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SPATIAL ABILITY, CREATIVITY, AND STUDIO PERFORMANCE IN ARCHITECTURAL DESIGN

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Abstract. Architectural design is a multifaceted discipline that requires many abilities, in particular creativity and spatial ability. In order to identify the relationships among spatial ability, creativity, and studio performance, an exploratory study was conducted at one Midwestern university in the USA. Twenty-one freshman architecture students participated in the study, which involved three tasks: (a) the Torrance Test of Creative Thinking that measures fluency and originality in creativity, (b) a group of general spatial ability tests, and (c) the computer-based Architectural Spatial Ability Test. Students' scores on the tasks were compared with their studio performance grades using SPSS. Results show that studio performance correlated with the ASAT but did not correlate with the TTCT or a group of general spatial ability tests. These findings indicate that a student's performing well does not necessarily mean that she or he can generate many different alternatives (fluency) or original ideas (originality) nor that the student possesses general spatial abilities. The findings show the complexity of architectural design components and reveal beginning design students' architectural abilities.

Keywords. Creativity; spatial ability; architectural spatial ability; studio performance; architectural design education.

1. Introduction

Architectural design is a multifaceted discipline requiring diverse abilities, in particular creativity and spatial ability. One of the goals of architectural education is to nurture students' capacity to generate creative solutions. In addition, because the ultimate aim of architectural design is to build three-dimensional structures, the ability to read, interpret, and visualise spatial information – spatial ability – is important (McKim 1972, Oxman 2002). The basic communication media of architecture information is either two-dimensional (2D), such as floor plans and section drawings, or three-dimensional (3D), such as physical or computer-generated models.

Despite the significance of creativity and spatial ability in architecture design, few studies have addressed the way they relate with each other and with the overall studio performance as many researchers have pointed out (Ho et al. 2006, Park et al. 2006). This paper discusses beginning architecture students' architectural spatial ability and its relationship with design creativity and studio performance.

2. Background

2.1. SPATIAL ABILITY

Spatial ability generally refers to the "skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information" (Linn and Peterson 1985, p. 1480). Several categories of spatial ability have been identified in term of the nature of measurement, such as Linn and Peterson's (1985) three categories—spatial perception, mental rotation, and spatial visualisation. Spatial ability is often regarded as related to mathematical and logical reasoning ability (McGee 1979). With regard to the architectural design domain, however, a literature review of spatial ability shows two limitations: (a) a lack of studies conducted in the design domain and (b) the use of excessively simple figures for a test that may be far from spatial ability in the architectural domain. Most tools used for spatial ability tests usually consist of simple figures (cf. Shepard and Metzler 1988), which are far less complex than architectural 2D and 3D media. Thus, a gap in measuring specific architectural spatial ability may result, and the test results may not tell much about spatial ability in the architectural domain.

2.2. ARCHITECTURAL SPATIAL ABILITY

The Architectural Spatial Ability Test (ASAT) was developed in response to the lack of tools to measure the spatial ability of architecture students specifically. A computer-based test, the ASAT was developed by the author of this paper in 2006. Following 10 years of observations of expert and novice designers, a strong hypothesis emerged: Designers who are adept at reinterpreting 2D information in 3D space and vice versa tend to be more creative in architectural design than those who are not.

With members of the Creative Design and Intelligent Tutoring System in Korea, where the author worked as a researcher, a task called the Plan-Perspective Matching Task was developed to measure part of architectural spatial ability. The pilot study in 2006 showed a potential correlation between architectural spatial ability and design creativity, but it also highlighted two problems to be solved: the need for a valid measurement tool for creativity and for a less difficult spatial ability task.

To illustrate, for the pilot study a small design-solution task was used as a measurement of design creativity, but a lack of internal consistency occurred among the task evaluators as a result of subjective criteria, raising the need to use a validated measurement of creativity.

2.3. CREATIVITY TEST: TORRANCE TEST OF CREATIVE THINKING (TTCT)

Among creativity tests the Torrance Test of Creative Thinking (TTCT) has been studied and used by researchers for more than 30 years, and its reliability and validity are reported as high (Kim 2006). The TTCT is also considered the best predictor for adult creative achievement (Torrance and Wu 1981). In addition, it has the largest norm (Kim).

Torrance (1966, p. 6) defined creativity as follows:

> "a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty; searching for solutions, making guesses, or formulating hypotheses about the deficiencies: testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results."

The TTCT is based on divergent thinking creativity theory (Kim 2006), which is a part of the model of the structure of intellect, proposed by Guilford (1959). He suggested five groups of intellectual abilities which contain divergent thinking and convergent thinking abilities. Divergent thinking involves producing a variety of solutions to a problem (Guilford). It is appropriate for tasks without a correct single answer and is not completely determined by the given information (Potur and Barkul 2009).

The TTCT has two versions: Thinking Creatively with Words (Verbal) and Thinking Creatively with Pictures (Figural) (Torrance 1990). The scoring of the TTCT is called the Creativity Index, which is the sum of the average of five creativity dimensions (fluency, originality, abstractness of titles, elaboration, and resistance to premature closure) and 13 creative strengths. The creativity index can be compared to the national average for the age (or the grade), so it informs the subject's rank in the nation compared to the average for the age (or grade).

3. Research method

Data collection was performed in June 2011. A total of 21 freshmen (16 males and 5 females) participated. Recruited from a summer architecture studio course in one Midwestern university in the United States, participants were homogenous in terms of their previous knowledge of architecture.

3.1. MEASURING TOOLS

A total of three measuring tools were used: (a) TTCT, (b) ASAT, and (c) three general spatial ability tests. A figural test was used because it was reported fair in terms of gender, ethnicity, and culture as well as language (Kim 2006). Because five international students participated, using a figural test appeared more appropriate than a verbal test.

General spatial abilities were assessed with three tests: the mental rotation test (Peters et al. 1995), paper folding (Ekstrom et al. 1976), and visualisation of viewpoints (Guay and McDaniels 1976). According to Linn and Peterson (1985), spatial ability consists of three abilities: spatial perception, mental rotation, and spatial visualisation. The paper folding test and visualisation of viewpoints measure spatial visualisation; and the mental rotation test measures mental rotation (McGee 1979).

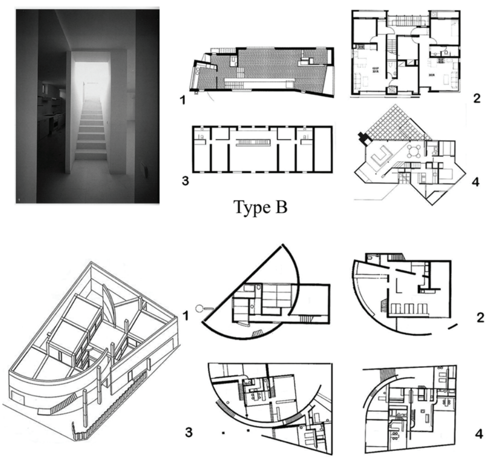

Figure 1. Example of Architectural Spatial Ability Test.

Architectural spatial ability was measured by the ASAT to measure domain-specific spatial ability in architectural design. Through a check of reliability and the degree of difficulty, 15 multiple-choice questions were finalised and divided into three types, depending on the type of architectural drawings used: (a) A 2D floor plan is provided, and then participants are asked to select a corresponding 3D picture of the space; (b) a 3D image of a space is provided, and then participants are asked to select a corresponding 2D floor plan of the space; and (c) a 3D-perspective view of one architectural structure is provided, and then they are asked to select a corresponding 2D floor plan of the space.

The format of the test offers two iterations of question and answer. To illustrate, a 2D floor plan is shown for 30 seconds; then the image is withdrawn. Next, multiple similar 3D pictures are shown for 50 seconds, and they are asked to select the one corresponding with the original floor plan. Then the question is shown again for 15 seconds, and the image is withdrawn. Multiple answers are shown for 25 seconds, and during that time participants are asked to choose the matching one and write the reason for their decision.

3.2. EXPERIMENT PROCEDURE

The TTCT was administered in the architecture library in order for each student to have her or his own table and a quiet environment. The ASAT and other general spatial ability tests were conducted in a computer lab adjacent to the library. The order of tasks was (a) TTCT, (b) ASAT, and (c) three general ability tests. The rationale for this order was that the TTCT measures fluency and originality, so administering it at the beginning of all experiments when test-takers would not be fatigued from other tasks seemed logical. The pilot study showed that students enjoyed taking the ASAT; therefore, it was provided in the middle of the whole experiment in order to maintain participants' interest. The three general spatial ability tests were conducted at the end of the experiment. Students had a 15-minute break between the TTCT and ASAT; thus, the entire experiment took 85 minutes.

3.3. STUDIO PROJECT

Participants' studio performance was evaluated by their instructor with a letter grade. The student project was a house design for an art centre curator considering "the inter-relatedness of two- and three-dimensional thinking and representations" (from syllabus, p. 1). Students were asked to design the house after studying the design principles of two early modern houses: Villa Stein de Monzie by Le Corbusier and Moller House by Adolf Loos. The suggested hypothetical location of the student-designed house was to be in proximity to these two houses. The final outcomes of the project were a set of drawings and a physical model of the designed house.

4. Results

4.1. DESCRIPTIVE ANALYSIS

Collected data were analysed using the SPSS program. A correlation analysis was used to identify the correlation among TTCT, ASAT, general spatial ability tests, and studio performance grade. Instead of the raw creativity index value, a National Percentile with grade was input and calculated. In addition, instead of the raw scores on the ASAT, general spatial ability tests, and studio performance grade, participants' converted scores on a scale of 100 were used. Table 1 shows the descriptive analysis of the TTCT, ASAT, three spatial ability tests, and studio evaluation. Figure 2 shows the Standard Deviations (SD) of those scores.

TABLE 1. Descriptive Analysis of TTCT, ASAT, Spatial Ability, and Studio Grade

		Minimum	Maximum	Mean	Std. Deviation
	Studio grade	72	88	83.33	3.582
	ASAT	46.67	100.00	72.06	13.60
	Mental_R	4.17	83.33	49.17	23.20
	Paper_F	30.00	90.00	65.95	15.78
	Visual_V	33.33	95.83	66.07	19.29
TTCT	Fluency	15	90	49.24	20.66
	Originality	1	87	42.43	29.89
	Abstractness of Title	6	93	42.38	24.59
	Elaboration	11	90	43.29	20.63
	Resistance	13	97	39.95	28.11
	TTCT Creative Index	8	90	46.38	26.74

The average TTCT scores of the students were lower than the National Percentile for the same grade at 46.38 (the national average is 50, Figure 3). Students' TTCT creativity index ranged very broadly (from 8 to 90). Among the five creative dimensions, the average 'fluency' score was highest, followed by 'elaboration'. Average ability to 'resist premature closure' was the lowest among the five. When comparing SD, students showed a more stable ability in 'elaboration' than in other creative dimensions; and the ability to generate 'original ideas' was the least stable and diverse among students.

In the three spatial ability tests, students felt the mental rotation the most difficult. Mental rotation also yielded the highest SD, which indicates that the ability in mental rotation was the least stable among students.

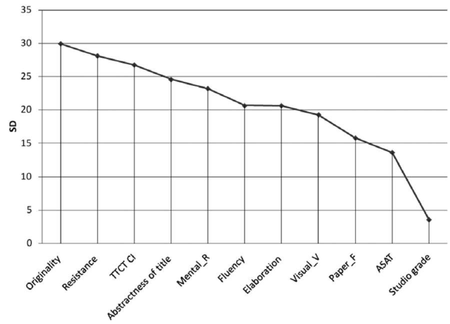

Figure 2. Standard deviation TTCT, ASAT, spatial ability, and studio grade.

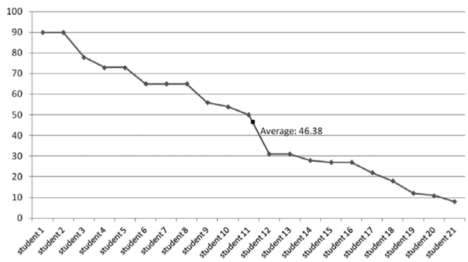

Figure 3. TTCT Creativity Index national percentile distributions among participants.

4.2. CORRELATIONS

TABLE 2. Correlation of TTCT, ASAT, Spatial Ability, and Studio Performance Grade

	Studio grade	TTCT CI	ASAT	Mental_R	Paper_P	Visual_V
Studio grade	1	.546	.011*	.466	.079	.365
TTCT CI		1	.548	.062	.526	.373
ASAT			1	.208	.423	.812
Mental_R				1	.021*	.015*
Paper_F					1	.037*
Visual_V						1

**Correlation is significant at the 0.01 level.

*Correlation is significant at the 0.05 level.

The scores of the TTCT, ASAT, three general spatial ability tests, and the studio grade were compared, using correlations. Table 2 shows that the ASAT and studio performance grade correlate at the statistically significant level; however, studio performance does not correlate with the TTCT or other general spatial ability test results. The ASAT does not correlate with all three general spatial ability tests. Statistically significant correlations emerged among the three general spatial ability tests.

The ASAT consists of three different types of questions. The scores of each type were compared with the studio performance grade in order to judge which part of the ASAT correlates with the studio performance.

Results show that only Type A correlated with the studio performance grade at a statistically significant level (Table 3). In addition, type C did not correlate with Type A, Type B, or the ASAT, showing that the ability to reinterpret 2D information as 3D is the most significant ability in studio performance in architectural education (Type A). The ability to reinterpret from 3D as 2D may not be a significant ability in architectural education.

TABLE 3. Correlation of Three Different Categories of ASAT, General Spatial Ability, and Studio Performance Grade

	Studio grade	ASAT	Q1-5	Q6-10	Q11-15
Studio grade	1	.011*	.005**	.071	.678
ASAT		1	.000**	.000**	.021
Q1-5			1	.002**	.930
Q6-10				1	.562
Q11-15					1

**Correlation is significant at the 0.01 level.

*Correlation is significant at the 0.05 level.

5. Discussions

5.1. TTCT CREATIVITY AND STUDIO PERFORMANCE

Deviating from the assumption that creativity plays a significant role in architectural design performance, the TTCT score did not correlate with studio performance perhaps because the TTCT is based on the divergent thinking creativity that basically measure fluency and originality among many features of creativity. Creativity is a "multifaceted phenomenon" that is hard to define with one simple term (MacKinnon 1978, p. 46).

The failure of the studio performance grade to correlate with the TTCT indicates that a student's performing well in the design studio may not necessarily mean that she or he can generate many relevant ideas (fluency) or unconventional/unique ideas (originality) or vice versa. In addition, it does not necessarily mean that the student is good at abstract thinking (abstractness of titles), elaborating ideas (elaboration), or being open-minded (resistance to premature closure).

5.2. ASAT AND STUDIO PERFORMANCE EVALUATION CRITERIA

Because the ASAT correlates with studio performance, it is important to understand the evaluation criteria for studio performance. The criteria comprise four aspects: (a) independent development, (b) project comprehension, (c) evidence of reading and research, and (d) articulation of intentions in graphic, constructional, and verbal presentations (from syllabus, p. 3). The learning objectives for that studio are to develop understanding of technical graphic skills, 2D and 3D formal and spatial relationships, media presentation skills, and 20th-century modernism in architecture. Considering that the ASAT tends to test the ability to connect 2D and 3D images, which is the fundamental ability in architecture design and a training target during the beginning stage of architectural education, one must conclude that it is reasonable to have such corresponding results.

5.3. GENERAL SPATIAL ABILITY, ASAT AND STUDIO PERFORMANCE

Studio performance correlates with the ASAT but not with general spatial ability. In other words a student's performing well means that he or she is good at the ASAT but not necessarily at spatial visualisation or mental rotation. Why the studio performance does not correlate with the general spatial abilities is not yet clear. The architectural design process may involve so many aspects and abilities that neither mental rotation nor originality can cover.

Another possible reason is that the ASAT requires ability different from what other general spatial ability tests entail. In order to perform the ASAT task, students need a working memory to maintain information (Park et al. 2006). They also need to recall information to find a matching shape; furthermore, they need to transform 2D information into 3D or vice versa. In addition to the content difference, the format difference is that the ASAT provides questions and answers in sequence, not simultaneously, in order to avoid simple matching forms that might appear in the simultaneous format.

The other possible reason is that the ASAT requires domain-specific knowledge, such as reading floor plans or 3D drawings. Whether laypersons who do not have any background in architecture can perform well on the ASAT remains uncertain. In addition, if advanced students are tested with the ASAT and TTCT, the result might be different due to the different criteria for evaluating studio performance. Seeing how spatial ability and individual learning style are related would be interesting.

The finding of this paper is tentative and exploratory, yet it may promote interesting discussions and questions about how architectural spatial ability relates to design performance, what good studio performance means, what abilities contribute to studio performance, and what creativity means in the architectural design domain.

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References

Guilford, J. P.: 1959, Three faces of intellect, *American Psychologist*, **14**(8), 469–479.

Guay, R., and McDaniels, R. E.: 1976, *The Visualization of Viewpoints*, The Purdue Research Foundation, West Lafayette.

Ho, C., Eastman, C. and Catrambone, R.: 2006, An investigation of 2D and 3D spatial and mathematical abilities, *Design Studies*, **27**(4), 505–524.

Kim, K.: 2006, Can we trust creativity tests? A review of the Torrance Tests of Creative Thinking (TTCT), *Creativity Research Journal*, **18**(1), 3–14.

Kim, Y. S., Cho, J. Y. and Park, J. A.: 2006, *Visual Reasoning and Design*, Paper presented at the Visuo-spatial Design Workshop in Computing and Cognition Conference, Eindhoven, Netherlands.

Linn, M. C. and Peterson, A. C.: 1985, Emergence and characterization of sex differences in spatial ability: a meta-analysis, *Child Development*, **56**, 1479–1498.

MacKinnon, D. W.: 1978, *In Search of Human Effectiveness: Identifying and Developing Creativity*, Creative Education Foundation, New York.

McGee, M. G.: 1979, *Human Spatial Abilities: Sources of Sex Differences*, Praeger, New York .

McKim, R.: 1972, *Experiences in Visual Thinking*, Cole Publishing Company, Monterey.

Oxman, R.: 2002, The thinking eye: visual recognition in design emergence, *Design Studies*, **23**(2), 135–164.

Park, J., Kim, Y. and Cho, J.: 2006, *Visual Reasoning as a Critical Attribute in Design Creativity*, Paper presented at the International Design Research Symposium, Korea.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R. and Richardson, C.: 1995, A redrawn Vandenberg & Kuse mental rotations test: different versions and factors that affect performance, *Brain and Cognition*, **28**, 39–58.

Potur, A. A. and Barkul, Ö.: 2009, Gender and creative thinking in education: a theoretical and experimental overview, *Z ITU Journal of the Faculty of Architecture*, **6**(2), 44–57.

Shepard, S. and Metzler, D.: 1988, Mental rotation: effects of dimensionality of objects and types of tasks, *Journal of Experimental Psychology: Human Perception and Performance*, **14**(1), 3–11.

Torrance, E. P.: 1966, *The Torrance Tests of Creative Thinking-Norms-Technical Manual Research Edition-Verbal Tests, Forms A and B-Figural Tests, Forms A and B*, Personnel Press, Princeton.

Torrance, E. P.: 1990, *The Torrance Tests of Creative Thinking Norms-Technical Manual Figural (Streamlined) Forms A & B*, Scholastic Testing Service, Bensenville.

Torrance, E. P. and Wu, T.: 1981, A comparative longitudinal study of the adult creative achievements of elementary school children identified as highly intelligent and as highly creative, *Creative Child and Adult Quarterly*, **6**, 71–76.