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Authors(s)	Laefer, Debra F., Farrell, Kelly-Ann
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26 **A Hybrid Method for Foundation Reuse Evaluation**
27 **Debra F. Laefer and Kelly-Ann Farrell**
28

29 **ABSTRACT**

30 This paper aims to provide a simple, multi-level method for engineers to conduct a pre-construction
31 viability assessment for reuse of existing foundations in congested urban areas. As part of this, the
32 first critical assessment is presented for three major foundation reuse evaluation tools in their ability
33 to predict the outcomes of five published case histories. Based on strengths and weakness identified in
34 that process, a hybrid system is proposed. This newly proposed, two-staged methodology is aimed to
35 address socio-economic drivers and technical requirements, as well as to promote future reuse where
36 current reuse is not viable. The proposed system was successfully verified by predicting the outcomes
37 of two other, previously published case histories. In that process, the main drivers were recognised,
38 while site-specific constraints and concerns were incorporated. Although the robustness and scalabil-
39 ity of the method will need further testing, this paper introduces a promising, new, multi-level ap-
40 proach that explicitly addresses future reuse.

41
42 **INTRODUCTION**

43 Foundation reuse has become an increasingly important topic in recent years because of a heightened
44 interest in sustainability and increased concern over ground congestion in urban areas (e.g. Butcher et
45 al. 2006a, Bian et al. 2008, Laefer and Manke 2008). While several decision-making aids and assess-
46 ment tools have been developed, none have been independently assessed. The goal of this paper was
47 to do such an assessment and then propose a new approach to overcome any identifiable shortcom-
48 ings.

49
50 **PREVIOUS ASSESSMENTS**

51 In this research, three assessment methods were used to evaluate and analyse five case studies for
52 their foundation reuse potential. In an extensive review of the literature only seven cases were found
53 that had sufficient information to apply the original three methods. Of those, five were selected to re-
54 flect unique outcomes. No pre-screening or pre-testing of any method was applied. The remaining two
55 cases had outcomes that replicated two of the five initial cases. These were subsequently used without
56 prejudice to test the proposed hybrid method. The initial five case studies were taken from the ‘Reuse
57 of Foundations for Urban Sites’ handbook and were considered using the following assessment meth-
58 ods: the modified SPeAR method as proposed by Laefer (2011), as a modification of Sustainable Pro-
59 ject Appraisal Routine (SPEAR) method as originally introduced by Strauss et. al. (2007); the RuFUS
60 method, as developed as part of the research project Reuse of foundations for Urban Sites (Butcher et
61 al. 2006b); and the CIRIA method, as proposed by Construction Industry Research and Information
62 Association document C653 (Chapman et al. 2007). The modified SPeAR method generates a visual

63 output (Figure 1) based on quantitative inputs generated from both site and community related factors
64 (Table 1). In contrast, both the RuFUS method and the CIRIA method use a flow chart approach (Fig-
65 ures 2 and 3, respectively). All three methods are largely self-explanatory.
66



67

68 **Figure 1. Unpopulated, modified SPeAR diagram (adapted from Laefer 2011)**

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Table 1. Quantitative input parameters for Figure 1 (as proposed by Laefer 2011)

Level	Site location on previously developed land: Unprotected Greenfield land as a percentage of total meterage of a community (%)	Level	Archaeology and historical constraints: Level of historic importance
1	<.1	1	Property - based architectural designation
2	.1 < x < 1	2	Neighbourhood/ district- based architectural designation
3	1 < x < 2	3	100 years old < x
4	2 < x < 5	4	50 years old < x < 100 years old
5	5 < x < 10	5	25 years old < x < 50 years old
6	10 < x	6	x < 25 years old
Level	Geological conditions and constraints: Soil type	Level	Sustainability and materials reuse: Quantity of material (m³)
1	Karst	1	250 <
2	High shrink- swell clay	2	200 < x < 250
3	Mixed	3	150 < x < 200
4	Low shrink- swell clay	4	100 < x < 150
5	Sand	5	50 < x < 100
6	Rock	6	< 50
Level	Land value and cash flow projections: Monthly ground floor rent for a retail unit as a multiplier of median monthly household in- come of community	Level	Approvals and development risk: Length of time for planning approval permission (months)
1	.25 <	1	12 <
2	.20 < x < .25	2	10-12
3	.15 < x < .20	3	7-9
4	.10 < x < .15	4	5-6
5	.05 < x < .10	5	3-4
6	< .05	6	< 2
Level	Construction costs on site: Number of Big Macs equivalent to the cost of a cubic metre of concrete delivered to the site (m³)	Level	Consistency in building location: Length of time a building is at the location (years)
1	75 <	1	50 <
2	60 < x < 75	2	25 < x < 50
3	45 < x < 60	3	10 < x < 25
4	30 < x < 45	4	5 < x < 10
5	15 < x < 30	5	2 < x < 5
6	< 15	6	< 2

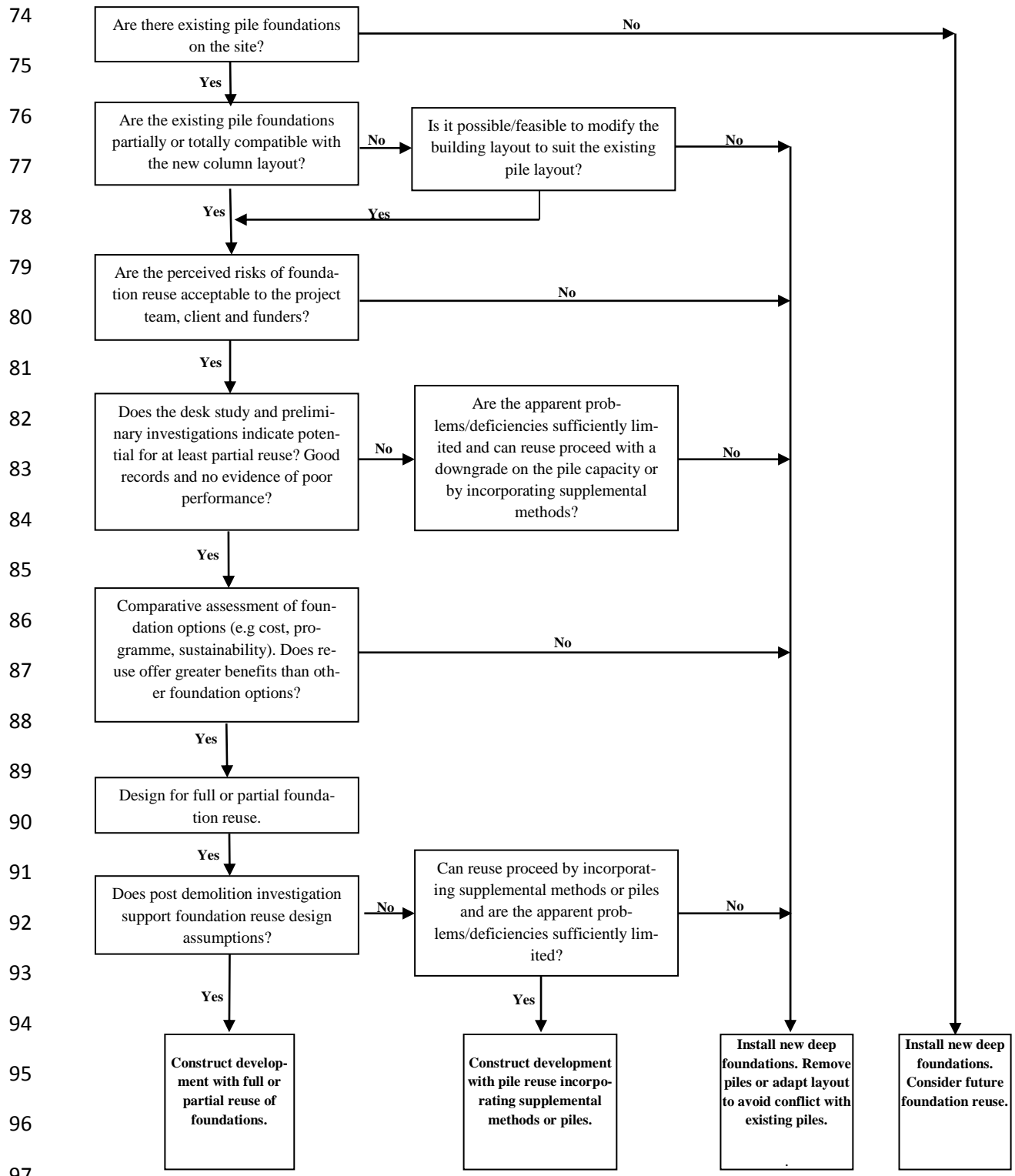
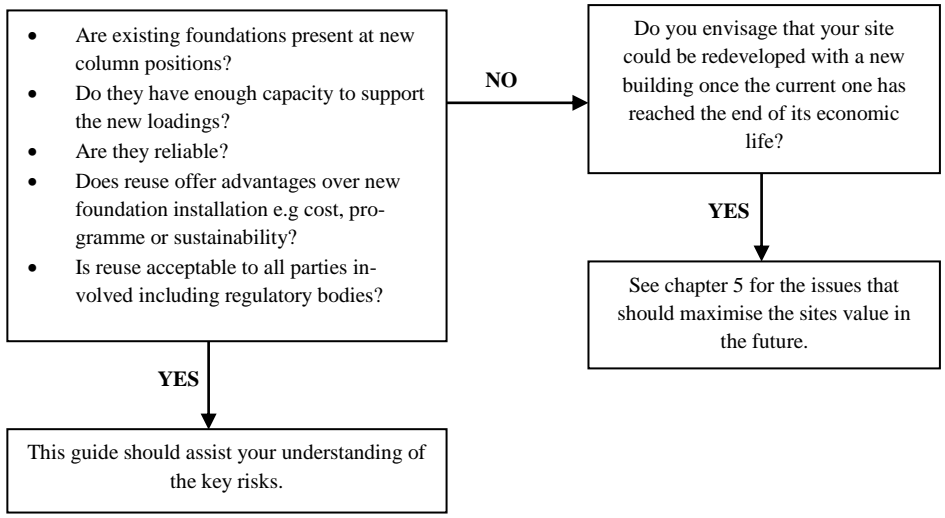


Figure 2. RuFUS method flow chart
[modified from Butcher et al. (2006a)]

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Figure 3. CIRIA method flow chart to evaluate whether existing foundations can be either partially or completely reused

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[adapted from Chapman et al. (2007)]

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117 ASSESSEMENT

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To assess the effectiveness of each of the three methods, the predicted outcomes from each were evaluated against the actual construction decisions that were taken in five previously published case histories; because of length restrictions, only the general outcomes of those assessments are described herein. Through this process, the benefits and difficulties associated with each method became readily apparent. In addition, where as-built documents and past site investigation results were available, the opportunity for reuse increased greatly. Conversely, where only design drawings or limited information was available, the possibility of achieving a reuse solution reduced dramatically.

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126 Modified SPeAR method

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The modified SPeAR method highlighted the main drivers for a reuse solution, despite certain input parameters being at times difficult to obtain, because of the need to find related community data. The strength of the method was its ability to generate an understanding for the reuse potential of an area. Where the results consisted of indicators as levels 1- 3, reuse potential was considered high. Where the resulting indicators were at levels 4-6, little potential for reuse appeared to exist. The number of categories necessary for sufficient drivers to be present to fuel foundation reuse adoption is likely to be community dependent. A further weakness of the method related to the absence of any in-depth consideration from an engineering perspective. So while the modified SPeAR method gave a clear in-

135 dication as to possible benefits of reusing foundations on a site, this was insufficient information to
136 make an actual assessment with respect to site-specific factors.

137

138 **RUFUS method**

139 The important factors found when using the RuFUS flow chart assessment for the various case studies
140 included the existence of foundations on site, the compatibility of the foundations, the acceptability of
141 a reuse solution to the stakeholders, the extent of site investigations, the criticality of comparing founda-
142 tion solutions, and the assessment that a reuse solution would be beneficial for the project. Alt-
143 hough the RuFUS flow chart was successfully implemented and the selected solutions were obtained
144 for all the case studies, the clarity of the questions was a concern. In certain instances, it was unclear
145 under which heading some factors should be considered. Another major disadvantage with this ap-
146 proach was the lack of distinction between sites. Findings showed that the RuFUS flow chart did not
147 highlight the importance of individual site constraints. Examples included the existence of archaeo-
148 logical remains, strict site boundaries, soil type, and various types of ground congestion (e.g. existing
149 foundations, existing tunnels). Furthermore, in some instances site restrictions and constraints were
150 not clearly addressed and, therefore, had to be included under the risk acceptability portion of the
151 RuFUS flow chart. In other instances, the desk study and preliminary investigations questions were
152 used to consider site restrictions and problems with the site. Finally, the RuFUS flow chart approach
153 did not highlight the importance of the capacity of the existing foundations. In the five case studies
154 examined, it was found that foundation capacity needed to be considered independently from other
155 factors, prior to any decision being made.

156

157 **CIRIA method**

158 The CIRIA assessment seemed to identify most of the major points in the case histories (e.g. compati-
159 bility of existing foundations and the proposed new structure, the capacity of the foundations, the reli-
160 ability of the foundations, and the available alternative foundation solutions). However, many signifi-
161 cant site constraints were not considered including ground congestion, site boundaries, and archaeolo-
162 gy. In comparison to the RuFUS method, the CIRIA process focused more on foundation material,
163 compatibility, reliability, and capacity. The CIRIA method also better considered the particulars of a
164 site; namely the compatibility between the existing structures and the newly proposed ones, as well as
165 the quality of the available records. Finally, the highly amalgamated version of the flow chart made
166 foundation reuse seem overly restrictive, generally with an “all or nothing” outcome, instead of rigor-
167 ously considering partial reuse or giving the option for future reuse.

168

169 **Assessment Summary**

170 Both the RUFUS and CIRIA assessment methods were straightforward and recognized the compati-
171 bility, risks of potential foundation solutions, advantages associated with various solutions and the

172 comparison of foundations solutions as important stages when assessing foundations for reuse. Addi-
173 tionally, the CIRIA approach addressed the importance of foundation reliability and capacity, which
174 was recognized as an integral step. However, neither method considered the larger socio-economic
175 site-specific factors. Without such components, the full advantages of a foundation reuse solution can
176 unintentionally be overlooked. These factors were, however, considered in the SPeAR method,
177 whereby site-specific elements (e.g. the land value, cash flow, sustainability, and archaeology) were
178 explicitly addressed. Additionally, none of the methods provided consideration for future reuse Based
179 on these findings, a new two-stage assessment process is proposed, as will be described in the next
180 section.

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182 **PROPOSED TWO-STEP, HYBRID METHOD**

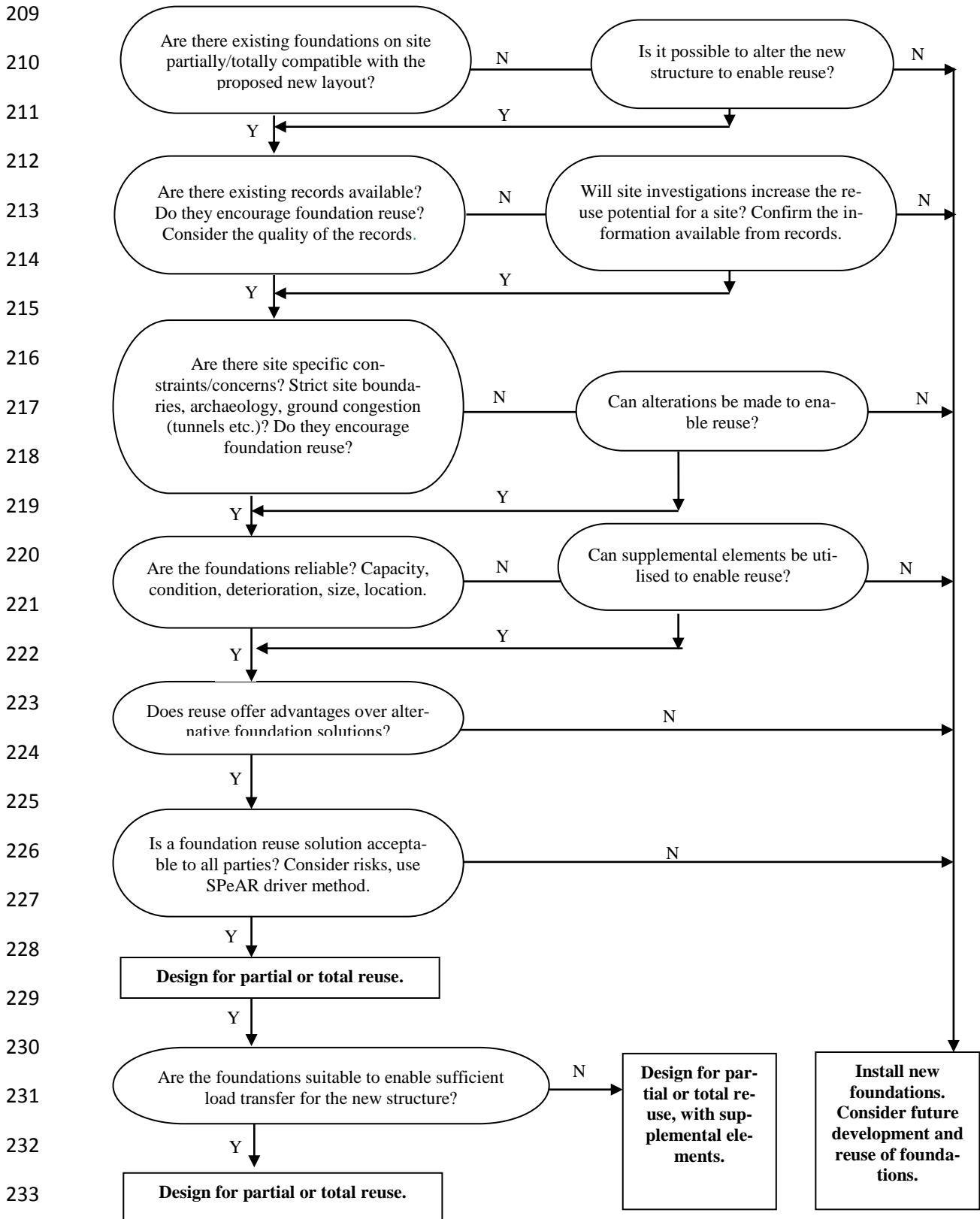
183 The proposed method is a hybrid of the three methods. It involves two steps. Step 1 is the application
184 of the modified SPeAR method. This is done to provide a preliminary socio-economic evaluation of a
185 project's main drivers with respect to the individual site and the larger community. A particular bene-
186 fit of using the modified SPeAR method is that it considers a wide variety of concerns including life-
187 cycle factors and embodied energy without having to engage in the onerous collection and evaluation
188 parameters needed for exact embodied energy calculations for the entire project. Step 1 is a beneficial
189 tool to provide valuable information that may not otherwise be considered, to allow for an informed
190 decision to be made on the possibility of reusing foundations on a site. Step 1 can be considered as an
191 initial screening mechanism but should not be employed as a standalone basis for decision-making.

192

193 Step 2 combines elements from both the RuFUS and CIRIA methods to produce an alternative as-
194 sessment flow chart (Figure 4). The proposed flow chart largely follows the RuFUS method, but the
195 language of the individual steps were altered to better incorporate the actual foundation properties, in-
196 cluding the capacity, reliability, and condition of the foundations, as proposed in the CIRIA method.
197 Furthermore by directing the projected outcomes, a greater emphasis was placed on achieving a reuse
198 solution. This was done by revising the chart to result in only 1 of 3 outcomes, thereby putting greater
199 emphasis on the possibility of foundation reuse (partial or total), while also considering future founda-
200 tion reuse. By modifying the outcome categories, foundation reuse is necessarily considered in all
201 projects, whether or not reuse is performed at the time of assessment. The above changes in the as-
202 sessment flow chart were designed to harness the benefits from both the RuFUS and CIRIA methods,
203 while eliminating the clearest disadvantages.

204

205 The results should be compiled into Table 2 to generate a more concise format from which they can
206 be evaluated. In this stage the capacity, condition, deterioration, size, and location of the foundations
207 were considered. The proposed process clearly identifies the need to consider the quality of the rec-
208 ords available when assessing foundations for reuse.



234 **Figure 4. Step 2 of proposed hybrid assessment method**

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Table 2. Tabulation of Step 2 of the proposed hybrid assessment process

Considerations	Yes	No
Are there existing foundations on site partially/totally compatible with proposed new layout?		
Are there existing records available? Do they support foundation reuse? Consider the quality of the records.		
Are there site-specific constraints/concerns? Strict site boundaries, archaeology, ground congestion (tunnels etc.) Do they encourage foundation reuse?		
Are the foundations reliable? Capacity, condition, deterioration, size, location.		
Does reuse offer advantages over alternative foundation solutions?		
Is a foundation reuse solution acceptable to all parties? Fully explain risks. Utilise SPeAR method in explaining drivers and illustrating reuse potential.		
Are the foundations capable of ensuring sufficient load transfer for the new structure?		

238

239 **ASSESSMENT OF THE PROPOSED METHOD**

240 To test the proposed method, the project outcomes of two case histories (A and B) were compared to
 241 the actual outcomes. Case A involved the construction of a new car park in Coventry, as part of the
 242 Belgrade Plaza development (Tester and Fernie, 2006). Case B was Caroone House, onto which a
 243 new office building was to be constructed (Clarke et al., 2006). These case studies were chosen to
 244 provide examples of one project where foundation reuse was adopted and one project in which the
 245 possibility of foundation reuse was thoroughly considered but in the end not deemed to be appropri-
 246 ate. The two-step assessment process as described in the Methodology section was applied to each
 247 case.

248

249 **Case A**

250 The Leigh Mills car park redevelopment project (Fig. 5) involved the addition of 4 storeys onto the
 251 original structure (Tester and Fernie, 2006). Two possible foundation solutions were proposed: one in
 252 which new piles were to be installed and the second to reuse the existing foundations. The installation
 253 of new foundations required the construction of new columns and the cutting of the floor slab for the
 254 installation of new piles. The reuse involved the incorporation of the existing piles with the addition
 255 of new mini-piles for additional capacity where required. This approach was possible by utilising the
 256 available reserve capacity in the existing piles. This scheme allowed for a less complicated foundation
 257 solution and superstructure to be constructed, thereby resulting in reductions in costs. The quantitative
 258 output of Step 1 (the modified SPeAR) for Case A is shown in Table 3.

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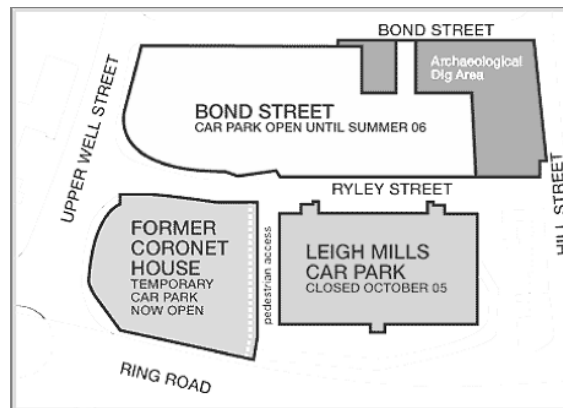


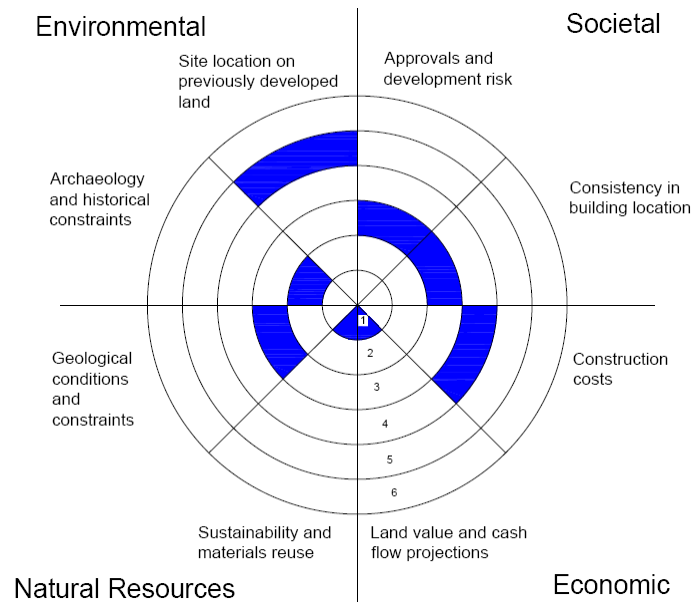
Figure 5. Location of car park redevelopment site (Belgrade Plaza partnership, 2011)

Table 3. Driver descriptions, Coventry

Sector	Driver	Rating for Coventry
Environment	Site location on previously developed land	Unprotected greenfield land as a % of total community metrage = level 5
	Archaeology & Historical constraints	Neighbourhood/district based architectural designation = level 2
Natural Resources	Geological conditions and constraints	Mixed = level 3
	Sustainability and materials reuse	309 m ³ = level 1
Economic	Land value and cash flow projections	Ratio of monthly rent over monthly median household income 1.15 = level 1
	Construction costs	37.03 Big Macs per cubic metre of concrete = level 4
Societal	Consistency in building location	16 years at location = level 3
	Approvals and development risk	Approval is 7 months = level 3

The modified SPeAR method shows potential for reuse with 6 of the 8 indicators being at level 3 or below. Especially high-level drivers were recognised in sustainability and materials reuse and land value and cash flow projections. Archaeology and historical constraints were also recognised as important, with a Level 2 driver designation. Medium level drivers were indicated in building location consistency, approvals and development risks, and geological conditions and constraints. The drivers for foundation reuse are illustrated in Figure 6.

In Step 2, concerns regarding the existing pile capacity and in situ column strength (with respect to the newly proposed loads) were identified. Alterations and supplemental foundations were highlighted as necessary requirements. The existing columns required strengthening, and the existing foundation was augmented with mini-piles. Table 4 illustrates the selected foundation solution.



275

Figure 6. Modified SPeAR Assessment, Coventry

276

Table 4. Proposed assessment table, Coventry

Considerations	Yes	No
Are existing foundations compatible with the proposed new layout?	The project was a redevelopment of an existing structure with the addition of 4 storeys. Reuse was seen to be a beneficial solution, as total compatibility was achievable.	
Are existing records available? What is their quality? Do they support foundation reuse?	Extensive records were available from the original 1989 construction. The original contractor and project engineer were also available.	
Are there site-specific constraints/concerns (e.g. boundaries, archaeology, ground congestion) Do they encourage foundation reuse?	There were concerns as to the capacity of the piles to support 4 additional storeys.	
Are the foundations reliable in capacity, condition, deterioration, size, and location?	Significant records were available and extensive testing was performed including concrete and bedrock sampling and coring of 4 existing piles. Testing included working load tests. Findings showed an increase in capacity on a certain number of piles therefore supplemental mini piles were proposed to take the additional loads. Concerns were also recognised with the increase in load to be carried by the columns, with strengthening however the concerns were mitigated.	
Does reuse offer advantages over alternative foundation solutions?	Reductions in the construction cost and time, as well as avoiding new foundations and new columns, were anticipated.	
Is foundation reuse solution acceptable to all parties?	The original contractor and engineer were available and they were confident in the reuse solution.	
Are the foundations suitable for sufficient load transfer?		Mini-piles are required.

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278

279 Since foundation reuse offered many advantages, including the reduction in construction activities and

280 in situ demolition, as well as savings in cost, time, and energy, the reuse solution was accepted by all

281 parties involved in the design and the construction. This was in part possible because of the existence

282 of good quality records and field testing. These allowed the risks related to pile reliability to be quan-

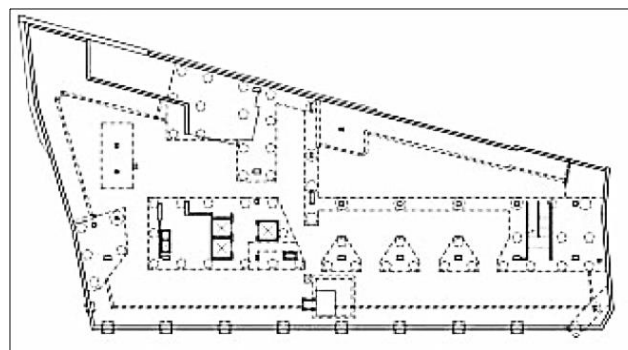
283 tified and mitigated with mini-piles. The associated risks with column overloading were similarly al-
284 leviated. The proposed hybrid method identified all major points. High-level drivers of archaeology
285 and historical constraints, sustainability, materials reuse, land value and cash flow projections were
286 recognised in Step 1. However capacity was a controlling consideration, as an additional four storeys
287 were to be added. The capacity factor would not have been identified had only the modified SPeAR
288 method been used. Similiarly, had only the RuFUS method been applied, a foundation reuse solution
289 would have been recommended, but the difficulties related to the site congestion and archaeology
290 would have been missed. Alternatively, the CIRIA assessment would have omitted the importance of
291 the reliability and the capacity of the foundations, as well as the the existence of high quality records,
292 which had a significant impact on the ability to proceed with a reuse solution.

293

294 **Case B**

295 The second case history involved Ludgate West (Fig. 7), a new office building to be placed on the
296 1970's site of Carroone House, London (Clarke et al., 2006). Preliminary site studies showed archaeo-
297 logical remains between the pile foundations and the basement. Due to anaerobic conditions beside
298 the Fleet River, in-situ preservation was deemed beneficial. The stage 1 drivers are shown in Table 5
299 and Figure 8. Step 1 successfully indicated high-level drivers in sustainability, materials reuse, land
300 value and cash flow projections, as well as archaeology and historical constraints, and consistency in
301 building location. For this particular site, archaeology was a main concern. Despite the relatively high
302 level of drivers, reuse was not the eventual solution, as determined in steps 2 and shown in Table 6.

303



304 **Figure 7. Foundations of original structure on site, Carroone House (Clarke et al., 2006)**

305

306 In this case, neither the RuFUS nor the CIRIA methods would have highlighted the historic surround-
307 ings or the sustainability issues. None of the methods adequately addressed the reliability and capacity
308 of the existing foundation with respect to the existing records. In fact, had the RuFUS method been
309 applied, the recommended solution would have been foundation reuse, which in the end was deemed
310 inappropriate for this site.

311

311 The decision to not reuse the foundations was influenced by several factors: (1) the inconsistencies
 312 with the existing and proposed layouts; (2) uncertainties associated with the compatibility of the
 313 foundations; and (3) the reliability of the existing foundations to perform as required over the struc-
 314 ture life cycle. The risks associated with the project were considered too great. Had a reuse solution
 315 been chosen, there would have been increased costs due to the requirement for transfer structures and
 316 supplemental methods. These factors lead to an outcome of constructing new foundations on site,
 317 while considering foundation reuse for future development. This resulted in high quality records being
 318 assembled as part of the “close out” reports. These included design, as-built, and construction draw-
 319 ings and information on tests performed and results obtained.

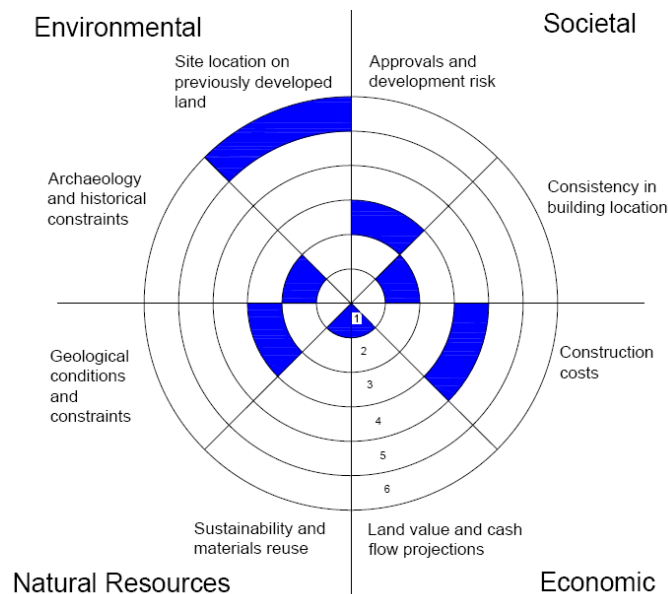
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Table 5. Driver descriptions for Ludgate West

Sector	Driver	Rating
Environment	Site location on previously developed land	Unprotected greenfield land as a % of total community meterage = level 6
	Archaeology & historical constraints	Neighbourhood/district based architectural designation = level 2
Natural Resources	Geological conditions and constraints	Mixed = level 3
	Sustainability and materials reuse	1651 m ³ < = level 1
Economic	Land value and cash flow projections	Ratio of monthly rent over monthly median household income 1.09 = level 1
	Construction costs	40.28 Big Macs per cubic metre of concrete = level 4
Societal	Consistency in building location	32 years at location = level 2
	Approvals and development risk	Approval is 7 months = level 3

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323

324

Figure 8. Step 1 assessment, Ludgate West

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Table 6. Summary of Step 2 assessment, Ludgate West

Considerations	Yes	No
Are existing foundations compatible with the proposed new layout?		Existing foundations were not compatible with the proposed structure. Significant alterations would be required for reuse to be a viable option.
Are existing records available? What is their quality? Do they support foundation reuse?	There were as-built records.	No existing construction or installation records found. Extensive testing would have been required, which was not deemed feasible.
Are there site-specific constraints/concerns (e.g. boundaries, archaeology, ground congestion) Do they encourage foundation reuse?	Existing archaeology would benefit from in situ preservation.	
Are the foundations reliable in capacity, condition, deterioration, size, and location?		Extensive testing would have been required which was not considered feasible or economical. Preliminary capacity assessment also showed there would be an increase in load on the existing foundations in order to carry the proposed new structure.
Does reuse offer advantages over alternative foundation solutions?		The majority of the reuse solutions were not considered economical. Excavations were undertaken to preserve remains, and therefore created space for the installation of new foundations. This was deemed the most viable solution.
Is foundation reuse solution acceptable to all parties?		No; the risks were considered too high.
Are the foundations suitable for sufficient load transfer?		No; costly transfer structures and supplemental foundations would have been required.

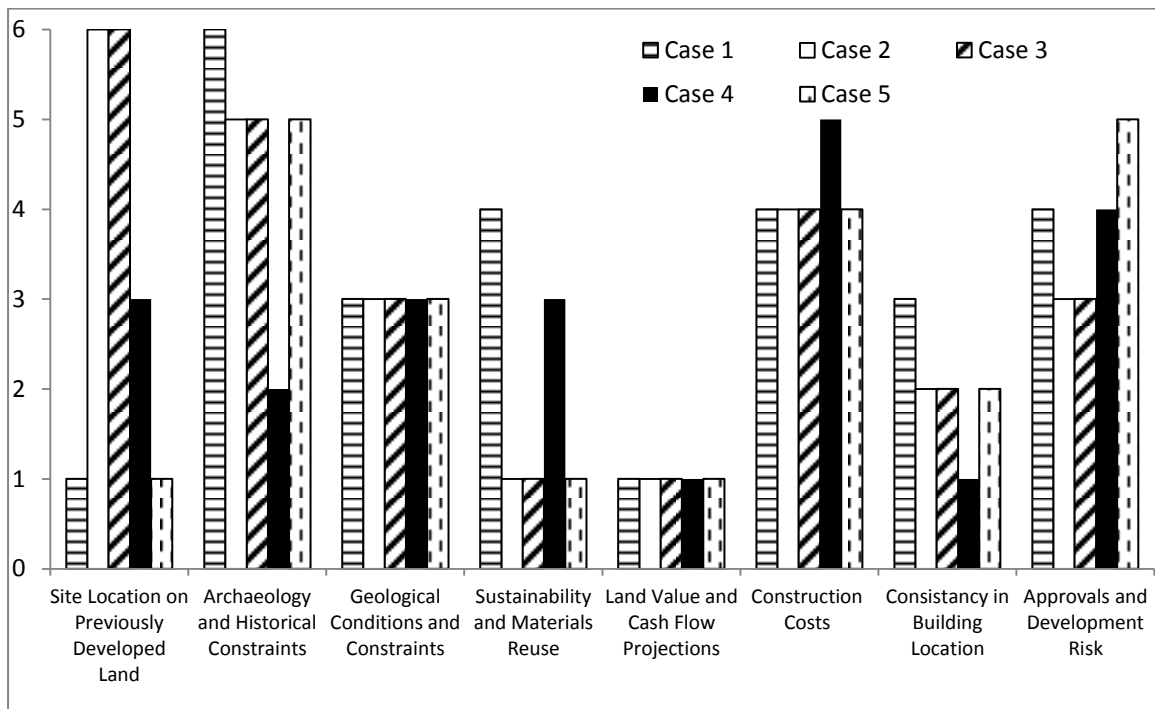
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329 **DISCUSSION**

330 One of the main advantages of the proposed hybrid approach, is that it incorporates a large number of
331 considerations, thereby giving more data to the designer and arguably allowing a more informed deci-
332 sion to be taken. While all of these factors have an impact on whether foundation reuse is a beneficial
333 approach to take, some factors are likely to be more important on some sites than on others. For ex-
334 ample, Figure 9 shows the outcome of the modified SpeAR approach for cases 1-5. In all of the cas-
335 es, the geological conditions and constraints were at level 3. This was also true for the Ludgate and
336 Coventry projects (Cases A and B). Scoring at this level for this factor may prove to be a necessary
337 but not sufficient indicator for foundation reuse. The same argument may be made for the category of
338 land value and cash flow projection scoring at a level 1 (as occurred in all 7 cases). Conversely the
339 category of sustainability and material reuse may not be that effective, as the Ludgate case scored a 1
340 but no foundation reuse occurred, while other cases scored above 3 and reuse did occur. A similar ar-
341 gument may be made for construction costs, as all 7 cases scored at least a 4 in this category, yet reuse
342 was done in 5 of the 7 cases. Many of the other categories gave inconsistent results. Further investi-
343 gation is clearly needed with the goal of narrowing the number of categories needed and/or instituting
344 some sort of weighting system to generate a very robust set of pre-qualifiers. Further work is also

345 needed to determine the scalability of the proposed system with respect to projects of different ages,
 346 sizes, functions and geographical locales.
 347



348

Figure 9. Comparative modified SPeAR outcomes from Cases 1-5

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350

351 **CONCLUSIONS AND RECOMMENDATIONS**

352 Overall, the proposed two-stage, hybrid method proved successful in assessing the available two case
 353 studies. The main drivers were recognised, while site-specific constraints and concerns were incorpo-
 354 rated. By combining the modified SPeAR method with that of the proposed flow chart, an overall re-
 355 view of a project and its potential for reuse of foundations can be achieved. The main considerations
 356 for foundation reuse such as foundation reliability, compatibility, site constraints, site surroundings
 357 and the drivers recognised in the SPeAR method were assessed. The proposed method was based on
 358 the first critical assessment of existing techniques and has the unique benefit of addressing future re-
 359 use considerations; something not addressed in any of the previous methods. While the new method's
 360 scalability and robustness must be tested further, the initial attempts proved promising.

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362

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