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‘A Knowledge-based Framework for Automated Space-Use Analysis’
Introduction

Why do practitioners care about the space-use?

Consistency

Transparency

Space-use analysis

Efficiency
Scope of research

- User information
  - User
  - Space

- Space information
  - Type
  - Number
  - Size
  - Equipment
  - Conditions

- Type
- Number
- Activity
- Priorities
- Preferences

Planning and design phases

• Utilization

Office and educational buildings

Number
Activity
Preferences

Feedback
Conventional or manual space-use analysis is unable to predict, document, and communicate the space utilization of facilities with sufficient consistency, transparency, and efficiency.

The construction industry currently lacks a framework that formalizes the concepts for space-use analysis and the relationships among them and steers the implementation of automated space-use analysis that is based on that formalization.
Case 1: Construction company building

Existing building
Employees information

New building design

The size of the gym should be increased!

It should be reduced!

Vice president
President
## Case 2: Publishing company building

<table>
<thead>
<tr>
<th>Space Name</th>
<th>Size (m²)</th>
<th>Number</th>
<th>Unit cost (k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage room</td>
<td>40</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Meeting room</td>
<td>20</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Work station</td>
<td>4</td>
<td>25</td>
<td>1.8</td>
</tr>
<tr>
<td>Gallery</td>
<td>40</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>Commemorative room</td>
<td>20</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>Others</td>
<td>200</td>
<td>1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

- Option 1, Option 2, Option 3 ...

“Increase the size of the storage room to hold an additional 10,000 books.”

“Oops, we should reduce the cost.”
Research objectives

Ontological relationships

User

Utilization

Equipment

Space

User activity

Concepts for space-use analysis

Automated analysis process

Framework for automated space-use analysis

Function 1

Function 2

Function 3
Prior work

Architectural programming

Post-occupancy evaluation

- TOP 6 “Most important development”
  1. Fresh and healthy working environment
  2. Increased collaboration
  3. Clear and visible signages
  4. Improved customer service, e.g.
     - Shared service rooms
     - Information security
     - Workplace
  5. All colleagues in the same floor
  6. Improved sense of collectivity

- TOP 6 “Most important things yet to be worked on”
  1. Need to finalize the customer service procedures
  2. Need for certain workspaces
     - E.g. training space for 20 people
  3. Need to finalize service procedures
  4. Need for more desk space
  5. Need for open plan protocols
  6. Air conditioning and air quality

Workplace planning

- Manual mapping

Operations research

- Non project-specific

- Not concerning current option
Utilization theory

- Cherry, 1999

Policy on the planned utilization:

100%: Unacceptable to users

Space-use is too high

75% for typical college or high school classrooms

0%: Unacceptable to clients

Space-use is too low

- Pennanen, 2004

<=50%: Activities can be done without waiting.

<= 75%: Activities may need to be scheduled.
Applying Darwiche’s ontology in space-use analysis

Editors **edit a book.**
- Frequency: 1 per day
- Group size: 1 person
- Duration: 2 hours
- Required space: workstation
- Preferences: whole room of any size with quiet conditions

Component (Object): `<Book>`
Action: `<Editing>`
Resources: `<Editors, Workstation>`
Spaces: `<Any room with quiet conditions>`

Darwiche, 1989
Akinci, 2000
Assisted iterative refinement in spatial design

Design Semantics (conceptual, qualitative, multiperspective representation)

Design (e.g., floor plan)

Reasoning for Design Intelligence (e.g., conceptual reasoning, hypothetical inference)

Spatial Design and Visualization Tool (e.g., ArchiCAD)

convergence
design feedback (e.g., analyse design requirements)

Bhatt and Freksa, 1989
How can the concepts for space-use analysis and their relationships be formalized to create the knowledge base for space-use analysis based on Darwiche’s (1989) <OAR> tuple and Akinci’s (2000) <CARS> tuple?

How can the automated space-use analysis process be formalized to automatically predict and visualize the utilization based on the utilization theory and Bhatt and Freksa’s (2010) assistive iterative refinement model?
Some users require a space with more than minimum requirements for their activities.

Some activities require having a designated space.

Some activities require occupying whole rooms while others need part of rooms, i.e., equipment.

Some activities are conducted in a specifically named space while others are conducted in any spaces with certain conditions.

Some atypical activities also require a space.

(from Pennanen, 2004; Cherry, 1999; case observation)
The ontology of user activities

- Concepts formalization
- Process formalization
- Case study

- **Activity**
  - **Object**: User
  - **Action**: Whole room use req.
  - **Resources**
    - Spatial requirements
    - Equipment use req.
    - Material

- **Spaces**

(Darwiche, 1989)

(Akinci, 2000)
Ontological relationships among the concepts

- **Concepts formalization**
- **Process formalization**
- **Case study**

**Spaces**
- Equipment
- Product
- Equipment set

**Activities**
- Action

**Spatial requirements**
- Organization

**Users**

**Utilization**
- Open time
- Activity load

**Policy on utilization**
- Implication

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*Mapped if all spatial requirements of an activity are met by a space or equipment*
Automated space-use analysis process in IDEF0

Concepts formalization
- ontology for space-use analysis
- data collecting templates

Process formalization
- Building the knowledge base (KBase)
  - Gather data!
  - Build the KBase!
- Mapping user activities onto spaces
  - Calculate metrics!
  - Find spaces!
  - Map activities!
- Computing utilization
  - Calculate utilization!
- Visualizing the results
  - Generate ALS!
  - Generate mapping diagram!
  - Summarize utilization!

Case study
- Facts
  - space mapping heuristics
  - metrics necessary for the mapping

- Rules
  - utilization theory
  - policy on utilization
    - ALS visualization method
- activity-loaded spaces (ALS)
- activity-space mapping diagram
- utilization summary
Case study on the Y2E2 Building, Stanford University

Concepts formalization  Process formalization  Case study

Select areas

Select areas

5 user types, 13 activities, 9 space types
Ontology for Space-Use Analysis (schema for the KBase)

Activity::Event[user *=> User, action *=> Action, ratio *=> float, frequency *=> float, constraints *=> SpatialReq, preferences *=> SpatialReq].

64 Facts (the KBase specific for the Y2E2 Building)

undergradsMeetingForClass:TypicalActivity[user -> undergrads, action -> haveMeeting, ratio -> 1.0, frequency -> 0.2, constraints -> cons3, preferences -> pref3].

33 Rules

?SP252[activity -> ?ACT252] :-
   ?ACT252:TypicalActivity,
   ?SP252:NonOccupiableSpace[equipped -> ?EQSET252],
Original settings: activity-space mapping diagram

**Concepts formalization**

1-1: gradsHavingClass
1-2: undergradsHavingClass
2-1: gradsMeetingForClassWithComputers
2-2: undergradsMeetingForClassWithComputers
3-1: gradsMeetingForClass
3-2: undergradsMeetingForClass
4: groupMeetingForResearch
5-1: gradsStudying
5-2: undergradsStudying
6: facultyWorking
7: staffWorking
8: researchersWorking
9: facultyMeeting

**Process formalization**

computerCluster
classRoom
smallConferenceRoomWithComputer
conferenceRoomWithComputer
privateOffice
sharedOffice
openOffice
smallConferenceRoom
largeConferenceRoom

**Case study**

9 space types

13 activities

26 links automatically

Legend:
- : No wait
- : Adequate
- : Inconvenient
- : Infeasible
Original settings: utilization summary + activity-loaded space

Concepts formalization  Process formalization  Case study

Legend:
- Used for an activity
- Cannot be used by other activities

conferenceRoomWithComputer (utilization = 0.58)

Size: 250 sf.

ACT1: facultyMeeting
ACT2: gradsMeetingForClass
ACT3: groupMeetingForResearch
ACT4: undergradsMeetingForClass

ACT1: 130 sf.  ACT2: 1.48 hrs  ACT3: 2.03 hrs  ACT4: 0.87 hrs

open time: 8 hrs
**Goal: Keeping utilization of all spaces ‘no wait’ or ‘adequate’**

**First option**

- Number: 2 → 3
- Size: 546 ft² → 389 ft²

**Second option (if necessary)**

preventing undergraduate students from using small conference rooms and letting them find any other conference rooms for their study on top of the first option
First option: activity-space mapping diagram

**Concepts formalization**

1-1: gradsHavingClass
1-2: undergradsHavingClass
2-1: gradsMeetingForClassWithComputers
2-2: undergradsMeetingForClassWithComputers
3-1: gradsMeetingForClass
3-2: undergradsMeetingForClass
4: groupMeetingForResearch
5-1: gradsStudying
5-2: undergradsStudying
6: facultyWorking
7: staffWorking
8: researchersWorking
9: facultyMeeting

**Process formalization**

- computerCluster
- classRoom
- smallConferenceRoomWithComputer
- conferenceRoomWithComputer
- privateOffice
- sharedOffice
- openOffice
- smallConferenceRoom
- largeConferenceRoom

**Case study**

Legend:

- **green** : No wait
- **yellow** : Adequate
- **red** : Inconvenient
- **gray** : Infeasible

24 links **automatically**

- **deleted links**
Second option: activity-space mapping diagram

Concepts formalization

1-1: gradsHavingClass
1-2: undergradsHavingClass
2-1: gradsMeetingForClassWithComputers
2-2: undergradsMeetingForClassWithComputers
3-1: gradsMeetingForClass
3-2: undergradsMeetingForClass
4: groupMeetingForResearch
5-1: gradsStudying
5-2: undergradsStudying
6: facultyWorking
7: staffWorking
8: researchersWorking
9: facultyMeeting

Process formalization

computerCluster
classRoom
smallConferenceRoomWithComputer
conferenceRoomWithComputer
privateOffice
sharedOffice
openOffice
smallConferenceRoom
largeConferenceRoom

Legend:
- **•**: No wait
- **○**: Adequate
- **□**: Inconvenient
- **■**: Infeasible

24 links automatically

- ****: deleted links
- ****: added links

0.82 -> 0.68
### Impacts of iterative refinement on space-use

#### Concepts formalization

<table>
<thead>
<tr>
<th>Space</th>
<th>Original settings</th>
<th>First option</th>
<th>Second option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer cluster</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Classroom</td>
<td>0.46</td>
<td>0.58</td>
<td>0.67</td>
</tr>
<tr>
<td>Small conference room with a computer</td>
<td>0.44</td>
<td>0.37</td>
<td>0.38</td>
</tr>
<tr>
<td>Conference room with a computer</td>
<td>0.58</td>
<td>0.48</td>
<td>0.63</td>
</tr>
<tr>
<td>Private office</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Shared office</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Open office</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Small conference room</td>
<td>0.99</td>
<td>0.82</td>
<td>0.68</td>
</tr>
<tr>
<td>Large conference room</td>
<td>0.74</td>
<td>0.48</td>
<td>0.63</td>
</tr>
</tbody>
</table>

#### Process formalization

#### Case study

[Diagram showing floor plans]
Discussion

- Conventional or manual method
  - Inconsistent
  - Unclear
  - Inefficient

- Proposed framework
  - Consistent
  - Clear
  - Efficient

Integrated concepts

Reasoning process

Activity-loaded spaces,
Activity-space mapping diagram
Darwiche (1989)’s <OAR> tuple + Akinci (2000)’s <S> component

Concepts formalization for space-use analysis

Object Activity Resources Spacing

User Action Spatial requirements

Policy on utilization Visualization

Mapping by rules Equipment

Automated space-use analysis process
Expected impacts on practice

- Impacts on space-use analysis
  - More consistent analysis
  - Clearer explanation
  - More efficient analysis
  → Supporting clients’ and architects’ decision-making about the design

- Impacts on sustainable design and construction
  - Input for various performance analysis tools
  - Having less space with better use
Thank you!

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