

# Moving beyond CAD to an Object-Orientated Approach for Electrical Control and Instrumentation Systems

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**Abstract:** The quality of computer-aided-design (CAD) generated ‘As-built’ documentation is evaluated for a High Voltage Switchgear System (HVSS), which forms part of a Supervisory Control and Data Acquisition up-grade within a geo-thermal power plant. A total of 267 CAD drawings for the HVSS were used to create a Systems Information Model (SIM) whereby the physical components and associated connections were constructed in an object orientated database. Throughout the modelling process a considerable amount of errors and information redundancy were identified and examples are presented. The aforementioned CAD drawings consumed 10,680 man-hours to produce in stark contrast to the 80 man-hours required to construct the SIM; thus illustrating the efficiency and effectiveness of SIM when compared to CAD for the design and documentation of electrical, control and instrumentation systems (ECIS). To realise this huge potential cost and productivity saving requires a shift in mindset and a move beyond the use of CAD, where there exists a 1:n relationship, to one that focuses on establishing a 1:1 relationship between objects in the SIM and components in the real world.

**Keywords:** ‘As-built’ documentation, computer-aided design, errors, systems information model

## Introduction

Accurate and reliable electrical documentation is pivotal for managing and operating constructed facilities (Clayton *et al.*, 1998). However, there is a propensity for ‘As-built’ documentation, which records the status of a facility at the completion of construction, to contain errors and considerable information redundancy (Gallaher *et al.*, 2004; Love *et al.*, 2014). Moreover, they often do not effectively express the information required to operate a facility. An array of factors contribute to this aforementioned scenario, including the working environment, and poorly designed processes and structures. When producing electrical instrumentation and control system (ECIS) drawings however, it has been suggested that use of Computer-Aided-Design (CAD) provides the medium for generating of poor quality ‘As-built’ documentation, which renders them obsolete during maintenance and operations (who suggested this – REF please?).

34 Within the construction and engineering industry, Building Information Modelling (BIM) has  
35 progressively been employed to improve the management of information throughout a project's  
36 lifecycle. BIM is typically created using an array of integrated software applications for architectural,  
37 structural, heating ventilation and air conditioning, and hydraulic elements. Such elements have  
38 scale and geometry that can be visualized within the BIM. However, ECIS are void of scale and  
39 geometry making visualized in a three-dimensional (3D) view impossible; albeit, cable trays and  
40 components can be modelled. Consequently, ECIS practitioners rely upon CAD to detail the  
41 connection and relationship between components (Love *et al.*, 2013).

42

### 43 **Documentation of ECIS in CAD**

44 Through CAD, electrical and system engineers may: experiment with various alternative design  
45 solutions; validate circuits more readily; and improve design accuracy. For example, the design of  
46 a bi-stable circuit can be readily checked in CAD (i.e. values of load resistance attributed to the  
47 various components). Similarly, faulty permanent magnet design previously posed significant  
48 problems for electrical engineers as it resulted in partial demagnetization. However, CAD's ability  
49 to verify the design's reasonability has been resolved. Other advantages offered by CAD for ECIS  
50 practitioners include an ability to:

51

- 52 • provide an understandable representation of the numerical results of what? (e.g. through  
53 graphs and other graphic devices);
- 54 • reduce the tediousness of solving common and complex equations;
- 55 • adapt simple numerical methods to solve complex problems that would be otherwise too  
56 time-consuming to undertake via manual calculations; and
- 57 • test the design efficacy (such as the maximum value of load resistance the design can  
58 support).

59

60 Typical types of drawings created within CAD for ECIS are: 1) block; 2) schematic; 3) termination;  
61 and 4) layout. In addition to these drawings, complementary cable schedules and 'Cause and Effect'  
62 (C&E) diagrams augment information provided within documentation produced; though this is  
63 dependent upon the nature of the system that is being designed and documented.

64

65 Despite CAD's many palpable benefits, ECIS engineers are dogged by errors and omissions,  
66 especially as objects are often replicated on several different drawing types. In addition, concepts  
67 and requirements from several sources are translated onto documents and drawings in varying

68 patterns. Often, the same information is replicated within several documents to form relationships  
69 between them. For example, different information about the same component will regularly be  
70 placed in various documents or drawings and so equipment and cable tags are often repeated. As  
71 a documentation package evolves it becomes increasingly difficult to ascertain which particular  
72 documents contain the same information or show related information. Monitoring and controlling  
73 documentation information accuracy and currency therefore forms a critical component of the  
74 engineering management process. Yet, the extant literature consistently demonstrates that effective  
75 audits are rarely undertaken due to time and financial constraints imposed on engineering firms  
76 (e.g., Lopez and Love, 2012). When meticulous audits are undertaken, errors and omissions are  
77 invariably found and consequently, several iterations of the documentation may be required Do  
78 you mean 'revisions of the documents?'. Unfortunately, engineers who are subject to tight  
79 programmes of working and associated time constraints may distribute incomplete or inaccurate  
80 documentation to contractors.

81

82 Incorrect labelling, missing labels and omissions represent typical errors found in ECIS drawings  
83 (Love *et al.*, 2013). Moreover, connections between various electrical devices (represented as  
84 shapes and lines) can be distributed among several drawings. Unclear please rewrite plus I'm not  
85 clear as to what the significance of this sentence is Errors and omissions identified by engineers  
86 on-site invariably result in a 'Request for Information' (RFI) being raised which seeks to identify  
87 and resolve issues on-site to avoid potential contract disputes and claims at a later date (Tadt *et al.*,  
88 2012). Raising an RFI can be costly and may adversely impact upon the contractor's productivity.  
89 This is because, when RFIs are addressed, drawings must be up-dated to accommodate  
90 consequential changes and thus better reflect what is actually being constructed; when this process  
91 is not robustly executed, the quality of 'As-built' documentation produced is questionable.

92

### 93 ***'As-built' Documentation within Electrical Engineering Projects***

94 'As-built' documentation represents a revised set of drawings submitted by a contractor upon  
95 completion of the works they were contracted to undertake. They reflect changes made in the  
96 specifications and working drawings during the construction process, and detail the exact  
97 dimensions, geometry, and location of all elements of the work completed under a contract.  
98 However, there is a proclivity for errors or omissions to be contained within the 'As-built'  
99 documentation as they are prepared using two-dimensional (2D) CAD (Love *et al.*, 2013; Zhou *et al.*,  
100 2015). Increasing competition, schedule and financial pressures invariably manifest in the  
101 production of incomplete tender documentation that fails to reflect the scope of works required

102 (Love *et al.*, 2015). Consequently, tender prices may increase as contractors account for potential  
103 risks. During construction, drawings may need to be amended as RFIs and change orders arise.  
104 Such amendments are ‘simply’ highlighted on selected drawings rather than comprehensively  
105 revising all information produced (and effectively communicating such to all parties involved).

106

107 Research undertaken by Love *et al.* (2013), for example, found a component or device may occur  
108 on as many as 20 drawings in electrical contracts. When a change is required to a 2D drawing, the  
109 drawing and each corresponding view has to be manually updated thus a 1:n relationship exists.  
110 In this case, every single drawing where a component or device exists is required to be up-dated,  
111 which increases costs to an engineering firm, and thus adversely impacts their fee if a fixed fee had  
112 been agreed. Contrastingly, if a cost reimbursement contract is awarded to an engineering firm,  
113 then the financial considerations associated with amending documentation are accommodated;  
114 they are in this instance being ‘paid’ to repeatedly issue paper, irrespective of its quality (i.e.,  
115 completeness and accuracy).

116

## 117 **Case Study**

118 Considering the paucity of research undertaken in this area, an exploratory case study approach was  
119 undertaken. This empirical inquiry sought to specifically investigate the potential inadequacies of ‘As-built’  
120 documentation produced using CAD when compared to the SIM approach. The case study selected for the  
121 research was based upon ‘As-built’ documentation supplied by a instrumentation and electrical systems  
122 organization who had been awarded a contract to upgrade the Supervisory Control and Data Acquisition  
123 (SCADA) system of a power plant. . Essentially, a SCADA is a system operating with coded signals  
124 over communication channels so as to provide control of remote equipment in real-time. The  
125 control system may be combined with a data acquisition system by adding the use of coded signals  
126 over communication channels to acquire information about the status of the remote equipment  
127 for display or for recording functions. SCADA systems ensure management are provided with  
128 timely and accurate data that can be used to optimize the operation of plant. The researchers worked  
129 collaboratively with this organization to produce an equivalent SIM from the ‘As-built’ drawings that had  
130 been provided by them in a CAD format.

131

### 132 *Case Background*

133 The Philippines is situated in the Western Pacific Ocean and consists of 7,107 islands with circa  
134 100 million inhabitants. It is located at the western fringes of the Pacific Ring of Fire and is  
135 subjected to frequent volcanic activity. This geographical position enables superb opportunities

136 for ‘green and renewable’ geothermal harvesting which currently contributes to 18% of the  
 137 country’s electrical power. In the early 1970’s, the Philippines and the New Zealand governments  
 138 initiated the ‘Colombo Plan’ to investigate the potential geothermal power reserve of the island of  
 139 Leyte. After a series of shallow and deep drillings, a number of wells were completed and used to  
 140 supply steam for the turbines for the Tongonan-1 Geothermal Power Plant, which was constructed  
 141 and commissioned in 1983.

142  
 143 The Energy Development Corporation (EDC) is the largest producer of geothermal energy in the  
 144 Philippines, second largest in the world and has invested in geothermal, hydro and wind energy  
 145 projects (REF). Green Core Geothermal, Inc. (GCGI) is a subsidiary of EDC and operates two  
 146 geothermal power plants, Tongonan-1 and Palinpinon, in Leyte and Negros Oriental respectively;  
 147 collectively, these plants have the capacity to generate 305 megawatts. The Tongonan-1 power  
 148 plant, which is the focus of the research presented in this paper, consists of three 37.5 megawatts  
 149 units that cumulatively generate a total of 112.5 megawatts. Why was this plant chosen over the  
 150 other one? Any reasons?

151  
 152 *Dataset: ‘As-built’ Documents*

153 The ‘As-built’ electrical documentation, comprising of 267 CAD drawings of a SCADA system,  
 154 identified in Table 1, were provided to a instrumentation and electrical systems organization by a  
 155 major international construction company. The SCADA system’s initial design was undertaken by  
 156 a Swiss electrical engineering company and it was estimated that the total number of drawings  
 157 produced was approximately 1800.

158  
 159  
 160 Table 1. Drawing list supplied  
 161

Equipment	Drawing Type	Number
Common for all Feeders	Cover sheet	7
	Index drawing	4
	Block diagram	3
	Schematic diagram	9
	Termination diagram	15
	Layout diagram	4
	Installation and designation	17

Feeder 1	Cover sheet	1
	Index drawing	6
	Schematic diagram	13
	Termination diagram	18
	Equipment technical data	32
	Cable schedule	2
	Layout diagram	2
Feeder 2	Cover sheet	1
	Index drawing	6
	Schematic diagram	13
	Termination diagram	18
	Equipment technical data	31
	Cable schedule	2
	Layout diagram	2
Feeder 3	Cover sheet	1
	Index drawing	5
	Schematic diagram	9
	Termination diagram	17
	Equipment technical data	29
<b>Total</b>		267

162

163 Would it not be better to move Figures 1 and 2 to after they are discussed not before?

164

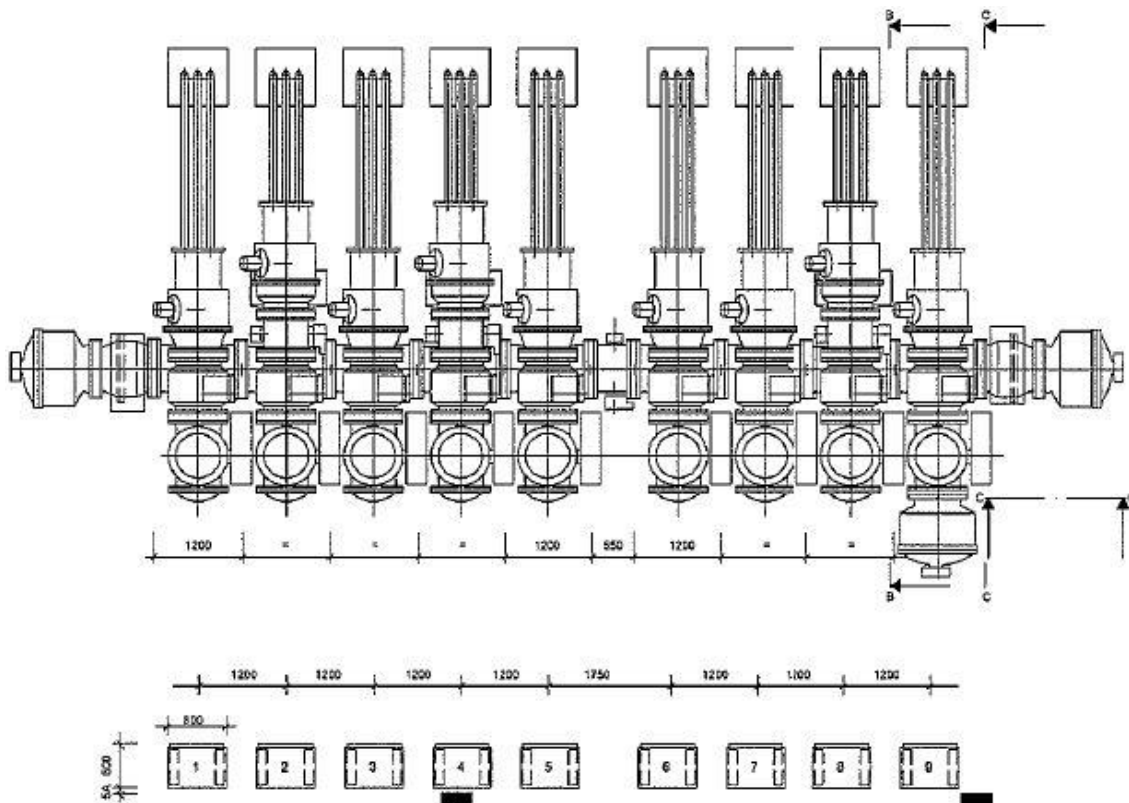


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166

167

Figure 1. High voltage switchgears

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169

170

171

Figure 2. Layout of switchgears and control panels



172 The supplied CAD drawings were used to document the design of the first three of nine high  
173 voltage (HV) switchgears for the plant's 138kV power Feeders (Figure 1). The layout of the  
174 switchgears and the corresponding control panels are presented in Figure 2. These HV switchgears  
175 are installed between generators and transformers and are critical for ensuring the power plant is  
176 operational. They act to protect equipment by clearing the short-circuit faults that could cause  
177 severe damage to them. Table 1 reveals that there are some common drawings that apply to all  
178 three Feeders. These drawings are used to demonstrate the general arrangement of the equipment,  
179 specify the designation for each individual device and illustrate the terminal connections for those  
180 commonly used sockets/plugs. Each Feeder has a corresponding set of specified drawings. The  
181 drawings indicate the equipment used for the switchgear and the panel side for each Feeder; inter-  
182 panel cable connections and wirings between component terminals are also illustrated.

183

### 184 **Systems Information Modelling**

185 In evaluating the quality (i.e., information redundancy and errors) of the documentation provided,  
186 the electrical components and cables were digitally modelled into a SIM. A SIM is a generic term  
187 used to describe the process of modelling complex EICS using appropriate software (e.g., Dynamic  
188 Asset Documentation (DAD)) and is akin to the development of a Building Information Model  
189 (BIM). When a SIM is used to design and document a connected system, all physical components  
190 and associated connections to be constructed can be modelled in an object orientated database.  
191 This results in a 1:1 relationship between objects in the SIM and components in the real world.  
192 Consequently, errors and information redundancy typically contained within documentation  
193 developed in a traditional CAD system can be eliminated (Love *et al.*, 2013; Love *et al.*, 2014).

194

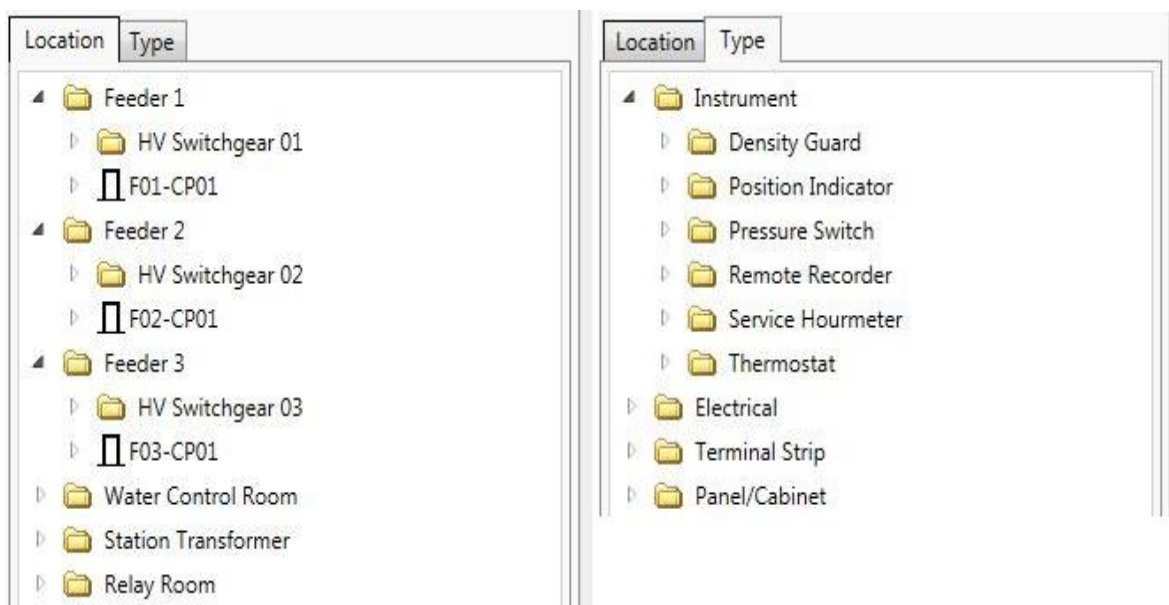
195 Two methods can be used to construct a SIM using software such as DAD: 1) manually; and 2)  
196 automatically. The manual method is appropriate for new projects or where a complete cable  
197 schedule is not available. In such circumstances, engineers are required to manually create a digital  
198 model of each real-world component and cable within the SIM to form a connected system. If  
199 complete cable schedules are available, then the modelling process is considered to be  
200 straightforward using software such as DAD, as it is equipped with a function that can generate a  
201 SIM automatically based on the information derived from the cable schedules.

202

203 For this research, the available cable schedules only provided scant information about the inter-  
204 panel cables. Hence, the information was insufficient to construct a SIM model automatically,  
205 particularly as internal cables within the inside panels were not made available to the



206 instrumentation and electrical contractor. With this in mind, a SIM was manually created by the  
207 researchers in conjunction with the contractor's engineers. Can you briefly describe how this was  
208 done? When the modelling process was completed a total of 525 components and 2451 cables  
209 formed the basis of the SIM. The components were classified according to their 'Location' and  
210 'Type'; that is, their physical location in the plant and their functionality (Figure 3). Cables were  
211 classified into various 'Types' according to the number of cores and their power rating. As a result,  
212 this enabled the design to be examined by directly reviewing the relationships of components  
213 through dynamically interconnected models rather than through the complicated connections  
214 presented on CAD drawings, which are invariably difficult to decipher.  
215



217 Figure 3. Location and type classification

218  
219 Previous empirically research undertaken by Love *et al.* (2013) revealed that an average of five  
220 components and cables (10 objects in total) requires one CAD drawing. Bearing this in mind, the  
221 2976 objects (525 components plus 2451 cables) modelled in this case would require approximately  
222 297 CAD drawings, which is akin to the number supplied. Love *et al.* (2013) also revealed that 40  
223 man-hours, on average, were required to produce each CAD drawing of an ECIS design. Thus, it  
224 is estimated that a total of 10,680 man-hours would be required to produce the 267 drawings. In  
225 addition, producing a complete set of 1800 project drawings would require a total of 72,000 man-  
226 hours. Having established an estimate of workload, the quality of the 'As-built' documentation, as  
227 a result of creating the SIM, could now be assessed in accordance with the information redundancy  
228 and errors contained within the 267 electrical CAD drawings that were provided.  
229

230 **Evaluation of Documentation Quality**

231 The frequency of components among various locations on the drawings is provided in Table 2.  
 232 From this table it can be seen that the number of components for the different Feeders are  
 233 analogous. The Feeders were designed to perform similar functions, which has resulted in their  
 234 configurations and the connections of components and cables being related. In fact, a detailed  
 235 examination of relevant drawings revealed that the majority of components installed on each of  
 236 the three Feeders were identical. Table 3 illustrates the distributions of those identical/ different  
 237 components that have been used by comparing each pair of the Feeders. The upper triangular  
 238 elements in Table 3 identifies the number of identical components that appear in the Feeders. The  
 239 lower triangular elements in Table 3 indicates the number of different components between any  
 240 two different Feeders.

241  
 242  
 243

Table 2. Distribution of components

Location	Number of components
Feeder 1	174
Feeder 2	183
Feeder 3	156
Relay Room	8
Station Transformer	1
Water Control Room	3
<b>Total</b>	525

244  
 245  
 246

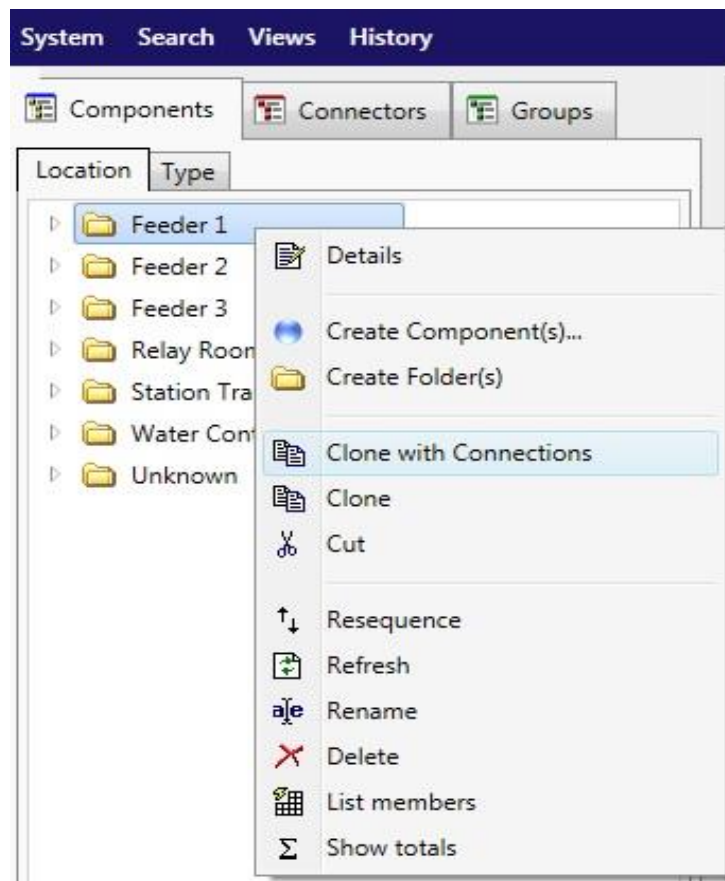
Table 3. Components comparison between Feeders

Identical / Different	Feeder 1	Feeder 2	Feeder 3
Feeder 1	NA	150	153
Feeder 2	57	NA	147
Feeder 3	24	45	NA

247  
 248  
 249  
 250

When Feeder 1 is compared with Feeder 2, a total of 150 identical and 57 different components (24 from Feeder 1 and 33 from Feeder 2) are detected. Explicitly, most of the components (over 86%) of Feeder 1 will be replicated and used in Feeders 2 and 3. Consequently, the time to produce

251 the SIM is significantly reduced, especially as software such as DAD provides the users with  
252 functionality that enables them to reproduce models using a 'Clone' command (Figure 4). Figure  
253 4 illustrates the two options provided to users; namely: 1) 'Clone'; and 2) 'Clone with Connections'.  
254 If the 'Clone' command is used, only the chosen components are replicated. If the 'Clone with  
255 Connections' command is used, both the components and cables are replicated. Noteworthy, all  
256 the objects that are cloned will have identical features and attributes as their source objects.  
257



258

259

Figure 4. 'Clone' Function

260

261 As the functionality of the components and cables are similar for each of the Feeders, the function  
262 'Clone with Connections' is used. The creation of the SIM for Feeder 1 is first developed and on  
263 completion is cloned to produce the models for Feeders 2 and 3. Then, the cables from the Feeders  
264 and control rooms are joined to form a single SIM. From Tables 2 and 3 it can be seen that through  
265 'cloning', 82% of the components in Feeder 2 and 98% of the components in Feeder 3 can be  
266 modelled instantly by replicating the corresponding components in Feeder 1. On completion of  
267 the model for Feeder 1, those for Feeder 2 and Feeder 3 are also deemed to be almost finished.  
268 Using this approach the 'cloning' function reduced the time and effort of the modelling process

269 by as much as two-thirds. When CAD is employed, each Feeder requires a specific set of drawings  
270 with the same information being reproduced (Table 1). These drawings are produced manually  
271 and as a result of complex relationships between components and cables, and the need to ensure  
272 the traceability of information, this becomes an arduous and tedious task for engineers and  
273 draftsmen. This manually-laden process significantly increases the propensity for human errors  
274 and omissions to be committed.

275

### 276 *Information Redundancy*

277 The distribution of components contained within the drawings was also examined. Figure 5  
278 illustrates the distribution of the 525 components on each of the 267 CAD drawings; five drawings  
279 each contained over 100 components whilst one contained more than 200 components. This  
280 finding was expected as these drawings were common for all Feeders containing the definitions  
281 and designations of the components. However, 45 drawings had no components recorded on  
282 them. Essentially, they consisted of cover sheets, index and definition of drawings, which are time-  
283 consuming and expensive to develop, but do not provide adequate information to ensure system  
284 integrity.

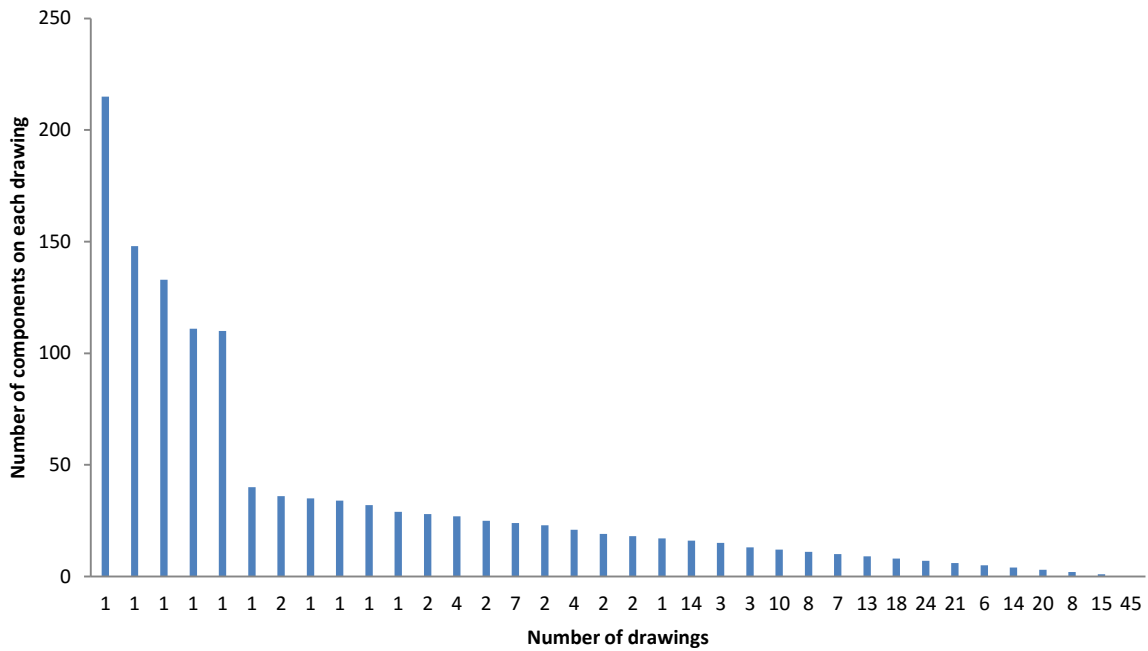
285

286 Most information contained on drawings was considered irrelevant to the electrical system design  
287 by the engineers (not sure that you say anywhere how many engineers were spoken to? Maybe add  
288 this detail earlier in the narrative?) who actively participated with researchers; the information  
289 mainly pertained to recording the title block, document number, revisions, drawing sheet  
290 specifications and notions. Documenting such information is an onerous and costly process and  
291 is typically the responsibility of a draftsman. If a mistake or omission arises a new revision of the  
292 entire drawing will have to be reproduced and reissued. This is an inefficient and ineffective  
293 method, which adversely impacts the productivity of the design and documentation process (Love  
294 *et al.*, 2014). Pete – this text here seems like a repeat of earlier text...

295

296 The number of drawings that are linked to each component was calculated and thus provided a  
297 measure of system design complexity. Research revealed that, on average, each component could  
298 approximately be presented on five various drawings (Love *et al.*, 2013; 2014). This figure Figure  
299 5? typically provides the basis for determining the estimated workload prior to performing the task  
300 of producing the detailed design.

301



302

303

Figure 5. Distribution of components on each drawing

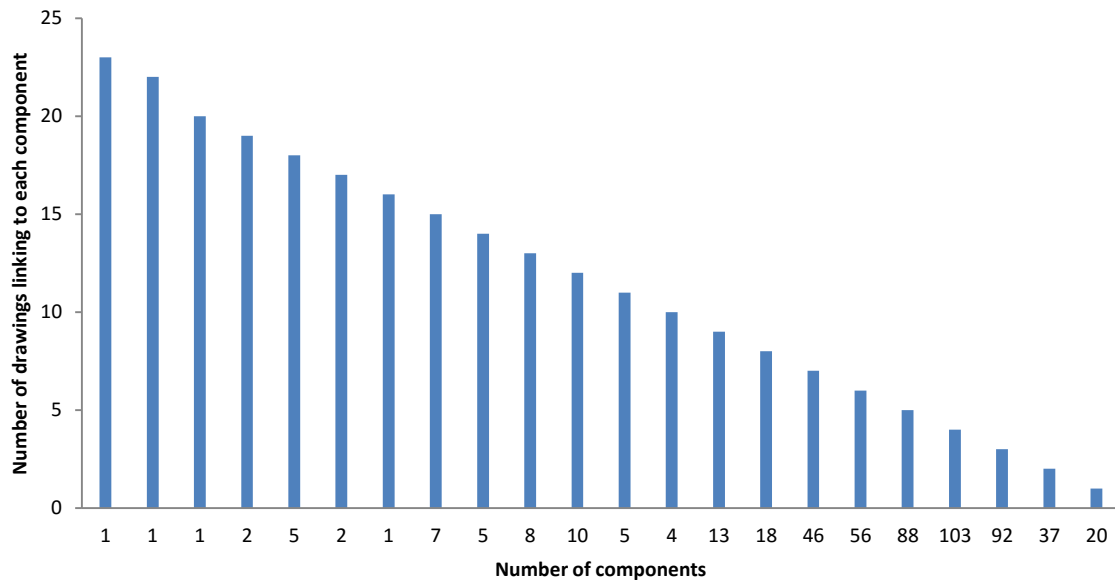
304

305 Figure 6 illustrates that a significant number of components appeared on more than ten drawings  
 306 and three occurring on more than 20 drawings. Not quite sure what you mean here. Most of these  
 307 components are 48 pin sockets and terminal blocks, which are connected to multiple pieces of  
 308 equipment. Considering the sheer number of components that were documented on a widespread  
 309 of drawings, the propensity for draftsman to create an error (by placing sockets in the wrong  
 310 location) significantly increases. A majority of the components (total 422 components, over 80%  
 311 of the 525 components) were found to reside on two to seven drawings. In this instance, each  
 312 component will appear on average on 4.4 drawings, which is akin to empirical research  
 313 promulgated by Love *et al.* (2013; 2014). Thus, the design complexity is considered to be ‘standard’  
 314 in this case.

315

316 As the original design was documented using CAD, each of the components would have been  
 317 manually reproduced approximately five times on different drawings. Engineers and draftsmen  
 318 must determine the types of drawings required (e.g., block, layout and schematic) and the  
 319 information contained within each to facilitate effective communication amongst all projects  
 320 parties regards what is to be physically constructed and installed. Noteworthy, no universal  
 321 standard exists for documenting and producing different electrical drawings, which can hinder an  
 322 engineer’s ability to understand them. When errors or omissions are identified on a drawing, the

323 contractor’s engineer must examine all other related drawings and documents to determine which  
 324 one is correct or simply raise a RFI; either way these are non-value adding activities.



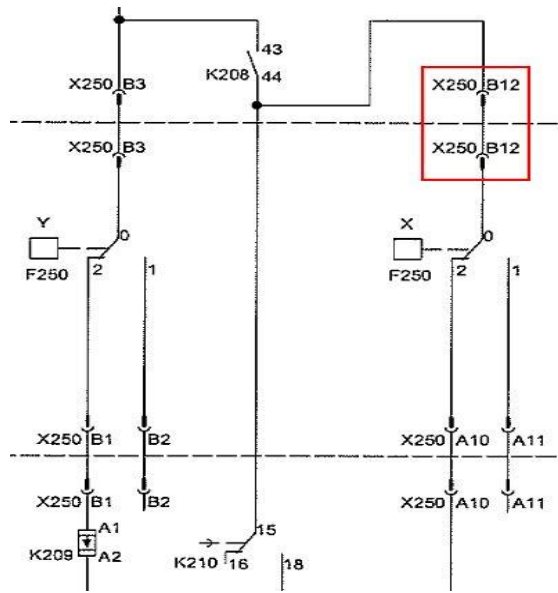
325

326 Figure 6. Number of drawings linked to each component

327 *Error Identification*

328 During the creation of the SIM, a plethora of errors (frequency ( $f$ ) = 89) and omissions ( $f$  = 49)  
 329 were discovered on the CAD drawings (Table 4 not sure we need this table when it can be  
 330 explained in the text). For example, in Figure 7, it is shown that terminals X1 and X2 of a ‘pressure  
 331 switch F250’ are connected to terminals A11 and A10 of a socket X250, respectively. However,  
 332 the terminal X0 of F250 is connected to terminal B12 of X250, which is shown to be unusual  
 333 compared with the connections (Y terminals) next to it; all the three Y terminals (Y0, Y1 and Y2)  
 334 are connected to terminals B3, B2 and B1 of X250 respectively. Notably, there is no mismatch  
 335 between A and B terminals. An examination of the drawings revealed that the ‘pressure switch  
 336 F250’ appeared on eight drawings and the socket X250 on 14 of them.

337



338

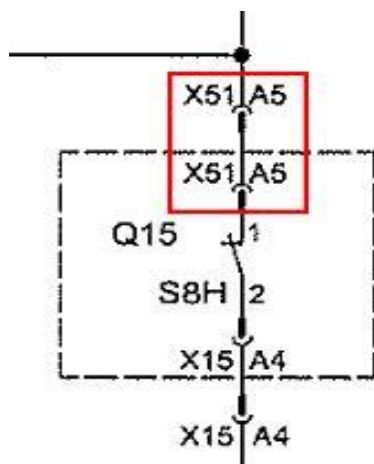
339

Figure 7. An example of error: incorrect terminal

340

341 The auxiliary contact K208 connected to X250 was found to occur on nine drawings. By examining  
 342 the related drawings three of them indicated that the terminal A12 had been mislabelled as B12.  
 343 If the site engineer had terminated the cables, as indicated by the drawing, the devices would have  
 344 malfunctioned and thus jeopardizing the integrity and safety of the entire plant. The pressure  
 345 switch is a critical component of the high voltage switchgear systems, which deals with the 138kV  
 346 power circuit. A ‘mistrip’ of the equipment could have catastrophic consequences for the  
 347 downstream devices and users. Similarly, the error identified in Figure 8 illustrates that terminal 1  
 348 of contact S8H had been connected to the terminal A5 of socket X51. However, the correct  
 349 connection should be terminal A5 of socket X15.

350



351

352

Figure 8. An example of error: incorrect socket





380 or imminent documents are modified. A plethora of scenarios may unfold here, but fundamentally  
381 the way in which ECIS are designed and documented needs to change in order to improve the  
382 integrity of assets, productivity and the competitiveness of firms specializing in providing design,  
383 engineering and contracting services. With the advent of BIM, it is expected that ECIS firms would  
384 adopt object-orientated approaches to align themselves with other disciplines and feed directly  
385 into a project's federated building information model. Explicitly, this is not the case and Hanna *et*  
386 *al.* (2013; 2014) reports upon the reluctance of electrical contractors to embrace BIM. In addressing  
387 this issue, education is pivotal to ensuring **its BIM's or SIM?** adoption, particularly as it requires  
388 engineers to switch from CAD to a new digital vis-a-vis paper based medium. Research, presented  
389 in this paper, provides a mechanism for ECIS engineers and contractors to realize that design and  
390 documentation can be undertaken more effectively and efficiently using a SIM, which is aligned  
391 with BIM.

392

### 393 **Conclusion**

394 **Pete the conclusion is the weak link for me – as it represents a partial summary of the narrative**  
395 **not a conclusion of it. I personally would change tack and starts by introducing the problem and**  
396 **stating how much of a problem this is. Then go into some of what you did and quantify the**  
397 **palpable benefits of it as a means of demonstrating the value of this important work. I would**  
398 **conclude by discussing some of the issued that will be faced by culturally trying to reorientate a**  
399 **whole industry to this new method of working and what may be need to assist in this process.**  
400 **Maybe a final line then to just suggest some direction for future work... just my initial thoughts**  
401 **and happy to review this section again 😊**

402 The quality of the 'As-built' documentation produced using CAD for a HVSS, which formed part  
403 of an up-grade of a SCADA for a geo-thermal power plant were evaluated. A total of 267 CAD  
404 drawings were examined for their errors and information redundancy and then used to create a  
405 SIM. The creation of the SIM required 80 man-hours, while to create the 267 CAD drawings  
406 required 10,860; a difference of 10,780. The empirical evidence clearly demonstrates that  
407 organizations that provide ECIS engineering and contracting services need to shift their mindsets  
408 from using CAD based systems where there exists a 1:n relationship, to one that focuses on  
409 establishing a 1:1 relationship between objects in the SIM and components in the real world. In  
410 doing so, it suggested that they will significantly improve the quality of their service, productivity  
411 and their competitiveness within their respective marketplaces.

412

413 **Acknowledgments**

414 The authors would like to thank the participating contracting organization for making available  
415 this invaluable case study and providing access to the Dynamic Asset Documentation (DAD)  
416 Software. The authors would also like to acknowledge the financial support provided by the  
417 Australian Research Council (DP130103018), which enabled this research to be undertaken.

418 **References** **References are a little light on the ground – I've highlighted places where a**  
419 **few more could be added to establish the context. Not essential though – more of a**  
420 **thought....**

- 421 Clayton, M.J. Johnson, R.E., Song, Y., and Al-Qawasmi, J. (1998). A Study of Information Content  
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