

FRAMEWORK FOR MODEL-BASED COMPETENCY MANAGEMENT FOR DESIGN IN PHYSICAL AND VIRTUAL WORLDS

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SUMMARY: *This paper presents the competency management approach for design in physical and virtual worlds. We suggest a framework with taxonomy for the identification, assessment and cataloguing of design competencies in the AEC (Architecture, Engineering and Construction) domain. Proposed competency management framework employs documented design results, especially digital models, including building information models (BIM), which can serve as a reference for the evidence of applied knowledge in the collaborative design.*

We explore differences and commonalities in competencies for the design in physical and virtual worlds by examining design input, process, and outcome. As the design of virtual worlds requires new skills and competencies, it also marginalises engineering aspects that depend on physical conditions; however, several design features, methodologies and even designs are common to projects in both worlds. The study is supported with a selection of designed artefacts from physical and virtual world projects. The results are important for the improvements in evaluation of design results, management of design process, virtual construction, knowledge, and human resources in the AEC; and the linkage between competencies for design in physical and virtual worlds.

KEYWORDS: *aec design, construction, virtual worlds, collaboration, competency management, digital models*

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1. INTRODUCTION

As professional domains develop, the need for a competitive workforce advantage requires better competency management. Consequently, we have witnessed intensified research, applications and commercial developments of ‘profile and competency management systems’ (PCMS). PCMS can be: (1) integrated into human resources management systems (e.g. SAP EICTM - Employee Interaction Centre, Oracle Human Resources Analytics); or (2) stand-alone competency management packages (i.e. WorkStreamTM).

The research on profiling and competencies especially brought to attention experts in the field of human resources (HR), employment and training on one side, and different domain experts on the other side. The corresponding studies cover basic research on the use of competencies for job performance, rating, impact, development of training and employment to meet critical competencies for specific roles (Strebel et al., 1999); while domain specific research targets the use of profiles for personalisation (Cerovsek & Padula, 2006), the use of competencies to domain specific jobs, such as construction project management (Dainty et al., 2005); while others focus on interdisciplinary uses, such as ontology for organisational competency management (Schmidt & Kunzmann, 2006), or competencies for virtual organisation breeding environments (Afsarmanesh et al., 2007).

1.1 What are competencies?

Competencies can be understood as *those characteristics that underlie a successful performance or behaviour at work* (Slivinski et al., 1996). Therefore, PCMS offerings aim to increase companies' levels and utilisation of knowledge, special talents and skills into overall competencies of individuals, groups and organisations. As illustrated in Fig. 1, only some, actionable (arrow), abilities and knowledge can be transformed into generic and professional competencies, which contribute to the unique competencies of an individual that turn a professional into a key player.

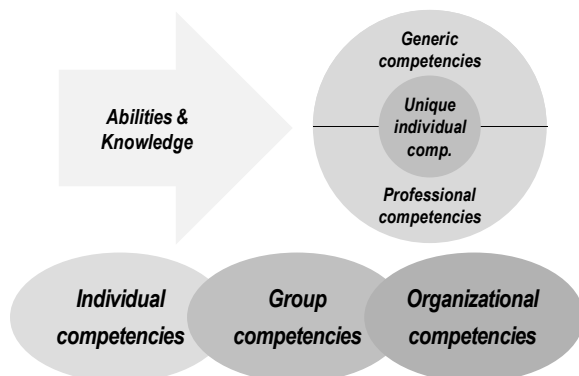


Fig. 1: Individuals' abilities and knowledge feed professional and generic competencies

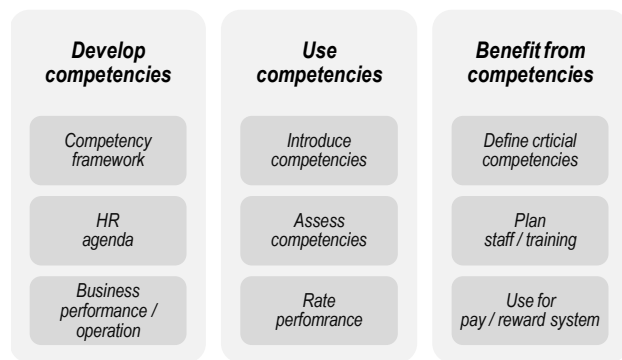


Fig. 2: Competencies research and development areas (derived from Strebler et al., 1997)

Unique individual competencies must be utilised in a broader, organisational context, which requires deeper studies. Fig. 2 illustrates related research topics on the development, use and benefits of competencies. The objective of PCMS is to identify, assess, measure, and monitor competencies. The core of PCMS is a competency framework for management of human resources (HR), knowledge and communication in business operations. Organisations use competencies to improve the performance and/or to extend current businesses operations. The business processes in different domains require different competencies, which must be managed adequately. Therefore, PCMS should meet *specific business* characters, subjects, processes, and artefacts.



Fig. 3: Design competencies are needed in the process of translation of design problems to design solutions

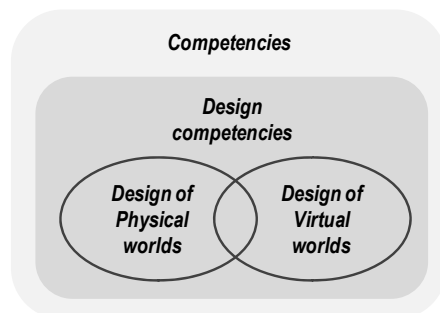


Fig. 4: The hierarchy and intersection of competencies for the design of physical worlds and virtual worlds

Our interest is in the AEC design competencies (Fig. 3), which are needed to translate design specification (design problem) into satisfactory design results (design solutions). We are interested in specifics and commonalities in design process (DP) in both, physical and virtual worlds (Fig. 4).

1.2 Problem statement

The main research questions addressed in this study are exclusively related to the AEC design:

- How can design competencies in physical and virtual projects be identified and classified?
- How can design competencies be assessed and measured in an objective and efficient way?
- How to implement design competency management into the software systems like PCMS?
- To what extent can designed digital models represent the competencies of the AEC practitioners?
- Are design competencies interoperable and/or transferable between physical and virtual projects?

2. METHODOLOGY

The methodology was conducted in 3 main steps: (1) literature survey, (2) review of design success indicators, and (3) validation through case studies from project tender competitions and student projects.

2.1 Literature survey

The literature review covered three main topics: competencies, design theories, and the connectivity between physical and virtual environments. The study of competencies focused on competency frameworks, use of competencies and best utilisation of competencies.

Furthermore, we studied competencies within specific applications, especially in the field of AEC, and in particular, design processes for both, physical, and virtual worlds.

2.2 Study of design success indicators

We have examined conditions and criteria for the selection of candidates and evaluation of the design solutions in competition entries and in student projects. We studied the design requirements and results in terms of urban context, effect of architectural solutions, functionality and technical solutions. We collected design specifications and results from student projects, and publicly available tender documentation for 10 typical projects.

2.3 Validation through case studies

The study is supported with a selection of designed artefacts from physical and virtual world projects. The projects were assessed against the design success criteria, as set by jury experts. We explore commonalities and differences for the design of physical and virtual projects.

The information processes that result in models and support material process (Bjoerk, 1998) have no role in the design of virtual worlds. However, digital models can be used as a common denominator for the analysis of competencies that may be useful for both worlds. Using the IPO (input design process), Table 1 summarises important criteria for the evaluation of design processes and related competencies.

Table 1: Issues in 'physical world project' and 'virtual world project'

| | Physical world project | Virtual world project |
|---------|------------------------------------|---------------------------------------|
| Input | Direct requirements for a building | Direct requirements for virtual model |
| Process | Information and material | Information |
| Control | Whole-building design issues | Software presentation and use issues |
| | AEC health and safety standards | Software industry standards |
| | Project team and office standards | Project team and office standards |
| Output | Facility inhabited by users | Virtual model inhabited by avatars |

2.4 Structure of the paper

In Section 3, we analyse the role of models and environments for design in physical and virtual worlds. Furthermore, we observe the design process as a learning opportunity. We conclude the section with an analysis of the evidence for competencies, where we make a link between design competency evidence and design re-use.

In Section 4, we develop the AEC competency management theory. For this purpose, we develop a taxonomy and a competency management schema, which is the core of the competency management framework. We also outline prototype implementation approach.

In Section 5, we validate the theory through two sets of representative case studies covering physical world and virtual world projects, with rich illustrations.

Finally, in Section 6, we discuss the competency theory and its application in case studies. We end with conclusions and future work towards the introduction of competencies for the design in physical and virtual worlds.

3. DESIGN COMPETENCIES FOR PHYSICAL AND VIRTUAL WORLDS

3.1 Digital worlds, environments, and models in design

There are many design theories; however, researchers cannot agree what exactly design is (Love, 2000). We use two definitions of design that are important for our further exclusive focus on AEC design:

- Galle (1996) described design as a rationalisation of decisions that lead to the design solution. As long as the design idea remains in the mind, it cannot be evaluated.
- Lawson (1997) said that design is as much as about finding problems as it is solving them. It is important to be aware that design solutions generate new problems in the same domain or in other domains.

Any realization of design that involves more than one person requires externalisation to communicate design to other project stakeholders. Kroes (2002) observed the design process and termed design input and output as 'functional description' and 'structural description' respectively. Accordingly, digital models are used to externalise, structuralize and realise project ideas that travel through virtual to physical worlds (see Fig. 5 below).

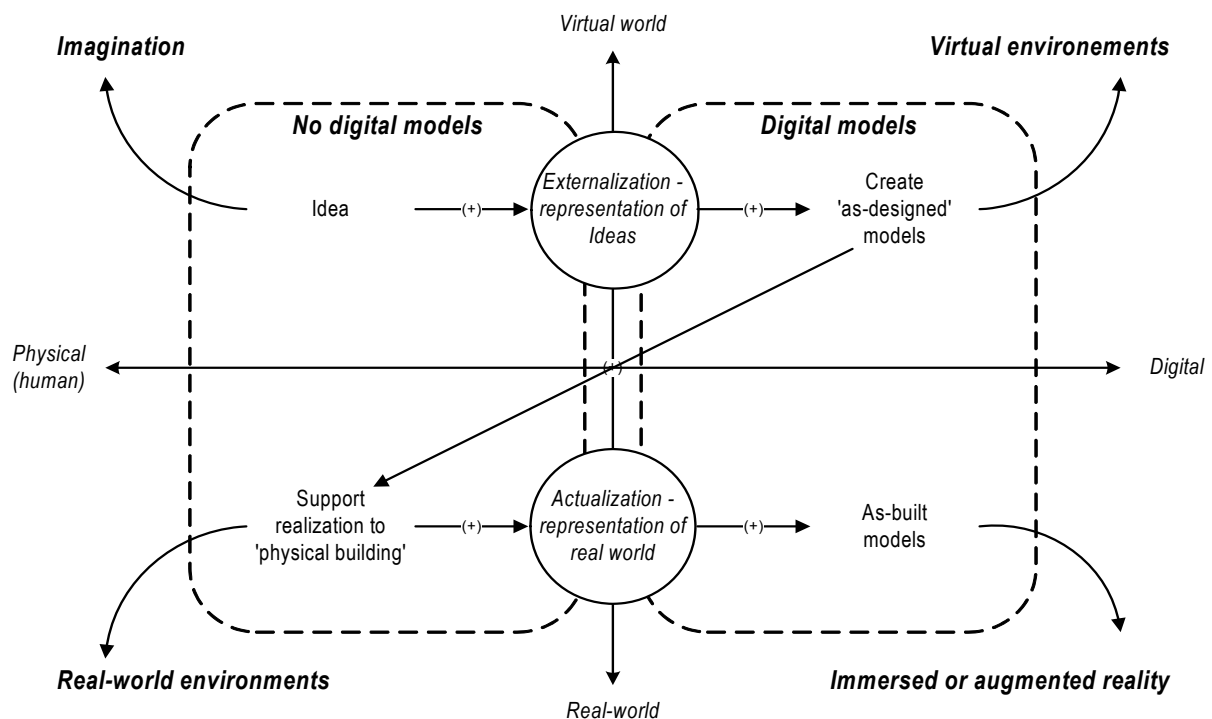


Fig. 5: The realization of project ideas from human imagination, virtual environments to real worlds. The same procedure also applies to the constructability studies that use virtual design and construction simulations.

The realization of AEC design connects virtual and physical worlds through the following steps: (1) a designer responds to project design specification with design ideas; (2) digital models are used to externalise design ideas; (3) digital models are further used to support realisation of materialized building in a physical environment; and (4) a digital model can be actualised to as-built model, which can be used (e.g. augmented) in mixed realities.

The approach is illustrated in Fig. 6 that divides worlds to 4 types: a horizontal line separates intangible-virtual (top), and tangible-physical (bottom) world; and a vertical line separates the human (left) from computer (right) world. This gives us four systems: (1) the imagination use the cognitive abilities; (2) virtual environments use computers representations, which may be self-sufficient, and not necessarily suitable for human-computer interaction; (3) the physical environment exists without computers; and (4) virtual and physical worlds are connected.

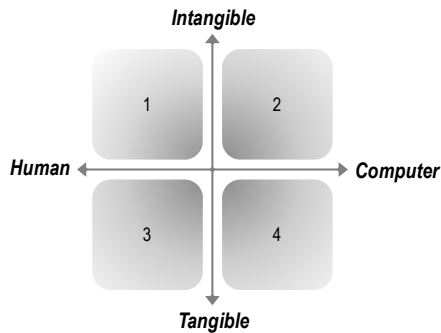


Fig. 6: Division of worlds: horizontal line divides tangible (real) and intangible worlds; vertical line divides human and computer worlds, which do contain digital models.

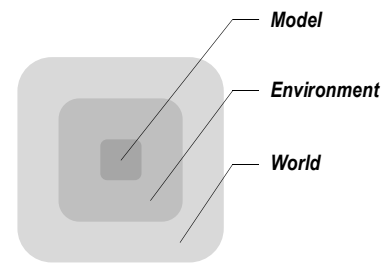


Fig. 7: Assumed dependencies between model, environment and world. We observe competencies needed to place a model into the environment.

Fig. 7 illustrates the whole-part relationship between worlds, environments and models. However, we are interested in the differences and commonalities between the physical (real) and the virtual:

- *Physical vs. virtual worlds.* The main difference between physical and virtual worlds is that laws of physics are suspended in the virtual worlds. However, there are nevertheless other laws and limitations which provide a design context for what may be called a ‘virtual tectonic’ (Frampton et al., 1995). Both worlds do share some common characteristics because virtual worlds usually mimic physical worlds.
- *Physical vs. virtual environment.* Virtual environments, compared to physical ones, are real in other ways to their designers if they build, work, and communicate in them; while there is no gravity, climate, or materiality, the design form of virtual environments can be subjected to other forces (Zupancic & Mullins, 2007). Both environments depend on models, which interpret and change the environment.
- *Physical vs. virtual models.* Virtual models are used as representations to reflect only some properties, which are required to address the issues that are relevant to a specific purpose. As the design process evolves, virtual models are actualised to reflect specific project needs, and finally, they may reflect appearance of a built facility. Both types of models represent only properties that are of creator’s interests.

Any *virtual model* can be characterised by three facts:

- A virtual model *has no mass or forces*. As there is no mass, gravity is suspended.
- A virtual model *is not tangible*. Imagination and sight is essential for the perception of models.
- A virtual model *is a representation*. A virtual model is always an incomplete representation.

‘Virtual world,’ ‘virtual environment’ and ‘virtual model’ are commonly accepted terms to denote intangible, non-physical, computer (digital) representations with a specific purpose (i.e. analysis, visualisation, and simulation). The term *digital model* is commonly used in AEC as a broader term for various types of models produced by computer (i.e. 3D models, building information models, structural models, and other AEC-specific models). Digital models document design solutions and may represent design competencies. Digital models may represent many aspects of buildings, which document responses to design requirements and solutions. Models can be developed for pre-construction, during construction, and post-construction. If the constructed physical (real) buildings and relation to a digital model are observed, there are 2 types of models:

- ‘As-designed’ models, developed before materialisation in the pre-construction phase; and
- ‘As-built’ models, developed in the post construction phase.

The relationship between physical and virtual worlds can be described with representations. Representations, like symbols, helped people to refer to things, organise and communicate information about them. A representation can be understood as a reflection of some properties that are typical to the referred object. The gap between physical and virtual worlds is often illustrated with the adverb 'realistic' for representations that can be made real. However, virtual environments provide a new context for architectural design and the future careers of today's students – that of design in virtual space. A virtual world can be connected to the physical world either conceptually, or through immersive interfaces. If we combine figures Fig. 6 and Fig.7 we get figure bellow.

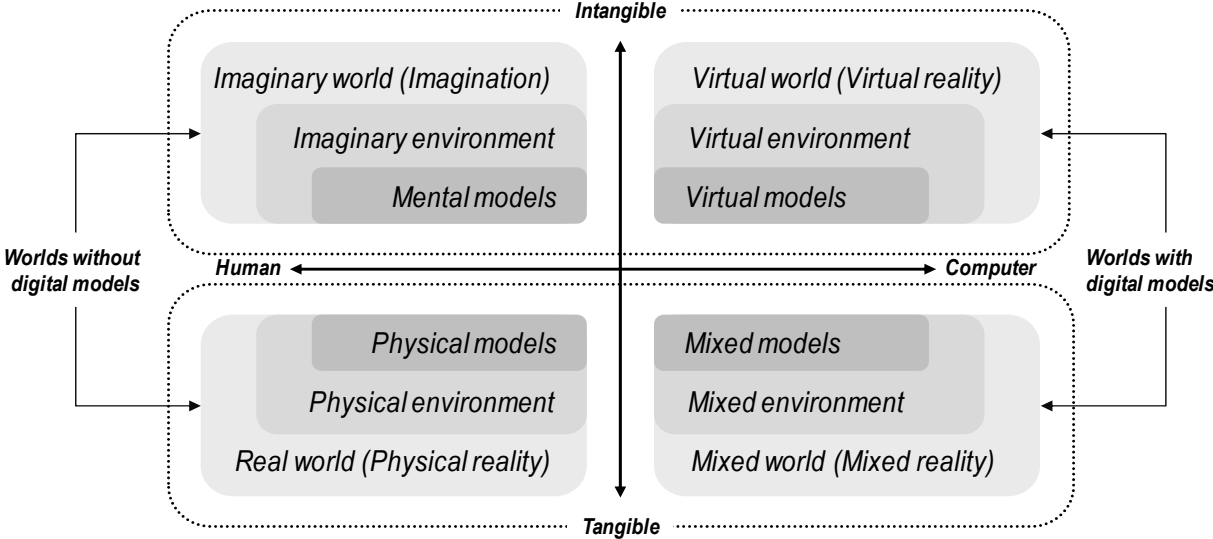


Fig. 8: The models, environment and worlds related to the use of digital models in AEC (Fig.6 + Fig.7)

Table 2 provides a detailed review of representations used in physical (real-world) and virtual projects, which can be classified according to the above described concepts: pre- or post-construction; and tangibility of models.

Table 2: The relationships between physical and virtual environments, and models.

| Project phase | World (model) | Physical world | Virtual world |
|-------------------|--|---|--|
| Pre-construction | Intangible (as-designed digital model) | As-designed digital model <i>represents</i> physical environment (Fruchter, 1999) | As-designed digital model <i>is a part of</i> a virtual environment (Fröst, 2002) |
| | Tangible (scale functional) | Scale physical model <i>represents (is used for)</i> a virtual/physical environment (Osman, 2001) | Physical environment <i>is transformed to</i> a virtual environment (Fradkin et al., 1999) |
| Post-construction | Intangible (as-built digital model) | As-built digital model <i>represents</i> a physical environment (Park et al., 2007) | As-built digital model <i>is a part of</i> the virtual environment (Timm & Kamat, 2008) |
| | Tangible (functional) | Physical environment <i>represents</i> as-designed model (Frampton et al, 1995) | Physical environment <i>is immersed/augmented</i> with virtual environment (Shin et al., 2008) |

3.2 Design competencies and learning opportunities

The design competencies can be observed through the following viewpoints:

- Context: surrounding affecting design and vice versa.
- Form: visual appearance.
- Function: user needs and other requirements.
- Technical solutions: Technical solutions that match desired form, function and context.

We assume that *every design is a learning process*. The learning processes can be steered individually, in a group or institutionally (Schmidt & Kunzmann, 2006). *In the learning process of design, we can distinguish three main steps to competencies: learning, knowing and doing (Fig. 9).*

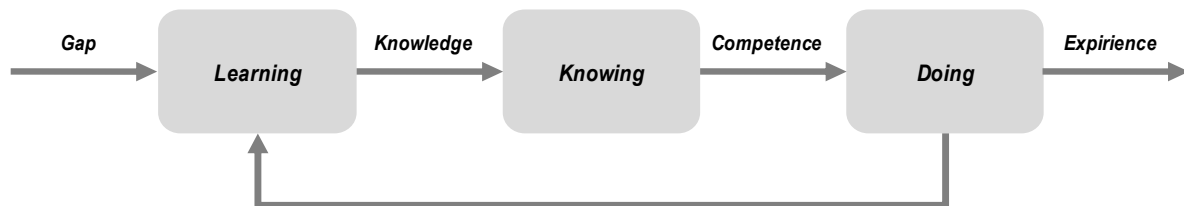


Fig. 9: The connection between learning, knowing and doing in the design process

For the implementation of competency management in AEC design, we must be able to capture the gaps in the design competencies that prevent individuals or groups to successfully cope with the design problem. Table 3 first classifies generic competencies that can be attached to an individual, his role in a group and organisation.

Table 3: Design competencies for individual, group and organisational work

| | Physical world project | Virtual world project |
|-----------------|----------------------------|--|
| Individual work | Independence | Independence (more freedom) |
| | Analyses | Analyses (limited) |
| | Synthesis | Synthesis (equally important) |
| | Creativity | Creativity (more freedom) |
| | Quality | Quality (different standards) |
| | Standard procedures | Standards procedures (important) |
| | Error level and frequency | The effect of errors is less devastating |
| Group | Team building | Team building (important, roles differ) |
| | Lead / manage team | Lead/manage team (equally important) |
| | Collaborative teamwork | Collaborative teamwork (limited) |
| | Communication skills | Communication skills (limited) |
| | Social networking | Social networking (important) |
| | Interpersonal skills | Interpersonal skills (very important) |
| | Time management | Time management (tighter schedule) |
| Organisation | Knowledge transfer | Knowledge transfer |
| | Business operation | Business operation |
| | Critical core competencies | Critical core competencies |

Table 3 focuses exclusively on the generic competencies for individual and collaborative work. However, the extent of collaboration differs in AEC design projects and can be measured with circumference of the collaboration, which must be observed through the process and process results (Cerovsek & Katranuschkov, 2006).

We can identify three main *areas of evidences* for design competencies:

- *Organisation*: the organisation depends on the project team, institutional and organisational boundaries and specific project requirements.
- *Design process*: the process depends on the design problem and interdisciplinary teamwork in problem solving. However, a good design process is not necessarily needed for a successful design results.
- *Design results*: models, as design process results, can provide essential information on the processes and organisation that utilized design competencies.

Table 4 gives an overview of overall competencies, which were established on the basis of review of the design theories, educational programs, professional qualifications and success criteria for competition projects. While Table 3 provides criteria that can be attributed generically, Table 4 provides criteria that can be attributed to design results and also implicitly judge the design competencies of designers. Hence, areas of evidences may link individual criterion from Table 3 to the design qualities that represent design competencies in Table 4.

Table 4: The overall design competencies

| Issue | Physical world project | Virtual world |
|--------------------|--|--|
| Context | Placement in environment (socio-physical) | Placement in environment (socio-virtual) |
| | Height and footprint limits (physical-fixed) | Height and footprint limits (virtual-flexible) |
| | Inclusion of surroundings | Inclusion of surroundings (real-time changes) |
| | Segmentation of volumes | Segmentation of volumes (art. visual effects) |
| | View axes | View axes (can be programmatically fixed) |
| Form | Composition | Composition |
| | Sculpture-space interrelation | Sculpture-space interrelation |
| | Diversity level | Diversity level |
| | Light and material selection | Light and material selection |
| | Transparency | Transparency (aligned with scenes) |
| Function | Accessibility and activity model | Accessibility and activity model (characters) |
| | Flexibility | Flexibility (virtualisation) |
| | Connectivity & organisation of spaces | Con. & org. of spaces (circular or limited) |
| | Communications | Communications (depend on characters) |
| | Technical domain function ^(a) | Technical domain function ^(b) |
| Technical solution | Structural efficiency | Structural efficiency (character dimensions) |
| | Constructability and maintainability | Implementation in the software systems |
| | Energy efficiency | Energy efficiency (processor energy) |
| | Cost efficiency | Cost efficiency (hardware and software) |
| | Time efficiency | Time efficiency |

^(a) Also covers technical problems, structural engineering, mechanical, electrical and plumbing (MEP)

^(b) Related to presentation and purpose of the model

4. THE AEC COMPETENCY MANAGEMENT FRAMEWORK

4.1 Theoretical premises

The assumption has been made that any competency can be determined through observation. The competency is as such observational report, which is defined by the observer, observed subject and interpretation:

- The competencies of individuals, groups and organisations are connected.
- The competencies are identifiable from design results, which are digital models used in the design.
- The observer influences the observation with his/her perceptual abilities and background knowledge.
- The subject of observation is defined, if and only if the attention and level of detail of observations are also ubiquitously defined.
- The interpretation is a consistent and logical assessment of design solution (output) against the context, form, function and technical solution criteria, which are determined with the design problem (input).

4.2 AEC competency framework schema

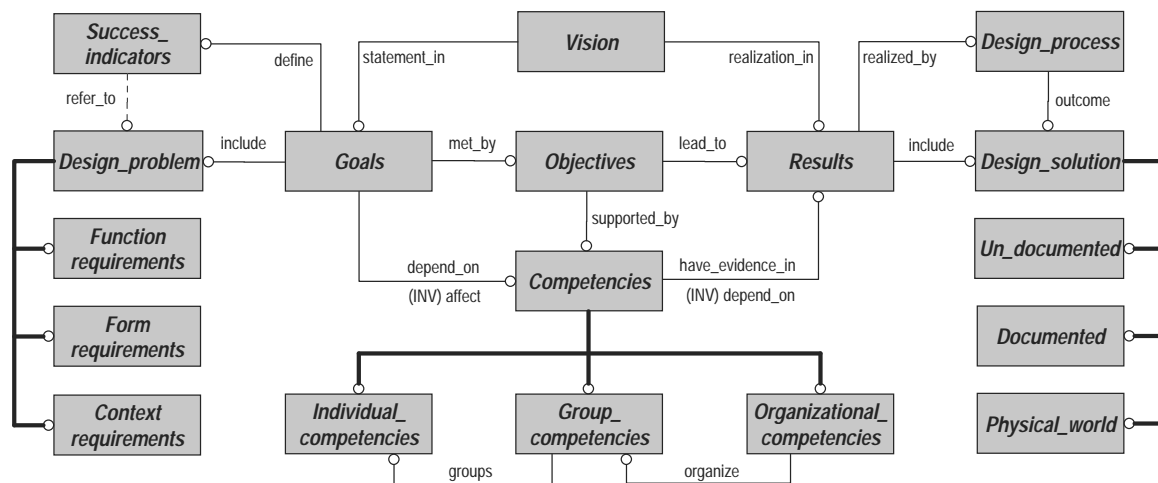


Fig. 10: The Competency management schema

AEC projects or organisations must have clear vision and goals that are achievable through objectives. Goals are defined by success indicators that refer to a design problem with requirements for context, form and function. Individual, group and organisational competencies (Fig. 11) lead to results that are realised by the design process, which leads to design solutions that can be undocumented, document or realized in the physical form.

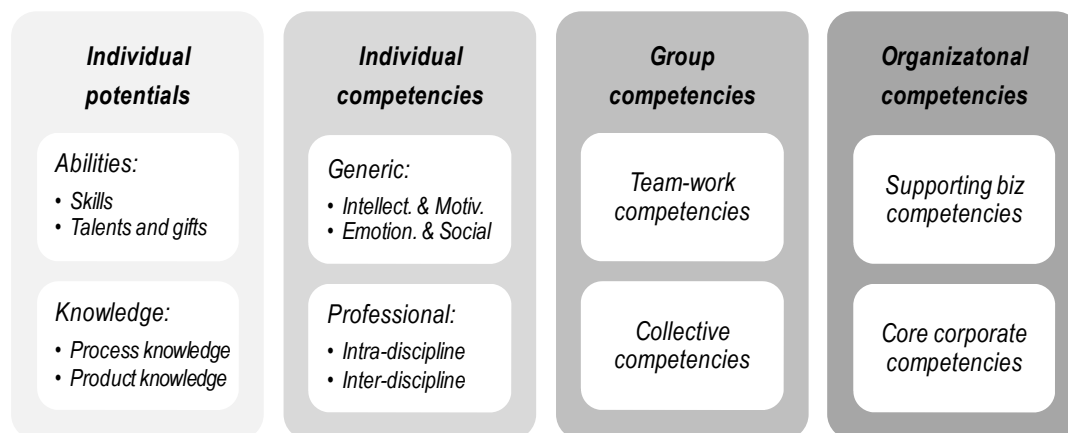


Fig. 11: The taxonomy of transformation of individual potentials to organisational competencies

4.3 Competency management implementation

Every design solution reflects competencies of an individual. Individual competencies may be used at individual work, in a group or organization (Fig. 11). The design group in a virtual world project is usually much smaller, but despite this fact we can draw some commonalities to the physical world project. As competencies throughout the design process, we also obtain valuable information on design competencies for future projects.

Actors, principal uses cases, and their triggers that are important for the implementation are identified:

- *Actors.* These are project design team members, educators, managers.
- *Use cases.* The following main use cases are:
 - Manage profiles of individuals, groups and organisations.
 - Capture knowledge about design processes and process results.
 - Identify and classify features from design results. (Table 4 & context, form, function)
 - Assess Competencies according to the requirements and
 - Manage competencies for pay/reward, planning of personnel, etc.
- *Triggers.* The events that trigger the execution of listed use case on the PCMS platform are executed manually or, if attached to another system, can trigger actions on defined set of states.

The profile and competency management systems can be integrated into three main types of systems:

- *AEC competency and human resources systems* are software systems that are used to manage competencies in organisations to improve business performance and support strategic decision making.
- *AEC information retrieval systems* should support tracking of competencies by enabling query processing. A complete solution that would allow identification of competencies through models would require tailored formulation, execution and retrieval of model based search results (Cerovsek, 2008).
- *Technology Enhanced Learning (TEL)* systems could be implemented as BIM-enhanced learning systems to serve to a variety of learning audiences. Models can be an excellent source of information for learning about buildings and building project phases.

Fig. 12: A 5-step Procedure for identification of design competencies

STEP 1: For each form of interest:

Identify required context and assign to current form

Identify required function and assign to form

Identify inter-relationships (meaning)

STEP 2: For each observed function:

Identify technical solution and assign to current function

If the function is derived from form, go to STEP 1 to find related forms

STEP 3: For each technical solution:

Compare required function against provided function of a technical solution

If the solution is not assigned to a function, go to STEP2 to find related functions

STEP 4: For each form/function/technical solutions:

Identify required competencies and underlying processes and process the resulting knowledge

STEP 5: For each Competency

Assign competencies to an individual, group or organisation

Iterate: Rank design solutions based on comparison of Required vs. Provided qualities.

** For Steps 1-4 use Table 4, for Step 5 use Table 3*

5. VALIDATION THROUGH CASE STUDIES

The approach is tested with two representative case studies from physical and two representative case studies from virtual environments projects. The objective is to manually test the approach prior to implementation in software systems. In order to achieve adequate objectivity, a two-iteration evaluation process has been used:

- 1st iteration: each competency is classified as poor, sufficient or excellent.
- 2nd iteration: the evaluation is corrected with ‘-’ and ‘+’ intermediate values resulting in a final scale for evaluation marking from 1 to 7: 1) POOR, 2) Poor +, 3) Sufficient -, 4) SUFFICIENT, 5) Sufficient +, 6) Excellent -, 7) EXCELLENT. A higher evaluation mark also means a higher level of competencies. The results can be numerically presented as percentages or numerals from 1 to 7 (Slak & Kilar, 2008b).

Graphical presentation of the competency evaluation is shown in the form of a radial diagram (Fig. 14), where quadrants present relevant issues from Table 4: 1) Context, 2) Form, 3) Function and 4) Technical solution. Each competency from Table 4 is presented with a marked radial axis. The line that connects evaluations for all competencies forms a radial *score line* that illustrates the wholeness as interpretation criteria (Table 5). The overall wholeness (*dashed line*) is presented as a circle with the radius equal to evaluation average (Fig. 4).

Table 5: The interpretation criteria

| Issue | Physical world project | Virtual world project |
|---------------------|-----------------------------|--|
| Wholeness | Architectural language | Designers’ creativity is completely open |
| Inter-relationships | Aesthetic expression | Aesthetic expression is unlimited |
| | Presentation communications | Presentation communications |
| | Design originality | Depends on the purpose of the model |
| | Cultural sustainability | Cultural sustainability (virtual) |

5.1 Case study: design results in physical environments

The proposed approach for competency management was applied to two physical world competition projects for the construction of a skyscraper in Ljubljana (Ljubljana’s new Northern Portal–west side), which was carried out in 2007 (ZAPS, 2007; Slak & Kilar, 2008a). The competition jury awarded two equal 2nd prizes which have been used as our test examples (Fig. 13 and Fig. 15).

Ljubljana's new Northern Portal is exceptionally important since it is located in a very sensitive context and represents a location with a high concentration of people and important content. The competition documentation required a tall building, placed close to the already-existing skyscraper, and a several-metre shift of the façade in the stories above the 4th story, which both projects solved by using long cantilevered balconies.

The decision of the jury was based on different criteria; of which, the competency of the project teams were not explicitly addressed. Using the proposed competency management approach, it is nevertheless possible to quantify the competencies of design experts as well as their expertise in the AEC (Architecture, Engineering and Construction) domain.

For both selected buildings, the overall design competencies were carefully evaluated, based on extensive competition documentation by examining the design input, process, and outcomes. Both buildings are similar in size and content, they are placed in the same context and they had the same design requirements given in the tender documentation.

In the evaluation process, we explored differences and commonalities in competencies for the design as well as established several specific advantages and disadvantages that significantly influenced the final scores. The detailed presentation and argumentation of the selected parameters is out of the scope of this paper; in the following paragraphs, only the short summary of the evaluation results will be presented.

5.1.1 Competition entry N°1

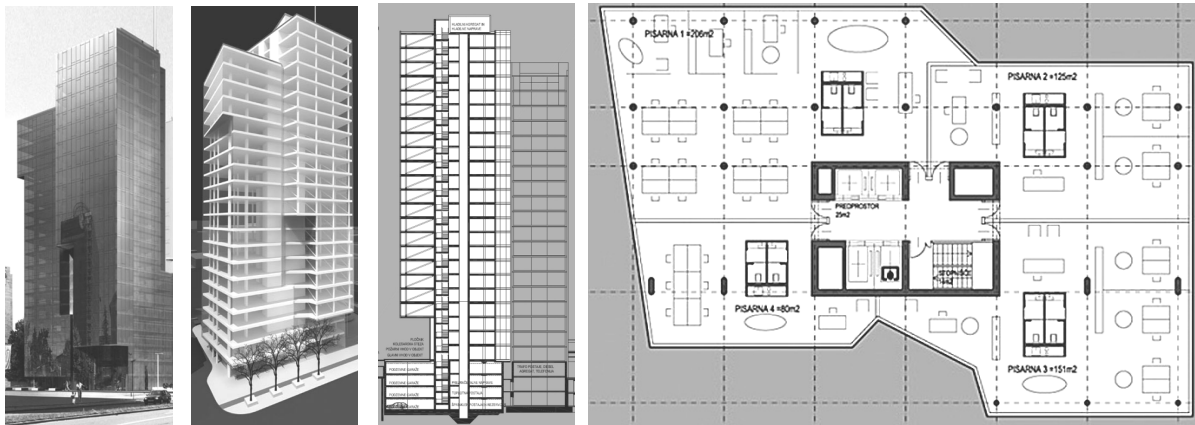


Fig. 13: Competition project No. 1 for Ljubljana's Northern Portal - west side

Table 6: The overall design competencies for competition project N°1

| Issue | Physical world project | Score | Average |
|--------------------|--|---------------|-----------------------|
| Context | Placement in environment (socio-physical) | 6 | 5.8 (- Excellent) |
| | Height and footprint limits (physical-fixed) | 5 | |
| | Inclusion of surroundings | 6 | |
| | Segmentation of volumes | 5 | |
| | View axes | 7 | |
| Form | Composition | 7 | 6.4 (Excellent) |
| | Sculpture - space interrelation | 7 | |
| | Diversity level | 5 | |
| | Light and material selection | 6 | |
| | Transparency | 7 | |
| Function | Accessibility and activity model | 5 | 3.4 (- Sufficient) |
| | Flexibility | 2 | |
| | Connectivity & organisation of spaces | 3 | |
| | Communications | 3 | |
| | Technical domain function ^(a) | 4 | |
| Technical solution | Structural efficiency | 5 | 4.8 (+Sufficient) |
| | Constructability and maintainability | 5 | |
| | Energy efficiency | 4 | |
| | Cost efficiency | 5 | |
| | Time efficiency | 5 | |
| | | Total average | 5.1 (+ Sufficient) |

Evaluation summary (wholeness/interrelation):

- The solution recognises the variety of existing architectural issues and offers an undisturbed urban solution, which takes into account given vertical limits and retains a respectful relation to the existing architectural heritage by withholding existing architectural expression.
- The intentionality of design result does not create a new ‘sign’ in space, but rather forms an interesting complementary appearance with new verticals and volumes.
- Both portal entry towers are recognised as urban symbols, but they are not forming twins, but rather an asymmetric composition.
- The business part consists of 15 stories. The premises of different depths are positioned around the central core. The residential part consists of five upper stories with apartments of different sizes.
- This project has the most excessive console parts as well as noticeable irregularities in the plan, which is also visible as a distinctive discontinuity in the building height.
- The project is designed as monolithic reinforced concrete structure with central RC core surrounded by columns.
- The columns are made of reinforced concrete, while at lower stories they are steel tubes filled with concrete. The slabs are made of reinforced or pre-stressed concrete without any visible beams and girders. The façade consists of glass and aluminium alloy supporting frames.

Fig. 14 graphically presents the evaluation of competencies from the Table 6. The circle is divided into four quadrants: (1st) Context, (2nd) Form, (3rd) Function, and (4th) Technical solutions. Each quadrant comprises 5 competencies that are presented with their individual radial axes. The *score line* connects the evaluations of different competencies and illustrates the wholeness, or coverage of the solutions. The overall wholeness of the design result (competencies) is represented with the dashed circle (radius is total average from Table 6).

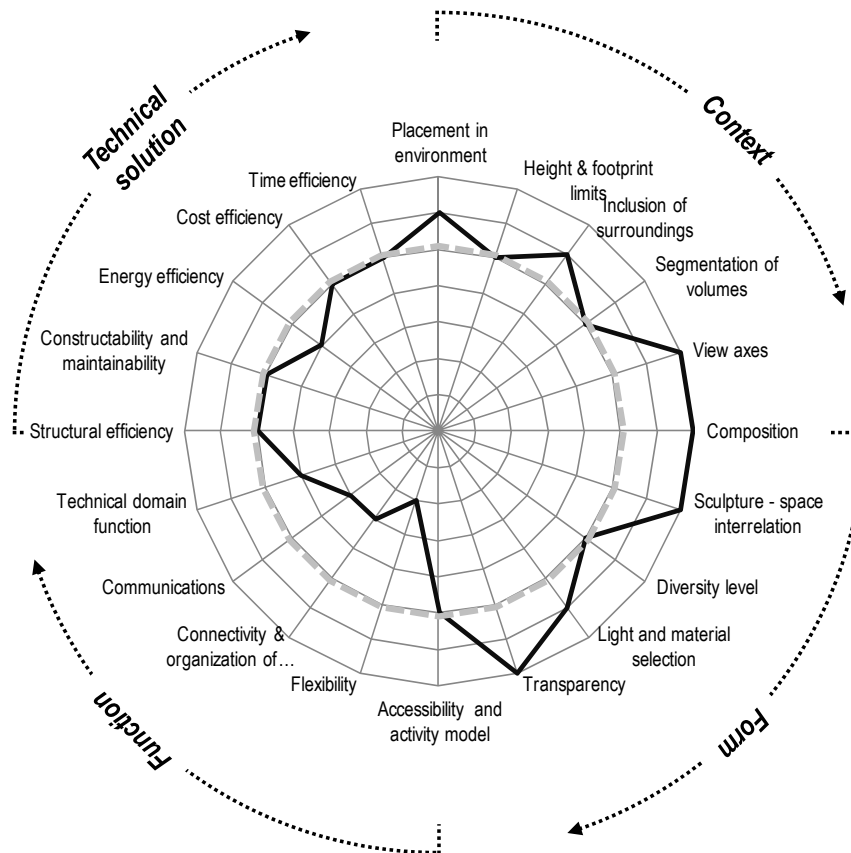


Fig. 14: Competency evaluation quadrants (solid line: score line, dashed: average score) for project No. 1

5.1.2 Competition entry N°2

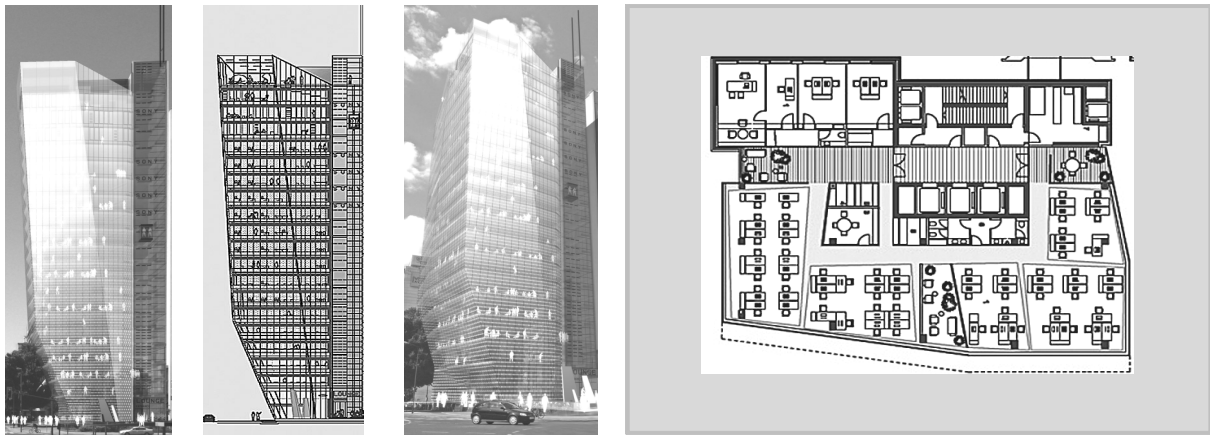


Fig. 15: Competition project No. 2 for Ljubljana's northern portal - east side

Table 7: The overall design competencies for competition project N°2

| Issue | Physical world project | Score | Average |
|--------------------|--|---------------|-----------------------|
| Context | Placement in environment (socio-physical) | 5 | 5.2 (+ Sufficient) |
| | Height and footprint limits (physical-fixed) | 4 | |
| | Inclusion of surroundings | 5 | |
| | Segmentation of volumes | 6 | |
| | View axes | 6 | |
| Form | Composition | 7 | 6.4 (Excellent) |
| | Sculpture - space interrelation | 5 | |
| | Diversity level | 7 | |
| | Light and material selection | 6 | |
| | Transparency | 7 | |
| Function | Accessibility and activity model | 6 | 4.8 (+ Sufficient) |
| | Flexibility | 5 | |
| | Connectivity & organisation of spaces | 4 | |
| | Communications | 4 | |
| | Technical domain function ^(a) | 5 | |
| Technical solution | Structural efficiency | 3 | 3.8 (- Sufficient) |
| | Constructability and maintainability | 3 | |
| | Energy efficiency | 4 | |
| | Cost efficiency | 4 | |
| | Time efficiency | 5 | |
| | | Total average | 5.0 (+ Sufficient) |

Evaluation summary (wholeness/interrelation):

- The solution suggests that the northern portal idea should be recognised as project that connects the space on all four intersection corners and not only as a dialog between east and west side corners.
- The main design component becomes the interpreted overhanging motive of a console part of the neighbouring multi-story building, which is expressed as dynamic overhanging volume over the main road.
- The idea of crystalline towers on both corners should create a ‘crystal canyon of urban stalagmites.’ From the vertical caesurae, the tower begins to dynamically change the shape on the northern and western façades, while the southern and western façade remain vertical.
- The overhangs are more extensive up to the sixth floor, while in higher stories the overhangs are minimal.
- The floor plan composition foresees the possibility of forming two separate blocks for residential and business contexts.
- In the upper stories, the business part is transformed into boarding house program with larger business spaces.
- The outward inclined shape, in the architectural sense, provokes a feeling of instability. For this reason, the centre of masses is unfortunately shifted away from the centre of stiffness.
- The long console overhangs are solved with inclined steel reinforced concrete columns, which might not be adequately connected with concrete core.
- The heating and ventilation technology is based on the inclusion of underground water and each story is designed as partially independent unit.
- The façade is designed as three layer glass blinds and additional inner glass. The design is energetically innovative and ecological.

A side-by-side comparison of the two competition entries is shown in Figs. 16 and 17. A quick visual inspection indicates that the first solution (Competition No. 1) is stronger in technical solutions (4th quadrant) (see Fig. 14.), on the other side Competition No.2 is stronger in form (3rd quadrant), while the averaged wholeness of both solutions is approximately the same (see dashed lines in Fig. 16 and 17). If necessary the average of the individual quadrants can also ease the comparison between particular issues of solutions.

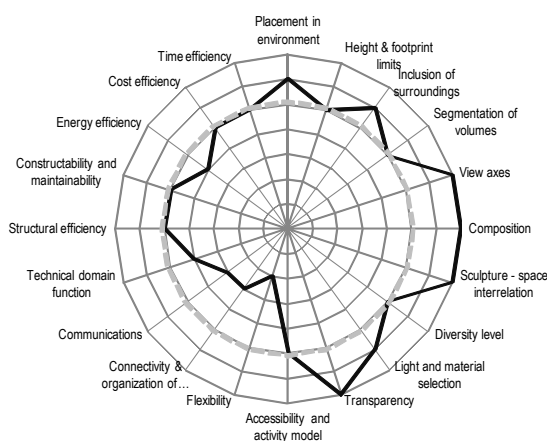


Fig. 16: Competition project No. 1
(solid line: score line, dashed: average score)

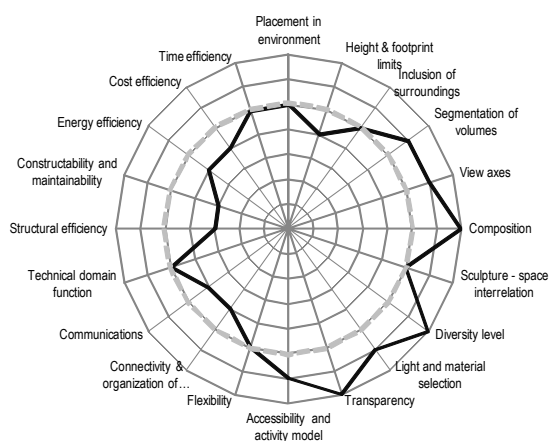


Fig. 17: Competition project No. 2
(solid line: score line, dashed: average score)

5.2 Case study: design results in virtual environments

The two examples from the virtual world are chosen from student work, both dealing with the questions of ‘inhabiting virtual environments’ at the Faculty of Architecture of the University of Ljubljana. Both cases start with the idea of transforming some ideas from the physical world for the user of virtuality, exploring the freedom of this transformation.

Both case studies combine a physical world simulation with their virtual world exploration. For the purpose of the present discourse, only their virtual aspect is evaluated. Inhabiting virtual environments requires identification with virtual places/flows; thus, both projects play with both physical and virtual experiences of the potential user. The first example is more individually focused, prepared within the design studio context, while the second one represents one of the results from an international intensive programme (10-day) student workshop.

5.2.1 Virtualisation of public space

The first example (Kaufmann, 2007) introduces an interface connecting the public physical environment in Ljubljana with the virtual representation and free interpretation of Gdansk and its architectural identity. It follows the idea of transforming the existing physical gap in the urban architectural environment, manifesting itself as an entrance to nowhere, into a portal to another place in virtual reality. Thus the physical building itself becomes a portal to VR.

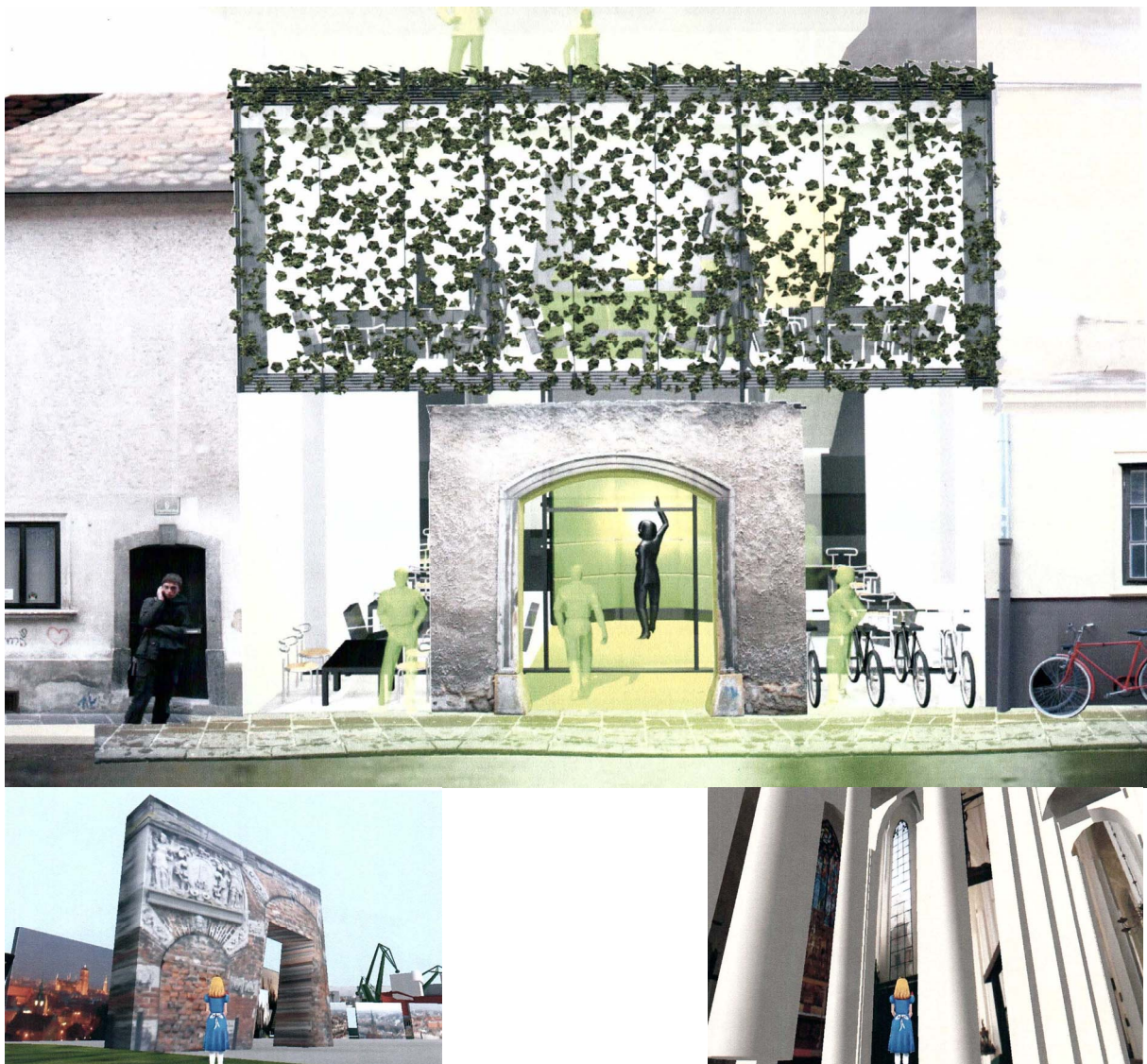


Fig. 18: Student project No. 1 – Virtualisation of physical space (by courtesy of M. Kaufmann)

Table 8: The overall design competencies for the design of Virtualisation of physical world

| Issue | Virtual world project | Score | Average |
|--------------------|---|---------------|-------------------|
| Context | Placement in environment (socio-virtual) | 5 | 5.8 (+Sufficient) |
| | Height and footprint limits (virtual-flexible) | 6 | |
| | Inclusion of surroundings (real-time changes) | 7 | |
| | Segmentation of volumes (art. visual effects) | 6 | |
| | View axes (can be programmatically fixed) | 5 | |
| Form | Composition | 6 | 6.0 (-Excellent) |
| | Sculpture - space interrelation | 6 | |
| | Diversity level | 7 | |
| | Light and material selection | 6 | |
| | Transparency (aligned with scenes) | 5 | |
| Function | Accessibility and activity model (characters) | 5 | 4.2(Sufficient) |
| | Flexibility (virtualisation) | 6 | |
| | Con. & org. of spaces (circular or limited) | 5 | |
| | Communications (depend on characters) | 3 | |
| | Technical domain function ^(b) | 2 | |
| Technical solution | Structural efficiency (character dimensions) | 5 | 5.0 (+Sufficient) |
| | Constructability and maintainability (software) | 6 | |
| | Energy efficiency (processor energy) | 3 | |
| | Cost efficiency (hardware and software) | 6 | |
| | Time efficiency | 5 | |
| | | Total average | 5.3 (+Sufficient) |

Evaluation summary (wholeness/interrelations):

- Openness of designers' creativity represents the intertwinement of a wide diversity of design factors.
- Aesthetic expression depends on the aspects focused on the specific part of the project.
- The presentation is interactive, fully explorable by the potential user; though his/her own design contributions are not enabled.
- The design originality is represented by reinterpretation of architectural identity.
- The project itself is developed to contributing to the awareness that culturally sustainable solutions are not only an issue of physical but also virtual worlds .

5.2.2 Inhabiting virtual environments

The second example (Zupančič & Juvančič, 2008) takes a selected physical starting point as the first conceptual reference only to think about scale-related questions as well as the existence of the natural elements in the selected physical location.

The next step represents relatively independent virtual playing with forms, developing a solution, which could lead to its physical realisation and application. It is even based on structural logic; it then fully turns into the openness of virtuality: dropping the structural logic away, playing with the identity of a natural element and its relation to human scale.

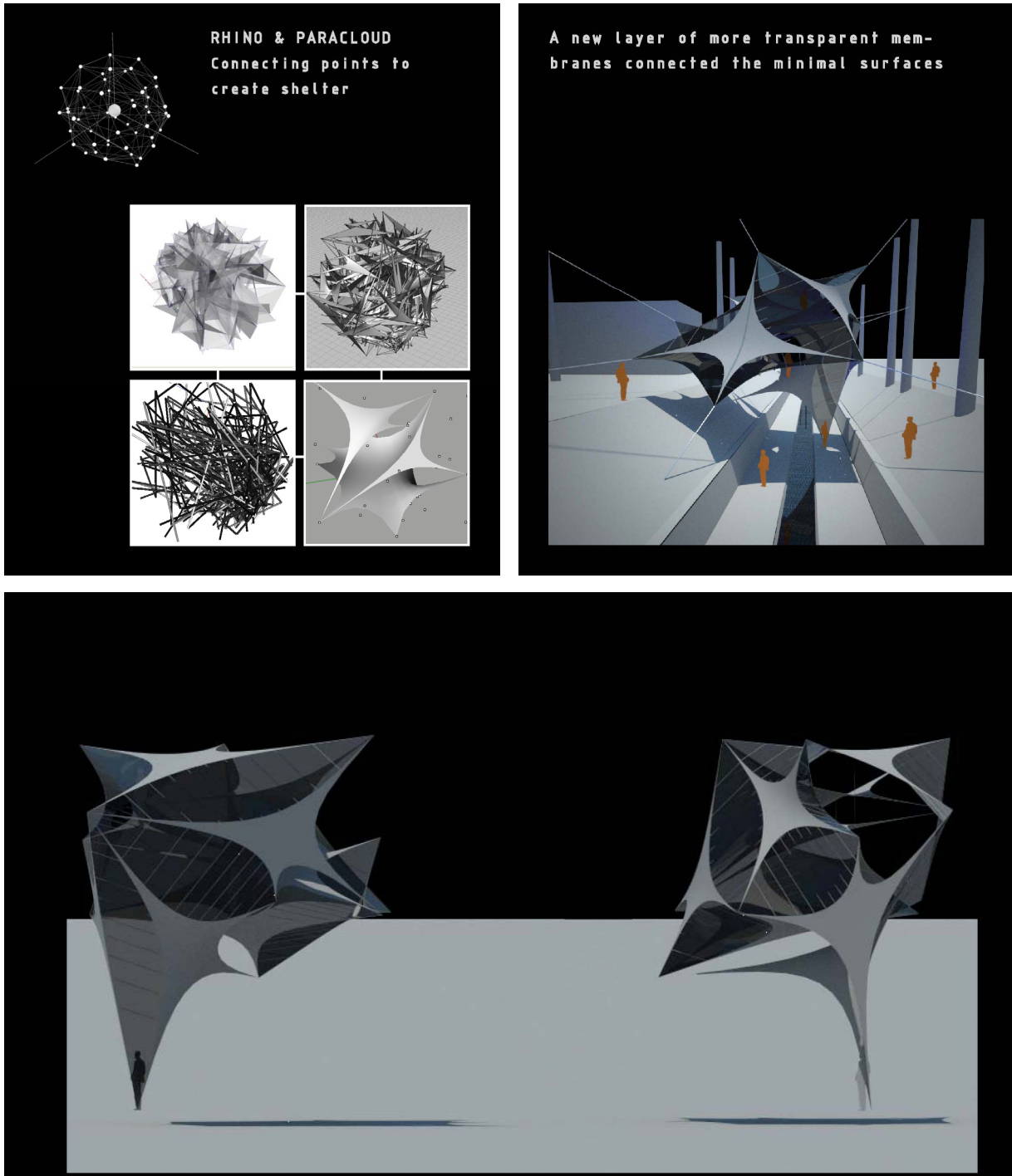


Fig. 19: Student project No. 2 – inhabiting virtual environments (by courtesy of J.T. Christensen)

Table 9: The overall design competencies for the design of inhabiting virtual environment project

| Issue | Virtual world project | Score | Average |
|--------------------|---|---------------|-------------------|
| Context | Placement in environment (socio-virtual) | 3 | 2.8 (+Poor) |
| | Height and footprint limits (virtual-flexible) | 4 | |
| | Inclusion of surroundings (real-time changes) | 1 | |
| | Segmentation of volumes (art. visual effects) | 4 | |
| | View axes (can be programmatically fixed) | 2 | |
| Form | Composition | 7 | 6.4 (-Excellent) |
| | Sculpture - space interrelation | 7 | |
| | Diversity level | 6 | |
| | Light and material selection | 6 | |
| | Transparency (aligned with scenes) | 6 | |
| Function | Accessibility and activity model (characters) | 3 | 1.6 (Poor) |
| | Flexibility (virtualisation) | 1 | |
| | Con. & org. of spaces (circular or limited) | 1 | |
| | Communications (depend on characters) | 1 | |
| | Technical domain function ^(b) | 2 | |
| Technical solution | Structural efficiency (character dimensions) | 4 | 3.4 (-Sufficient) |
| | Constructability and maintainability (software) | 2 | |
| | Energy efficiency (processor energy) | 2 | |
| | Cost efficiency (hardware and software) | 6 | |
| | Time efficiency | 3 | |
| | | Total average | 3.6 (-Sufficient) |

Evaluation summary (wholeness/interrelations):

- The openness of designers' creativity is limited to formal explorations (project period is too short, group competences are not high enough to overcome this difficulty).
- Aesthetic expression is the focus of the project, neglecting its potential complexity.
- The presentation is not interactive.
- Design originality is represented by reinterpretation of partially known solutions.
- It cannot be concluded that the solution is culturally sustainable, in general, due to the lack of the resulting complexity; however, there is a reference which cannot be neglected.
- The idea of scale-related explorations in virtual environments, in spite of the common understanding that scale is not important/relevant in virtuality as it 'belongs' to physical worlds.

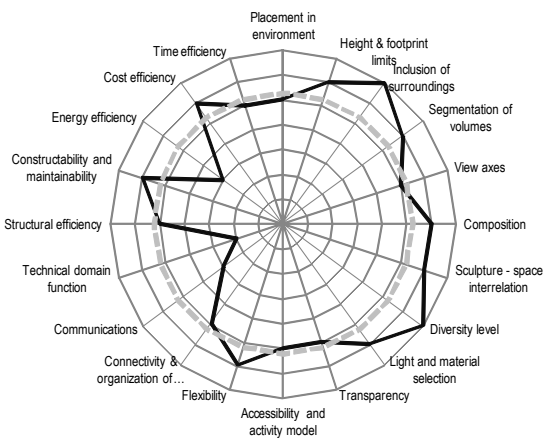


Fig. 20: Evaluation of virtualisation of physical space (solid line: score line, dashed: average score)

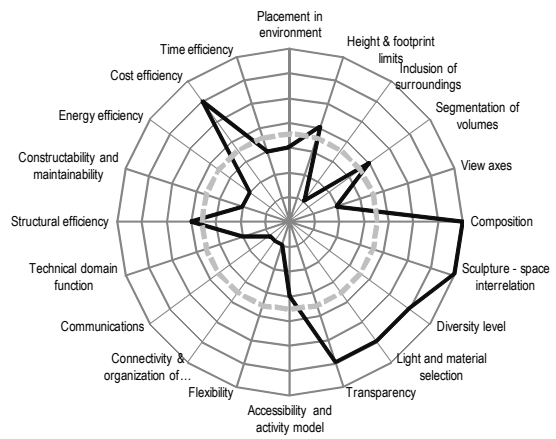


Fig. 21: Evaluation of inhabiting virtual environments (solid line: score line, dashed: average score)

6. DISCUSSION AND CONCLUSIONS

The presented research has proved to be relevant for AEC practitioners and other stakeholders in physical and virtual projects. AEC company, its management, and human resources departments, could use the proposed solution to identify, track, and plan development of core competencies. Both, companies and individuals can use the proposed competency management framework to identify learning opportunities and to establish a fair reward system. The proposed framework could be used by evaluators and assessors of building projects in academia and industry tenders, providing them a consistent ranking methodology.

Models from design may be used to represent design competencies only if design problem is known. Models could serve as an excellent source for organisational learning and competency building. The gaps revealed through reference models can serve as learning opportunities and as for building the collective intelligence.

The presented research contributes to the understanding of the relationships between physical and virtual worlds that are important for the development of design competencies.

- Physical architecture is touchable, gravity dependent, and available to all the senses. The physical world possesses more details than virtual ones. Therefore, the design in physical worlds requires more details.
- Virtual tectonics can be seen as an experiment which application to general architectural education requires a critical approach and responsibility towards the people and places the architecture affects. We must take into account that digital models and virtual worlds are always representations, either of the real world or imaginary world.

The competencies that affect the design process can be grouped into three main types:

- Individual competencies are: (i) actionable skills, talents gifts that are required for individual and team work; (ii) operational process and product knowledge that are required for professional work;
- Group competencies refer to: (i) collective teamwork skills required for successful collaboration; (ii) collective competencies and collective wisdom summarized from individual team members.
- Organisational competencies may be group into: (i) core organisational competencies that assure participation in the market; and (ii) support competencies which support core business operations.

However, competencies cannot be assigned *a priori* to an individual, team or organization without a detailed understanding of the background and relationships between roles and processes that lead to design results. The evaluation mechanism enables identification of critical competencies that were decisive for the success or failure of the project. The interpretation of the models that are used for the identification of competencies is not absolute, but also depends on the presentation of the model, its interpretation and attention of the evaluator. Design process workflow and its results can be used as evidence of design competencies for physical and virtual worlds. Models, like BIM, can be used for capturing and building collective competencies. A company could use their digital models, e.g. BIM, to monitor and develop core competencies.

This paper establishes, on the basis of the performed evaluations, that the proposed AEC competency management framework provides a widely useful instrument for revealing the competences in AEC design in physical and virtual words, thus confirming the hypothesis that models can be used to determine competencies. The competencies that are related to the presentation skills are common to physical and virtual projects and can be easily transferred between the two projects types. However, basic design competencies can be more easily transferred from physical to virtual projects and not vice versa. Fig. 22 gives a graphical comparison of competencies for both types of projects from the case studies. The graphical presentation of competencies clearly indexes the outcome of design and provides a high level overview of coverage and wholeness of design solutions.

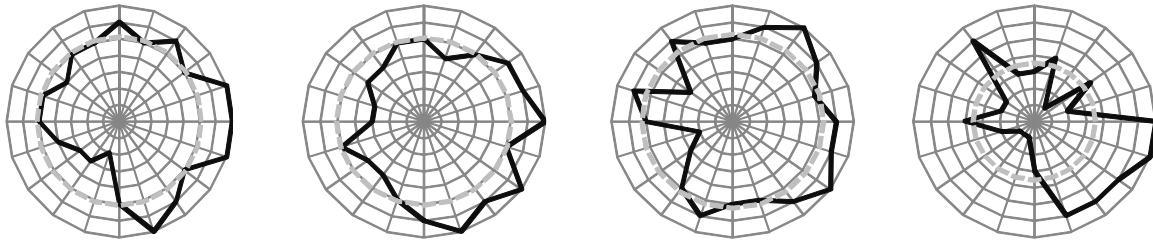


Fig. 22: A comparison of design competencies in physical (two on the left) and virtual (two on the right) worlds, wholeness quadrants: Context, Form, Function, Technical Solution (see Fig. 14 for details on graph definition).

The case studies, examined in the paper, validated the proposed framework, which may be implemented into the software systems, which could link projects, models and AEC practitioners' competencies. The proposed competency evaluation, however, requires certain architectural and structural expertise and should be performed by an experienced practitioner from the architectural or engineering field. The method is useful for research purposes, comparative studies (among similar buildings or groups of buildings) and as an aid in arguing competency evaluations, whenever the architectural/aesthetic value must be evaluated in combination with the technical requirements and guidelines. We claim that the framework also has educational value, as it can contribute to the identification and improvement of interdisciplinary knowledge that is required for successful collaboration in the modern competitive architecture and in the engineering world. The future work will focus on the refinements of the framework that are required for the implementation in software systems and its introduction in practical use in academia and in the industry, especially for the introduction and use of the virtual design and construction.

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