

QUALITY INSPECTION PROCESSES IN RESIDENTIAL CONSTRUCTION

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Advances in technology that can be used to improve commercial and residential construction processes, including quality, are not always readily adopted by the two industries. The purpose of this study was to develop a bar code based quality inspection process that demonstrated the speed and accuracy with which data can be collected and used by residential construction contractors for analysis of quality improvement trends. Items of commonality from three sources of checklists were combined into a general post-construction residential quality inspection form for the framing stage of home building. Three inspectors each completed 28 inspection checklists during the pilot study. The chi-square test for independence found the error rates were related to the data entry method used. Based upon the data results of 8 data entry errors for the scanner method compared to 78 for the manual method, there was a 3.87% error rate for the manual method compared to a 0.397% error rate for the scanner method. The scanner method produced reports that were 98.8% accurate compared to 60% for the manual method, and the scanner method was 65% faster in providing the data necessary to produce inspection reports and evaluate possible trends in quality.

Key Words: Quality; Inspection Processes; Bar Coding; Residential Construction

Introduction

Advances in technology that can be used to improve commercial and residential construction processes and procedures, including quality, are not always readily adopted by the two industries. While quality is important to residential contractors, the procedures and technology being used by contractors in their quality assurance programs vary. Residential construction quality inspection procedures and processes are not standardized. In addition, residential quality inspection data gathered through manual data collection and keyboard data entry may be incomplete, inaccurate, and time consuming to collect and process. This paper will report current residential quality inspection procedures being used by contractors and new technological advances. Lastly, the paper will describe current research and the potential use of Automatic Data Capture (ADC), specifically bar coding technology, in the quality inspection processes for residential construction.

Significance

Competitiveness among construction companies warranted an investigation addressing the use of ADC for various activities including quality inspections in the construction industry (Finch, Flanagan, & Marsh, 1996). TQM procedures may require large amounts of data to be collected to evaluate trends and patterns in quality performance. The collection of this data would be facilitated by the implementation of ADC technologies. Checklist responses of activities to be performed in a quality control program would be bar coded. - Bar coding ~~S~~standardized

checklists has the potential to help improve overall product quality ~~among for all home builders residential contractors in the industry who~~ that may not currently perform regular repetitive inspections ~~during the construction phase~~. Improved data collection ~~of the inspection results~~ methods for quality control inspections ~~will~~ would allow for faster ~~analysis~~ identification of problem contractors, products, crews, and construction methods ~~of construction after evaluation of patterns in the data collected~~. Furthermore, the data analysis would summarize trends in the quality of residential construction.

Problem Statement

Processes that may increase the amount of accurate, and timely, quality inspection data for residential construction companies are needed.

Current Inspection Processes

The improvement of residential quality procedures is a current area of study. Rogers and Christofferson (1997) stated that residential construction companies must improve their organizations in order to operate more efficiently and competitively. One component of a residential contractor's overall quality procedures, quality inspections checklists, was investigated by the author. A review of literature found that published home inspection texts are generally written by, and for, the professional home inspector not residential contractors (Becker, 1993; Cauldwell, 2001; Hoffman, 1985; Howard, 1987; Irwin, 1995; McNeill, 1979; Traister, 1997). The National Association of Home Builders (NAHB) contracted with Rogers and Christofferson to write a production manual to assist home builders improve quality as well as their processes and construction methods efficiency. The manual, published in 2002 titled *Building Quality: An Operations Manual for Home Builders*, also contains inspection checklists for each stage of construction that can be customized for any residential company to assist them in evaluating or measuring quality. Quality measurement is a tool to evaluate the performance of the construction contractor, measuring customer satisfaction or conformance to design and code requirements (Torbica & Stroh, 1999).

Inspection checklists, whether customized for each company or developed by other sources, are consistent in residential quality programs and can be used to measure quality of the home. During interviews conducted in 2003 by the author with three different residential contractors it was found that each used custom, proprietary inspection checklists. These inspection checklists are used repeatedly during home construction. Two of the contractors had their construction managers complete the forms by hand. These forms were then sent to the home offices for data entry into their main computer database. Of these two companies, one was going to implement a Palm Pilot based inspection checklist program with daily uploads to their home office computer. There were no plans to link this application to the daily schedule, or develop a web site to house the information.

The third contractor had not previously been entering any data from the regular field inspections into computer files or sharing the information with the home office. The construction managers at each community of this contractor dealt with any issues related to the inspection results. However, the data was not shared with other community construction managers or the home

office even though the same suppliers and subcontractors were used in multiple communities. This contractor also used Palm Pilots, but use was limited to daily schedule information. The schedules were on a website updated daily with access available to all subcontractors and suppliers. Separate variances or back charge forms were issued by all three of the contractors as needed and linked to non-conforming inspection results for homes. Limitations for the traditional manual data collection method using the checklists include inaccurate data entry by separate individuals, time lag between inspection completion data availability, and lack of communication between parties that may be affected by subcontractors or suppliers with poor quality performance.

Available Technology

PDA's, digital photography, Application Service Providers (ASP), mobile computing, wireless networks, project websites and cameras are some of the technological advances that can be adopted for use in residential construction quality management programs. Research conducted by Dubey-Villinger and Dubey (2003) reported that residential quality could only be ensured by the labor-intensive training and oversight activities. Caldeira (2003) grouped these activities into four different areas: 1) Controlling use of qualified crews, 2) Instituting field training on key issues, 3) Using inspections to reinforce accountability for quality, and 4) Measuring zero-punch lists or first-time quality performance. Caldeira and McCune (2003) suggest that tool-box talks could be included in the field training step. Tool-box talks traditionally disseminate information and train workers about safety related issues, but can also be used to educate workers about quality. During the talks the instructor could show examples of poor quality work, detailed pictures of how various construction activities should be completed, and the desired quality of the finished work.

Tool box talks and training sessions are a perfect application for digital photograph technology. Digital pictures taken during quality inspections could be emailed to affected subcontractors and suppliers showing problems or imperfections needing to be completed, and can also be used in training sessions with new workers. Remote site cameras can also be used in similar ways. These cameras can record construction sequences and procedures which can later be studied for process improvements, increased efficiency of operations, and ways to increase quality (Angelo, 2001; AzPath, 2001; Hampton, 2003; Lang, 2000; Phair, 1996; Riley & Whitesides, 1999). Other contractors are investigating the use of wireless communication and project websites. Whether in-house websites or using ASP's to provide the data storage locations and operations, many companies are leery of security issues and availability of the data.

Residential Contractor Technology

One of the three residential contractor interviewed by the author in 2003 was forcing all of their suppliers and subcontractors to use their website to find current construction schedule and delivery information for the houses under construction (T. Wickstrom, personal communication, July 15, 2003). One of the other two residential contractors said they did not wish to force their subcontractors, partners, and suppliers to use this technology. This contractor wastes time and money by faxing each of their subcontractors, partners, and suppliers updated schedules each morning and does not provide this information on a website for those who would wish to use the

technology. This company currently uses a computer version of their inspection checklist. The Project Managers link their Palm Pilots each night to upload the information, but they do not have wireless connections to the home office computer database so the upload over regular phone lines takes significant amounts of time (B. Anderson, personal communication, July, 11, 2003). Wireless systems for daily upload of reports and inspections, while in development, are often not perfect in operation. Increased accuracy from field reports that are not processed by office clerks are just one foreseen benefit of this type of system (Sawyer, 2003).

Mobile computers and punch list software programs are additional technologies that can be used in residential quality inspection processes. Rugged mobile computing terminals suitable for use on construction sites make plans, schedules, and quality inspection checklists available to project managers (Albright, 2001). Add wireless communication ability to these mobile computing terminals and quality inspections can be expedited and results quickly shared with multiple parties. Similarly, punch list software programs, while expensive, can be used by residential contractors to track quality issues and generate punch lists (Staff, 2002). Data can be transferred electronically to the home office and sorted for relevant information on subcontractors, items of nonconformance or any other pertinent issue.

One application of current technology not observed in residential construction, either in practice or in published literature, is the use of Automatic Data Capture, or more specifically bar coding technology. The author has explored the use of bar coded quality inspection checklists in residential applications.

Current Research

TQM programs, including quality inspections, if done well, require significant amounts of data to be collected to ensure continuous improvement. Residential contractors are performing quality inspections on their homes, but the methods for collection and processing of the data are not standard throughout the industry as demonstrated by the residential contractors interviewed in 2003. Current residential industry inspection methods using manual data collection and computer keyboard entry are often inaccurate, untimely, and prohibit sharing of data. A possible improvement to this traditional process is the incorporation of Automatic Data Capture (ADC) technology into the process.

ADC and identification technologies are currently used in industrial applications. Fales (1990) stated that they have been found to reduce costs for material and equipment tracking as well as improve quality performance due to the availability of more accurate and timely data for analysis. Bar coding is only one of the ADC technologies available for use, but is the technology of choice for many applications due to its relative ease of use and reasonable cost. Commercial construction applications have been studied in the United States since the late 1980's by the Construction Industry Institute among others, but little documented progress has been made toward use of ADC in the industry. The author proposed the use of bar coding technology in quality inspection procedures to reduce data entry errors, speed up data collection on inspections, and expedite the sharing and evaluation of the collected data. The research, completed during the summer of 2004, was conducted in three phases.

Methodology

This study was composed of three phases where phase one included the development of a quality inspection checklist from previously identified sources. The checklist form design and contents were then validated by a panel of experts. Phase two of the study included the bar coding of checklist responses, development of a custom bar code scanning program, testing of the process by the author, and development of a training program for the pilot study inspectors. Phase three was the pilot study of the quality inspection process in field conditions and evaluation of the error rates for the two data collection methods.

The data collection occurred over two days with the selected contractor employees. August 16, 2004 was the first date for data collection. On this day all of the 28 framing inspection checklists were completed by the three company employees, one of which created the control or Master inspection checklist forms for each house inspection. After the completion of the inspections and marking the checklist forms to indicate the desired question responses, data entry for the manually completed checklists and the scanning of the bar coded forms began. The typed data entry of the manually completed checklists begun on August 16 was completed on August 20, 2004. All of the scanned data from the checklists was collected on August 20, 2004. Once complete, the data was uploaded into a text file created for the scanned data, and then imported into an Excel spreadsheet. This spreadsheet, and the spreadsheet containing the manually completed checklist data entered via computer keyboard, was linked to the Access database created for detailed summary report generation.

Results

The checklist summary reports for the two methods were used to evaluate the accuracy of the data entered into the database through comparison with the Master inspection checklists. There were 2014 data entries for the 28 inspection checklists used; 34 for each checklist plus 45 Comment Form numbers and ten Variance numbers. The manually completed checklists had nine errors in them due to a failure in communication between the Master inspector and the person completing the manual inspection checklists. The wrong response was marked on the checklist forms. Similarly, there were three communication errors in the bar coded inspection checklist forms. If the communication error resulting from incorrect question responses marked on the forms were typed or scanned correctly into the databases they were not included in the error totals.

Table 1

Summary of Results for Both Data Collection Methods

METHOD	Data Entry Errors	Total Errors	Data Entry Time (Minutes)
Scanner	8	12	2
Manual	78	402	153

The manual checklist method with keyboard data entry resulted in 78 data entry errors and 324 copy or Excel auto fill errors for a total of 402. The 78 manual data entry errors included incorrect spelling, numbers not typed in correctly, missed question numbers, missed comment form numbers, missed variance numbers, missed lot number changes, and incomplete entered numbers or those missing digits and prefixes. The scanned data method had eight data entry errors, five due to missed question responses, two due to the wrong response being scanned, and one missed Variance number. There were also four instances of partially scanned bar codes, resulting in a total of 12 errors for the scanner method as shown in Table 1. The data entry error values indicate that for this study there was a 3.87% error rate for the keyboard data entry versus a 0.397% error rate for the scanner data entry method.

The comparison of the database reports with the Master checklist data allowed the researcher to count the number of errors generated by the inspectors using the two different data collection methods. The total errors counted and the chi square analysis is shown in Table 2. For one degree of freedom, contingency tables indicate the critical chi-square value for an α of 0.001 is 10.83, or only a 0.1% of incorrectly rejecting the null hypothesis (Sheskin, 1997). For this study, the null hypothesis was that the error rates between the two methods were the same. Thus, it is appropriate to reject the null hypothesis for the calculated χ^2 value equal to 462.453 per Table 2. With less than 0.1% chance of error, it can be concluded that the data entry errors that occurred during the keyboard entry of the manually completed inspection checklists were related to the manner of data entry, and the scanner method was more accurate than the manual method.

Table 3 Table 2. Chi square test of independence results.

Chi-square Test of Independence Results for All Errors

CHI-SQUARE RESULTS	y_{ij}	e_{ij}	$y_{ij} - e_{ij}$	$(y_{ij} - e_{ij})^2$	$[(y_{ij} - e_{ij})^2 / e_{ij}]$
No Errors/Scanned	995	800	195	38025	47.53125
Date Entry Errors/Scanned	12	207	-195	38025	183.6956522
No Errors/ Manual	605	800	-195	38025	47.53125
Data Entry Errors/Manual	402	207	195	38025	183.6956522
TOTAL				$\chi^2 =$	462.4538043

While the completion of the checklists using the scanner to record the data was twice as slow as the manual checking of the appropriate responses, the typed data entry of the manually completed checklist information into the Excel spreadsheet took a total of 153 minutes, or 5.46 minutes on average per inspection checklist. This is compared to the less than two minutes to upload all 28 scanned checklists data into a text file which was then imported into an Excel spreadsheet. This was a data entry time reduction of approximately 150 minutes. Thus, the scanner method was 65.2 % faster than the manual method in providing the data necessary to produce reports and evaluate possible trends in quality.

Summary

Identified benefits derived from ~~particular~~ bar coding of ~~used for~~ the inspection forms checklist responses could include, among others, the speed and accuracy of information processing (Cooper, 1989; Fales, 1990; Marsh, 1997; Malovany, 1998). It can be concluded from the statistical analysis in this study that the bar coded checklist, in conjunction with the use of the PT40 scanner, did provide more accurate data collection. However, the data collection process using the PT40 scanner was not perfect. The operator of the scanner can still make data collection errors by missing questions, and scanning the incorrect question answer and not correcting wrong answers before proceeding to the next question. The data collector must consciously concentrate on the data collection process and read the screen prompts on the PT40 to ensure the collection of the correct inspection data.

The scanner method produced reports that were 98.8% accurate compared to 60% for the manual method, and the scanner method was 65% faster in providing the data necessary to produce inspection reports and evaluate possible trends in quality. These study results indicate that the process developed by the researcher is faster and more accurate than the traditional manual data collection method and report generation. Thus, adoption of ADC technology can increase the amount of accurate and timely quality inspection data for residential construction companies. This could be expanded upon by using wireless technology and scanner units that also function as PDA's with screens that can accept written notes as well as keyed and scanned data entry.

References

- Albright, B. (2001, March). Construction industry adds mobile computing to toolbox. *Frontline Solutions*, 2, 3, 52-53.
- Angelo, W. (2001, February). Webcams cast unblinking eye on good and bad project events. *ENR*, 246, 8, 56.
- AzPath, (2001, September). Data Collection on a residential foundation slab construction using time-lapse photography. *Del E. Webb School of Construction Research Series Report No.1*.
- Becker, N. (1993). *The complete book of home inspection* (2nd ed.). McGraw-Hill, Inc.
- Caldeira, E. (2003). Closing the quality gap. *Professional Builder Magazine*. Retrieved June 7, 2004 at: <http://www.housingzone.com/topics/pb/management/pb03aa003.asp>
- Cauldwell, R. (2001). *Inspecting a house*. Newtown, CT: The Taunton Press.
- Cooper, T. (1989). Construction related applications of barcode technology. *Proceedings ASC Annual Conference*, 25, 27-32. University of Nebraska- Lincoln.

- Creswell, J. (2003). *Research Design*. Thousand Oaks, CA: Sage Publications, Inc.
- Dubey-Villinger, N., & Dubey, K. (2003, August 14). Quality is not free for U. S. homebuilders. *Journal of Organizational Excellence*, 22, 4, 21-28.
- Fales, J. (1990, September). Who cares about data collection? *Industrial Engineering*, 22, 9, 16-17.
- Finch, E., Flanagan, R., & Marsh, L. (1996). ADC application in construction. *Construction Management and Economics*, 14, 121-129.
- Hampton, T. (2003). Project teams use digital cameras to shoot it, then share it; Digitography is changing the way builders track progress. *ENR*, 251, 26, 16.
- Hoffman, G. (1985). *How to inspect a house: Exactly what to look for before you buy* (pp. 145-163). Addison-Wesley Publishing Company.
- Howard, H. (1987). *The home inspection handbook* (pp. xv, 207-223). Garden City, NY: Doubleday & Company, Inc.
- Irwin, R. (1995). *The home inspection troubleshooter* (pp. ix, 3-9). Dearborn Financial Publishing, Inc.
- Lang, L. (2000). Remote camera system keeps an eye on projects. *ENR*, 244, 20, 70.
- Marsh, L. (1997). Bar coding for construction. *Construction Computing*, 54, 30.
- Malovany, S. (1998, June). Bar coding: A benchmark of efficiency. *Foodservice Equipment & Supplies*, 51, 7, 65.
- McCune, H. (2003). Turn toolbox talks into real-time quality improvement. *Professional Builder Magazine*. Retrieved June 7, 2004 at: <http://www.housingzone.com/topics/pb/management/pb03ca009.asp>
- McNeill, J. (1979). *Principles of home inspection* (pp. 17, 286-288). New York: Van Nostrand Reinhold Company.
- Phair, M. (1996). Digital pics smooth communication while decreasing project costs: Scanners and cameras create versatile images for users. *ENR*, 237, 23, 26.
- Riley, D., & Whitesides, J. (1999, Summer). Implementing digital image photography in the building industry. *Journal of Construction Education*, 4, 2, 162-174.
- Rogers, L., & Christofferson, J. (1997). Standardizing residential construction procedures: NAHB production manual. *Proceedings ASC Annual Conference*, 33, 195-202.

Rogers, L., & Christofferson, J. (2002). *Building quality: An operations manual for home builders*. NAHB Business Management & Information Technology Committee; Single Family Production Builders Committee.

Sawyer, R. (2003, June 23). Taking job data to the air: Cell phone technology and wireless networks pave the way. *ENR*, 250, 24, 26.

Sheskin, D. (1997). *Handbook of parametric and nonparametric statistical procedures* (p. 680). Boca Raton, FL: CRC Press LLC.

Staff (2002, July). Just like paper, BuilderOnline Magazine. Retrieved August 6, 2003 at: <http://builderonline.com/article-builder.asp?channelID=59&ArticleType=1&ArticleID=100>

Torbica, Z., & Stroh, R. (1999). An assessment model for quality performance control in residential construction. *Proceedings ASC Annual Conference*, 35, 363-370. California Polytechnic State University, San Luis Obispo, California.

Traister, J. (1997). *Home inspection handbook*. Carlsbad, CA: Craftsman Book Company.