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ASSESSING INNOVATION IN HYBRID DESIGNS USING SHAPE GRAMMARS

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Abstract. Al-kazzaz et al (2010) described hybrid adaption technique to generate innovative designs from heterogeneous precedents using shape grammars. An evaluation of the degree of innovation in the hybrid designs gave feedback to grammar users before and after applying a rule. Innovation was assessed using variables derived from the internal structure of the grammar such as: the number of antecedents in the corpus having the same rule; the number of rules in a subclass rule set having the same geometry; etc. However, the validity of the innovation assessment was unclear and the use of the feedback measures was not demonstrated. Accordingly, this study aims to verify the credibility of the innovation measures and to identify the independent variables that a user can control to achieve a significant impact on each innovation measure as a dependent variable.

Keywords. Shape grammars; hybrid design; innovation assessment.

1. Introduction: Assessment methods in shape grammars

In shape grammars, evaluation systems have been used to satisfy different goals. Three approaches can be distinguished according to their roles in the shape grammar process. They are the generating role only, the assessing role only, or both. In the first approach, the problem specific knowledge of design goals is hard-coded in a grammar. The evaluation criteria are added to grammar rules as constraints on the rule selection algorithm to prevent the designers from searching the space of infeasible designs (for example, see Soman et al (2003)). The second approach seeks the optimal design within fixed configurations resulting from applying shape grammars in which the forms of the solutions are known but specific values are needed to be determined, such as in Stiny and Gips (1978). In the third one, combining both the generating and

assessing roles, rules are written to derive valid designs then problem specific models of evaluation criteria are used to search the language for purposeful designs (such as in shape annealing (Shea and Cagan 1998)). Within this approach, Al-kazzaz et al (2010) uses innovation metrics along with rules and grammar to create a powerful feedback mechanism for a grammar user during both the selection of rule and after its application. This paper investigates the validity of the hybrid design innovation measures in Al-kazzaz et al (2010), and identifies the indicators that direct grammar users to obtain hybrid designs with high innovation values.

2. Innovation measures of hybrid design using shape grammars

A hybrid design is an entity that is made up of elements drawn from heterogeneous multiple sources. The main characteristics of a hybrid design are being a mixture of elements of its antecedents on one hand, and having individuality which makes it distinct from its antecedents on the other hand. These characters are translated into innovation measures of hybrid design in Al-kazzaz et al (2010). The independent variables that a grammar user can control in the derivation process are: the number of rules (NR) used to derive the hybrid design, and the rules' evaluation metrics as default values attached to each rule in a grammar to measure the following:

- Rule prevalence value (RPV) is an indicator of the mixed character of a generated design. It is calculated as the percentage of antecedents in the corpus having this rule.
- Rule geometrical difference values (RGDV) and rule sequential difference values (RSDV) are indicators of the individuality of a generated hybrid design. They are calculated as the percentage of antecedents having a different geometry or a different sequence than this rule.

The dependent variables are innovation metrics of mixture and individuality in a generated hybrid design. They are updated values added after rule application at grammar runtime to measure a mixture in terms of variety and density, and individuality in terms of matching and difference, as follows:

- Diversity is a measure of variety in the design mixture. It is calculated as the percentage of antecedents in the corpus having rules in the generated design.
- Abundance is a measure of density of the design mixture. It is calculated as the total average of antecedents in each rule of the generated design.
- Matching is an inverse measure of the individuality in a hybrid design. It is calculated as the higher percentage of applied rules in the generated design belonging to one antecedent in the corpus.
- Geometrical or sequential difference values are direct measures of individuality in a hybrid design. They are calculated as the total average of rule geometri-

cal or sequential difference values in the generated design.

3. Validation of the innovation measures

To verify the validity of the proposed innovation measures, the study compares the innovation values obtained from hybrid designs with ones of copies of antecedents. The ability of metrics to identify that hybrid designs have higher innovation values than copies of existing designs is an index to its soundness. The implementation is done using sample of 12 traditional minaret designs. The hybrid designs are generated according to the method in Al-kazzaz et al (2010). However, to generate a copy of any antecedent, variable state label (n1 or nx) of right hand side of each original rule (OR) is replaced by a state label of an antecedent to be copied. It is one of the constant state labels of left hand side of applied rules, as shown in Figure 1.

Original rule of subclass rule set of minaret body	User guide grammar for a hybrid design	User guide grammar for a copy of existing design
d3, d11 → nx Db>Dt Db=, + or =H Dt<M	nx={n(x-1)\d3, d11}	nx=d3 if the generated copy is d3 or nx=d11 if the generated copy is d11

Figure 1: User guide grammar for copies of existing designs and hybrid designs

The study compares the innovation values of 12 copies of antecedents (Figure 2) with 24 hybrid designs: 12 of them are composed of original rules (ORs) (Figure 3), and the other 12 are composed of hybrid rules (HRs) (Figure 4). Each copy of the antecedent has two corresponding hybrid designs created from the same number of ORs and HRs separately.

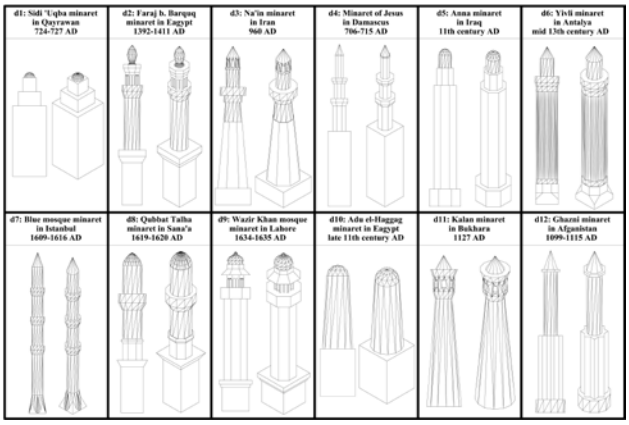


Figure 2: Copies of antecedents in the corpus

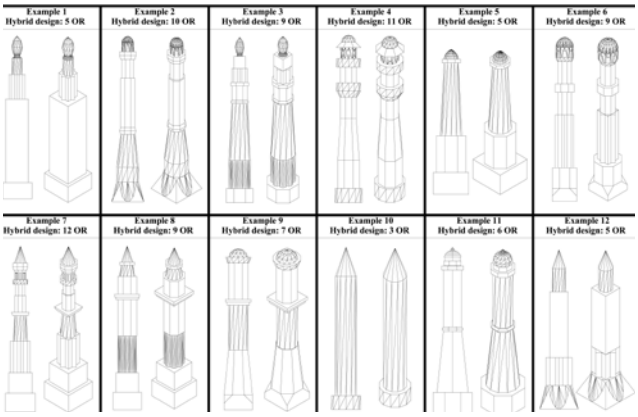


Figure 3: Hybrid designs composed of original rules (OR)

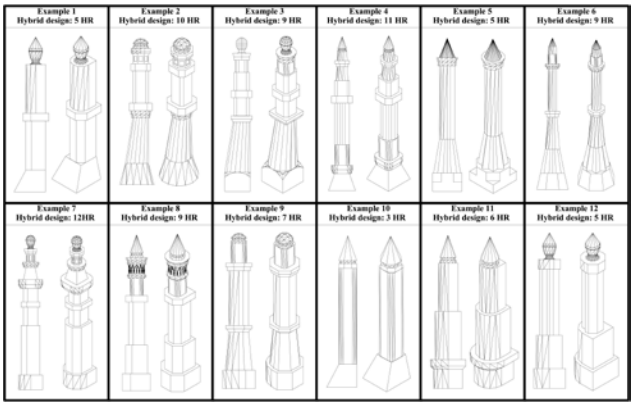
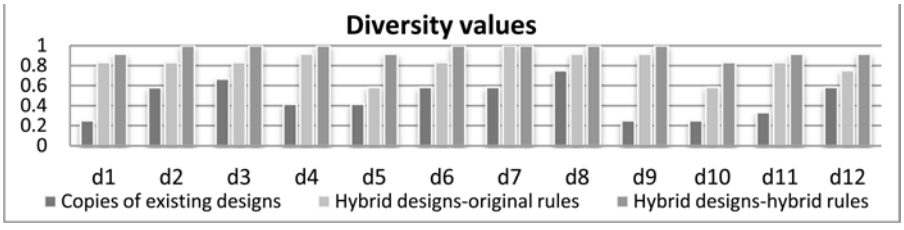


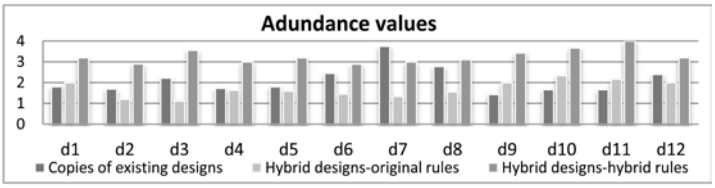
Figure 4: Hybrid designs composed of hybrid rules (HR)

To avoid the effect of the different NRs on the innovation measures, each copy of antecedent is compared with two hybrid minarets having the same number of ORs or HRs. In Graph 1, diversity results show the amount of variety in the mixture of existing and hybrid designs. The diversity of hybrid designs is higher than the copies of antecedents in all of the examined cases.



Graph 1: Comparison between diversity values of copies of antecedents and hybrid designs

The results of abundance values represent the density of the mixture in existing and hybrid designs. Graph 2 shows that 11 of 12 hybrid designs derived by HRs have higher abundance than the copies of existing designs.



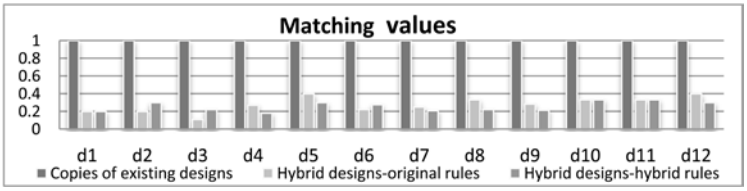
Graph 2: Comparison between Abundance of copies of existing designs and hybrid designs

It is noteworthy to mention that 66.6% of the copies of antecedents have higher abundance values than the hybrid designs derived by ORs. The reason can be attributed to the small percentage (5.5%) of ORs having high RPV which are rules derived from more than 3 antecedents (Table 1). The high abundance of the existing designs such as d7 results from repeating rules with high RPV, in contrast to hybrid design in which the user guide grammar prevents any rule repetition except the cases in which the set of designs in a user guide grammar for hybrid design is Ø (Al-kazzaz, Bridges et al 2010).

Table 1: Percentages of the rule prevalence values (RPV) in original and hybrid rules

	High RPV (4-8) labels	Medium RPV (2-3) labels	Low RPV (1) label
Original rules	5.555%	22.222%	72.222%
Hybrid rules	18.888%	74.444%	6.666%

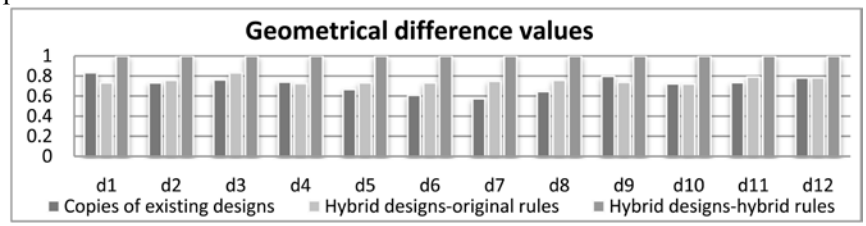
The copies of existing designs have certainly minimum individuality having maximum matching (1) to the antecedents, while the individuality of hybrid designs varied between (0.111) maximum and (0.4) minimum, Graph 3.



Graph 3: Comparison between matching of copies of existing designs and hybrid designs

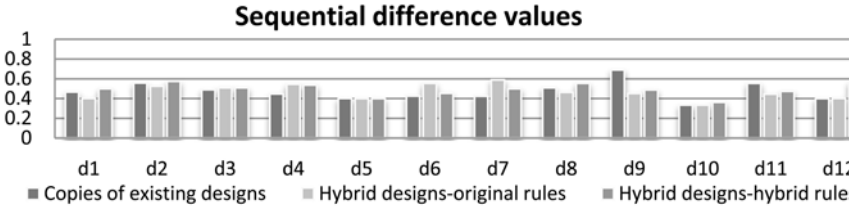
The results of individuality in terms of geometrical difference are presented in Graph 4. They show that all hybrid designs composed of HRs have maximum geometrical difference value (1). Additionally, in 7 of 12 cases, the hybrid designs composed of ORs have geometrical difference values higher than the

copies of antecedents, and in two cases their geometrical difference values are equal.



Graph 4: Comparison between GD values of copies of existing designs and hybrid designs

Lastly Graph 5 shows small variance in the sequential difference values between copies of existing designs and both hybrid designs. Even so, in nine cases, the values of sequential difference of hybrid designs (original or hybrid rules) are higher than those of copies of existing designs.



Graph 5: Comparison between SD values of copies of existing designs and hybrid designs

In conclusion, comparing the innovation measures of both the mixture and individuality in the generated designs reveal that the values of hybrid designs are higher than the copies of antecedents. This result confirms that the assessment method is able to find differences between copies of antecedents and hybrid designs which is regarded as a proof of its validity as innovation measures of the hybrid designs. The other concern of this paper is to identify the factors which the grammar user can take into account to direct the generated hybrid design to have high innovation values.

4. Factors affecting the innovation of hybrid design

Being a mixture and having individuality are the innovation characteristics of the hybrid designs measured by diversity and abundance for the former, matching and geometrical and sequential differences for the latter. They are dependent variables affected by the independent variables which a grammar user can control such as: rule prevalence (RPV), rule geometrical difference (RGDV), rule sequential difference (RSDV), and the number of rules (NR) used to derive a hybrid design. The initial expectations of the relations are:

- High NR may have a positive effect on the variety of the design mixture.
- High RPV may affect positively the variety and density of the mixture, while it may affect negatively the individuality by increasing the matching degree.
- High RGDV and RSDV have definitely a positive effect on individuality by increasing the geometrical and sequential difference of the generated design.

The first two assumptions need to be verified, while the third has no need because it is inevitable. Therefore, the study concentrates on examining the relations between the innovation metrics and each of the NR and RPV.

Correlation coefficients have been calculated to measure the effect of changing the NR and RPV on each of the dependent variables in 12 copies of existing designs and 24 hybrid designs derived in the previous stage. The results are presented in Table 2 which shows predictive relations such as:

- Relation type: (+) means direct, (-) means inverse, or (0.0) means no relation.
- Relation strength: (0.7-1) is strong, (0.4-0.7) is moderate, or (0-0.4) is weak.

Table 2: Correlation coefficient values between innovation measures and each of NR and RPV in copies of existing designs CED and hybrid designs HD using OR and HR

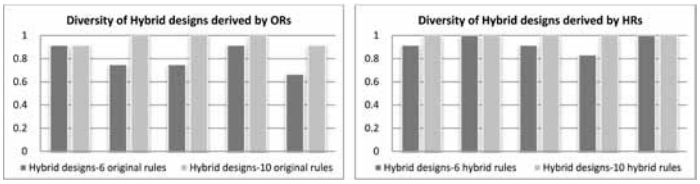
		Innovation measures				
		Diversity	Abundance	Matching	Geo. difference	Seq. difference
CED	NR	+0.589	+0.519	0.0	-0.47	+0.232
	RPV	+0.662	+0.997	0.0	-0.72	-0.353
HD-OR	NR	+0.786	-0.781	-0.5	+0.114	+0.96
	RPV	-0.363	+0.996	+0.592	-0.299	-0.77
HD-HR	NR	+0.887	-0.562	-0.565	0.0	+0.551
	RPV	-0.649	+0.919	+0.418	0.0	-0.553

The results reflect differences between existing and hybrid designs. Some results of hybrid designs are contrary to expectation and need more investigation, such as the inverse relations between the RPV and diversity values.

Accordingly, the research aim is to verify the effects of each predictor variable: NR and RPV on innovation measures of mixture and individuality in hybrid designs. Both variables can direct a user to generate hybrid designs with high innovation. To reduce the mutual influence of the NR and RPV on each other, the research derives 10 pairs of hybrid designs, 5 of them using ORs and the others using HRs. Each pair consists of hybrid designs having 6 and 10 rules derived from the same (4-5) rules to reduce the effects of varied RPV. In this case, the comparison between designs of 6 and 10 rules in each pair reveals the impacts of different NR on the innovation measures. On the other hand, comparison between hybrid designs composed of 6 or 10 rules separately, explains the effects of various RPV on the innovation measures.

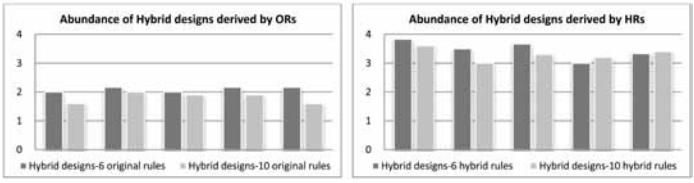
5. The effects of NR and RPV on the innovation of hybrid designs

The effects of NR on diversity, as shown in Graphs 6 and 7, reveal that all hybrid design composed of 10 rules have either equal or higher diversity than hybrid designs composed of 6 rules. These results are compatible with their strong direct relations concluded in Table 2.



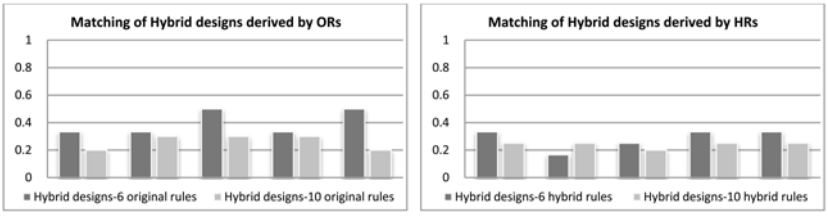
Graph 6 (left) and Graph 7 (right): Diversity values of hybrid design

The results of abundance values in Graphs 8 and 9 show that all hybrid designs composed of 6 OR have higher values than hybrid designs composed of 10 OR. In addition, half of hybrid designs composed of 6 HR have higher abundance than designs composed of 10 HR. The results are compatible with the strong and moderate inverse relations, concluded in Table 2, which are attributed to the higher average of RPV in designs of 6 rules than 10 rules.



Graph 8 (left) and Graph 9 (right): Abundance values of hybrid design

The matching results in Graphs 10 and 11 reveal that all hybrid designs composed of 6 OR have higher matching values than ones composed of 10 OR. Also, in 4 of 5 cases, the matching values of hybrid designs composed of 6 HR are higher than those composed of 10 HR. These results refer to strong inverse relations between matching values and NR, and have some differences than the moderate inverse relations shown in Table 2.



Graph 10 (left) and Graph 11 (right): Matching values of hybrid design

The design geometrical and sequential difference values are innovation metrics of individuality in hybrid design. They are fully influenced by rule geometrical difference (RGD) and rule sequential difference (RSD) values. Thus, there is no need to investigate the effects of the RN and RPV on them. On the other hand, the results of correlation coefficient between the average of the RPV and both diversity and matching values show some random relations which varied between weak and strong. In addition, all diversity values of hybrid designs composed of 10 HR are 1.0, therefore there is no correlation relation with RPV. These results reveal that the RPV factor alone is not enough to indicate the diversity and matching as the innovation measures of variety and individuality in the mixture of generated hybrid design. Lastly, the correlation coefficient between abundance values and RPV reflects strong direct relations for all hybrid designs derived by (6 and 10) ORs and HRs. The abundance outcomes are consistent with the results in Table 2.

6. CONCLUSION

The study has sought to achieve two objectives. Firstly, it is to verify the innovation measures of mixture and individuality in the hybrid designs. The ability of these measures to distinguish between copies of existing designs and hybrid designs is the test of their validity. The results show that most hybrid designs have higher innovation metrics than the copies of antecedents. Accordingly, the validation of these measures is verified.

The second aim is to highlight the signals of grammar user feedback that contribute efficiently in deriving hybrid design with high innovation values. The study focused on two independent variables: the number of rules (NR) used to derive a design, and the rule prevalence value (RPV); and three dependent variables of innovation metrics: diversity, abundance and matching.

High NR enhances the diversity of the mixture in hybrid designs composed of ORs and HRs. In contrast, the high NR may affect negatively the abundance value which represents the density of the hybrid design mixture. The reason can be attributed to the fact that a grammar, because of the heterogeneity of antecedents in corpus, has a limited number of rules with high RPV (Table 1). Accordingly, the percentage of rules with high RPV is more likely higher in designs having few rules than many rules. Lastly, high NR strengthens the design individuality by decreasing the matching degree. It can be justified, to some extent, for the same reason mentioned above.

The relations between RPV and innovation measures are random in case of diversity and matching. In contrast, high RPV boosts the abundance measure of density in the mixture of hybrid design. The reason why the applied rules with high RPV may not enhance the diversity values can be attributed to the

fact that the applied rules have some common antecedents in their state labels. Additionally, this reason is more likely to raise the matching value. These results revealed the need to add indicators to represent the dependency of diversity and matching values on RPV. Diversity and matching indicators are two updated values added at grammar runtime beside the LHS state labels of each rule. Diversity indicator calculates the percentage of rule antecedents in the user guide grammar. While, matching indicator calculates the percentage of rule antecedents that do not exist in the user guide grammar. For example, if the set of antecedents in the user guide grammar is {d2, d3, d6, d9, d12}, then the diversity indicator of a rule having LHS state labels {d3, d4, d9} is 2/5=0.4, and the matching indicator is 1/3= 0.333.

Based on the results, a key for rule selection is shown in Figure 5. The effects of the varied NR to the number of existing designs in the corpus (D): (NR<0.5D, NR=D or D>NR>0.5D) and the varied RPV: (high, medium or low) on the innovation measures: diversity, abundance and matching are extracted. The grammar user can follow the tactics to derive hybrid designs with high innovation values and can distinguish the rules (original or hybrid) that meet the required level of innovation measures (high, medium or low).

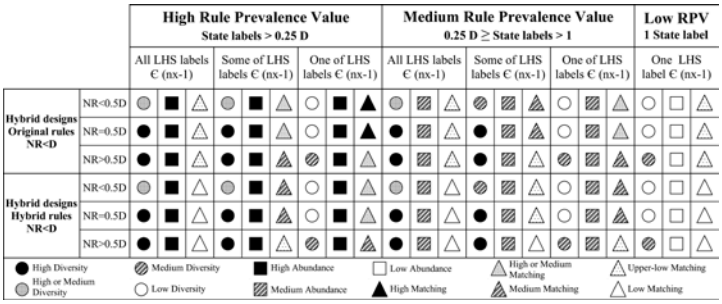


Figure 5: The effects of RPV and NR on innovation measures of hybrid designs

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