2D Change Detection from satellite imagery: Performance analysis and Impact of the spatial resolution of input images

Nicolas Champion*, Didier Boldo, Marc Pierrot-Deseilligny, Georges Stamon

July 26th, 2011
General and specific contexts
Method description and Evaluation Criteria
Experiments
Conclusion

General Context

General Issue

Updating maps → a crucial and topical issue in most western countries
**General Context**

**General Issue**

Updating maps → a crucial and topical issue in most western countries

**General trends**

- to use remote-sensed images to perform the detection of changes
- to start the procedure from satellite images
  - Quickbird (Bailloeul et al., 2005)
  - Pléiades-HR (Poulain et al., 2009)
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Some questions remain unanswered...

What is the optimal Ground Sample Distance (GSD) to use for input images?
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Some questions remain unanswered...
What is the optimal Ground Sample Distance (GSD) to use for input images?
  - The main goal of this presentation is provide possible answers to this question
General Context

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Upgrading maps → a crucial and topical issue in most western countries

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Some questions remain unanswered...

What is the optimal Ground Sample Distance (GSD) to use for input images?
- The main goal of this presentation is to provide possible answers to this question
- Methodology used for this paper → Evaluating the method by (Champion et al., 2009) using 3 test areas and 2 different GSD for input images

Specific context

- Updating the French topographic vector database (DB)
Updating the French topographic vector database (DB)

- changes to detect
Specific context

- Updating the French topographic vector database (DB)
  - changes to detect
  - Demolished
Specific context

- Updating the French topographic vector database (DB)
  - changes to detect
    - Demolished / Modified - Errors in the DB

Images used to perform change detection

- Pléiades-HR (c) CNES
  - A tri-stereosocpic system
    - RGB + NIR (Near InfraRed)

2 datasets
- GSD=50cm and GSD=70cm

Products derived from input images
- DSM (processed with MICMAC 1)
- RGB + NIR Orthophotos
- Vegetation mask (NDVI)

1 - www.micmac.ign.fr
Specific context

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Outline

2 Method description and Evaluation Criteria
- Method Workflow : Step 1/Step 2
- Method Description : Step 1
- Evaluation criteria
Method Workflow

Input Data

- Database (DB) to update
- Satellite images
- DSM
- Orthophotos
Method Workflow

Input Data

- Database (DB) to update
- satellite images
- DSM
- Orthophotos

Output

- nDSM
- DTM
**Method Workflow**

**Input Data**
- Database (DB) to update
- Satellite images
- DSM
- Orthophotos

**Step 1**
- Matching
- Robust Primitives
- nDSM
- Decision
- Database partially updated

- Identifying non-changed buildings...
- ...and changed buildings
**Method Workflow**

**Input Data**
- Database (DB) to update
- Satellite images
- Orthophotos

**Step 1**
- Matching
  - Robust Primitives
- nDSM
- Decision
- Database partially updated

**Output**
- Updated DTM
- nDSM

*Identifying non-changed buildings...
...and changed buildings*
**Method Workflow**

**Step 1**
- Database (DB) to update
- Robust Primitives
- nDSM
- Decision

**Step 2**
- Overground Mask $t$
- Overground Mask $t-1$
- Identifying **non-changed** buildings...
- Identifying **changed** buildings
- New Building detection
Method Workflow

Method Workflow: Step 1/Step 2

Method Description: Step 1

Evaluation criteria

Experiments

Conclusion

General and specific contexts

Method description and Evaluation Criteria

Database (DB)
to update

Robust Primitives

Matching

nDSM

Decision

updated DTM

Database partially updated

Identifying non-changed buildings...

...and changed buildings

Overground Mask $t$

Overground Mask $t-1$

Morphological comparison

New Building detection

Step 1

Step 2

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2D Change Detection from satellite imagery
a Digital Terrain Model (DTM) = a digital representation of the ground surface
Method used for processing the DTM

Method described in (Champion et al., 2009)

**Method used for processing the DTM**

- **Building and Vegetation Mask**

- **DSM**

**Method described in (Champion et al., 2009)**

N. Champion, D. Boldo, M. Pierrot-Deseilligny and G. Stamon. Automatic estimation of fine terrain models from multiple high
Method used for processing the DTM

Method described in (Champion et al., 2009)

Database Verification (Step 1)

Method Workflow:
1. Database (DB) to update
2. satellite images
3. updated DTM
4. nDSM
5. Overground Mask $t$
6. Overground Mask $t-1$
7. Morphological comparison
8. Matching
9. Robust Primitives
10. nDSM
11. Decision
12. Database partially updated
13. Identifying non-changed buildings...
14. ...and changed buildings
15. New Building detection

Champion et al. IGARSS 2011
2D Change Detection from satellite imagery
Database Verification (Step 1)

Step 1

Database (DB) to update

satellite images

Matching

Robust Primitives

nDSM

Decision

updated DTM

DSM

Orthophotos

NEW BUILDING DETECTION

Identifying non-changed buildings...

... and changed buildings

Database partially updated

Overground Mask $t$

Overground Mask $t-1$

Morphological comparison

New Building detection

updated DTM

nDSM
Database Verification (Step 1)

**Database (DB) to update**

- Satellite images
- DSM
- Orthophotos

**nDSM**

**Robust Primitives**

**Matching**

**Decision**

- Database partially updated
- Identifying non-changed buildings...
- ...and changed buildings

**New Building detection**

**Overground Mask**

- Overground Mask \( t \)
- Overground Mask \( t-1 \)

**Morphological comparison**

**Updated DTM**
Database Verification (Step 1)

Step 1

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- Satellite images
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- Robust Primitives
- Matching

Champion et al. IGARSS 2011
2D Change Detection from satellite imagery
Database Verification (Step 1): Robust Primitives

(1) Information about Overground

based on the nDSM = DSM – DTM

- **input DSM**
- **nDSM**

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2D Change Detection from satellite imagery
Database Verification (Step 1): Robust Primitives

1. Information about Overground
   based on the nDSM = DSM – DTM

2. Linear Primitives: 2D Contours
   extracted from the DSM (Deriche, 1987)
Database Verification (Step 1): Robust Primitives

(1) Information about Overground
based on the nDSM = DSM – DTM

(2) Linear Primitives: 2D Contours
extracted from the DSM (Deriche, 1987)

(3) Linear Primitives: 3D Segments
Reconstructed from input multiscopic images (Taillandier and Deriche, 2002)
Database Verification (Step 1)

Step 1

Matching

Robust Primitives

nDSM

Decision

Database partially updated

Identifying non-changed buildings...

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Database (DB) to update

satellite images

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updated

Orthophotos

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Overground Mask t

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Matching
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New Building detection
Based on the a contrario paradigm

Dissimilarity Scores

\[ nDSM \rightarrow S_{Dissimilarity}^{nDSM} \quad Linear \ Primitives \ (2D \ contours \ & \ 3D \ segments) \rightarrow S_{Dissimilarity}^{Linear \ Primitives} \]

Database Verification (Step 1): Matching and Decision

- based on the a contrario paradigm

**Dissimilarity Scores**

\[ nDSM \rightarrow S_{nDSM}^{Dissimilarity} \quad \text{Linear Primitives} \quad (2D \ contours \ & 3D \ segments) \rightarrow S_{Linear \ Primitives}^{Dissimilarity} \]

- Illustration of the computation of \( S_{nDSM}^{Dissimilarity} \)

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Database Verification (Step 1) : Matching and Decision

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Database Verification (Step 1) : Matching and Decision

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Dissimilarity Scores

\[
\text{nDSM} \rightarrow S^{\text{nDSM}}_{\text{Dissimilarity}} \quad \text{Linear Primitives} \ (2D \ contours \ & \ 3D \ segments) \rightarrow S^{\text{Linear Primitives}}_{\text{Dissimilarity}}
\]

- Illustration of the computation of \( S^{\text{nDSM}}_{\text{Dissimilarity}} \)

Area not covered by overground pixel in the nDSM

nDSM

Building to verify

Decision Rules

Hypothesis : "a few changes in the scene" \( \Rightarrow \) "a building already present in the database is likely still to be in the scene at the time of investigation."

\Rightarrow A weak indication is enough to validate it during Step 1

\Rightarrow A small value for \( S^{\text{Linear Primitives}}_{\text{Dissimilarity}} \) or \( S^{\text{nDSM}}_{\text{Dissimilarity}} \) \( \{ \text{Unchanged Buildings} \} = \{ \text{Building}_i : S^{\text{nDSM}}_{\text{Dissimilarity}}(\text{Building}_i) < M_1 \} \) \( i \in [1, N] \) \bigcup \{ \text{Building}_i : S^{\text{Linear Primitives}}_{\text{Dissimilarity}}(\text{Building}_i) < M_2 \} \) \( i \in [1, N] \)

Our change detection system is actually a no-change detection system : changes are inferred from \( \{ \text{Unchanged Buildings} \} \) by taking the complementary...
Based on the a contrario paradigm\(^1\)

**Dissimilarity Scores**

\[
nDSM \rightarrow S_{nDSM}^{Dissimilarity} \quad \text{Linear Primitives (2D contours & 3D segments)} \rightarrow S_{Linear Primitives}^{Dissimilarity}
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- Illustration of the computation of \(S_{nDSM}^{Dissimilarity}\)

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2D Change Detection from satellite imagery
Database Verification (Step 1) : Matching and Decision

Based on the a contrario paradigm

Dissimilarity Scores

\[ nDSM \rightarrow S^n_{Dissimilarity} \]

Linear Primitives (2D contours & 3D segments) \( \rightarrow S^{Linear\ Primitives}_{Dissimilarity} \)

Illustration of the computation of \( S^n_{Dissimilarity} \)

\[ S^n_{Dissimilarity} = A \left( P_{Building}(x,y) : nDSM(x,y) < T_H \right) \]

\[ \mathcal{A}_{Building} \]
Database Verification (Step 1) : Matching and Decision

- based on the a contrario paradigm

**Dissimilarity Scores**

\[ nDSM \rightarrow S_{nDSM}^{\text{Dissimilarity}} \quad \text{Linear Primitives} \ (2D \ contours \ & \ 3D \ segments) \rightarrow S_{\text{Linear Primitives}}^{\text{Dissimilarity}} \]

**Decision Rules**

**Hypothesis** : “a few changes in the scene” ⇒ “a building already present in the database is likely still to be in the scene at the time of investigation.”

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Database Verification (Step 1) : Matching and Decision

▷ based on the a contrario paradigm\(^1\)

### Dissimilarity Scores

\[ nDSM \rightarrow S_{\text{Dissimilarity}}^{nDSM} \quad \text{Linear Primitives} \ (2D \ contours \ & \ 3D \ segments) \rightarrow S_{\text{Dissimilarity}}^{\text{Linear Primitives}} \]

### Decision Rules

**Hypothesis** : “a few changes in the scene” ⇒ “a building already present in the database is likely still to be in the scene at the time of investigation.”

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Database Verification (Step 1) : Matching and Decision

- based on the a contrario paradigm\(^1\)

**Dissimilarity Scores**

\[ nDSM \rightarrow S^{nDSM}_{\text{Dissimilarity}} \quad \text{Linear Primitives} \quad (2D \text{ contours} \& \text{3D segments}) \rightarrow S^{\text{Linear Primitives}_{\text{Dissimilarity}}} \]

**Decision Rules**

**Hypothesis** : “a few changes in the scene” \(\Rightarrow\) “a building already present in the database is likely still to be in the scene at the time of investigation.”

\(\Rightarrow\) A weak indication is enough to validate it during Step 1

\(\Rightarrow\) A small value for \(S^{\text{Linear Primitives}_{\text{Dissimilarity}}}\) or \(S^{nDSM}_{\text{Dissimilarity}}\)

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Database Verification (Step 1) : Matching and Decision

database verification (step 1) : matching and decision

based on the a contrario paradigm

Dissimilarity Scores

\[ nDSM \rightarrow S_{nDSM}^{Dissimilarity} \]

Linear Primitives (2D contours & 3D segments) \( \rightarrow \) \( S_{Linear Primitives}^{Dissimilarity} \)

Decision Rules

Hypothesis : “a few changes in the scene” \( \Rightarrow \) “a building already present in the database is likely still to be in the scene at the time of investigation.”

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\[
\{ \text{Unchanged Buildings} \} = \{ \text{Building}_i : S_{nDSM}^{Dissimilarity}(\text{Building}_i) < M_1 \}_{i \in [1,N]} \cup \\
\{ \text{Building}_i : S_{Linear Primitives}^{Dissimilarity}(\text{Building}_i) < M_2 \}_{i \in [1,N]}
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Database Verification (Step 1) : Matching and Decision

▷ based on the *a contrario paradigm*\(^1\)

### Dissimilarity Scores

\[ n_{DSM} \rightarrow S_{_{DSM}}^{n_{DSM}} \text{ Dissimilarity } \quad \text{Linear Primitives (2D contours & 3D segments)} \rightarrow S_{_{Linear Primitives}}^{n_{DSM}} \text{ Dissimilarity} \]

### Decision Rules

**Hypothesis** : “a few changes in the scene” ⇒ “a building already present in the database is likely still to be in the scene at the time of investigation.”

⇒ A weak indication is enough to validate it during Step 1

⇒ A small value for \( S_{_{Linear Primitives}}^{n_{DSM}} \text{ Dissimilarity} \) or \( S_{_{DSM}}^{n_{DSM}} \text{ Dissimilarity} \)

\[ \{ \text{Unchanged Buildings} \} = \left\{ \text{Building}_i : S_{_{DSM}}^{n_{DSM}}(\text{Building}_i) < M_1 \} \right\}_{i \in [1, N]} \bigcup \left\{ \text{Building}_i : S_{_{Linear Primitives}}^{n_{DSM}}(\text{Building}_i) < M_2 \} \right\}_{i \in [1, N]} \]

⇒ Our change detection system is actually a no-change detection system: changes are inferred from \{ Unchanged Buildings \} by taking the complementary

Method output - Illustration on Amiens Pont de Metz (GSD = 50cm)

Change Map

Evaluation Map

unchanged / modified / demolished / new

TP / FN / FP / TN

Champion et al. IGARSS 2011

2D Change Detection from satellite imagery
### Evaluation Criteria

**Success criteria used in this project** *(Champion et al., 2009)*

#### Confusion Matrix

<table>
<thead>
<tr>
<th></th>
<th>System (S)</th>
<th>Unchanged (S)</th>
<th>M&amp;D&lt;sup&gt;2&lt;/sup&gt; (S)</th>
<th>New (S)</th>
<th>Bg.&lt;sup&gt;3&lt;/sup&gt; (S)</th>
</tr>
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<tbody>
<tr>
<td>Ref.&lt;sup&gt;1&lt;/sup&gt; (R)</td>
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<td></td>
<td></td>
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<tr>
<td>Unchanged (R)</td>
<td>⊳&lt;sup&gt;1&lt;/sup&gt; NU(S)→U(R)</td>
<td># N&lt;sub&gt;C&lt;/sub&gt;(S)→U(R)</td>
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<td>-</td>
<td>-</td>
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<td>M&amp;D&lt;sup&gt;2&lt;/sup&gt; (R)</td>
<td># NU(S)→C(R)</td>
<td># NC(S)→C(R)</td>
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<td>-</td>
<td>-</td>
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<td>New (R)</td>
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<td>-</td>
<td># NN(S)→N(R)</td>
<td># NB(S)→N(R)</td>
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<td># NN(S)→B(R)</td>
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1. Ref. = Reference  
2. M&<b>D = Modified and Demolished  
3. Bg. = Background

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## Evaluation Criteria

### Success criteria used in this project *(Champion et al., 2009)*

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- **Ref.** = Reference
- **M&D** = Modified and Demolished
- **Bg.** = Background

#### Computing the Recall and Precision for each change class - e.g.:

1. Ref. = Reference
2. M&D = Modified and Demolished
3. Bg. = Background

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Evaluation Criteria

Success criteria used in this project *(Champion et al., 2009)*

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<th>Bg.(^3) (S)</th>
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\(^1\) Ref. = Reference \(^2\) M&D = Modified and Demolished \(^3\) Bg. = Background

Computing the Recall and Precision for each change class - e.g.:

\[
\text{Recall}_{M&D} = \frac{\# N\(_C(S)→C(R)\)}{\# N\(_C(S)→C(R)\) + \# N\(_U(S)→C(R)\)}
\]
Success criteria used in this project \textit{(Champion et al., 2009)}

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</tr>
<tr>
<td>Bg.(^3) (R)</td>
<td>-</td>
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<td># N(N(S))(\rightarrow)B(R)</td>
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</tr>
</tbody>
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Computing the \textbf{Recall} and \textbf{Precision} for each change class - e.g.:

\[
\text{Recall}_{M&D} = \frac{\# N\(C(S)\)\(\rightarrow\)C(R)}{\# N\(C(S)\)\(\rightarrow\)C(R) + \# N\(U(S)\)\(\rightarrow\)C(R)}
\]

\[
\text{Precision}_{M&D} = \frac{\# N\(C(S)\)\(\rightarrow\)C(R)}{\# N\(C(S)\)\(\rightarrow\)C(R) + \# N\(C(S)\)\(\rightarrow\)U(R)}
\]

\(^1\) \textit{Ref. = Reference} \quad \(^2\) \textit{M&D = Modified and Demolished} \quad \(^3\) \textit{Bg. = Background}

---

Success criteria used in this project *(Champion et al., 2009)*

Confusion Matrix

<table>
<thead>
<tr>
<th></th>
<th>System (S)</th>
<th>Unchanged (S)</th>
<th>M&amp;D $^2$ (S)</th>
<th>New (S)</th>
<th>Bg. $^3$ (S)</th>
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<tbody>
<tr>
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<td># $N_C(S) \rightarrow U(R)$</td>
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- Computing the Recall and Precision for each change class
- **1st success criterion (qualitative effectiveness)**
  - $\Rightarrow$ a high recall for all changes = *Demolished & Modified and New*

---

Evaluation Criteria

Success criteria used in this project *(Champion et al., 2009)*

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▷ Computing the Recall and Precision for each change class

▷ 1st success criterion *(qualitative effectiveness)*

⇒ a high recall for all changes = *Demolished & Modified and New*

▷ 2nd success criterion *(economical effectiveness)*

to limit the number of false alarms ⇒ a high precision for modified and demolished buildings
⇔ a high recall for unchanged buildings *(a lower precision for new buildings is not critical)*

Evaluation at 50cm

Quantitative Evaluation (50cm)

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1 - Modified and Demolished

Analysis
**Evaluation at 50cm**

### Analysis

- **Recall (Qualitative Effectiveness)**
  - Very good for modified and demolished buildings ($\sim 95\%$)

### Quantitative Evaluation (50cm)

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1 - Modified and Demolished

### Analysis

- **Recall (Qualitative Effectiveness)**
  - Very good for modified and demolished buildings (≈ 95%)
  - Good for new buildings (on average 85%) . . .
Evaluation at 50cm

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**Analysis**

- **Recall (Qualitative Effectiveness)**
  - *very good* for modified and demolished buildings ($\approx 95\%$)
  - *good* for new buildings (on average 85%) ... but sometimes critical (< 80%)

---

1 - *Modified and Demolished*
Evaluation at 50cm

Quantitative Evaluation (50cm)

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1 - Modified and Demolished

Analysis

- **Recall (Qualitative Effectiveness)**
  - very good for modified and demolished buildings (≈ 95%)
  - good for new buildings (on average 85%) ... but sometimes critical (< 80%)

- **Precision (Economical Effectiveness)**
  - relatively low for new buildings
Evaluation at 50cm

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Analysis

- **Recall (Qualitative Effectiveness)**
  - **very good** for modified and demolished buildings ($\sim 95\%$)
  - **good** for new buildings (on average 85%) ... but sometimes critical ($< 80\%$)

- **Precision (Economical Effectiveness)**
  - relatively low for new buildings
  - $< 20\%$ in Toulouse Rocade

1 - Modified and Demolished
Evaluation at 50cm

Quantitative Evaluation (50cm)

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1 - Modified and Demolished

Analysis

- \textbf{Recall (Qualitative Effectiveness)}
  - \textbf{very good} for modified and demolished buildings ($\approx 95\%$)
  - \textbf{good} for new buildings (on average $85\%$) . . . but sometimes critical ($< 80\%$)

- \textbf{Precision (Economical Effectiveness)}
  - \textbf{relatively low} for new buildings
    $\rightarrow < 20\%$ in Toulouse Rocade
  - \textbf{better} for demolished and modified buildings (70% in Amiens Pont-de-Metz)
### Evaluation at 50cm

#### Quantitative Evaluation (50cm)

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1 - *Modified and Demolished*

#### Analysis

- **Recall (Qualitative Effectiveness)**
  - *very good* for modified and demolished buildings (\(\approx 95\%\))
  - *good* for new buildings (on average 85%) . . . but sometimes critical (\(< 80\%\))

- **Precision (Economical Effectiveness)**
  - *relatively low* for new buildings
    \(\rightarrow\) \(< 20\%\) in Toulouse Rocade
  - *better* for demolished and modified buildings (70\% in Amiens Pont-de-Metz)

- a high recall for **unchanged buildings**
  \(\rightarrow\) work saved for operators
Impact of the resolution of input data

### Quantitative Evaluation (70cm)

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<td>Recall [%]</td>
<td>92,41 (-3,44%)</td>
<td>92,42 (-3,17%)</td>
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<tr>
<td>Precision [%]</td>
<td>99,66 (-0,14%)</td>
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<tr>
<td>Recall [%]</td>
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<td>96,55 (-0.0%)</td>
<td>82,02 (-10,97%)</td>
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<td>Precision [%]</td>
<td>98,44 (-0,13%)</td>
<td>60,87 (-12,61%)</td>
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### Impact on the Qualitative Effectiveness

→ in our experiments, independent of the resolution

1 - *Modified and Demolished*
## Impact of the resolution of input data

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### Impact on the Qualitative Effectiveness

→ in our experiments, independent of the resolution

### Impact on the Economical Effectiveness

→ in our experiments, a clear impact of the resolution . . .

1 - *Modified and Demolished*
Impact of the resolution of input data

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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall [%]</td>
<td>92,41 (-3,44%)</td>
<td>92,42 (-3,17%)</td>
<td>80,3 (+0,0%)</td>
</tr>
<tr>
<td>Precision [%]</td>
<td>99,66 (-0,14%)</td>
<td>33,7 (-29,92%)</td>
<td>28,49 (+0,0%)</td>
</tr>
<tr>
<td><strong>Amiens Pont-de-Metz</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall [%]</td>
<td>77,83 (-9,19%)</td>
<td>96,55 (-0,0%)</td>
<td>82,02 (-10,97%)</td>
</tr>
<tr>
<td>Precision [%]</td>
<td>98,44 (-0,13%)</td>
<td>60,87 (-12,61%)</td>
<td>33,03 (-15,0%)</td>
</tr>
<tr>
<td><strong>Toulouse Rocade</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall [%]</td>
<td>73,98 (-8,12%)</td>
<td>97,74 (+0,77%)</td>
<td>79,41 (+3,85%)</td>
</tr>
<tr>
<td>Precision [%]</td>
<td>99,63 (+0,08%)</td>
<td>31,25 (-16,91%)</td>
<td>19,01 (+3,09%)</td>
</tr>
</tbody>
</table>

### Impact on the Qualitative Effectiveness

→ in our experiments, independent of the resolution

### Impact on the Economical Effectiveness

→ in our experiments, a clear impact of the resolution ... but the recall for unchanged buildings is not impacted too much

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1 - Modified and Demolished
Conclusions

- Evaluation of a method for detecting changes in a 2D building database from satellite images.
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- Analysis of the impact of the resolution of input images on its performance.
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  - many false alarms generated at 70 cm $\Rightarrow$ loss in performance $\ldots$
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Future Works

- Adding new datasets (homogeneity of the results + scalability)
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    No! the rate of unchanged buildings correctly detected is still high!

Future Works

- Adding new datasets (homogeneity of the results + scalability)
- Testing with aerial images (GSD=25cm) to prepare the advent of Very High Resolution Earth Observation satellites (e.g. Geoeye-2)
Thank you for your attention