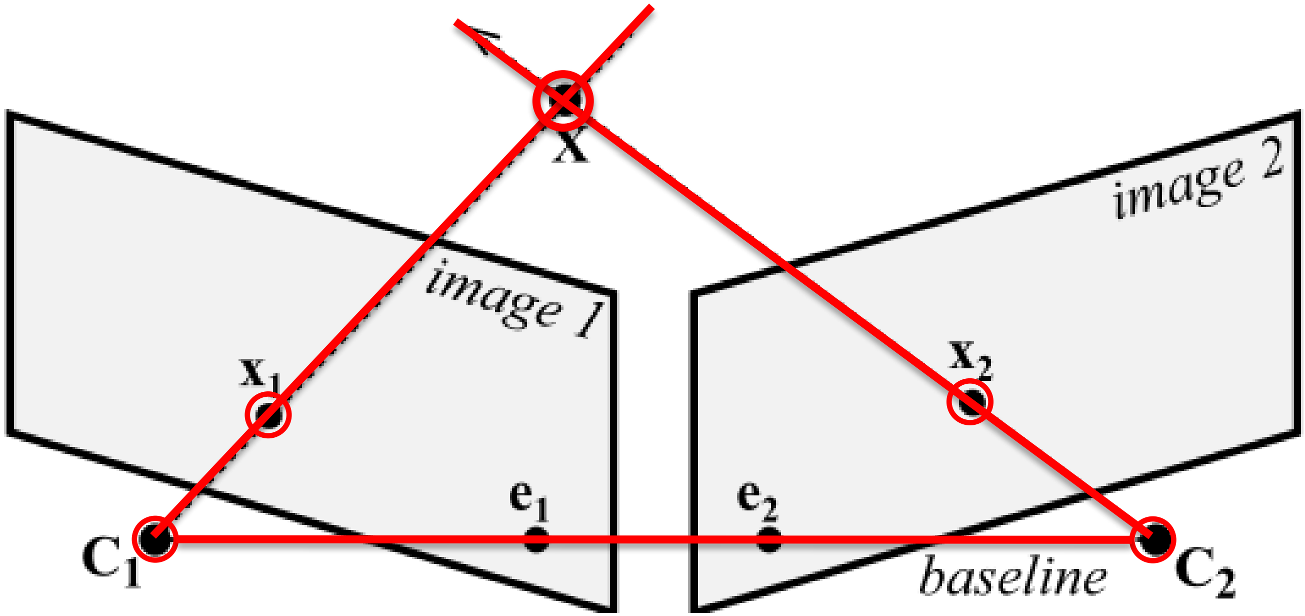
A.1 Fundamentals of Stereo

- **Stereo Geometry**
  - We need a second image with x2 corresponding to x1



A.1 Fundamentals of Stereo

- **Stereo Triangulation**



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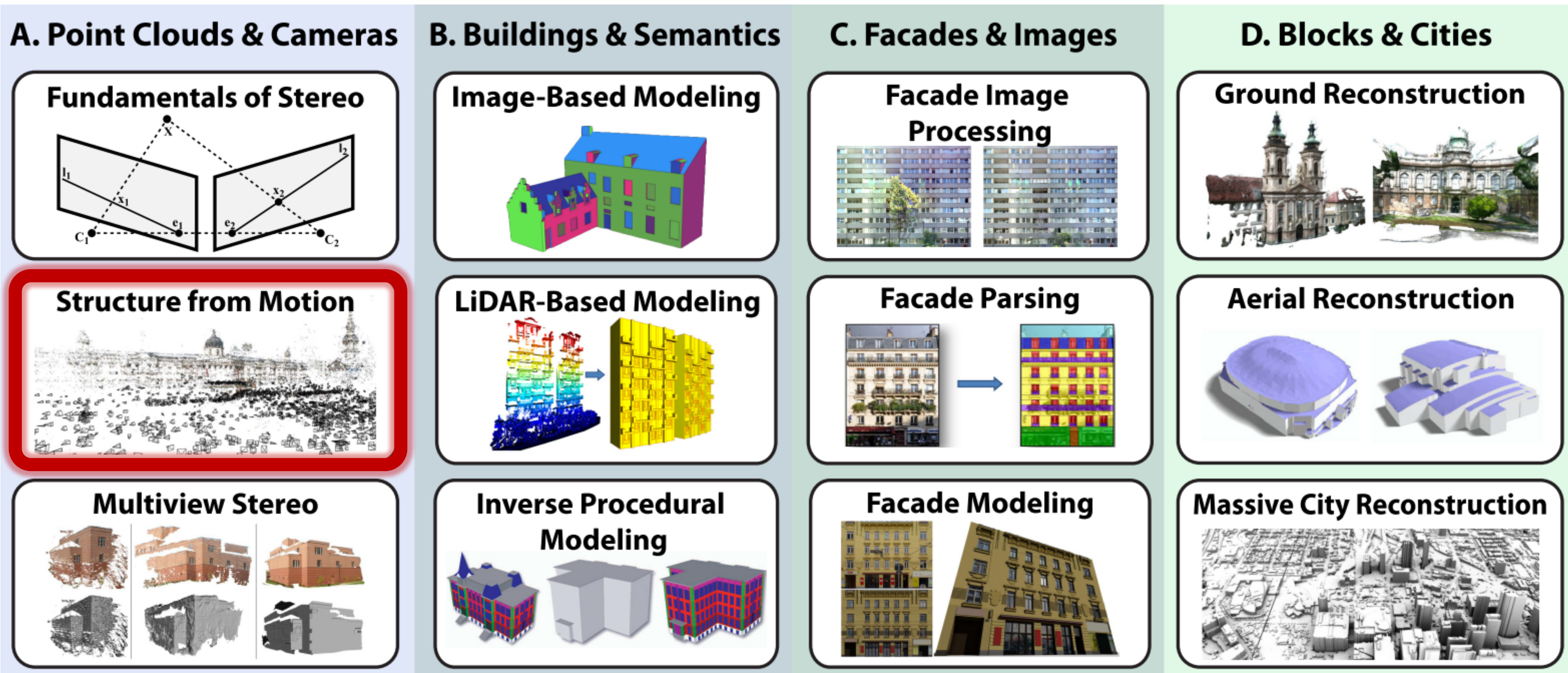
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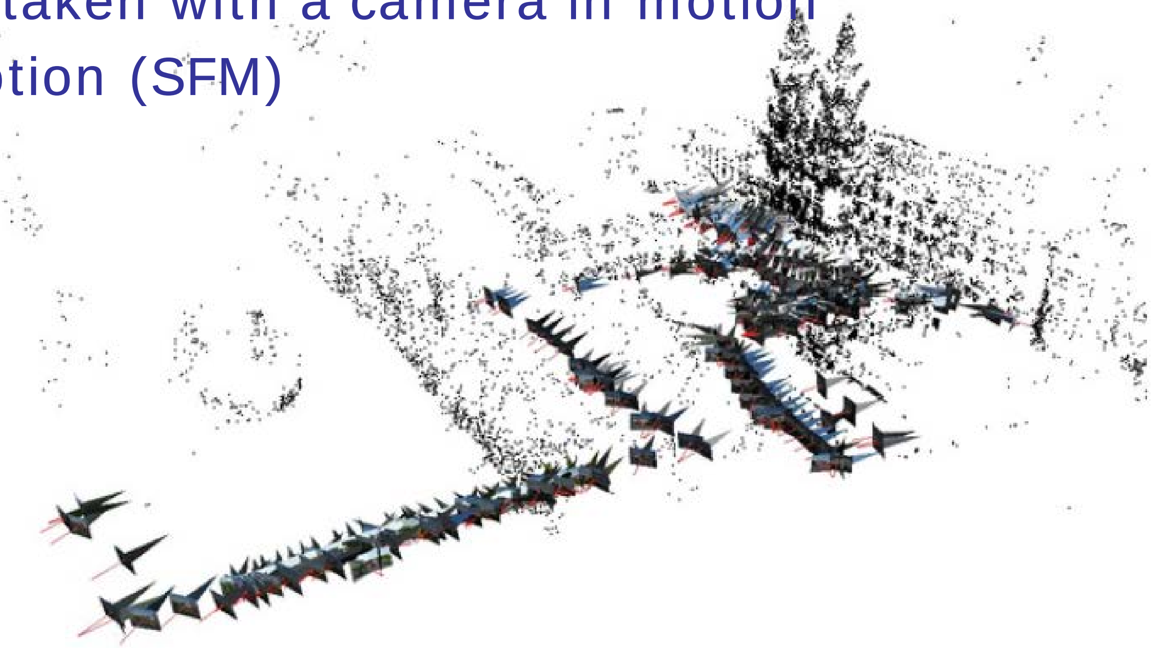
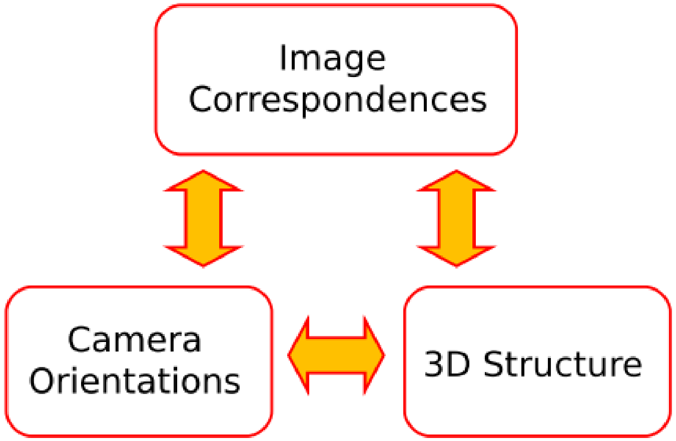
A.2 Structure from Motion

- **Structure from Motion**
  - Only images as input
  - A high number of images can be registered
  - A high number of points can be triangulated
  - Since images where taken with a camera in motion
    → Structure from Motion (SFM)



A.2 Structure from Motion

- **Structure from Motion**
  - Input: set of images
  - Challenges:
    - Correspondence Problem
    - Structure Triangulation Problem
    - Additional product: Camera poses

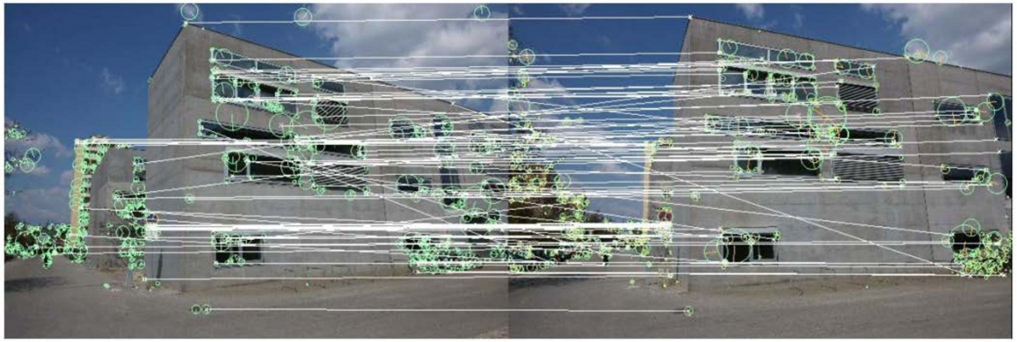


(a) Structure from Motion

A.2 Structure from Motion

- **Correspondence Problem**
- **Feature Detection and Matching**

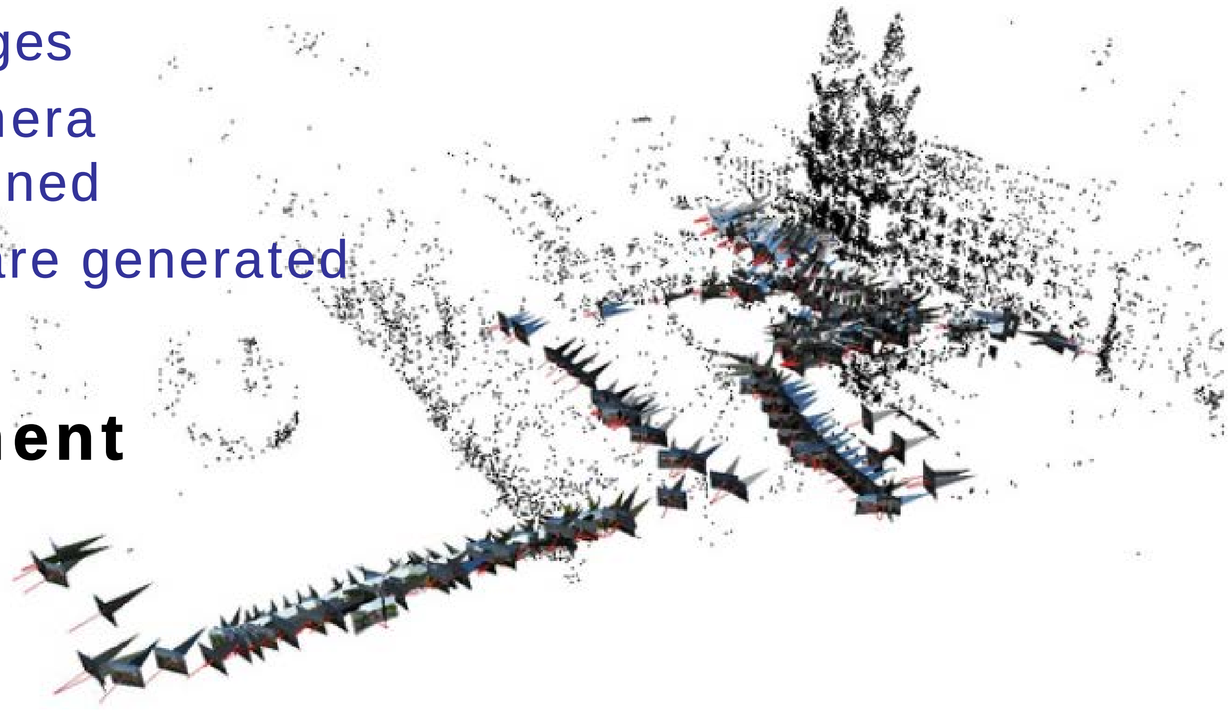
  - Mutual matching
    e.g. KD-Tree



  - Geometric verification:
    (RANSAC)
    - Fischler & Bolles [FB81]

A.2 Structure from Motion

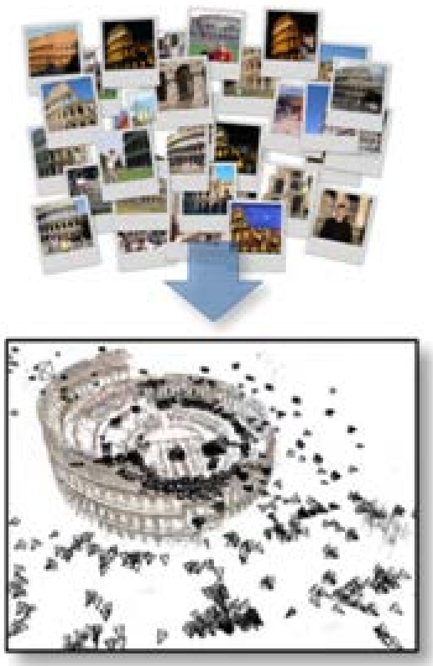
- **Incremental process**
  - Starting from initial image pair
  - Adding more images
  - Features and Camera Poses are determined
  - Image networks are generated



- **Bundle Adjustment**
  - Non-linear optimization of the whole network

A.2 Structure from Motion

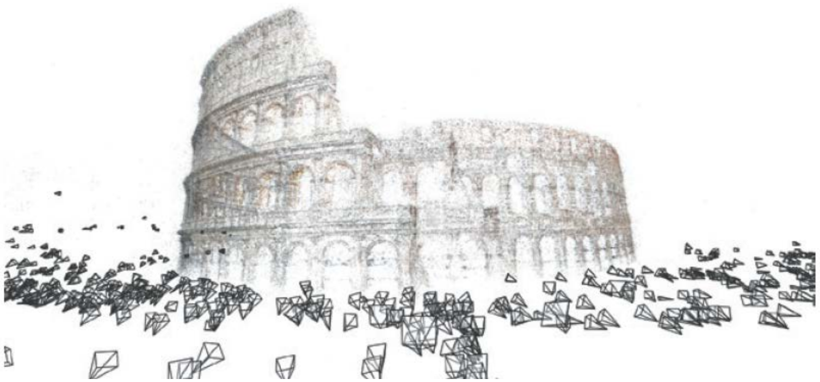
- **Photo Tourism**
  - Snavely et al. [SSS06,SSS07,SGSS08, SSG*10]
  - Use collections of images of sight seeing from the Internet
  - Generate sparse point clouds
  - Use image-blending in order to smoothly move from image to image

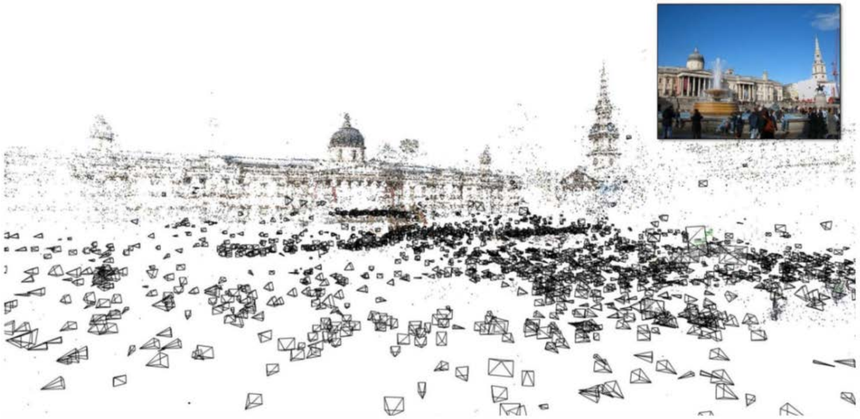


A.2 Structure from Motion

A.2 Structure from Motion

- **Building Rome in a Day**
  - Agrawal et al. [ASS*09]
  - Optimization of the pipeline
  - Over 150 000 images of Rome
  - (250 000 from Venice)
  - Processed in parallel in a processor-cluster
  - Reconstructs sparse point clouds





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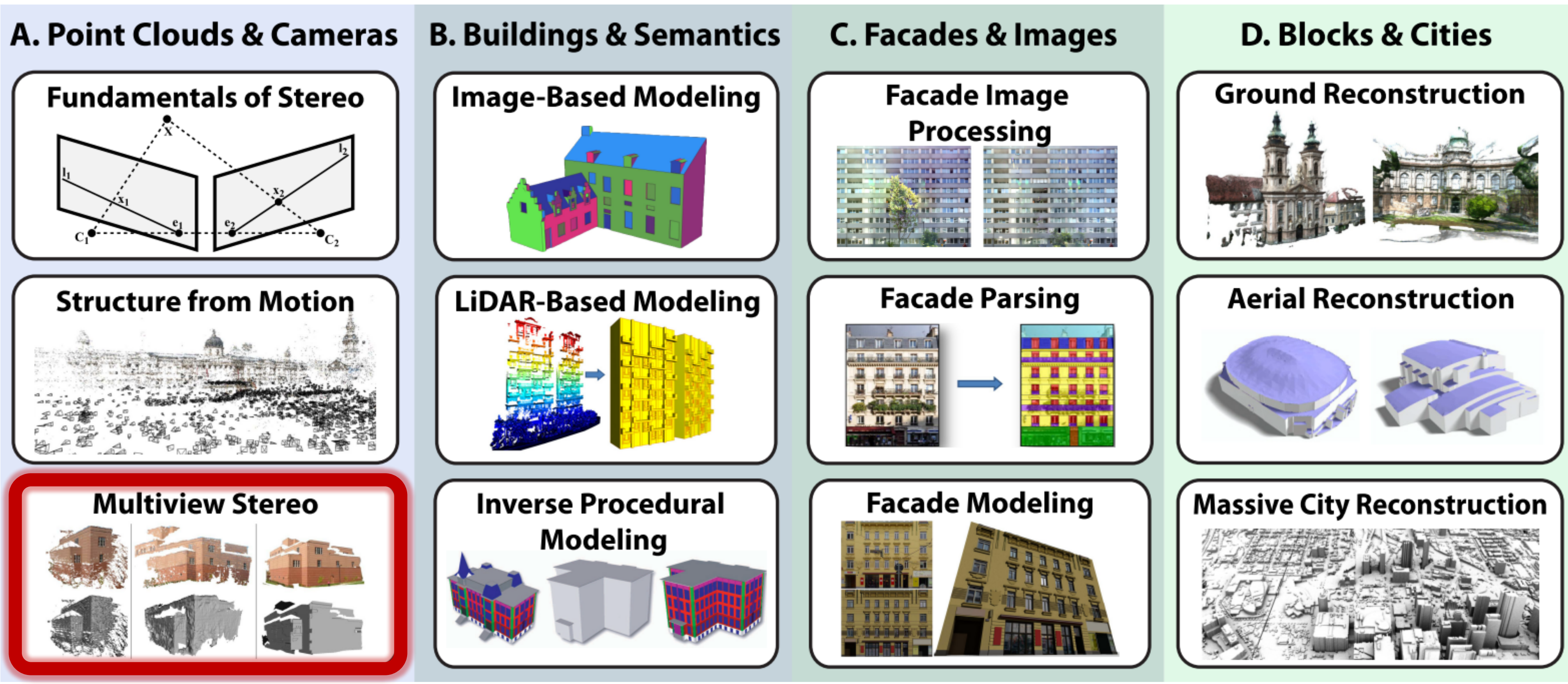
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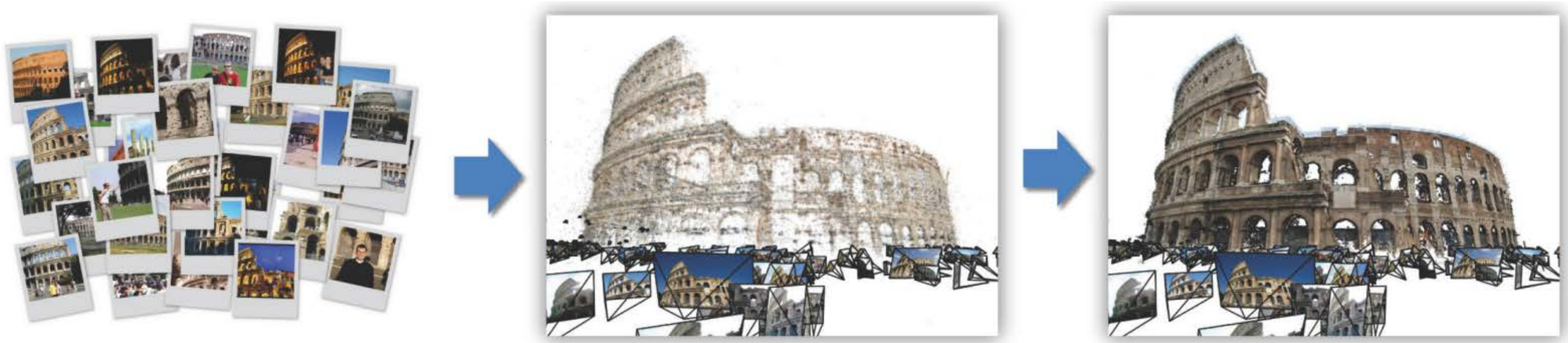
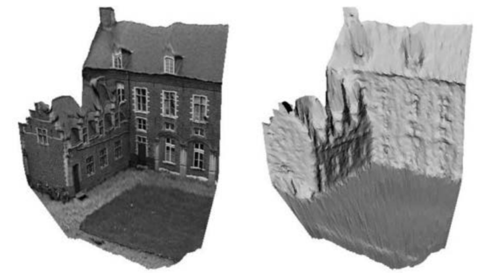
A.3 Multiview Stereo

- **Dense Multiview Stereo**
  - Use sparse stereo and camera networks as input
  - Compute dense, possibly water-tight, reconstructions



Input photos Sparse reconstruction Dense reconstruction

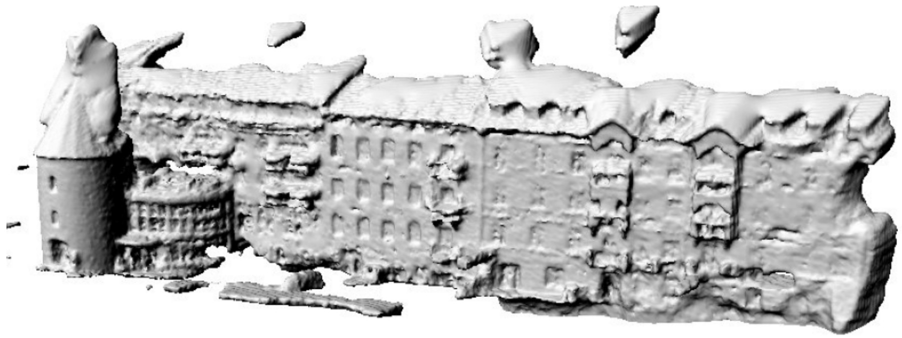
A.3 Multiview Stereo



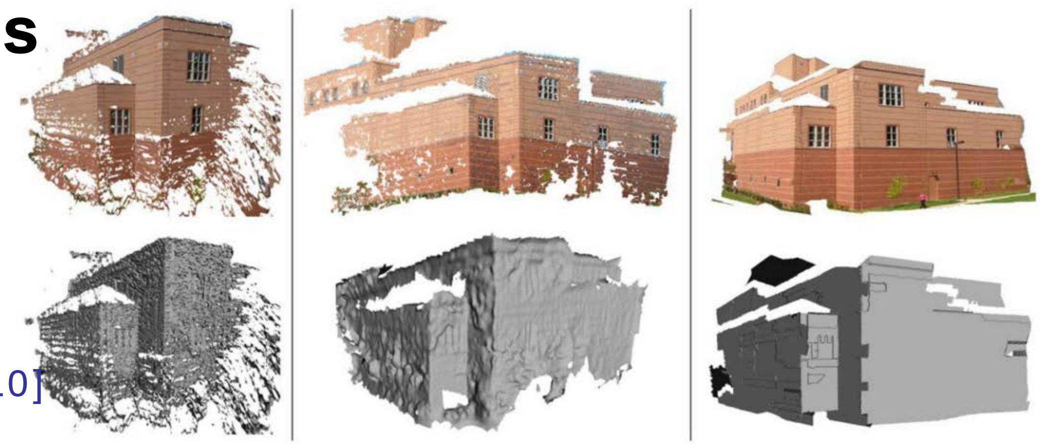
- **Dense Matching Systems**
  - Pollefeys et al. [PvGV*04,PNF*08]
  - Vergauven and van Gool [VvG06]
  - Akbarzadeh et al. [AFM*06]
  - Frahm et al. [FFGG10]
  - Furukawa and Ponce [FP07,PF9]
  - Agrawal et al. [AFS*11,FP09]

A.3 Multiview Stereo

- **Problem:**
  - Dense reconstructions are not perfectly flat



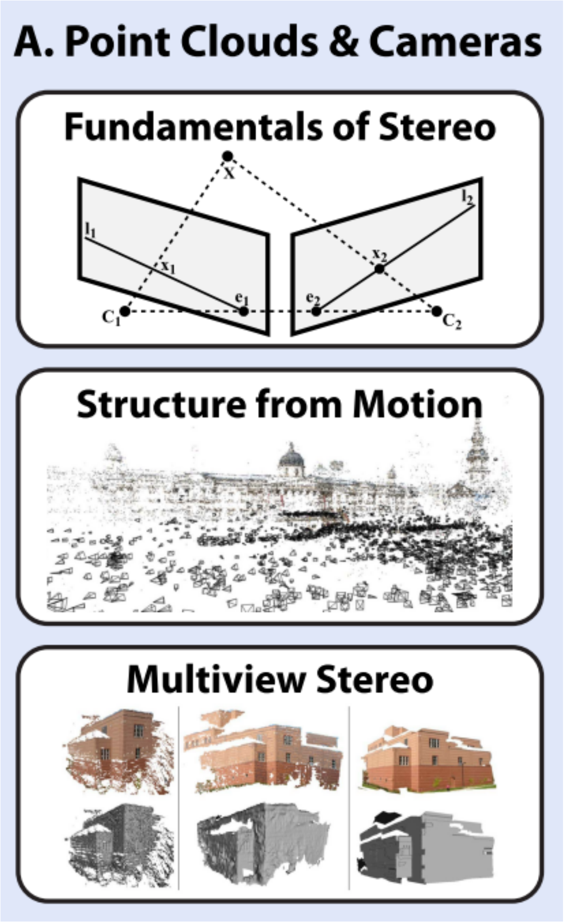
- **Solution: Planar Priors**
  - Manhattan World Priors
    - Furukawa et al. [FCSS09]
  - Piece-Wise Planar Priors
    - Micusic and Kosecka [MK09,MK10]
    - Sinha et al. [SSS09]
    - Chauve et al. [CLP10]
    - Gallup et al. [GLP10]



[VvG06] [FP07] [MK10]

A. Point-Clouds and Cameras

- **Summary**
  - Sparse MVS and SfM are mature and robust
  - Dense MVS deliver also quite impressive results
  - Systems are very generic – not only urban reconstruction
  - Scale well as shown by Frahm et al. [FFGG10]:
    - 3 million images on one day on a single PC
  - Downside: results are usually dense meshes, not segmented and semantic objects



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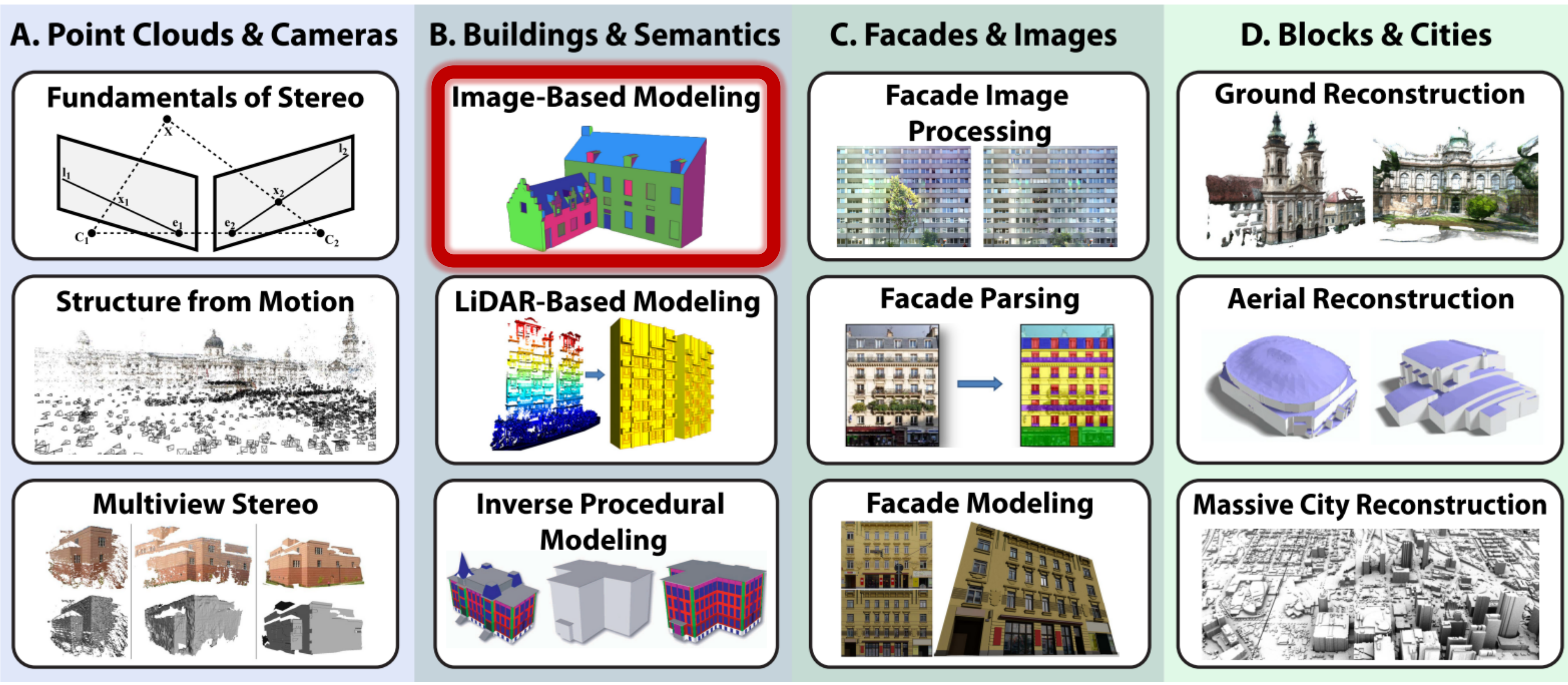
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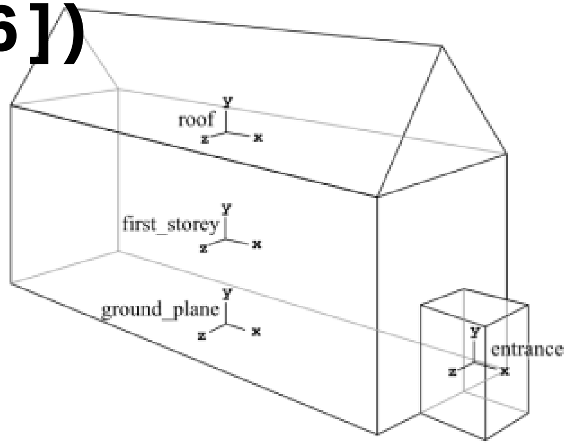
B.1 Image-Based Modeling (IBM)

- Also referred to as ***Photogrammetric Modeling***

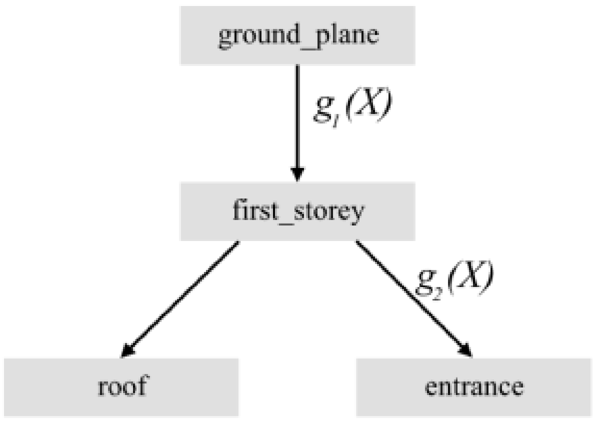
- **Subcategories**
  - Interactive Multiview Modeling
  - Automatic Multiview Modeling
  - Interactive Singleview Modeling
  - Automatic Singleview Modeling

B.1 Image-Based Modeling (IBM)

- **Façade (Debevec et al. [DTM96])**
  - Primitive polyhedral elements
  - Parallel and Orthogonal
  - Constrained to each other to reduce the parameter space



- **Good layer of abstraction**
  - Low-level features are difficult to deal with
  - Surface model is implicit



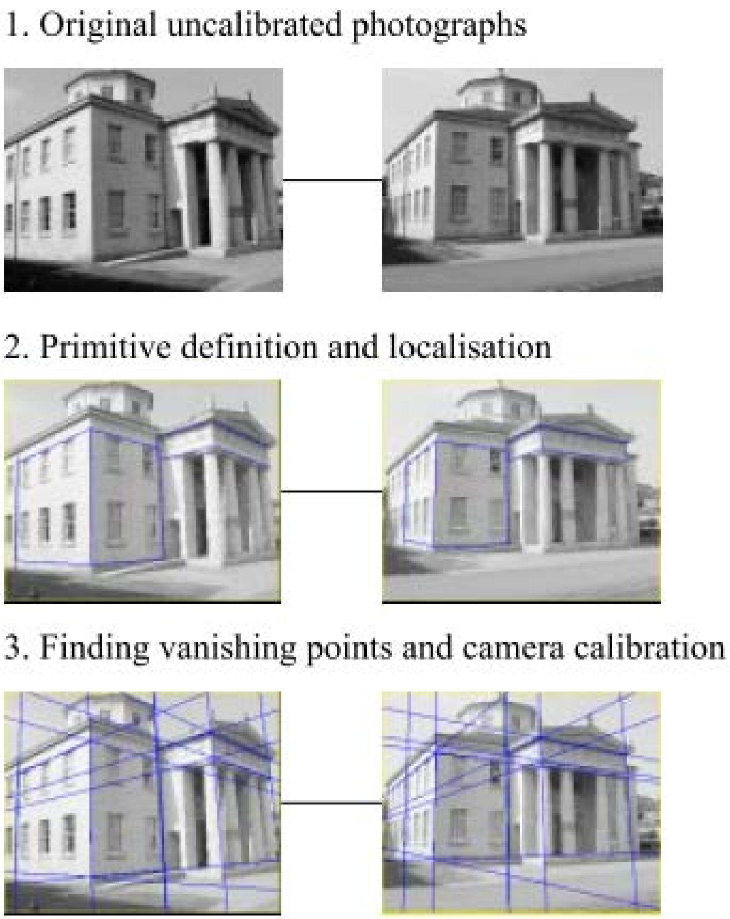
B.1 Image-Based Modeling (IBM)

- **Façade Modeling Process [DTM96]**
  - Multiview Input
  - Automatic edge detection in images
  - User establishes corresponding edges in images interactively
  - System optimizes in background (non-realtime)

- **Iterative modeling process**
- **Finally projective texturing from input images**

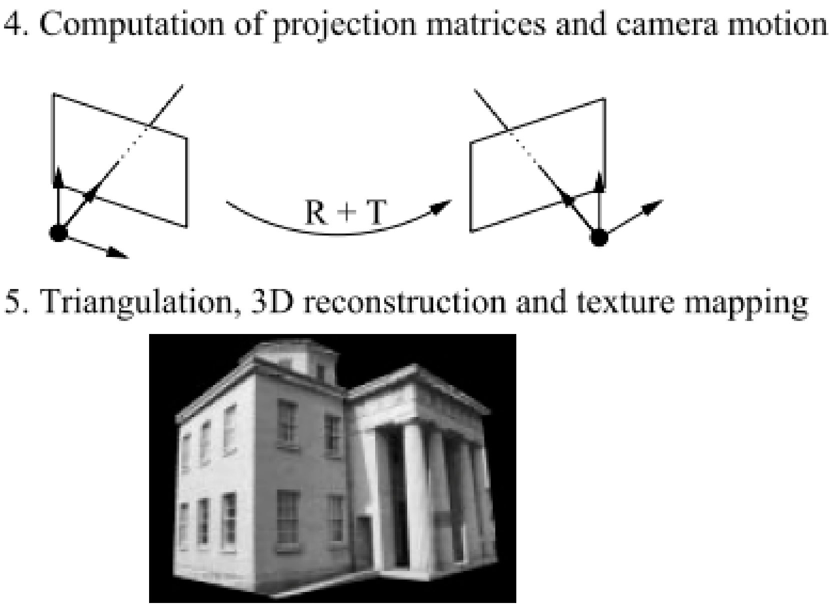
B.1 Image-Based Modeling (IBM)

- **Photobuilder:**
  - Cipolla and Robertson [CR99,CRB99]
  - Automatic edge detection
  - User interactively labels a few parallel and orthogonal edges
  - Camera parameters can be determined
  -



B.1 Image-Based Modeling (IBM)

- **Photobuilder:**
  - Cipolla and Robertson [CR99,CRB99]
  - Automatic edge detection
  - User interactively labels a few parallel and orthogonal edges
  - Camera parameters can be determined
  - System computed this model



B.1 Image-Based Modeling (IBM)

- **Interactive Modeling from Video (VideoTrace)**
  - Van den Hengel et al. [vdHDT*06, vdHDT*07]

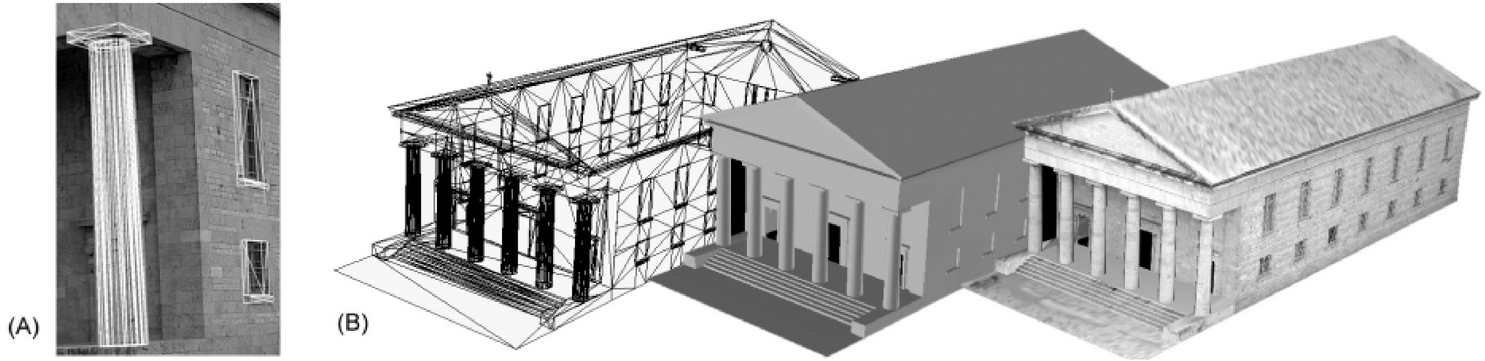
  - Camera and point-cloud network from SFM as input
  - Hierarchy of primitive shapes as model
  - User-input to establish relations
  - Automatic optimization in background (near-realtime)

B.1 Image-Based Modeling (IBM)

- **Interactive Multiview Modeling from Unordered Sets of Photographs**
  - Sinha et al. [SSS*08]
  - Image-Network as input
  - Automatic detection of vanishing points
  - Simple interactions like rough sketching
  - Realtime interactive optimization in background

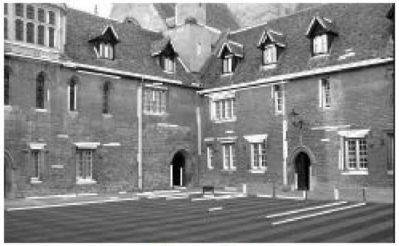
B.1 Image-Based Modeling (IBM)

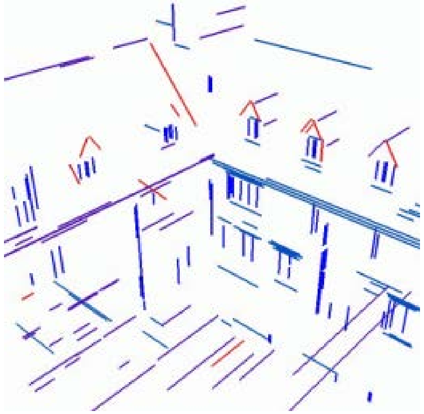
- **Further methods and improvements**
  - Combination of ground and aerial imagery
    - Lee et al. [LHN00, LJN02, LN03,...]
  - Database with reusable elements
    - El-Hakim et al. [EhWGG05,EhWG05]
  - Automatically snapping polygons
    - Arikan et al [ASW*12]



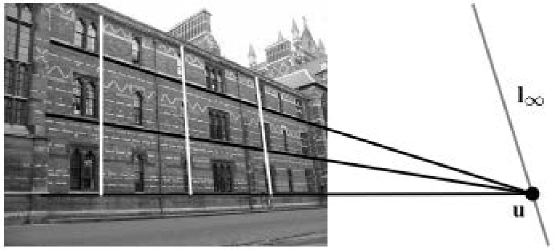
B.1 Image-Based Modeling (IBM)

- **Automatic Multiview Modeling**
  - Buildings are well suited due to parallelism and orthogonality
  - Line features, contours and vanishing points can be found automatically
  - Using least-squares and robust estimation (RANSAC) planes can be fitted



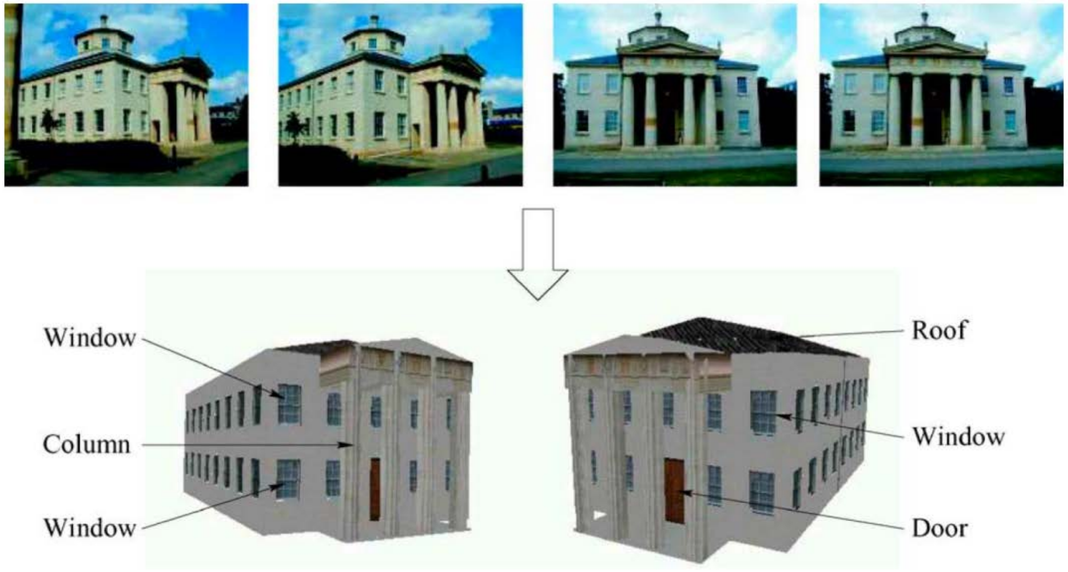


- **Automation of the Interactive Modeling Approach**
  - Libowitz and Zisserman [LZ99]
  - Coorg and Teller [CT99]
  - Werner and Zisserman [WZ02]



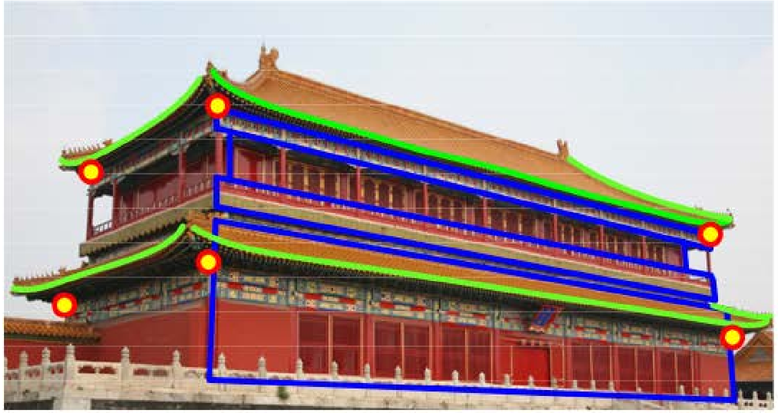
B.1 Image-Based Modeling (IBM)

- **Automatic Multiview Modeling**
  - Dick et al. [DTC00,DCT04]
  - Probabilistic model with predefined prior distributions
  - Parameters fitted from a set of images using MCMC
  - Semantically annotated objects



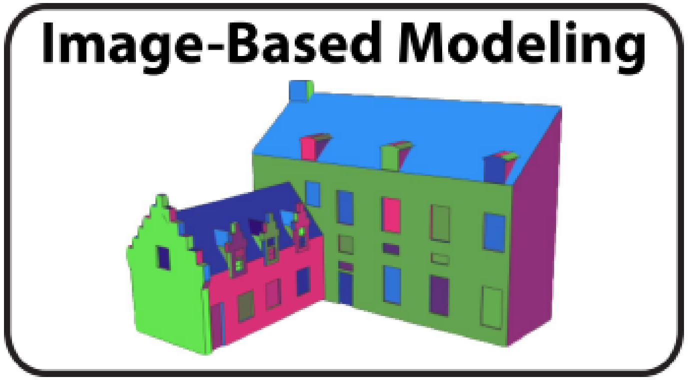
B.1 Image-Based Modeling (IBM)

- **Single Image Interactive Modeling**
    - Utilize the symmetry of the building to reconstruct 3d structure
      Jiang et al. 2009 [JTC09]
    - Interactively determine a frustum
    - Determine camera pose (calibration)
    - Use mirror-symmetry for stereo-reconstruction

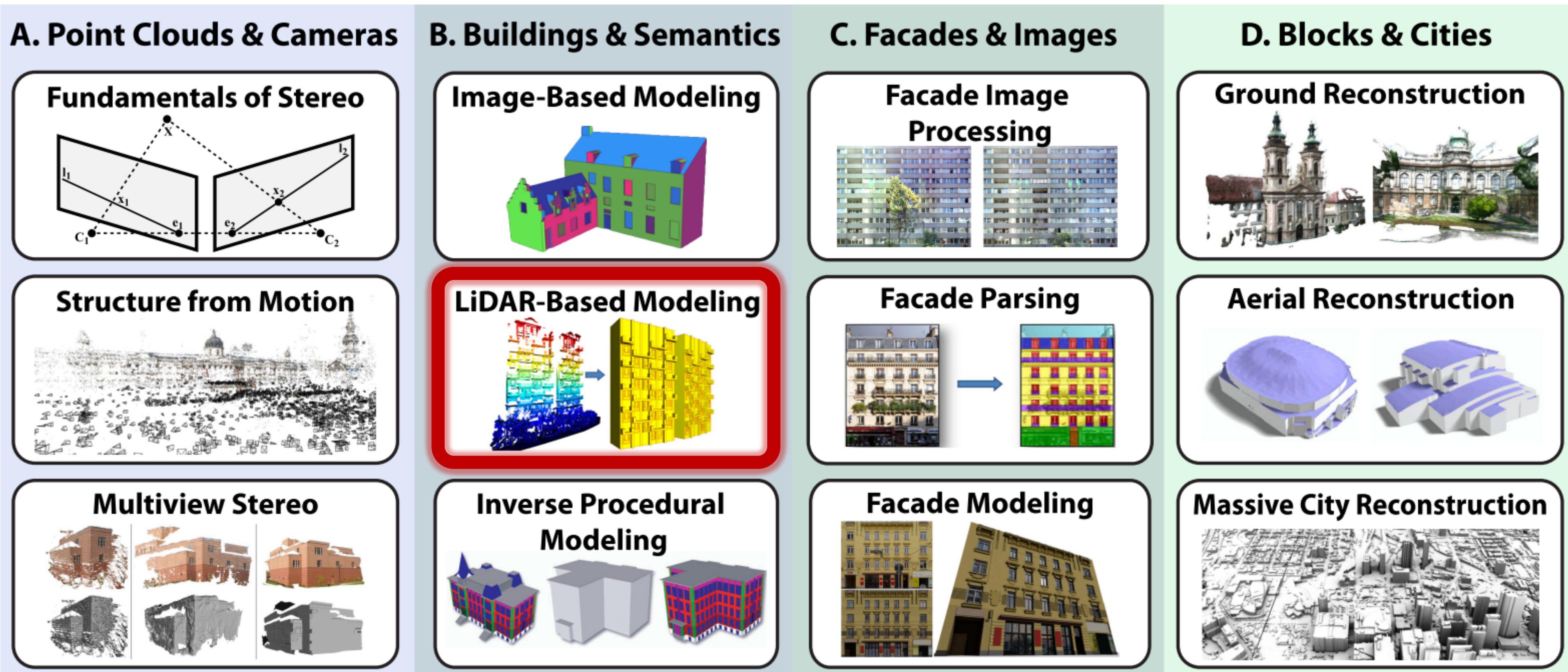


B.1 Image-Based Modeling (IBM)

- **Summary**
  - There is a large number of approaches
  - Some methods attempt automatic solutions
  - Nonetheless, the quality of fully-automatic systems is still below expected production standards
  - Due to the demand of high-quality models, interactive/semi-manual modeling is still interesting



Overview


A. Point Clouds & Cameras
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Structure from Motion
Multiview Stereo
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LiDAR-Based Modeling
Inverse Procedural Modeling
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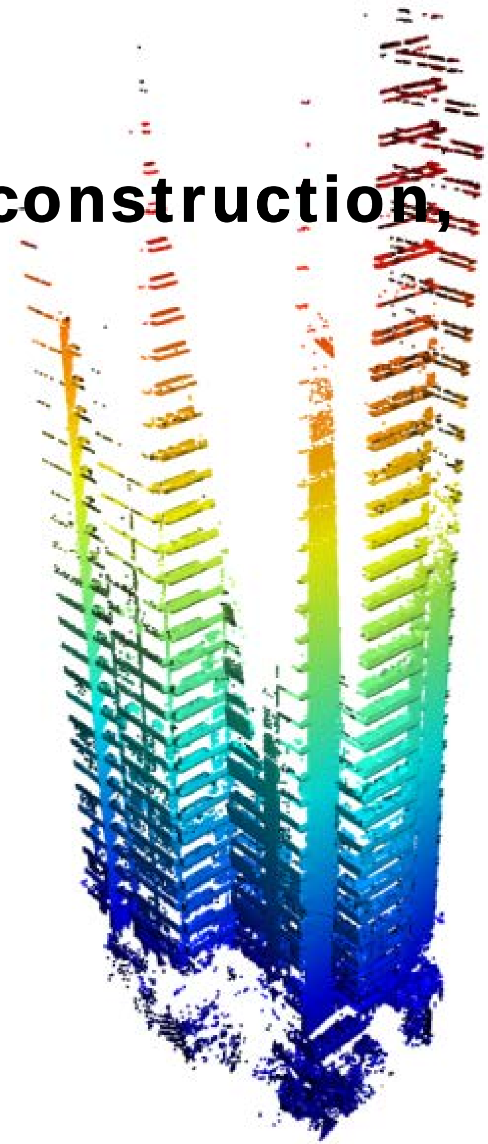
Ground Reconstruction
Aerial Reconstruction
Massive City Reconstruction

B.2 LiDAR-Based Modeling

- **LiDAR (Light Detection and Ranging)**
- **scans are well suited for reconstruction, but**
- **Problems:**
  - Point cloud contains holes due to occlusions

  - Especially in ground-based LiDAR

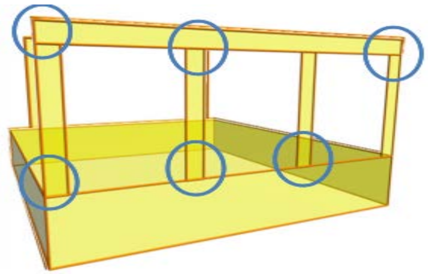
B.2 LiDAR-Based Modeling

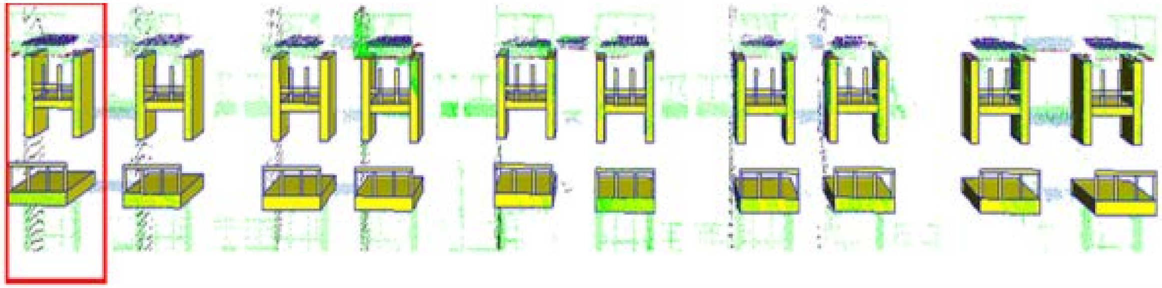


- **LiDAR scans are well suited for reconstruction, but**
- **Problems:**
  - Oblique scanning angles
  - Laser energy attenuation on range
  - Especially in ground-based LiDAR

B.2 LiDAR-Based Modeling

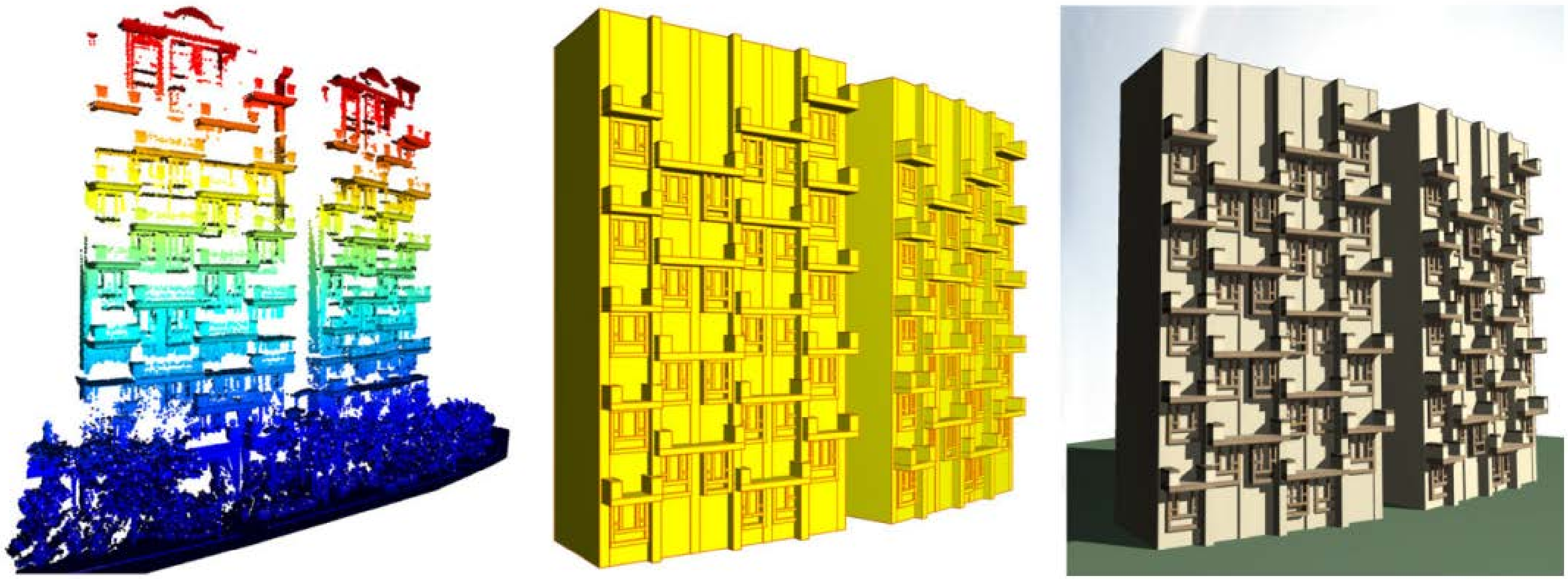
- **Interactive Modeling from LiDAR (SmartBoxes)**
  - Nan et al. [NSZ*10]
  - User assembles small sets of “boxes” from primitive shapes
  - These are automatically fitted to the point cloud minimizing a sum of two energies:
    - Data: how well does each box fit to the local point cloud
    - Context: how well are the boxes synchronized





B.2 LiDAR-Based Modeling

- **Interactive Modeling from LiDAR (SmartBoxes)**
  - Nan et al. [NSZ*10]

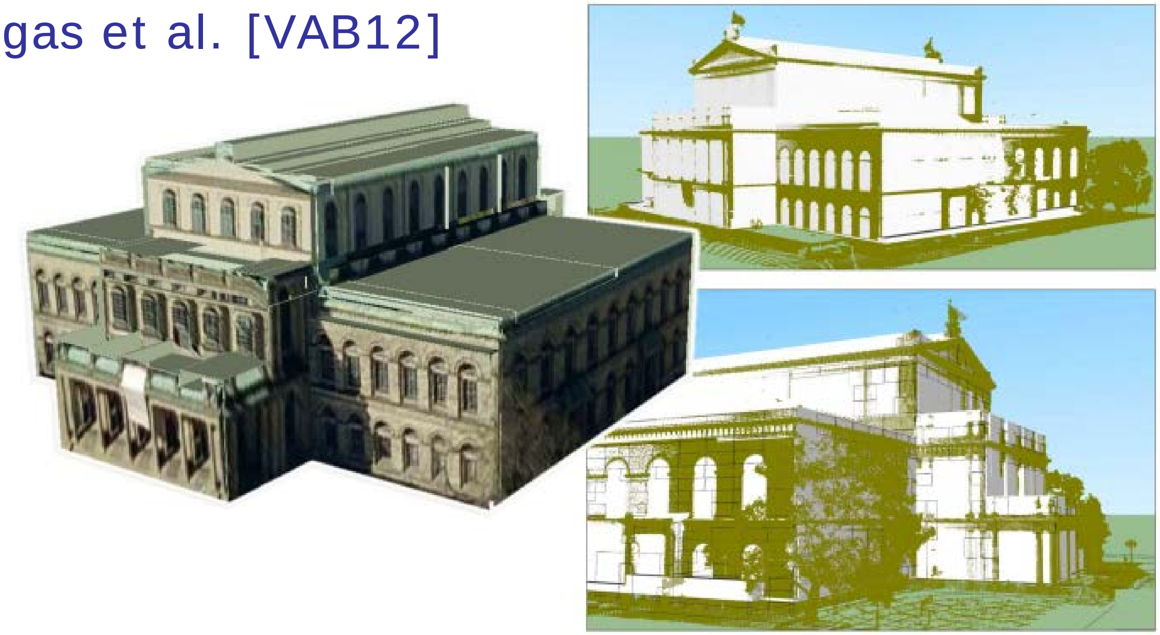


B.2 LiDAR-Based Modeling

- **Automatic Modeling from terrestrial LiDAR**
  - Scans of buildings are well suited for automatic reconstruction
    - Stamos and Allen [SA00,SA02]
    - Früh and Zakhor [FZ03,FZ04]
    - Pu and Vosselman [PV09]
    - Vanegas et al. [VAB12]
    - and more
  - Segmentation into planar regions
    - Clustering of Normals
  - Plane Fitting
    - RANSAC
    - Least-Squares
  - Fitting of Outline Polygons

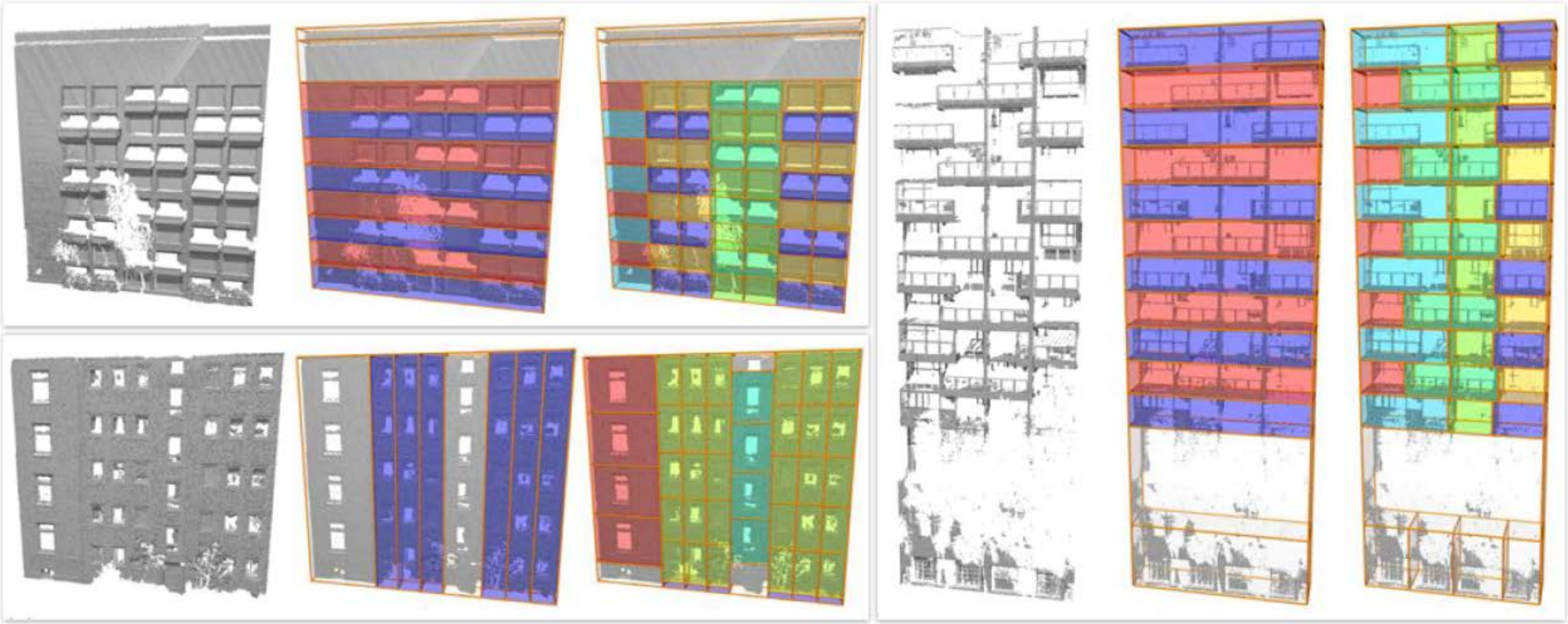
B.2 LiDAR-Based Modeling

- **Automatic Model Fitting**
  - Manhattan-World assumption in order to improve the robustness of the fit
    - Vanegas et al. [VAB12]



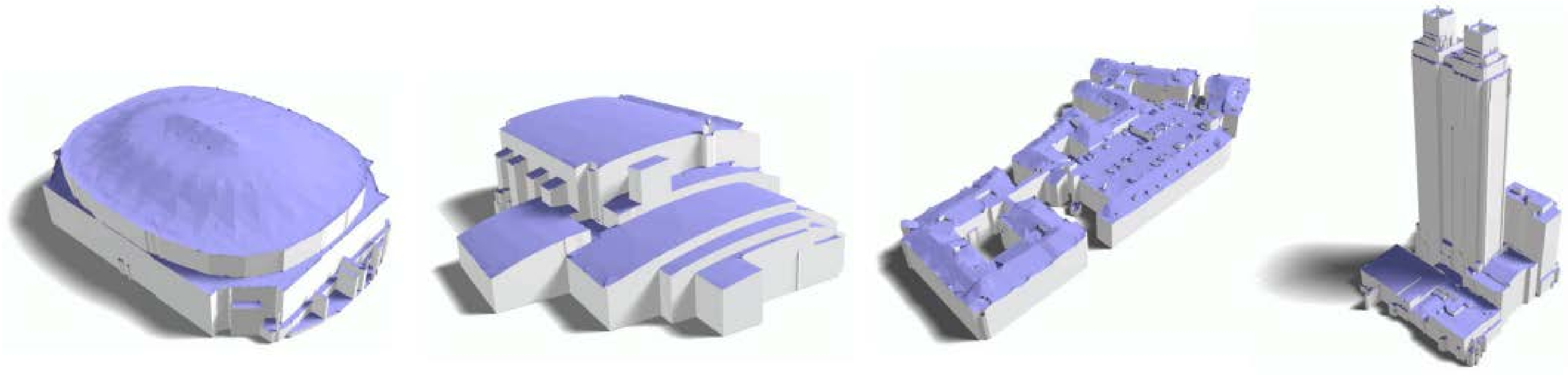
B.2 LiDAR-Based Modeling

- **Automatic Segmentation of LiDAR**
  - Recursive Heuristic Splitting using Symmetry
    - Shen et al. [SHFA11]



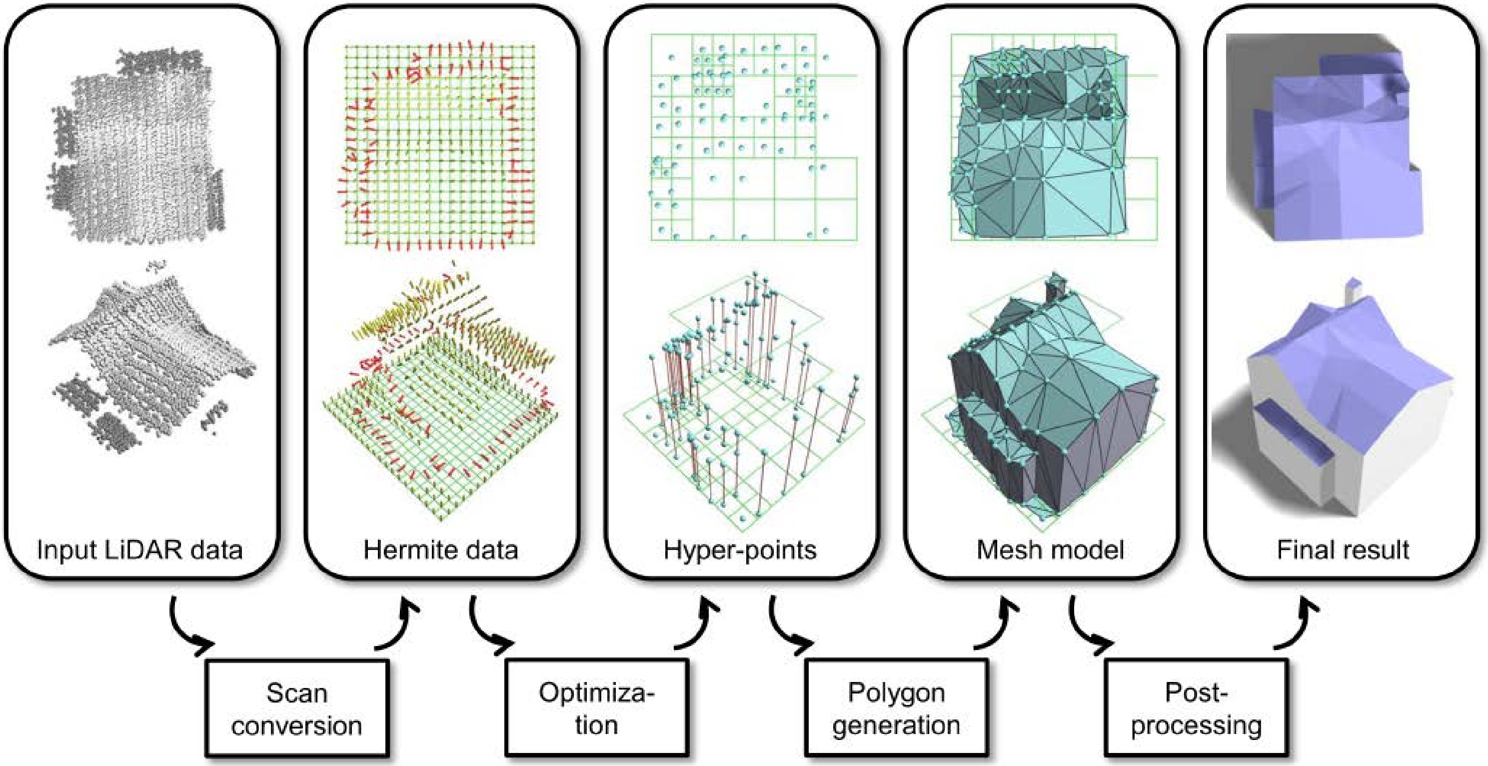
B.2 LiDAR-Based Modeling

- **Automatic Modeling from aerial LiDAR**
  - 2.5D dual contouring (Zhou and Neumann [ZN08,ZN10])
  - Detailed results



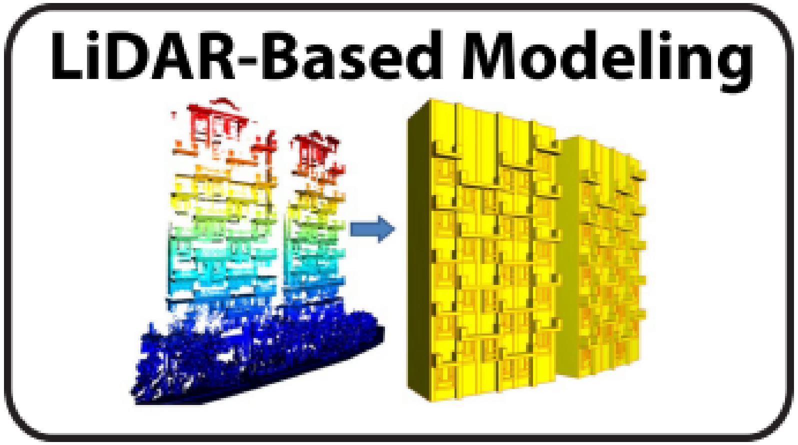
B.2 LiDAR-Based Modeling

- **Automatic Modeling from aerial LiDAR**
  - 2.5D dual contouring (Zhou and Neumann [ZN08,ZN10])

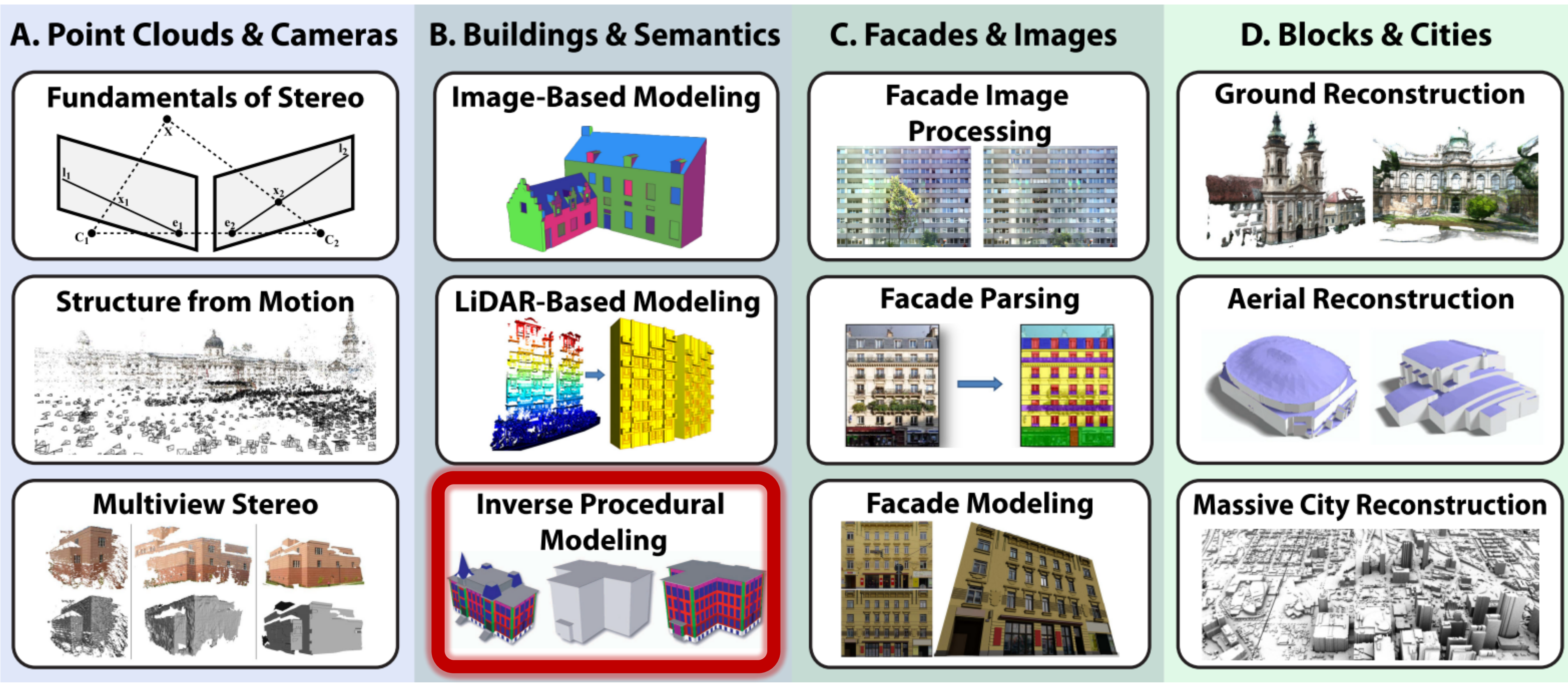


B.2 LiDAR-Based Modeling

- **Summary**
  - LiDAR is accessible for quite a while
  - Top-down fitting of buildings into the data delivers good results
  - The full potential of LiDAR-driven reconstruction is still not explored
  - More interesting methods are expected to appear in the near future



Overview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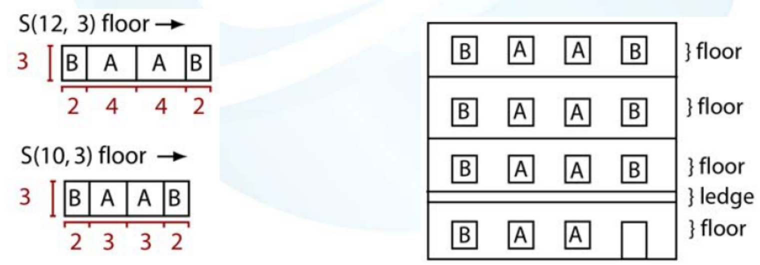
B.3 Inverse-Procedural Modeling (IPM)

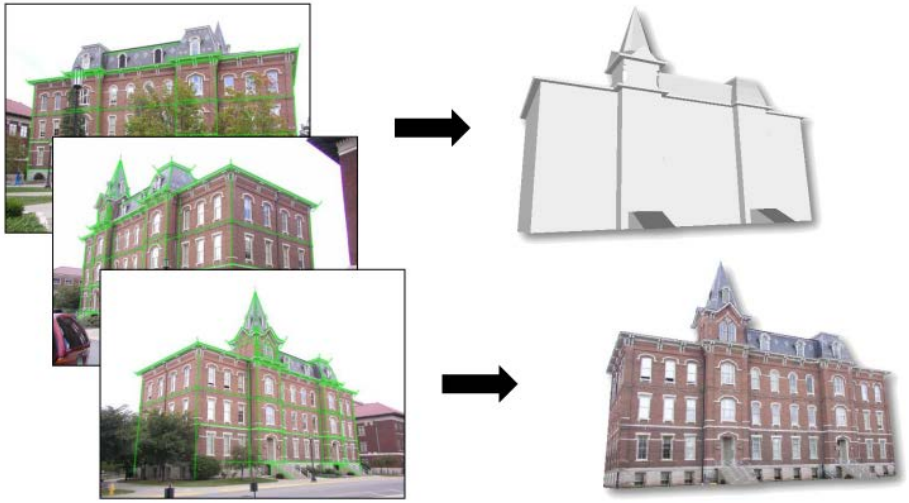
- **Rather novel approach**
  - Related to Procedural Modeling
  - Idea: derive a grammar from the structure
- **Infer from the input (Imagery or LiDAR)**
  - (1) A grammar
  - (2) Parameters of the grammar
  - Some methods predefine (1) and infer only (2)
- **Interactive and Automatic approaches**

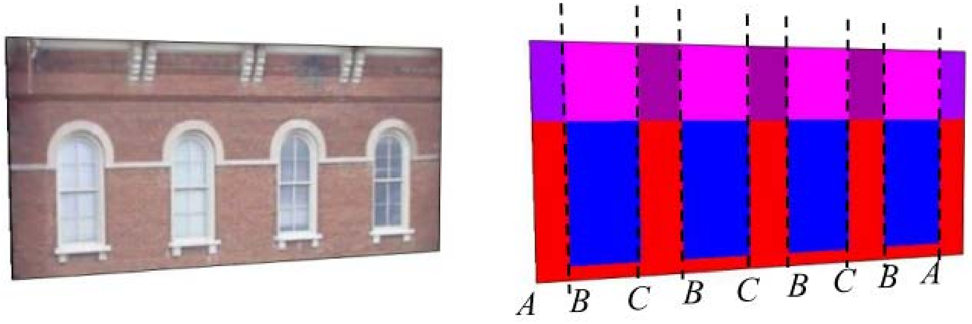
- *façade* → *Subdiv*("*Y*",3.5,0.3,*1r*,*1r*,*1r*) (*fl*1 | *ledge* | *fl*2 | *fl*2 | *fl*2 }



B.3 Inverse-Procedural Modeling (IPM)

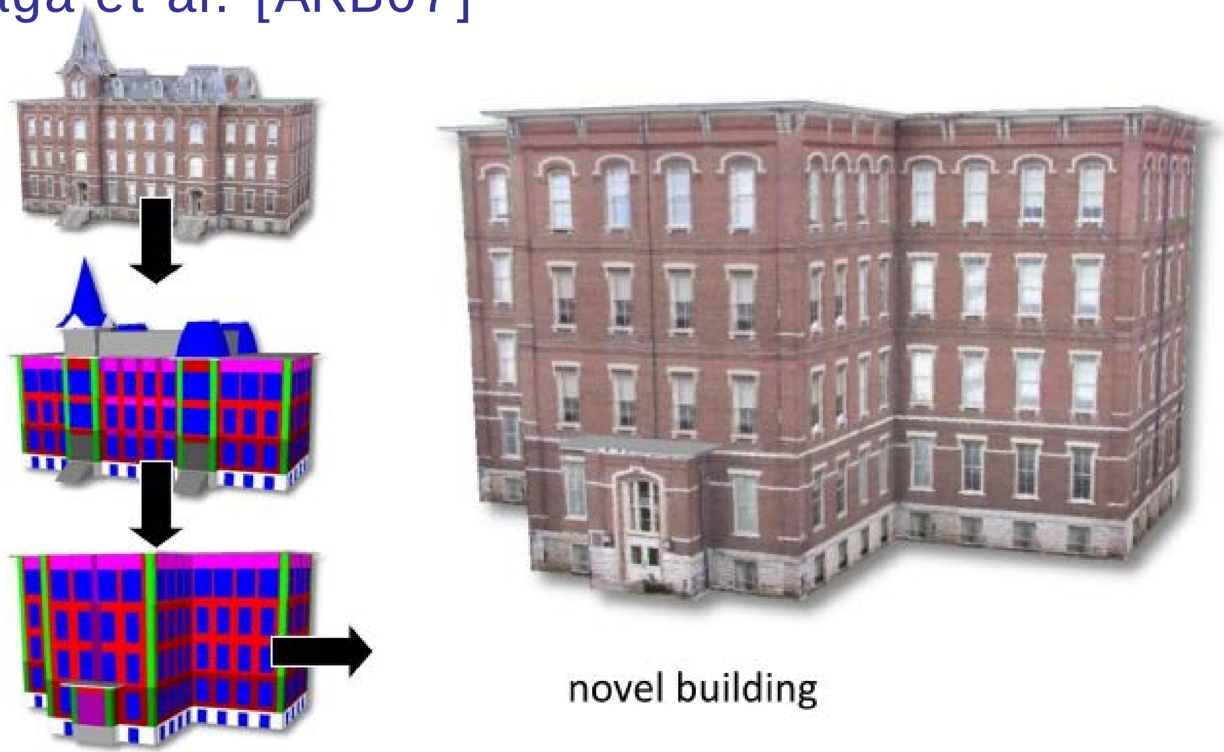
- **Interactive Systems**
  - Aliaga et al. [ARB07]
  - Model a geometric model interactively from a few photos
  - Segment the model interactively and assign grammar





B.3 Inverse-Procedural Modeling (IPM)

- **Interactive Systems**
  - Aliaga et al. [ARB07]



  - Use grammar to generate novel variations of the building

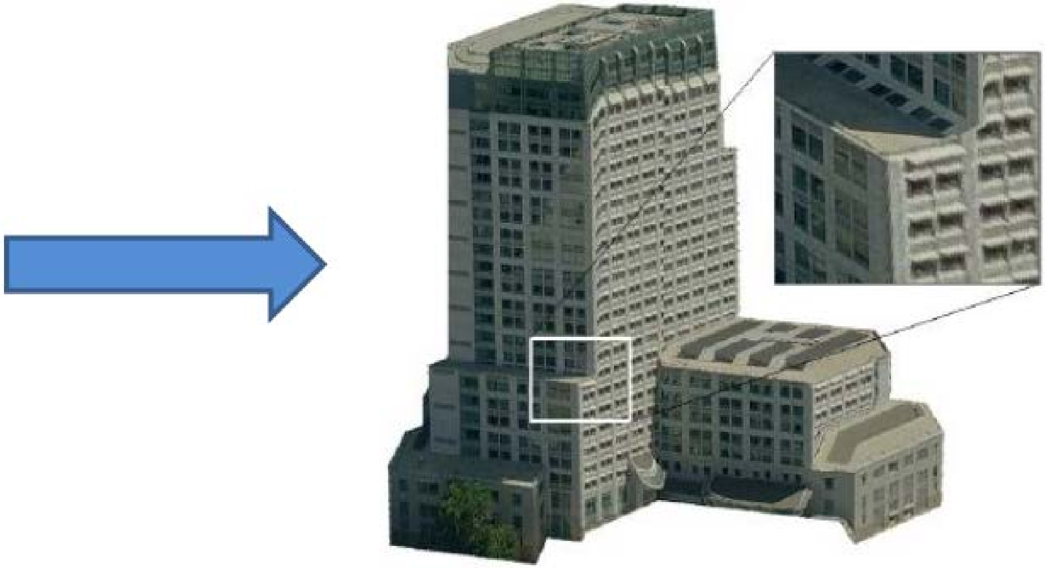
B.3 Inverse-Procedural Modeling (IPM)

- **Interactive Systems**
  - Aliaga et al. [ARB07]

  - Use grammar to generate novel variations of the building

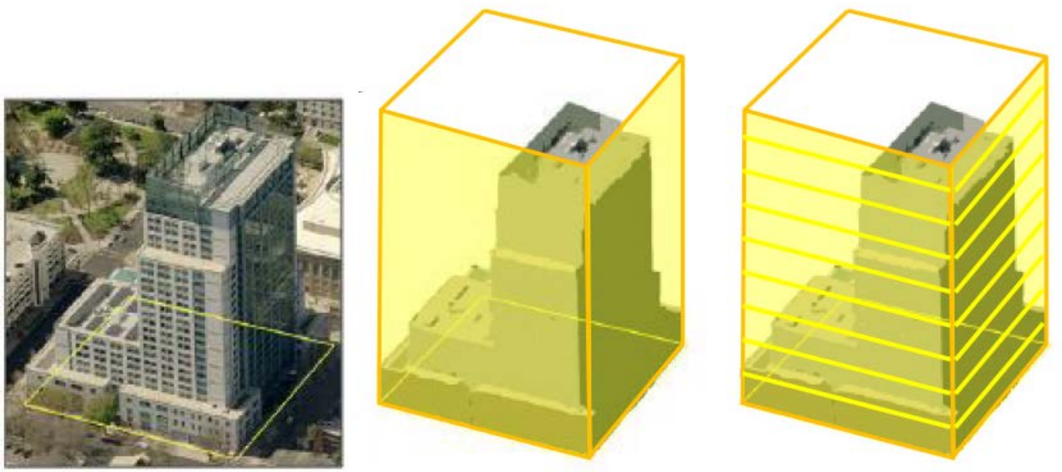
B.3 Inverse-Procedural Modeling (IPM)

- **Automatic Methods**
  - Simplification:
    predefine grammar and fit only the parameters
  - Vanegas et al. [VAB10]
  - Using aerial imagery and GIS-data



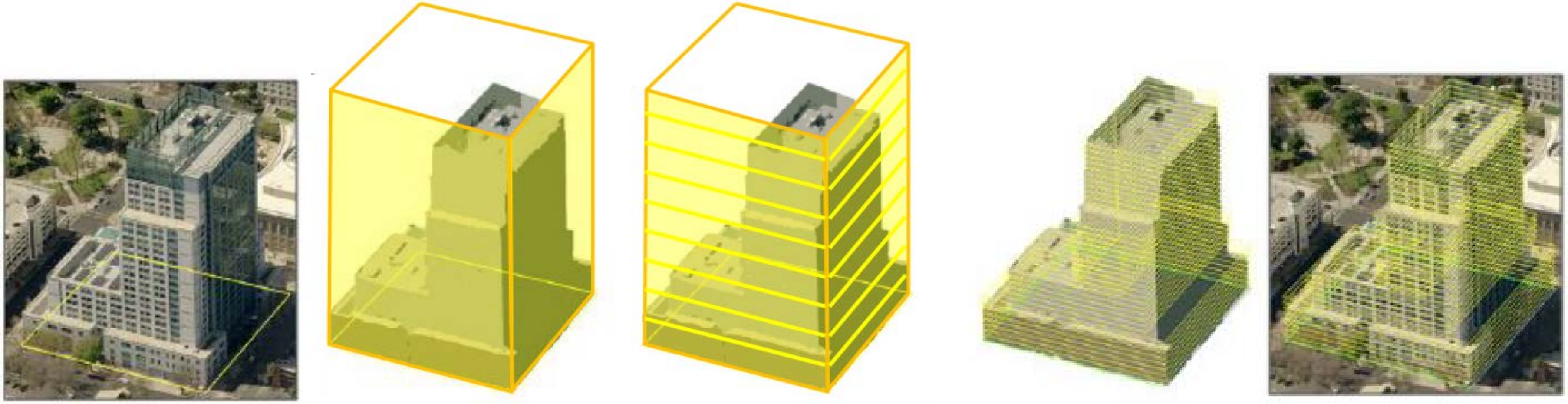
B.3 Inverse-Procedural Modeling (IPM)

- **Automatic Methods**
  - Generate initial 3D building envelope
    - Use the footprint from GIS and extrude
  - Divide the bounding box into floors



B.3 Inverse-Procedural Modeling (IPM)

- **Automatic Methods**
  - Generate initial 3D building envelope
    - Use the footprint from GIS and extrude
  - Divide the bounding box into floors
  - Adjust each floor automatically from the information from images and the constraints of the grammar



B.3 Inverse-Procedural Modeling (IPM)

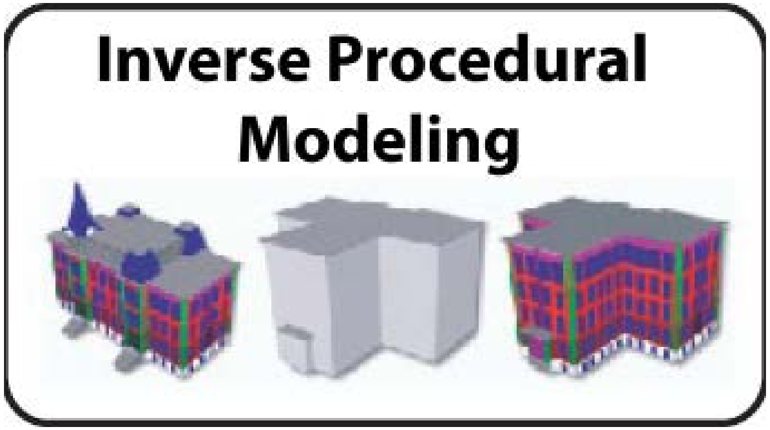
- **Further methods**
  - Use partial symmetry to derive shape grammars of 3D models
    - Bokeloh et al. [BWS10]

  - Generative Modeling Language (GML)
    - Havemann [Hav05]
    - Hohmann et al. [HKHF09,HHKF10]

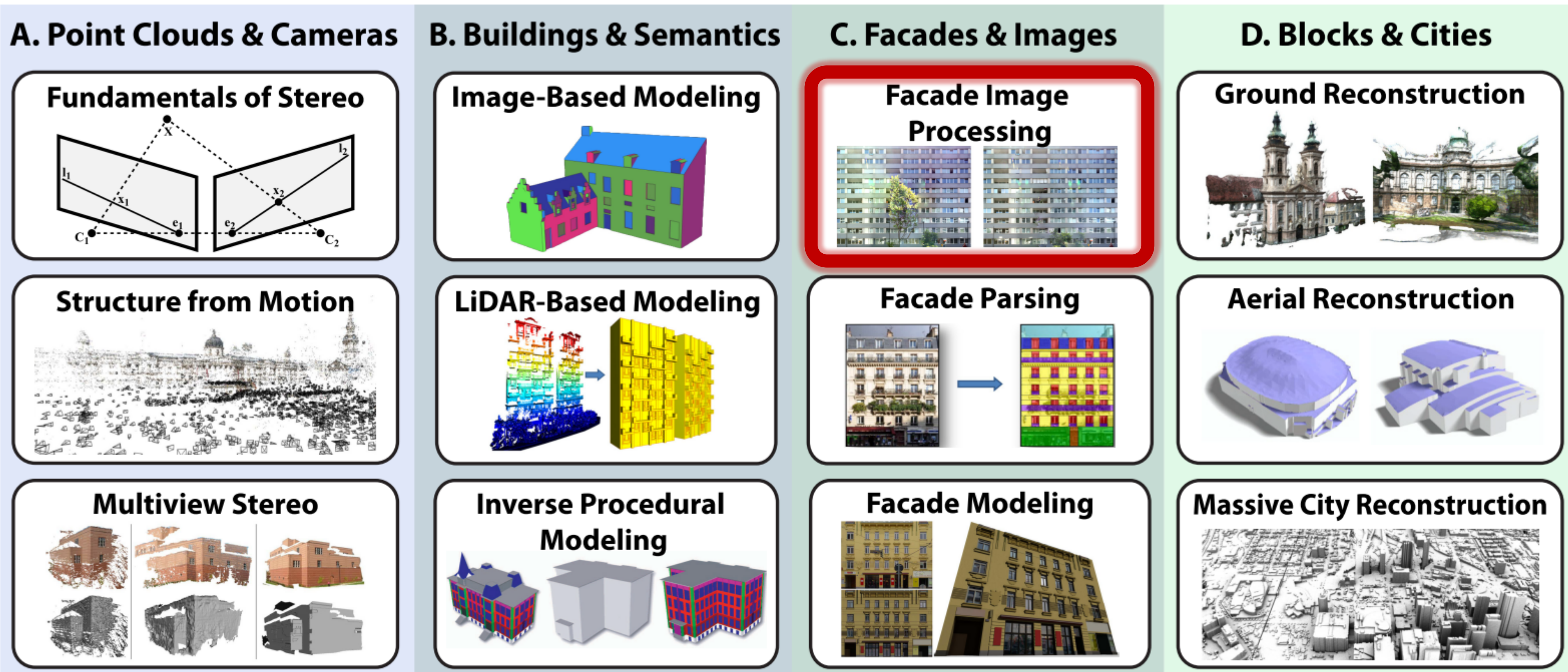
  - Façade Image Segmentation
    - Coming in the next section!

B.3 Inverse-Procedural Modeling (IPM)

- **Summary**
  - IPM is a quite new field
  - It enables a very compact description of the models
  - Very suitable for generation of content
  - Many further exciting papers to appear!



Overview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C.1 Façade Image Processing

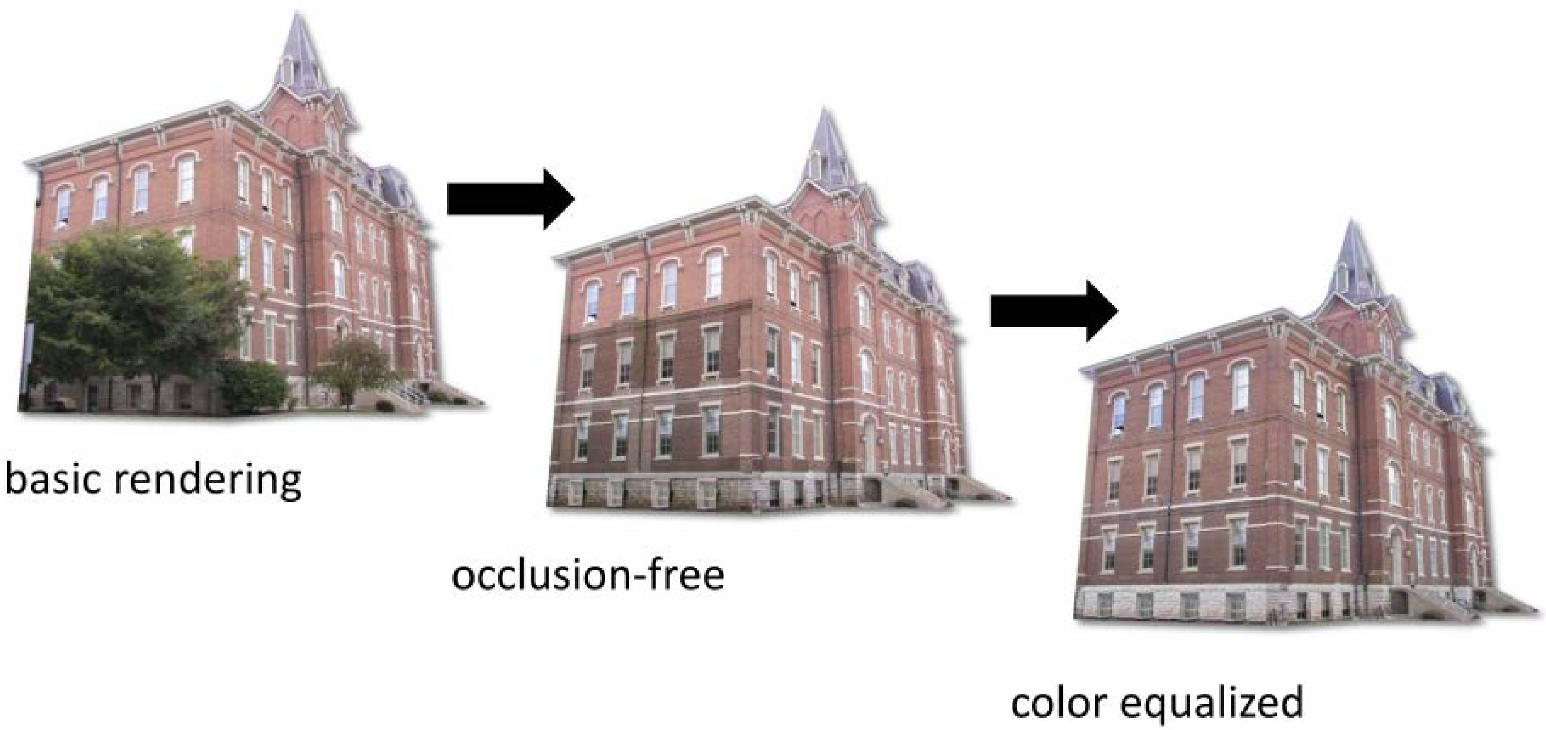
- **Imagery is essential in Urban Reconstruction**
  - For a realistic look
  - As source for reconstruction
- **Applications**
  - Panoramas
  - Projective Textures
  - Source for 3D structure

C.1 Façade Image Processing

- **Strip-Panoramas**
  - Agrawala et al. [AAC*06]

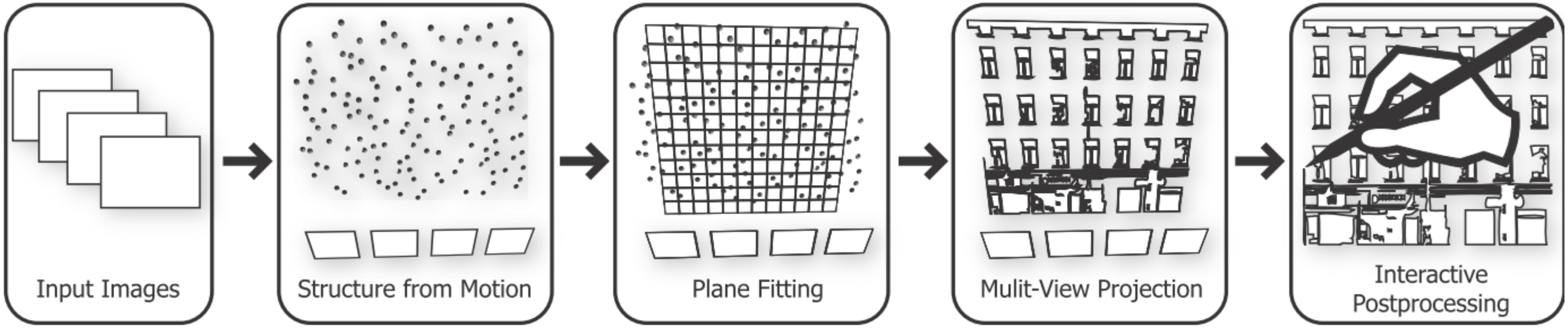
C.1 Façade Image Processing

- **Multiview Projective Texturing**
    - Aliaga et al. [*10]



C.1 Façade Image Processing

- **Multiview Projective Texturing**
  - Musialski et al. [MLS*10]



C.1 Façade Image Processing

- **Multiview Projective Texturing**
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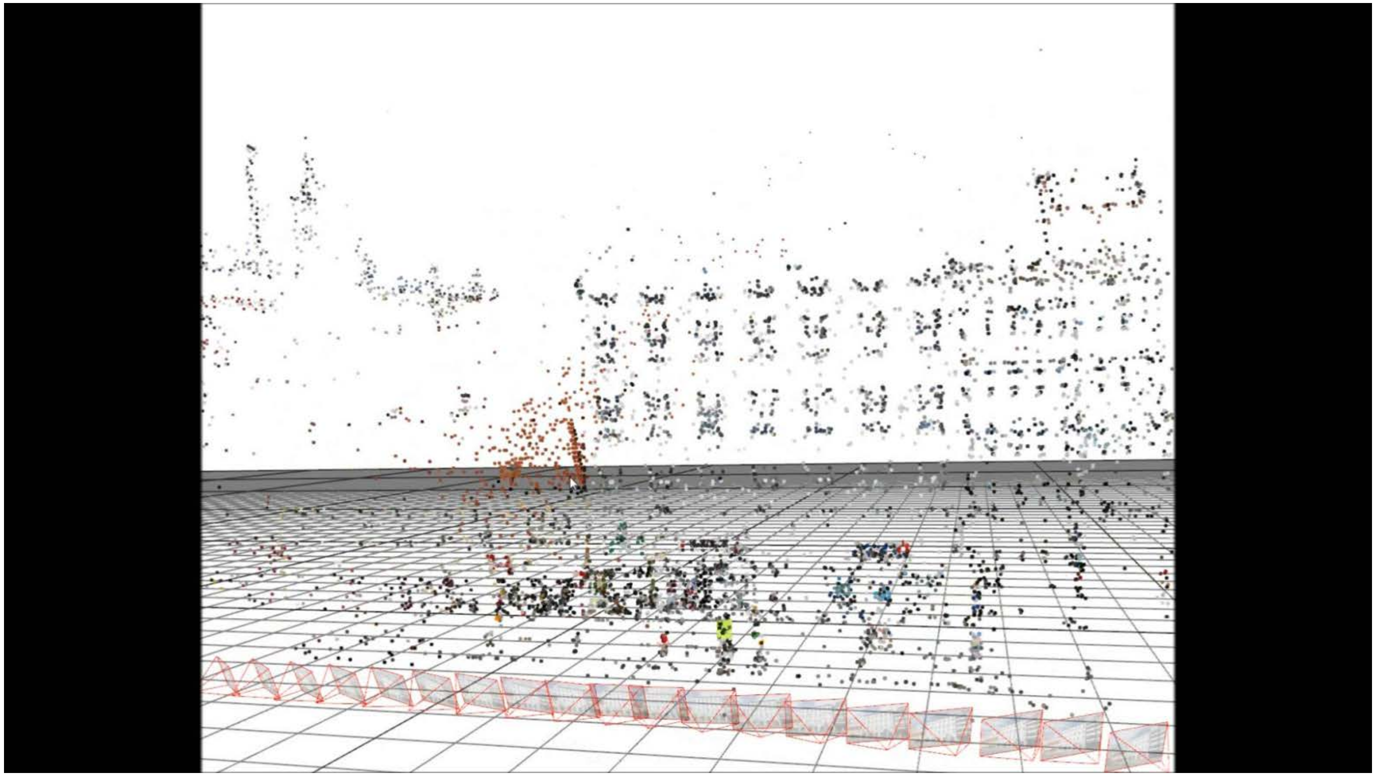
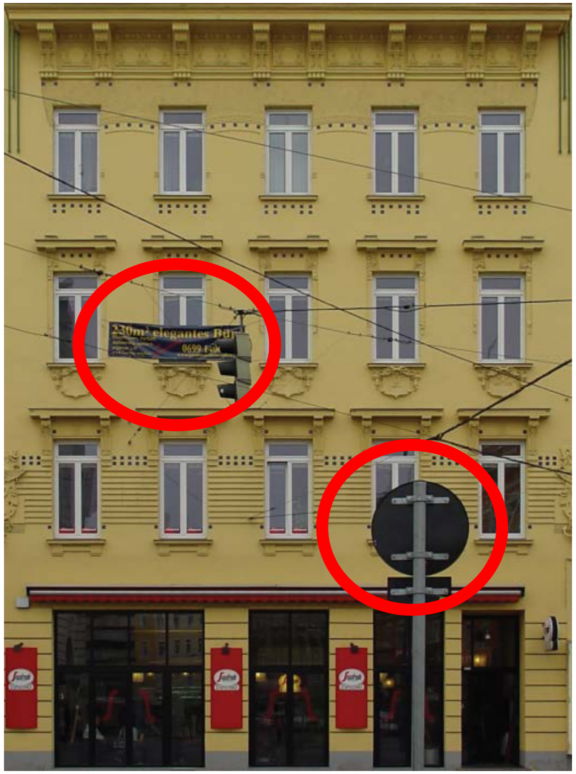


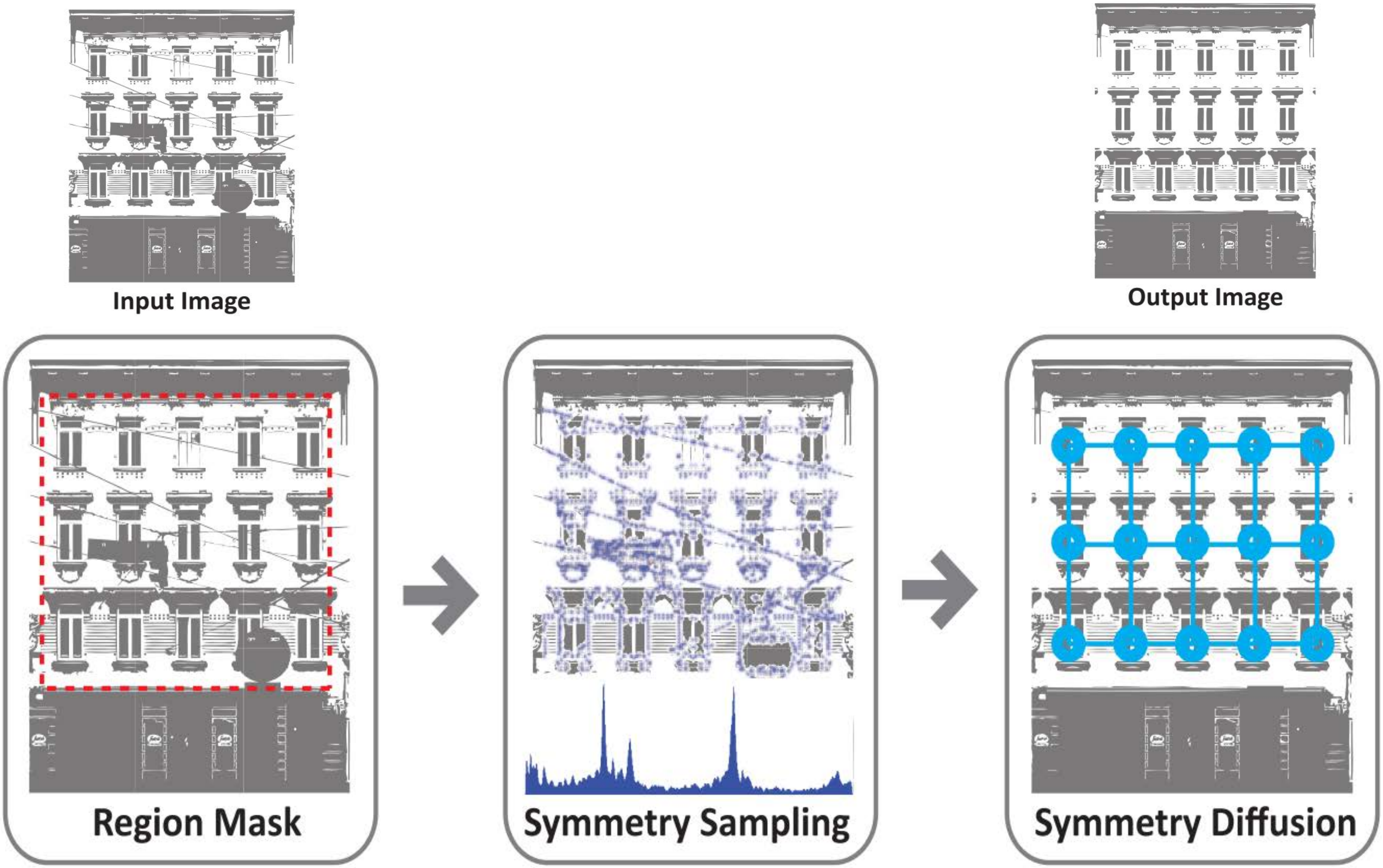
C.1 Façade Image Processing

- **Multiview Projective Texturing**
    - Musialski et al. [MLS*10]

C.1 Façade Image Processing

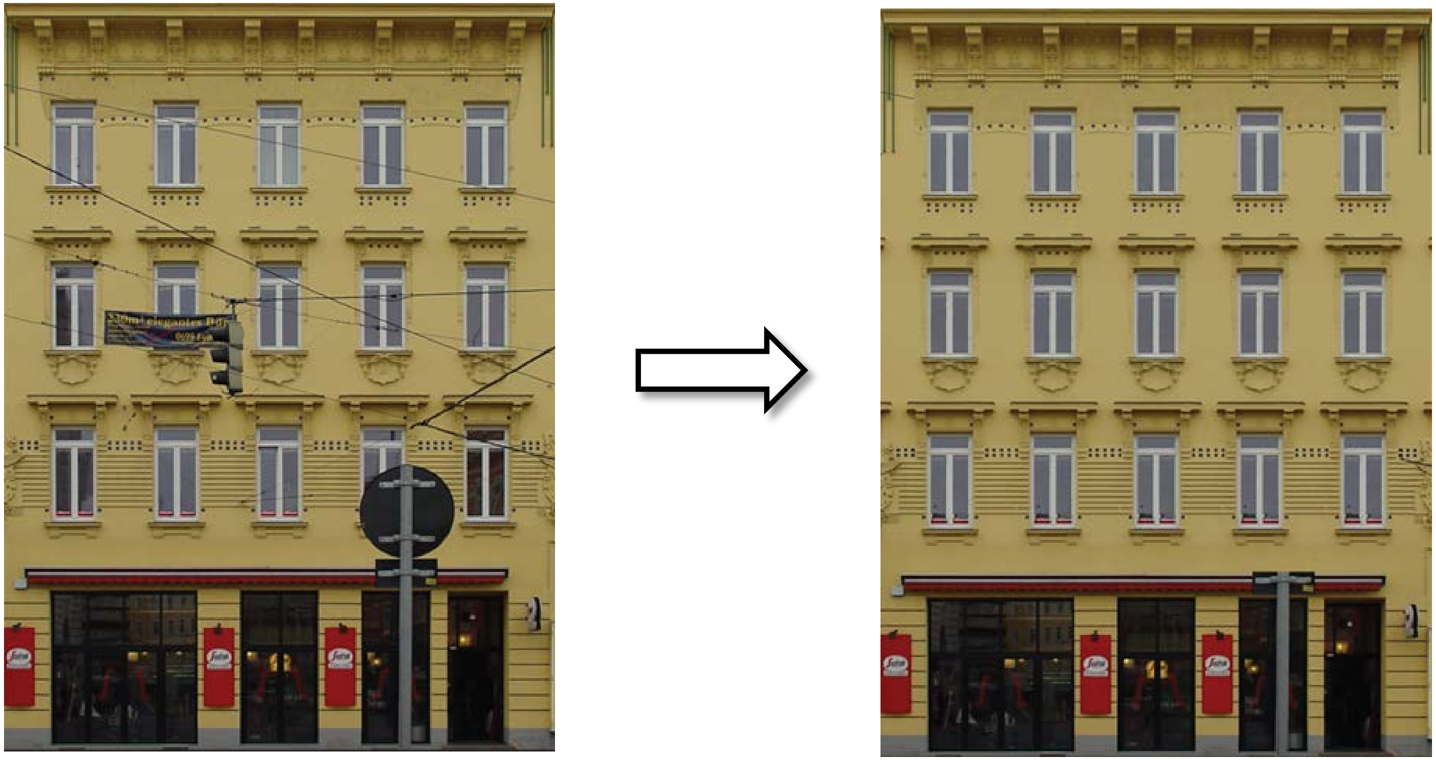
- **Symmetry-based façade image repair**
  - Musialski et al. [MWR*09]




Input Image
Output Image
Region Mask
Symmetry Sampling
Symmetry Diffusion

C.1 Façade Image Processing

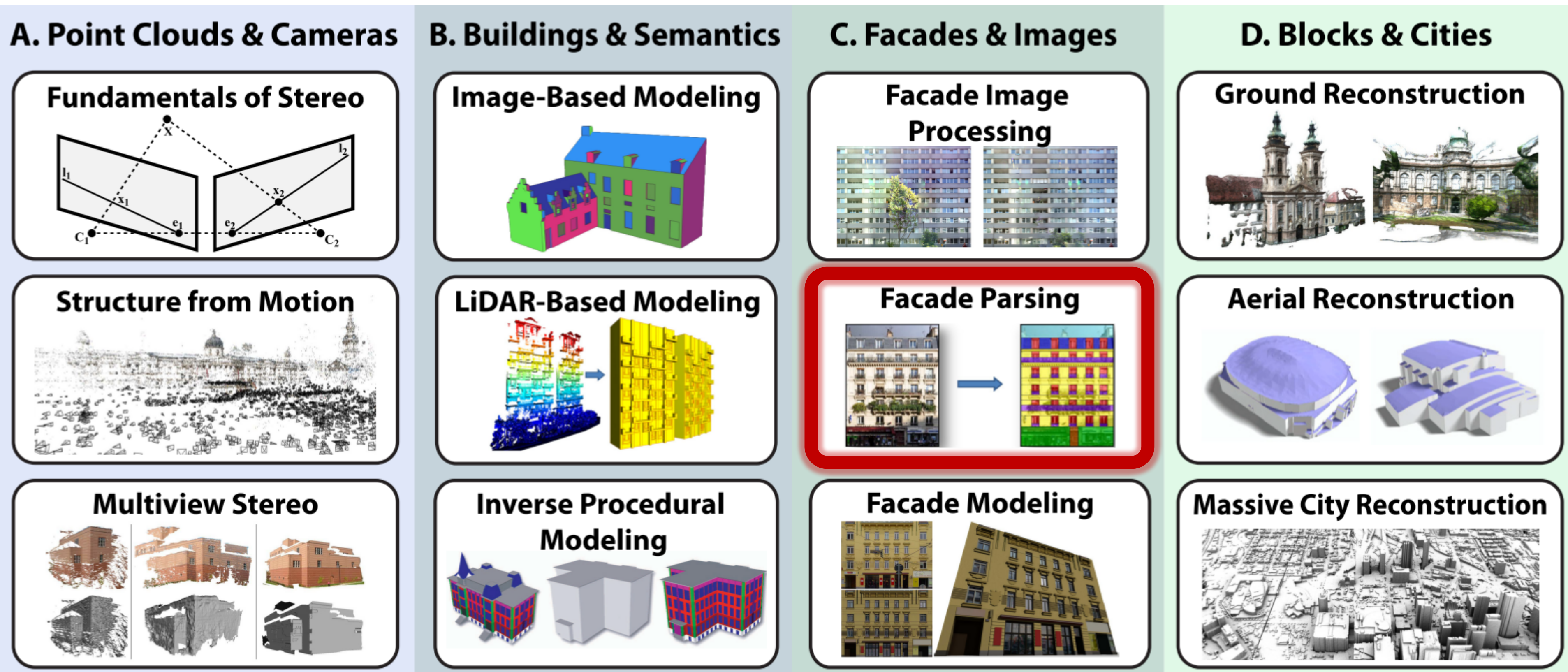
- **Symmetry-based façade image repair**



C.1 Façade Image Processing

- **Summary**
  - Panoramas are a kind of reconstruction by themselves
  - Processing of urban imagery is quite well researched
  - There are still challenges
    - Automatic segmentation
    - Parsing and semantic extraction

Overview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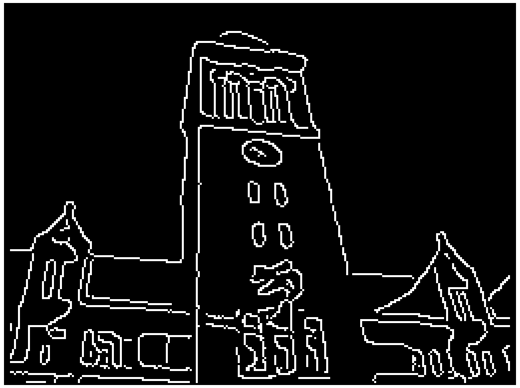
C.2 Façade Parsing

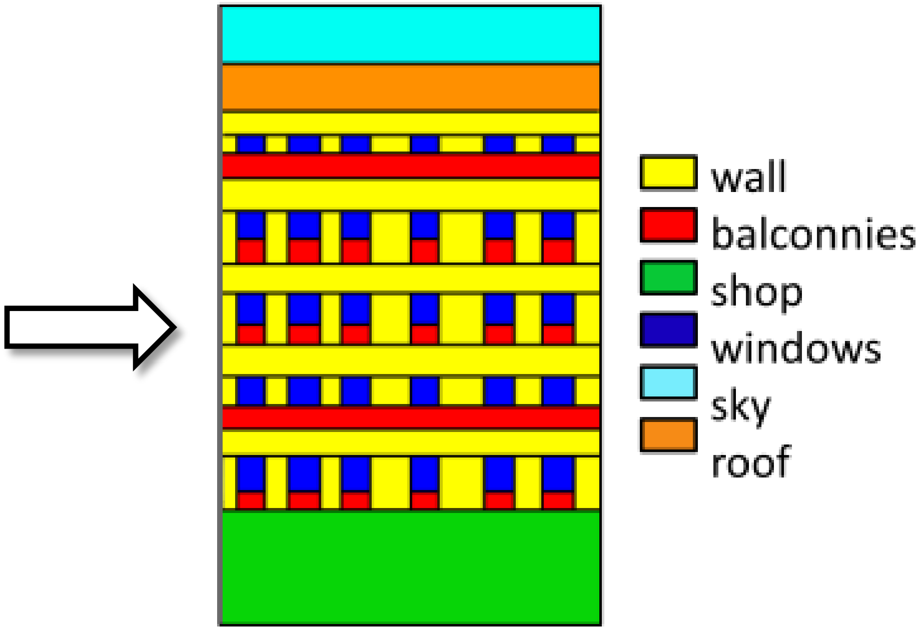
- **Façade parsing**
  - Automatic semantic segmentation façade data
    - Images or Laser Scans
  - Often use of higher-order models, like grammars

- **First step is low level processing**
  - Feature-, Edge-, Blob-Detection



C.2 Façade Parsing

- **Façade parsing**
  - Automatic semantic segmentation of façade data
    - Teboul et al. [TSKP10,TKS*11]



C.2 Façade Parsing

- **Façade parsing**
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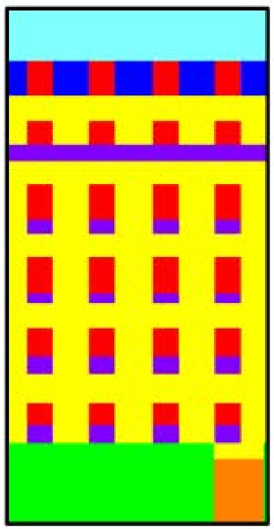
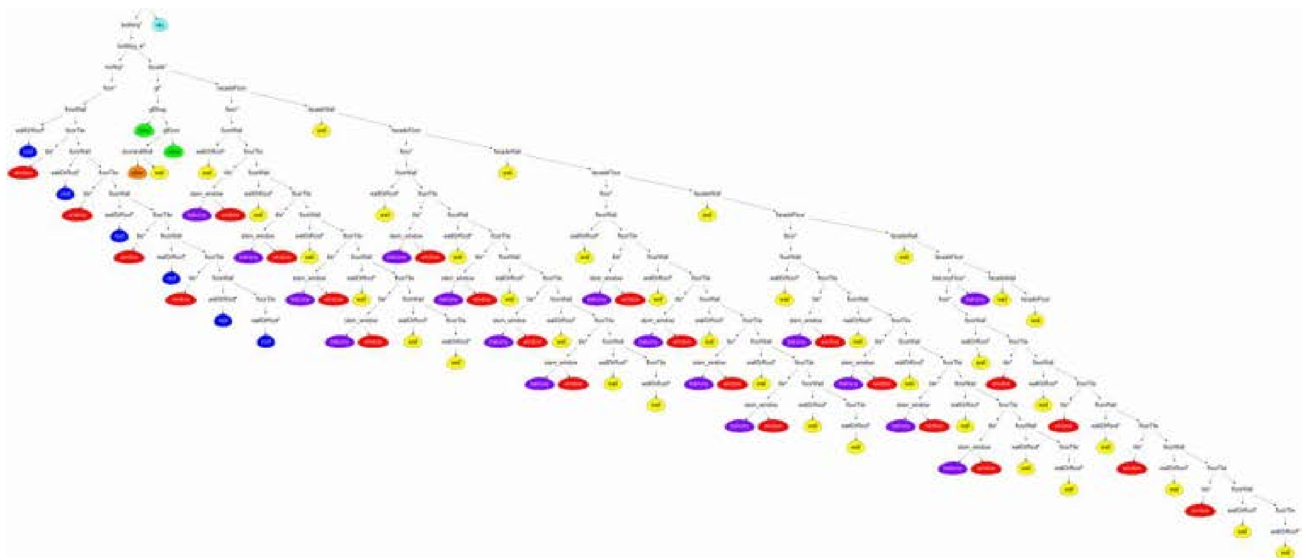
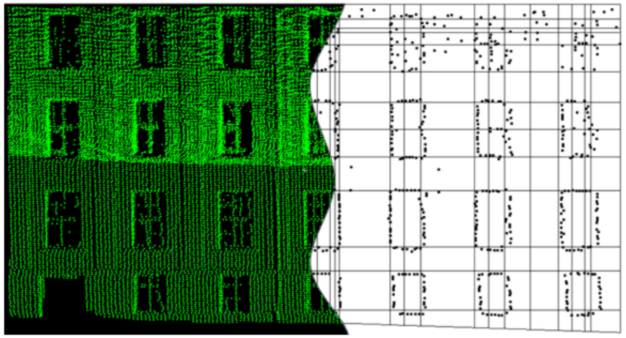




C.2 Façade Parsing

- **Further methods**
  - Predefined grammar based segmentations of images
    - Allegre and Dalleart [AD04]
  - Predefined grammar based segmentations of image and LiDAR
    - Brenner and Ripperda [BR06,RB07,RB09]
  - Inference of both grammar and parameters from LiDAR
    - Becker and Haala [BH07,NH09]



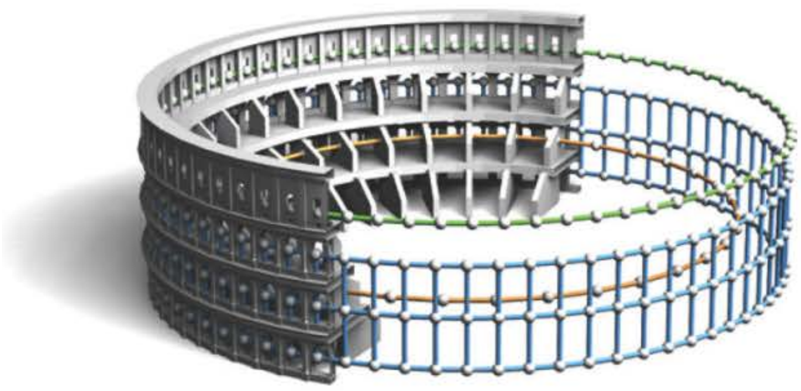
C.2 Façade Parsing

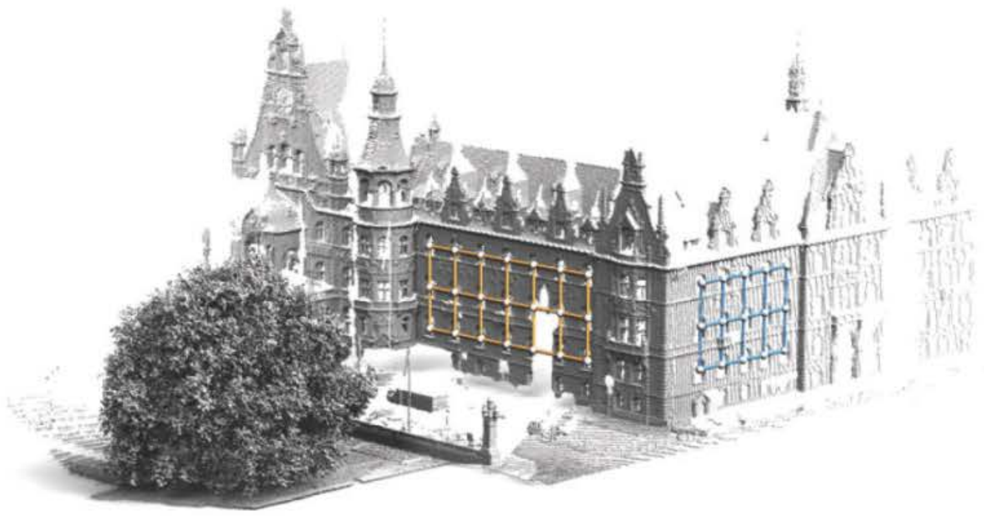
- **Symmetry Detection**
  - Another example of higher-order knowledge is symmetry
  - Number of methods detect symmetry in façades

  - In perspective images
    - Wu et al. [WFP10]
  - In ortho-rectified, occluded images
    - Musialski et al. [MRM*10]

C.2 Façade Parsing

- **Symmetry detection in point clouds**
  – Pauly et al. [PMW*08]

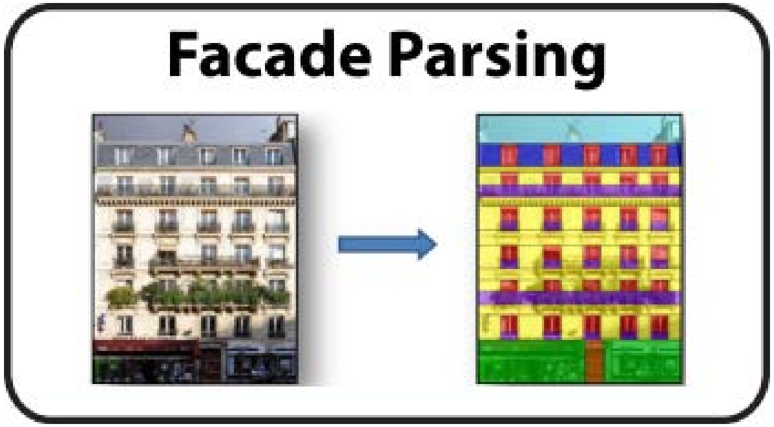




  – The symmetries can be used to complete missing data

C.2 Façade Parsing

- **Summary**
  - Recent automatic methods provide quite stable results
  - The downside is the still quite low level-of-detail
  - Also, errors are often difficult to fix
  - This field is still in active research



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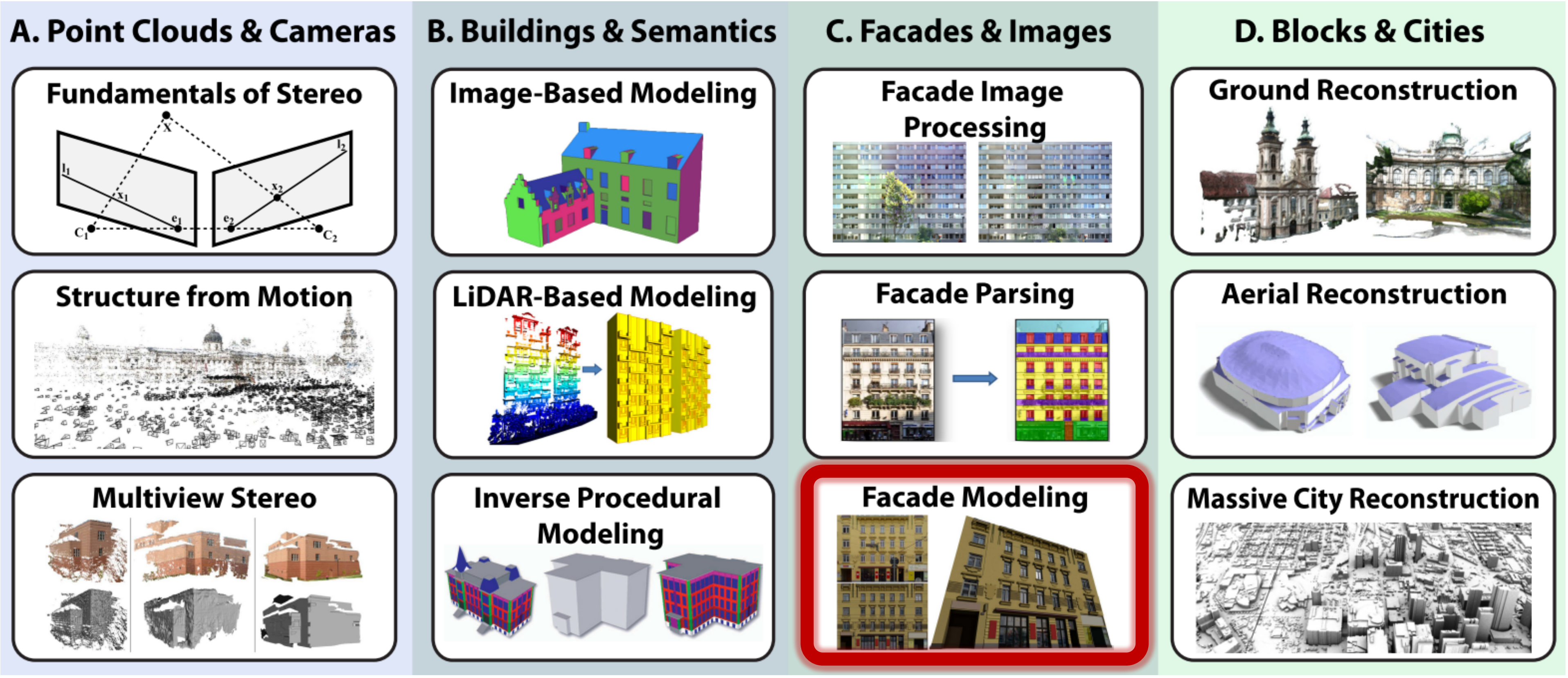
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C.3 Façade Modeling

- **Interactive Modeling**
  - Pro: provides very good quality
  - Con: slower and does not scale very well

C.3 Façade Modeling

- **Post-processing of automatic methods**
  - Xiao et al. [XFT*08]

– Use automatic heuristics to generate initial segmentation

– User interactive post-processing to fix errors in the initial segmentation

– Infer depth from multi-view setups

– Post-process interactively to fix errors

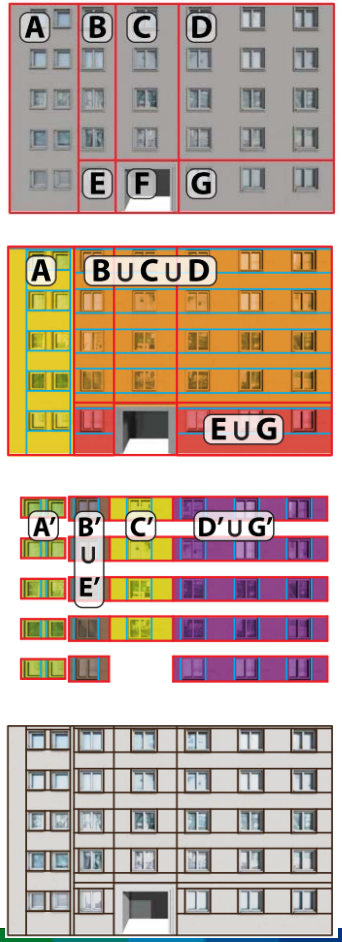
C.3 Façade Modeling

- **Post-processing of automatic methods**
  - Xiao et al. [XFT*08]

– Very good results
– But a quite a time consuming task

C.3 Façade Modeling

- **Coherence-Based Interactive Modeling**
  - Musialski et al. [MWW12]
  - Incorporate the user from the beginning
    - Let the user define high-level structure
    - Group coherent regions
    - Perform automatic splits on overlapping groups
    - Combine these splits for final segmentation
    - Add depth interactively



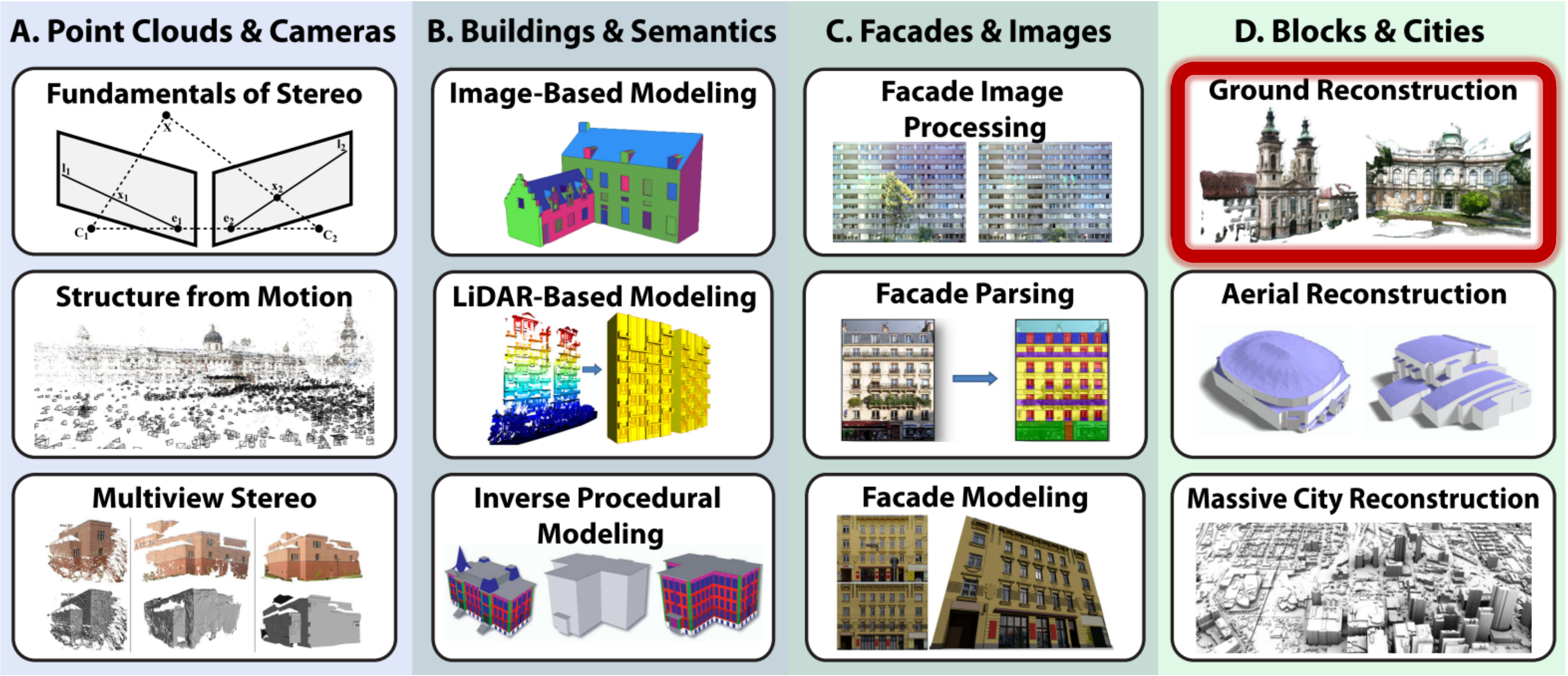
C.3 Façade Modeling

- **Coherence-Based Interactive Modeling**
  - Very good results
  - Better high-level structure
  - Still quite time-consuming

C.3 Façade Modeling

- **Summary**
  - Interactive Modeling is slow and does not scale well
  - Today's productions still rely mostly on interactive methods
  - Integration of user-interaction and automatism is still to improve

Overview


A. Point Clouds & Cameras
B. Buildings & Semantics
C. Facades & Images
D. Blocks & Cities
Fundamentals of Stereo
Image-Based Modeling
Facade Image Processing
Ground Reconstruction
Structure from Motion
LiDAR-Based Modeling
Facade Parsing
Aerial Reconstruction
Multiview Stereo
Inverse Procedural Modeling
Facade Modeling
Massive City Reconstruction

D.1 Ground-Based Reconstruction

- **Algorithms work well with small data sets**
- **Challenge: large scale**
  - Irschara et al. [IZB07,IZB11]
  - Data acquisition problem: incorporate users to provide photos (Wiki-Principle)

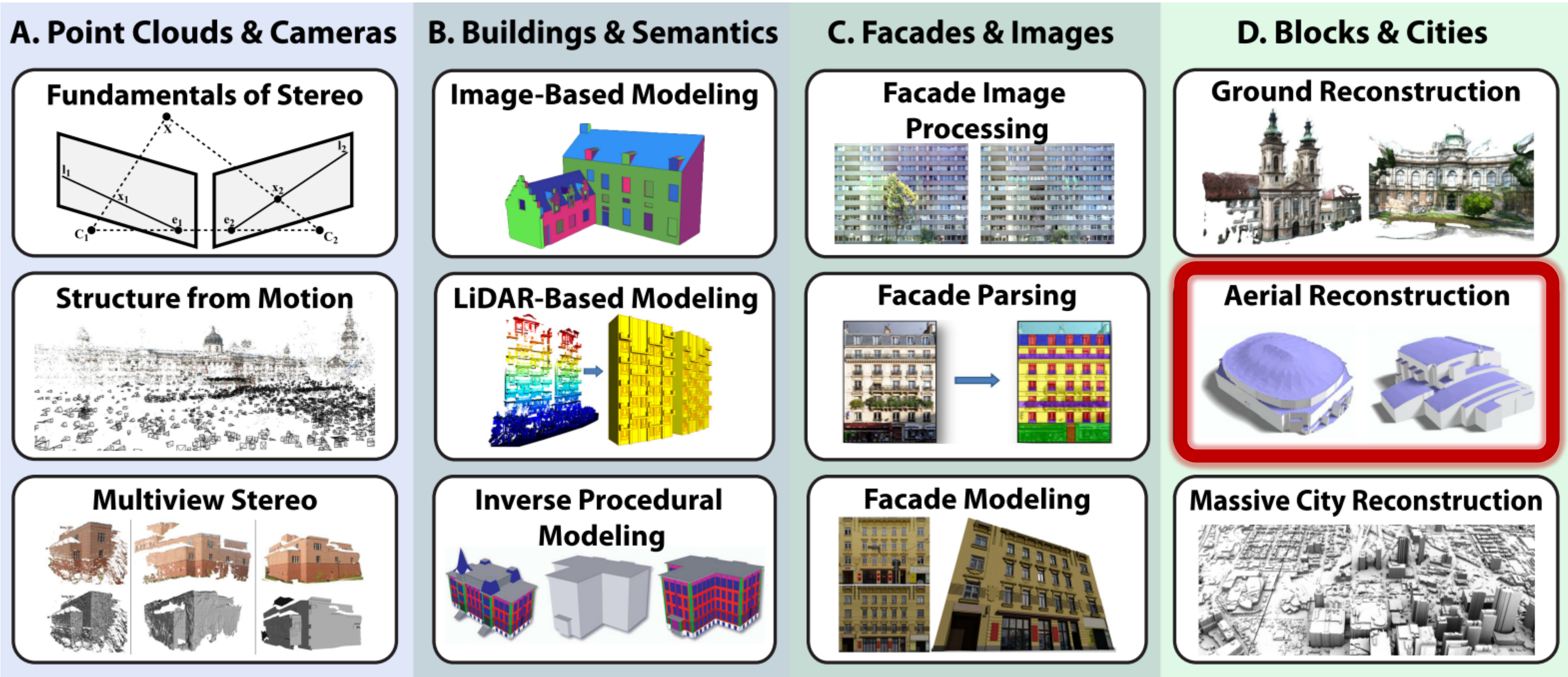

D.1 Ground-Based Reconstruction

- **Generate reconstructions during acquisition**
  - Cornelis et al. [CLCvG08]
  - Use a vehicle to drive and acquire input images
  - Run reconstruction in “real-time”, during diving

D.1 Ground-Based Reconstruction

- **Summary**
  - Generally limited to smaller areas compared to aerial approaches
  - But the only way to provide high-detailed street level models

Overview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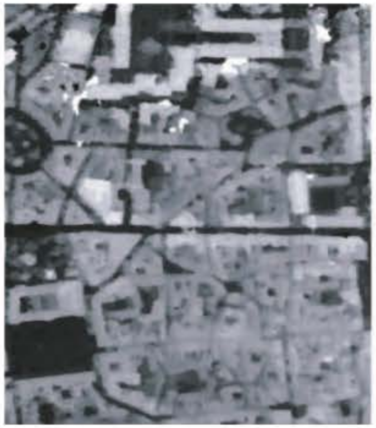
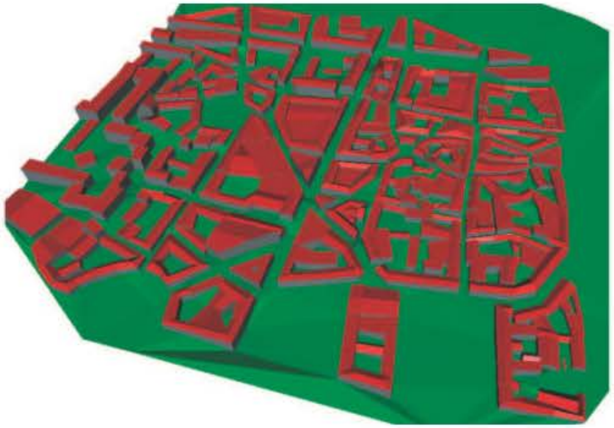
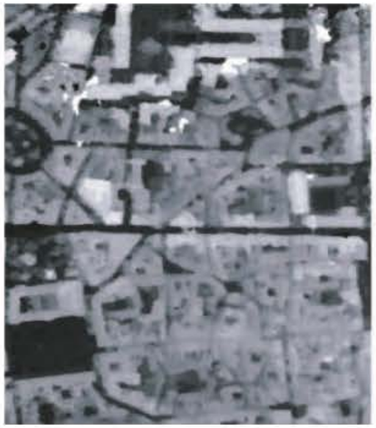
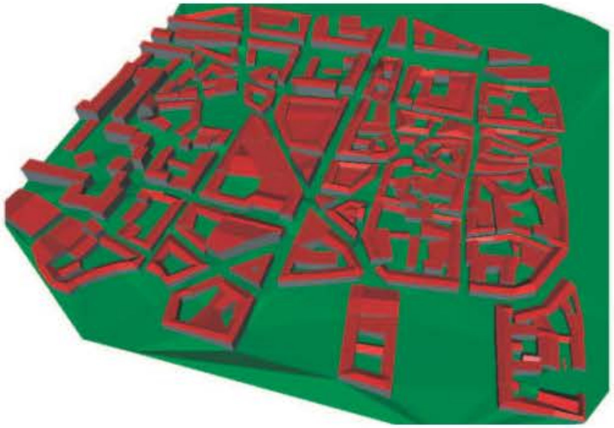
D.2 Aerial Reconstruction

- Aerial data is very well suited
- Good for documenting and measuring

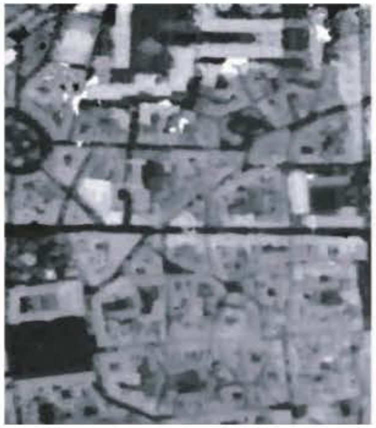
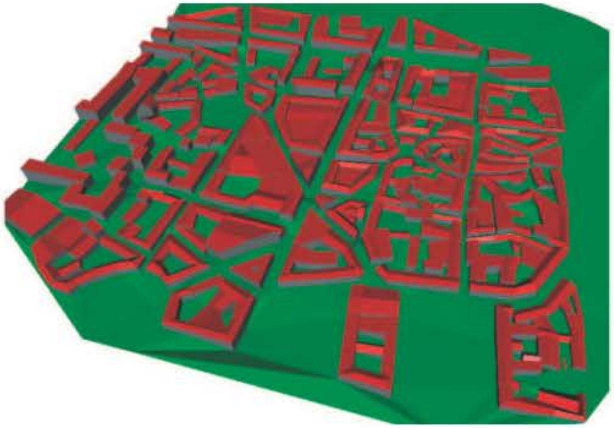

D.2 Aerial Reconstruction

- **Often, combination of different inputs**
  - Digital Surface Model (DSM)
    - Surface with man-made objects
  - Digital Terrain Models (DTM)
    - Pure terrain surface

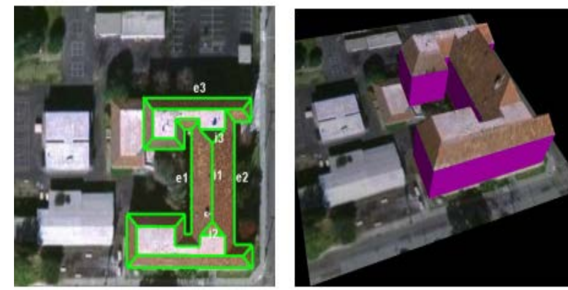

D.2 Aerial Reconstruction

- **Often, combination of different inputs**
  - Lafarge et al. [LDZPD11]
  - Extract buildings from DSM
  - Treat each building as a 3d parametric block of geometric primitves

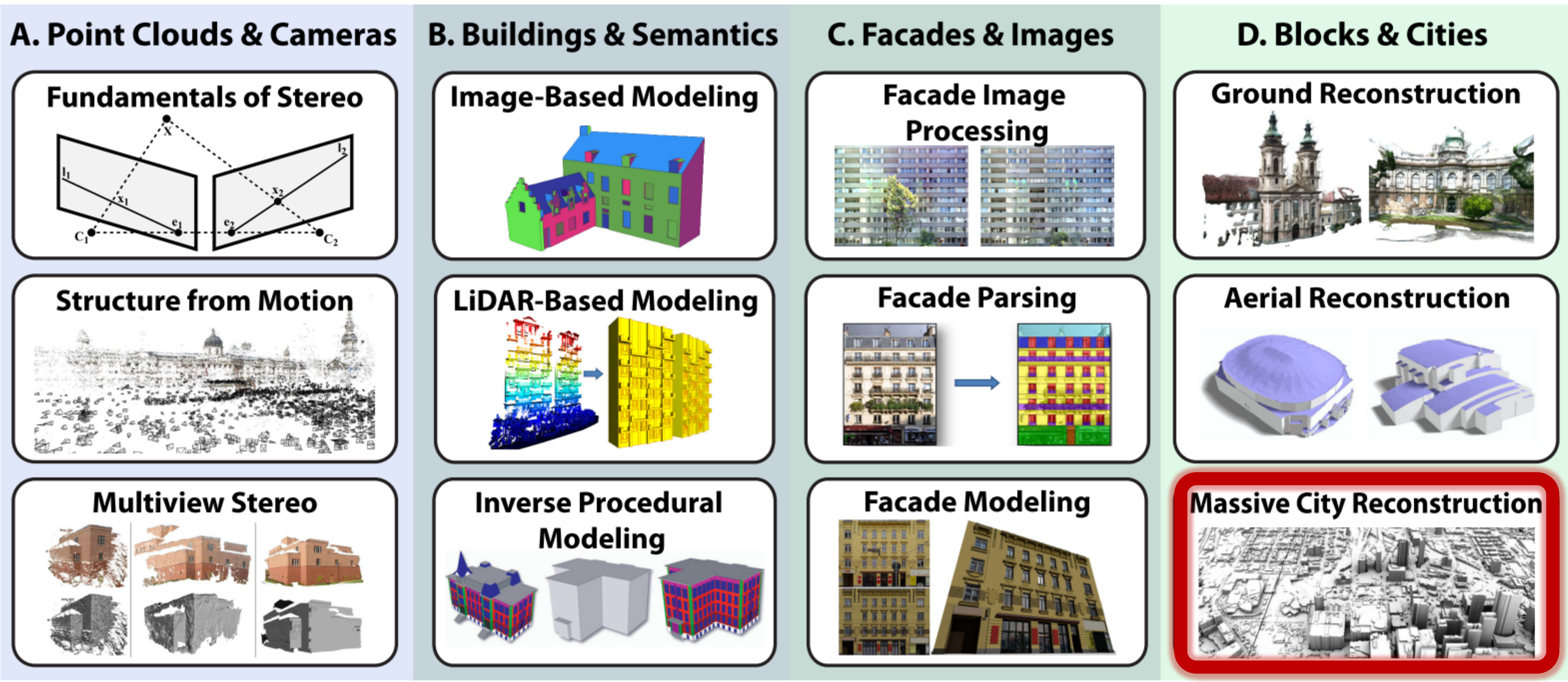




D.2 Aerial Reconstruction

- **Further methods**
  - Combine aerial and ground imagery
    - Wang et al. [WYN07]
    - Stitch ground-images to panoramas
    - Detect footprints in aerial imagery
    - User interaction for fine tuning
  - More automatic methods with DSM
    - Zebedin et al. [ZBKB08]
    - Karantzalos and Paragios [KP10]



Overview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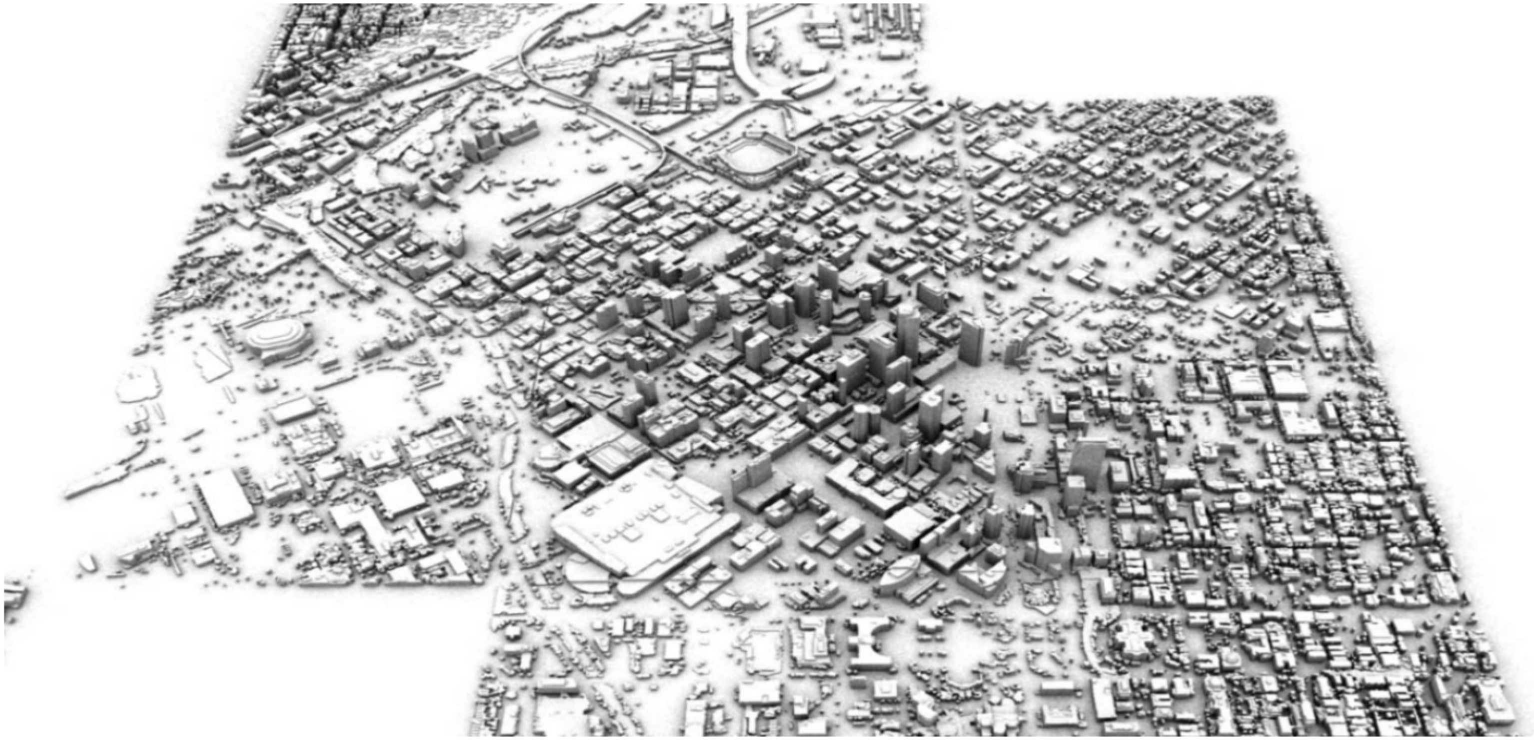
D.3 Massive City Reconstruction

- **Imaged-Based ground dense reconstruction**
  - Frahm et al. [FFGG*10]
  - Tuning and optimization of existing algorithms
  - 3 Million input images
  - 1 single PC
  - 1 day of computing

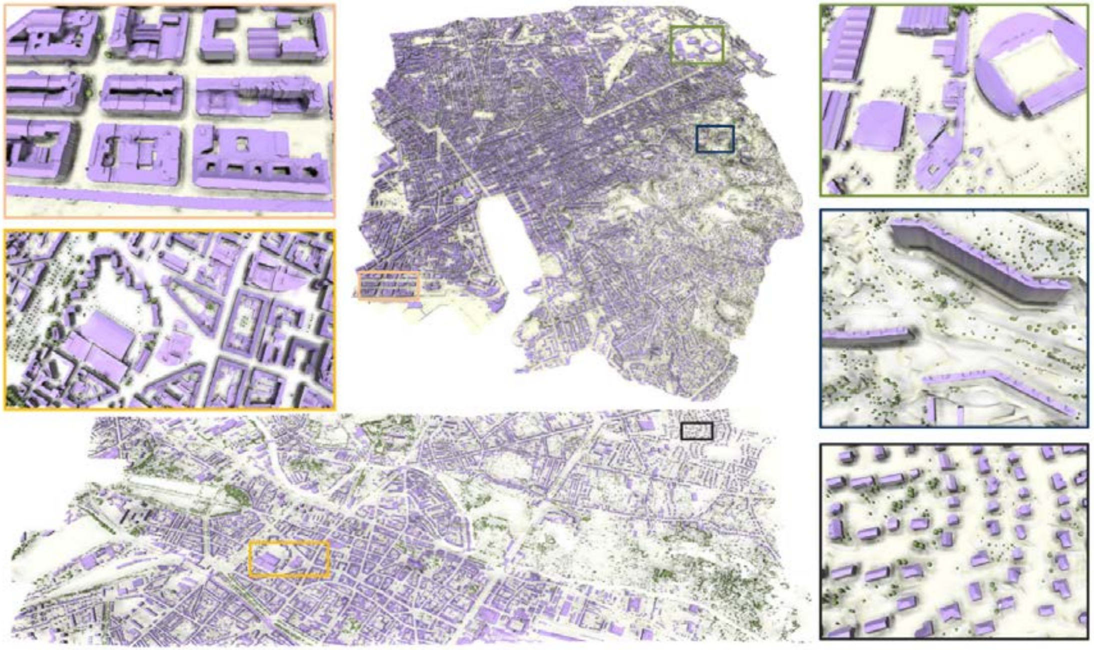

D.3 Massive City Reconstruction

- **Water-Tide Polygonal Meshes from LiDAR**
  - Poullis and You [PY09,PY11]
  - Areas of several thousands of buildings



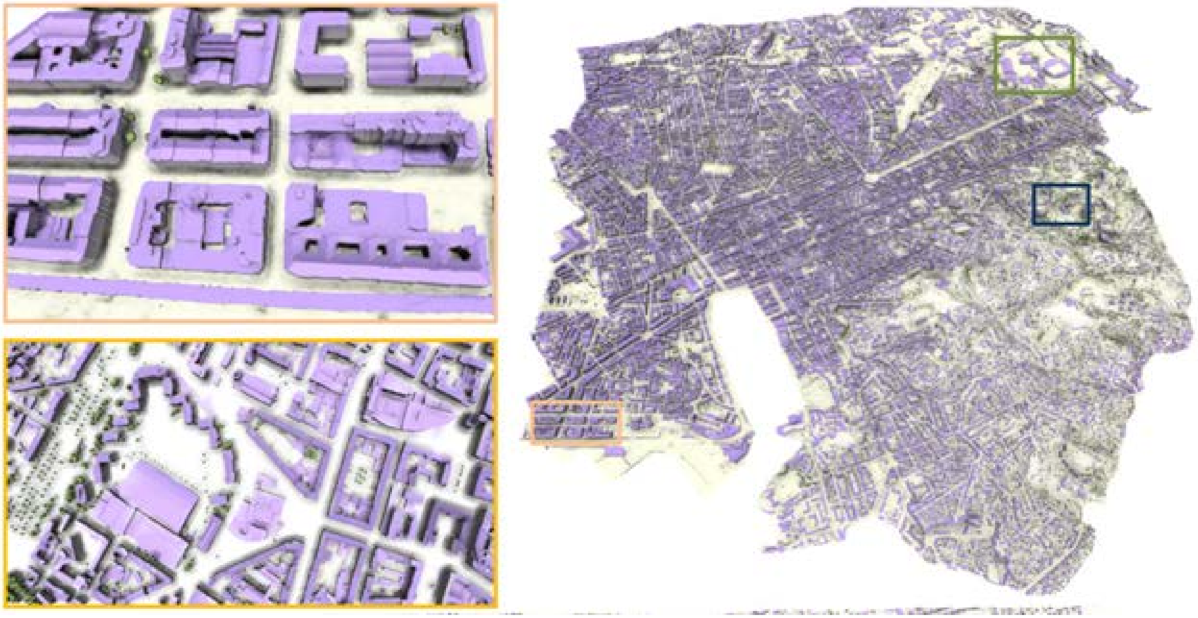
D.3 Massive City Reconstruction

- **Massive reconstruction from LiDAR**
  - Lafarge and Mallet [LM11]

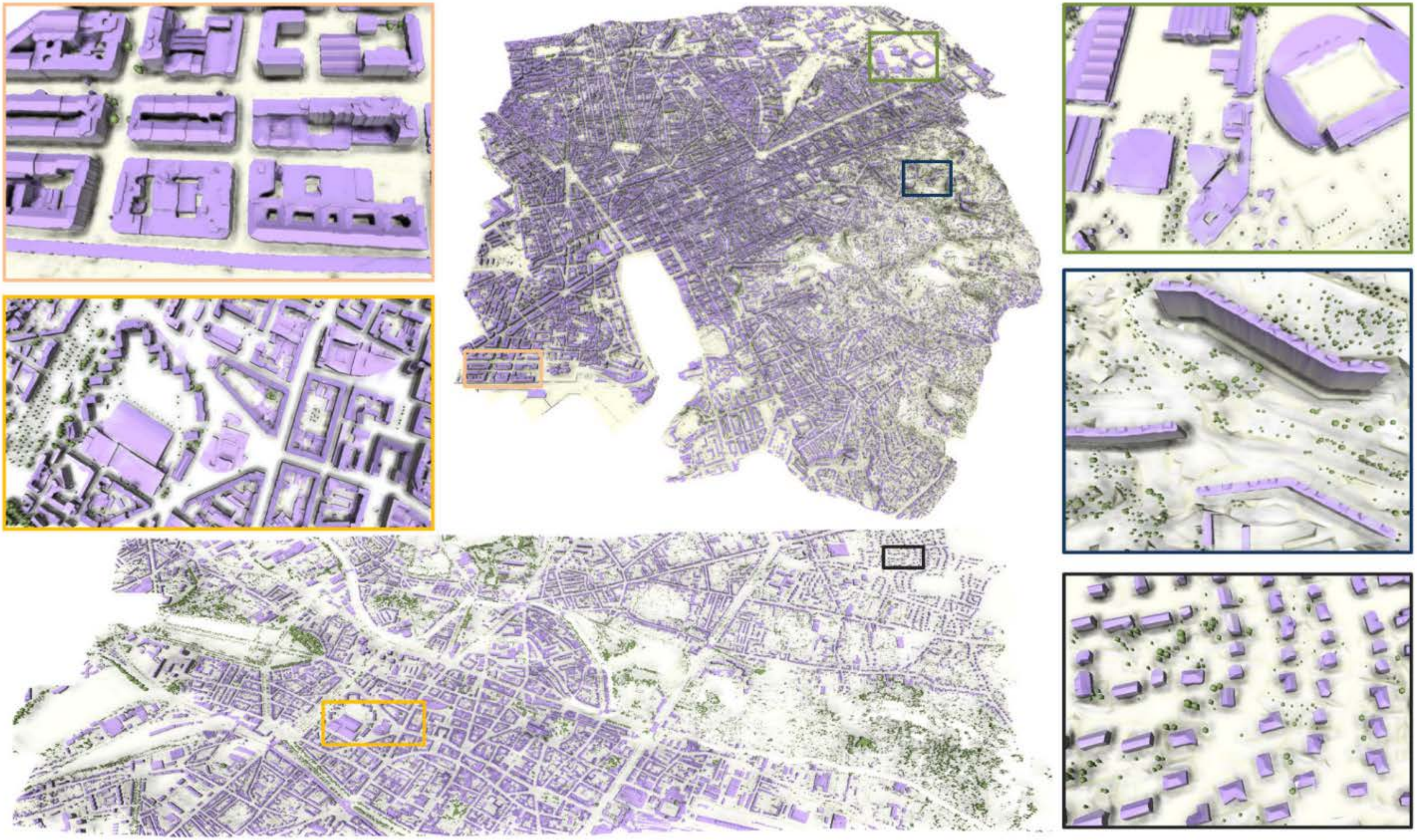


D.3 Massive City Reconstruction

- **Massive reconstruction from LiDAR**
  - Lafarge and Mallet [LM11]
  - Complete reconstructions:
    - Particular polygonal buildings
    - Vegetation
    - Terrain
  - Generalized for any urban environments



D.3 Massive City Reconstruction



D. Blocks and Cities

- **Summary**
  - Current results are impressive
  - Problems remain in
    - Processing of huge amounts of data
    - Scalable algorithms
    - Integration of different data types

Conclusions and Outlook

- **Automatic reconstructions**
  - often rely on assumptions which are not true in practice
  - Combination of user-interaction and automatic methods can be improved
- **Collaborative reconstruction**
  - Many projects incorporate Internet or user data
  - Simple methods could animate user to contribute to the reconstructions
- **More interdisciplinary work**
  - The borders between Graphics and Vision are thin
  - But the interdisciplinary cooperation between those and the Photogrammetry and Remote Sensing could be improved

The End

- **Thank you!**
- **Questions?**

The End

- **Thank you!**
- **Questions?**